553 (423.7)
347.249 : 622 (423.7)

The Mineral Potential of Cornwall

K. F. G. HOSKING, M.Sc., Ph.D., A.M.I.M.M., and
J. H. TROUNSON, A.C.S.M., A.M.I.M.M.
Respectively, Lecturer in Geology at the Camborne School of Metalliferous Mining; and Surveyor at South Crofty, Ltd., and Chairman of the Cornish Mining Development Association

★ ★

Synopsis.—A discussion of the major distribution characteristics of the economic minerals in Cornwall is followed by reference to the difficulties likely to be encountered when assessing the mineral potential of certain of the areas. Notes are presented on a number of specific areas which, from all evidence at present available, appear to have distinct potentialities.

★ ★

ALTHOUGH A VAST AMOUNT OF LITERATURE exists concerning the Cornish mines it is, nevertheless, difficult, or impossible, to determine the mineral potential of the county with any degree of certainty. Furthermore, the subject being so large that it cannot be adequately treated in its entirety in a comparatively short paper, the authors have limited their discussion to the following three topics which have been somewhat neglected recently:

1. The major distribution characteristics of the economic minerals;
2. Difficulties likely to be encountered when assessing the mineral potential of certain Cornish areas;
3. An appraisal of certain areas which, from the evidence at present available, appear to have a distinct potential.

1. THE MAJOR DISTRIBUTION CHARACTERISTICS OF THE ECONOMIC MINERALS*

In any consideration of the distribution of economic minerals in Cornwall the following are of paramount importance:

(i) In the south-west of England hypothermal (Sn/W/Cu) mineralization is most intense in the Godolphin/Carn Brea/Carn Marth/St. Agnes zone and decreases progressively to the SW and the NE so that on the Scilly Islands barren greisen-bordered veins are the nearest approach to lodes, and on the eastern fringes of Dartmoor hypothermal lodes are

* For reasons of space an account of the fundamental geology of Cornwall has been omitted. It is assumed that the majority will either be familiar with it or will have no difficulty in obtaining access to information. Furthermore, the Cornish stanniferous alluvials are ignored and major consideration is given to the distribution of the hypothermal minerals rather than to those of the mesothermal group.

few in number and neither particularly large nor rich. This distribution pattern, in which the most intense hypothermal mineralization is approximately coincident with the centre of the granite batholith, can be matched elsewhere and, in the authors' opinion, is the one which might be expected to develop.

(ii) Pegmatities containing cassiterite and/or wolframite are rare in Cornwall, and those investigated have proved to be — not surprisingly — of minor economic importance. They are most abundant in the NE corner of Bodmin Moor, but a few also occur in the mines of the Camborne/Redruth belt. The components of heavy-mineral pegmatities do not fit into the primary zone pattern displayed by spatially-related hydrothermal lodes. Thus, at South Crofty mine, near Camborne, there is a pegmatite — the Complex Lode — at the 335-fm level which is locally rich in wolframite, and it is intersected by hypothermal lodes which at that horizon contain cassiterite. Wolframite, however, does not occur in the 'normal' lodes of the mine below the 260-fm level.

Finally, perusal of the literature relating to the tinfields of the world suggests that in any given area cassiterite and wolframite are either confined largely to pegmatites or to hypothermal veins; they are rarely, if ever, distributed more or less equally between these two types of deposit.

(iii) A number of swarms of greisen-bordered cassiterite/wolframite-bearing veins are known in Cornwall and although some of these have been subjected to mining operations they were probably not very profitable. Such veins are rarely more than a few inches wide and the valuable minerals are erratically distributed. Furthermore, such deposits are usually too closely spaced to be mined individually and when combined vein and country rock samples are assayed the $Sn+WO_3$ content rarely amounts to more than a few pounds per ton. Also, there is reason for believing that a given greisen-bordered vein-swarm alters but little in value from one horizon to another.

Greisen-bordered veins often occur on, or near, the tops of comparatively small granite masses, as at St. Michael's Mount, Carn Brea, and Cligga, and others which do not now show this relationship probably originated in granite cusps which have since been largely destroyed by erosion. As the location and the structural and mineralogic characteristics of the greisen-bordered veins differ so markedly from those of the large, rich 'normal' hypothermal lodes of the county, it is probable that the two types of deposit were formed under considerably different sets of circumstances.

(iv) Dines (1956, pp. 7–8)* has emphasized the fact that throughout the south-west of England there are a number of centres of mineralization — 'emanative centres' — around which the mines are clustered. These centres are closely associated with granite which may not, of necessity, crop out. Around each centre the lode minerals were deposited in a series of zones which are often flatter than the neighbouring granite/

* See list of references at the end of the paper.

killas junction. The lowest zone — which in plan is the smallest — contains dominant amounts of tin, while above it, and overlapping it slightly in the vertical plane and considerably in plan, is the copper zone; this, in turn is covered by a still more extensive lead zone. In any given area some or all of the zones may have been removed by erosion.

Appreciation of this distribution pattern is important, because it indicates, for example, that tin is unlikely to be found in economic quantities below copper except well inside the periphery of the copper zone. It also points to the fact that, provided temperature/pressure conditions are favourable, cassiterite can accumulate just as effectively in slate as in granite.

The maximum thicknesses of the primary zones, as calculated by Dewey (1948, p. 50), are noted in Table I. It must be pointed out, however, that in most of the Cornish mines the zones — particularly those of tin and copper — do not attain these thicknesses.

TABLE I

Mineral Zone	Thickness in ft
Zone of carbonates (iron, manganese, etc.)	400
Zone of sulphides of antimony, etc.	200
Zone of sulphides of lead and silver, giving place in depth to zinc	1800
Zone of sulphides of copper intermixed with wolfram and tin for 700 ft	2500
Zone of oxides of tin with wolfram in the upper parts	2500

The primary-zone conception of the distribution of minerals in Cornwall does not represent the facts completely because, towards the end of the phase of lode development, minerals such as galena, sphalerite, and siderite were laid down at those horizons where cassiterite, wolframite, and chalcopyrite had been deposited earlier.

The views of one of the authors (K.F.G.H.) of the general order of deposition and distribution characteristics of the Cornish lode minerals are summarized in Table II. Amplification of this table not being possible here, it may be stated that field and laboratory studies yield ample evidence in support of the sequence and also indicate that the development of the major lodes was due primarily to repeated re-opening of the feeder channels by normal faulting. This repeated re-opening on occasion lessened the value of the lode by crushing some of the earlier components, e.g., cassiterite, and by permitting an inordinate number of species to be deposited at the same horizon.

In most of the hypothermal lodes there was a marked deposition of heavy minerals in the wall-rock adjacent to the feeder channels as well

TABLE II.—*General Order of Deposition, etc., of the Cornish Lode Minerals*

Gangue	Zone	Ore-Minerals		Economically important Elements	Composition of Wolframite and Sphalerite	Trace Element Data *
			Latest Minerals			
Quartz; Chalcedony; Calcite; Dolomite; Barite; Chlorite; Hematite; Fluorite; Tourmaline; Felspar; Mica	7	Barren : (pyrite)	MESOTHERMAL AND EPITHERMAL LODES Generally at right-angles to granite ridges.			
	6	Hematite. Stibnite. Jamesonite. Tetrahedrite. Bournonite Pyrargyrite? Siderite. Pyrite : (marcasite)		Fe. Sb.		
	5b	Argentite. Galena Sphalerite		Ag, Pb. Zn.		
	5a	Pitchblende. Niccolite. Smaltite. Cobaltite. (Native bismuth : bismuthinite?)		U, Ni, Co. Bi		Hi and Sn decrease in galena
	4	Chalcopyrite Sphalerite Wolframite : (scheelite) Arsenopyrite Pyrite	HYPOTHERMAL LODES Generally parallel to granite ridges and dykes.	Cu	Fe increases in wolframite & decreases in sphalerite	Mn, Mn, & Sn decrease, and Ge & Ga increase in sphalerite
	3	Chalcopyrite : (stannite). Wolframite : (scheelite) Arsenopyrite. Cassiterite : (wood tin)		Sn W As		
	2	Wolframite : (scheelite) Arsenopyrite : (molybdenite?) Cassiterite				
	1	Cassiterite. Specularite				
	Greisen-bordered veins	Arsenopyrite. Stannite. Wolframite. Cassiterite	Veins often in granite cusps			
	Pegmatites	Arsenopyrite. Wolframite. Cassiterite.	Earliest Minerals			

* See EL SHAZLY, E. M., WEBB, J. S., and WILLIAMS, D. Trace elements in sphalerite, galena and associated minerals from the British Isles. *Trans. Instn Min. Metall., Lond.*, **66**, 1956-57, 241-271.

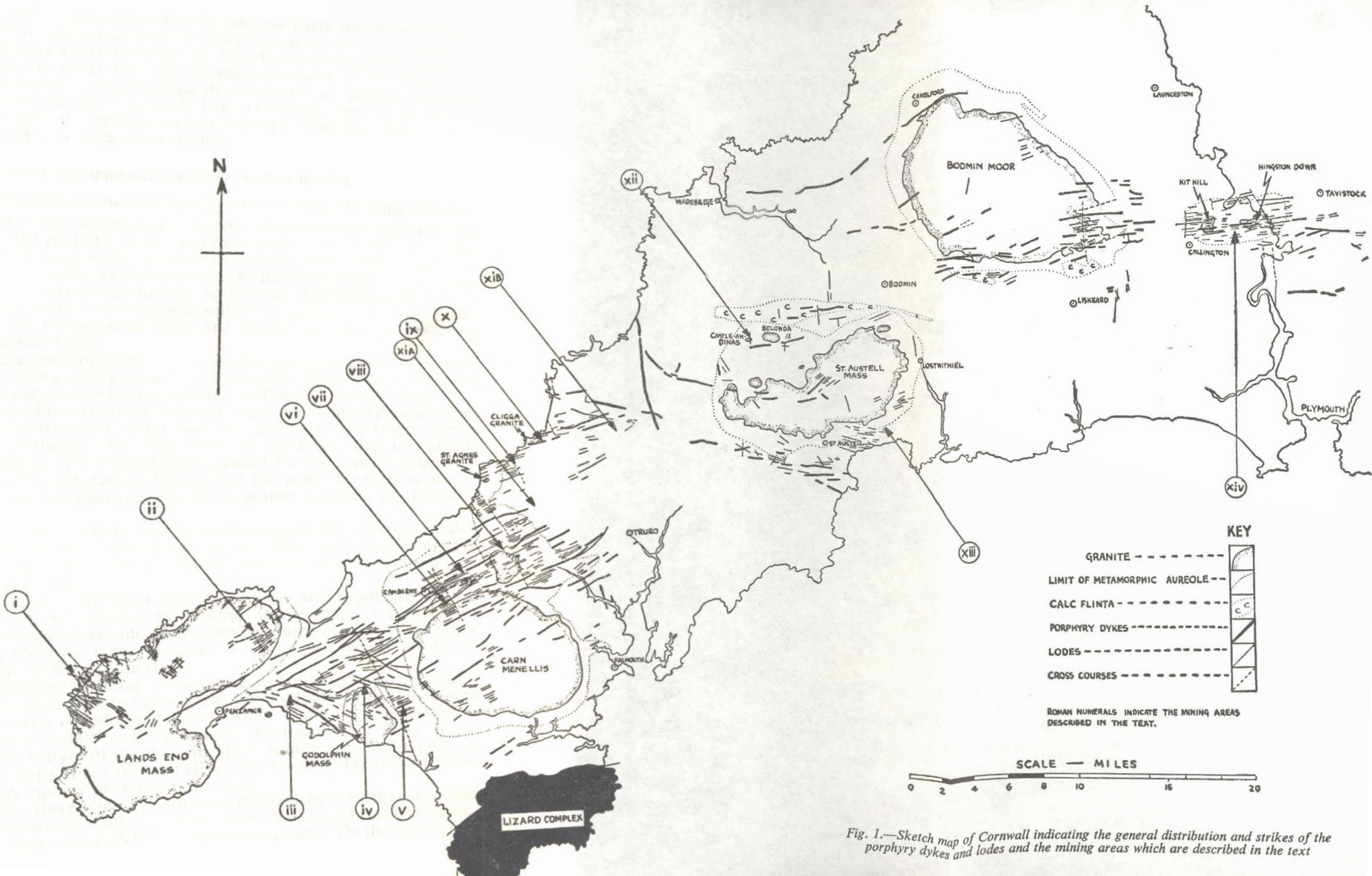

Fig. 1.—Sketch map of Cornwall indicating the general distribution and strikes of the porphyry dykes and lodes and the mining areas which are described in the text

as in the open spaces, and often the steepest parts are the widest and richest. Particularly rich pockets of ore occur at the intersections of lodes of approximately the same age. Usually the nature of the wall-rock did not greatly affect the mineralogical character of the lodes, but tungsten tended to be deposited partly, or entirely, as scheelite where the country rock contained available lime. Generally, but not invariably, cassiterite lodes are impoverished in dolerites, while their behaviour in porphyry dykes is quite unpredictable.

(v) *The Cornish hypothermal lode/dyke pattern in plan*

The following facts emerge from a perusal of Fig. 1 (folding Plate I):

(*a*) In any mineralized area a number of lodes strike approximately parallel to the porphyry dykes and there is usually a later set of lodes and barren fissures which intersect the earlier at an angle of approximately 90°. Usually the lodes parallel to the dykes contain the earlier hypothermal minerals (cassiterite, wolframite, chalcopyrite, etc.), while the others contain a mesothermal suite (e.g., galena, sphalerite, pitchblende). The mesothermal lodes and barren crosscourses frequently fault the earlier lodes.

(*b*) To the north of the St. Austell granite there are several cassiterite/wolframite lodes which possess an anomalous N–S strike. The most notable of these is the Castle-an-Dinas wolframite/löllingite lode.

(*c*) Many of the dykes and veins are near the granite/killas junctions and comparatively few occur near the centres of the larger granite outcrops. Although the shallowness of the lodes near the granite centres suggests that erosion may account for the general paucity of orebodies there, the authors believe that this is not the main reason.

(*d*) Certain marginal portions of the granite outcrops are devoid of lodes.

(*e*) Many dykes, and certain associated and parallel tin/copper lodes, are several miles from outcropping granite. This is true, for example, of some of the dykes and associated tin-lodes of the Gwinear and Perranporth districts.

(*f*) Often the distribution pattern of dykes and hypothermal lodes bears little, or no, obvious relationship to the shape in plan of the nearest outcropping granite. The Carn Brea area constitutes a notable exception; there the lodes and dykes strike approximately parallel to the long axis of the granite ridge.

(*g*) Throughout Cornwall marked 'streams' of lodes and dykes occur. Thus, in the coastal strip between the Land's End and the Godolphin granites a series of lodes and dykes swings round in an arc which is approximately parallel to the coastline. Another stream 'flows' across the southern margin of the Bodmin Moor granite mass and thence via the granite cusps of Kit Hill and Hingston Downs to Dartmoor. Other 'streams' are equally obvious on the map.

(*h*) Finally, there is an approximate parallelism between the majority of the lode/dyke streams and those portions of the arcuate Lizard/Dodman/Start Point thrust to which they happen to be closest. On the other hand,

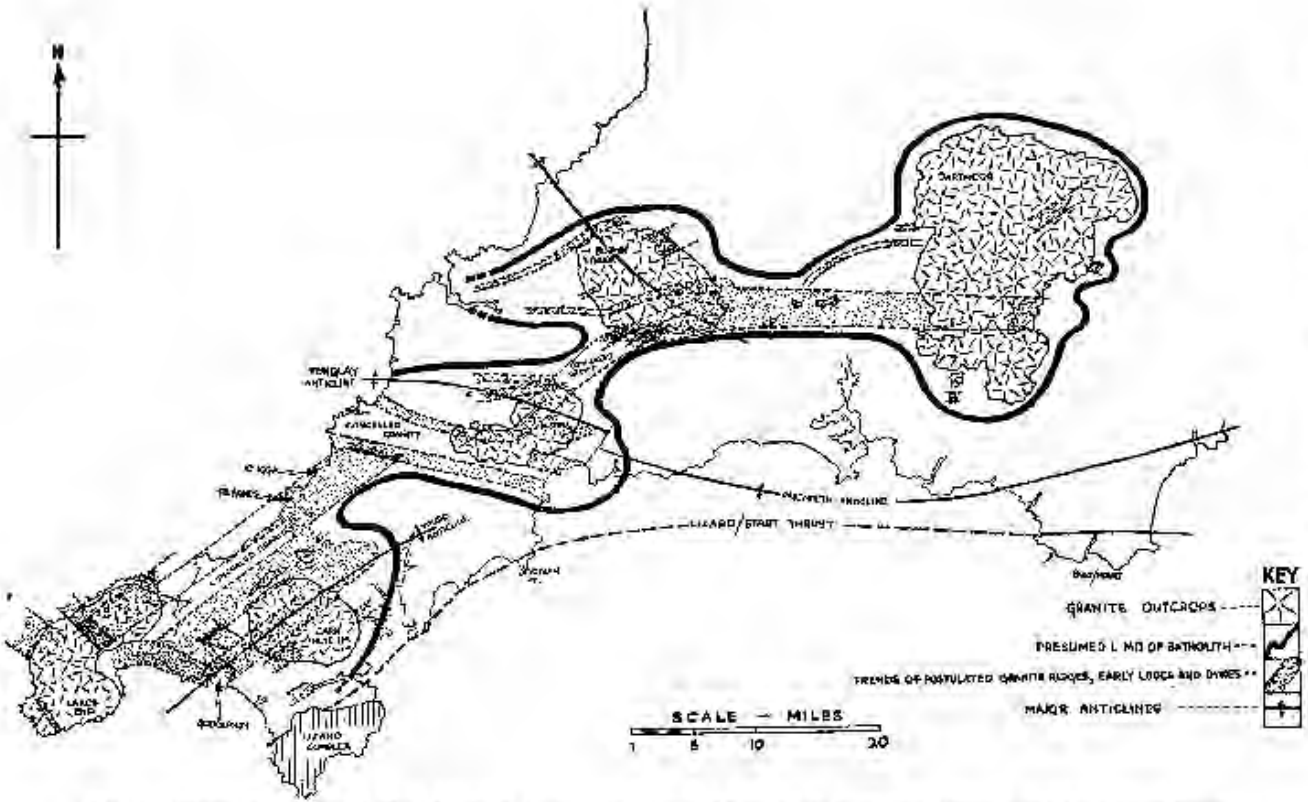

Fig. 2.—Sketch map of South-West England showing the presumed form of the batholith, together with the general trends of the early lodes, dykes, and the postulated controlling granite ridges.

the late mesothermal lodes and barren crosscourses are, when projected, approximately normal to tangents to this thrust.

It is believed that the fundamental characteristics of the Cornish dyke/hypothermal lode pattern can be accounted for by assuming that these lodes and dykes are for the most part orientated approximately parallel to the long axes of granite ridges which possess undulating crest lines. (It is, however, probable that some of the lodes — particularly those with anomalous strikes — are essentially pre-granite faults which were subsequently mineralized.) It is considered that the disposition of these ridges was determined largely by the moulding action of minor anticlines which were present in the country-rock invaded by the granite, and which were generally parallel to the Lizard/Start Point thrust. Doubtless the same forces caused the development of the thrust and the anticlines. Further 'moulding' anticlines were developed by the rucking of the sedimentaries due to the emplacement of certain closely-spaced large granite knots in the major anticlines. Thus, it is thought that such anticlines were formed in the Mounts Bay coastal strip sedimentaries by the compressive rucking forces which developed as a result of the simultaneous development of the Land's End and Godolphin granites.

As a result of forces operating from the S during the development of the batholith, 'fingers' of granite were forcibly intruded into the country-rock to the N of the major granite knots and associated with these are certain approximately N–S striking lodes, of which that at Castle-an-Dinas, mentioned earlier, is one of the best known. Furthermore, it seems probable that centres of mineralization developed where there were 'high-spots' (cusps) on the ridges. (Note, for example, the development of lodes around the cusps of St. Agnes, Carn Brea, Kit Hill, and Hingston Downs.) Greisen-bordered veins often developed first in such places from the local residuum which accumulated in such traps during the consolidation of the ridges. Subsequently the lodes of economic importance were formed from the heavy-metal differentiate which accumulated below the highest points of the roof during the consolidation of the 'body' of the batholith. It is reasonable to expect that these centres of accumulation were below the cusps of the ridges. Observation suggests that in a given area of limited extent the most intense mineralization was associated with the largest granite cusp.

Finally, it must be stressed that there is considerable evidence for the existence of concealed granite in certain areas far removed from the surface granite masses (see Hosking, 1949), and, therefore, the general form of the granite batholith can be predicted with considerable confidence; it is indicated on Fig. 2.

Observations and Conclusions

From the foregoing discussion the following observations and conclusions can be made regarding the hypothermal mineral potential of Cornwall:

(i) Areas outside the batholith zone indicated on Fig. 2 have no potential.

(ii) Lodes near the centres of the major granite outcrops are likely to be of very limited depth — due to erosion — and, therefore, of slight economic interest.

(iii) Swarms of greisen-bordered veins must be regarded, for reasons stated earlier, as deposits of marginal importance.

(iv) Centres of mineralization are associated with 'high spots' on the granite ridges and the strongest hypothermal mineralization in any given area developed in the vicinity of the largest cusp (which in some cases has since been partly destroyed by erosion). Therefore, the ground beneath the sea immediately to the north of the St. Agnes and Cligga cusps is well worth prospecting, as are also the submarine areas in the vicinity of St. Michael's Mount.*

(v) The application of geophysical methods might well indicate concealed cusps in the area to the north of the Carn Brea–Carn Marth line. In particular, the thermally-metamorphosed strip between Carn Marth and St. Agnes should receive special attention in this connexion. It is, of course, likely that if any such cusps are found in those areas the mineralization associated with them will be less intense than that occurring in the vicinity of the outcropping granites of the district.

2. DIFFICULTIES LIKELY TO BE ENCOUNTERED WHEN ASSESSING THE MINERAL POTENTIAL OF CERTAIN CORNISH AREAS

Before mining can be started in any area in Cornwall it is necessary to obtain the approval of the local planning authority and to make the necessary arrangements with the owners of the mineral rights. As the mineral rights of a comparatively small area may be owned by a number of parties with no business connexions, negotiations may well be prolonged. Furthermore, as much of Cornwall is of agricultural importance, preference must normally be given, in the early stages of exploration, to prospecting techniques which do not mutilate farming land.

However, it is in the determination of the potential of ground in and around areas which have been mined that a number of special difficulties are encountered. Obviously, when confronted with such a problem it is desirable to obtain all the available information concerning earlier mining activities. The plans, sections and reports from which these data may be collected may be very difficult to locate. Much is still in the possession of private persons, and it is certain that many important plans and records have been destroyed. Furthermore, extant plans may well be incomplete, while the contents of some of the earlier reports are unreliable and the conclusions, in particular, are, on occasion, unduly biased, either in favour of, or against, the actual potential of the mine.

* It must be pointed out that Dines (1956, p. 8) also recommends investigations seawards in the St. Agnes area.

The values of ground are often recorded in the earlier reports as pounds sterling per fathom — or in some other equally meaningless form — and hence they are virtually useless to the present-day investigator.

Statements of the numbers of people employed during the various phases of a mine's activity and the records of sales of ore are not of much assistance — as is sometimes claimed — in determining the potential of a property. However, the prices paid for metals during the time when a given mine was being worked may suggest one of the reasons for the eventual cessation of the venture. Nevertheless, it is often impossible to determine precisely why a given mine was abandoned.

In many parts of Cornwall a number of factors militate against the use of geophysical and geochemical methods of prospecting. In particular, difficulties arise from considerable areas being contaminated by the waste products from mines, while others of interest have been built over. Furthermore, because of the nature of the Cornish deposits, diamond drilling can do little more than prove the presence of a lode.

The difficulties attendant on underground investigation of the older mines are well known.

3. AN APPRAISAL OF CERTAIN AREAS WHICH, FROM THE EVIDENCE AT PRESENT AVAILABLE, APPEAR TO HAVE A DISTINCT POTENTIAL

(i) *St. Just/Pendeen*

This consists of a narrow coastal strip of highly altered sedimentary rocks resting on granite. Its southern extremity is 4 miles N of Land's End and it extends from there 4 miles northward to Pendeen lighthouse. This area embraces the greater part of the St. Just and Pendeen mining district. Although the central and especially the landward part of the area is worked out, its northern and southern extremities still contain good prospects. This applies particularly to the seaward extension of the numerous NW–SE striking lodes which cross the slate/granite contact approximately at right-angles. The principal mineralization follows the contact in its dip seawards but at a lesser angle.

In the southern part of the area, S of Cape Cornwall, the sedimentary rocks have all been removed by sea erosion and the cliffs consist entirely of granite. Here numerous tin-bearing lodes pass seawards, but little has been done to explore them in that direction though they have been extensively worked inland. By analogy with conditions in other mines in this part of Cornwall the tin zone pitches beneath the sea and therefore these lodes merit development seawards.

Towards the northern end of this coastal strip the lodes of the celebrated old Levant mine have been followed for more than a mile beneath the sea and there is still room for a lot of development in and around the vicinity of Levant.

(ii) *Trink Hill*

The very prominent Trink Hill, composed of granite, is situated

2 miles SW of the town of St. Ives. On its western and southern flanks several tin lodes have been extensively worked in the past in the Giew and Wheal Reeth mines. The former was abandoned during the great slump in tin in 1922 though the main lode of the mine gave every promise of continuing much further east than it has yet been worked.

Several surface indications of tin lodes have been found at least a mile E of the Giew workings and the numerous lodes traversing this virgin ground, and standing parallel to the eastern part of the once very productive Wheal Sisters mine, deserve much more attention than they have yet received.

(iii) *Marazion*

Half a mile north of Marazion a group of tin lodes occurs which extend 1½ miles eastward to the village of Goldsithney. This appears to be an emanative centre which is surrounded by old copper mines previously very productive. It is worthy of note that the tin lodes in question occur approximately equidistant between the granite bosses of Land's End and Tregonning Hill, and the small granite outcrop at St. Michael's Mount lies only one mile S.

The comparatively small mines worked on these lodes are, from W to E, named East Wheal Rodney, Wheal Hampton, Tregurtha Downs, and Owen Vean. The workings are all very shallow, the deepest being at Tregurtha Downs which only reached 700 ft in depth before being closed in the great slump of the 1890s. Subsequent shallow mining at the newer Wheal Hampton property gave a milling recovery of 26·5 lb of black tin per ton of ore (with an inefficient dressing plant), but the enterprise foundered in 1914 for want of sufficient capital to open up the mines on an adequate scale. The available evidence about these lodes indicates that they are probably worthy of more attention.

(iv) *Godolphin Hill*

There is a relatively small but economically important granite outcrop 6½ miles SW of Camborne that constitutes the Godolphin and Tregonning Hills, the former being the northern end of the elongated boss. About 300 yd NE of the northern extremity of the granite outcrop there is a number of lodes which were worked most profitably for copper in the old Godolphin mine. Work there ceased about 1847 when the mine was only 700 ft deep. Henwood, the celebrated geologist, examined the lodes and recorded the fact that they were becoming stanniferous in depth. Wolfram is also reputed to have been making its appearance in this mine. Charles Thomas, a noted mining writer of his day, stated, in 1867, that the Godolphin mine was changing from copper to tin, but it was abandoned during a period of low tin prices. These lodes certainly seem to merit a great deal more attention.

In addition to the lodes which traverse the slate at the foot of the Godolphin Hill, the granite of the hill itself contains numerous small tin lodes which were worked further W in the West Godolphin mine. It has long been thought that they are worth systematic development further eastward, but, for some reason, this has never been done. As

the hill rises over 400 ft above the valley at its northern foot, a really deep adit-crosscut could be put in for a mile through this most promising piece of ground and enable the lodes to be examined without incurring sinking or pumping costs.

(v) *Wheal Vor*

The celebrated Wheal Vor is 1½ miles SE of the Godolphin mine and situated in the slate east of the Tregonning Hill granite, and the Wheal Metal mine is ¼ mile still further S. These two properties were probably the richest tin mines ever worked in the West of England and both were abandoned prematurely for purely local reasons. In the case of Wheal Vor, a long-standing legal dispute ruined the enterprise, which, over a considerable period yielded 200 tons of black tin per month. Wheal Metal collapsed in the slump of 1877 through the company's failure to keep developments ahead of milling requirements.

The plans of these mines show a strange lack of crosscutting and there may well be other parallel lodes in this outstandingly rich district that await development. Furthermore, there are grounds for thinking that the great orebody of Wheal Vor persists in depth further E than any development in the old mine. This, and other possibilities in the area, could be tested by means of a series of bore-holes from surface.

(vi) *The Great Flat Lode District*

The great central mining district of Cornwall between Camborne and Redruth is situated on either side of the Carn Brea granite ridge. The principal lode of the mines S of the granite is the Great Flat Lode, which dips S at angles varying from 30° to 40° and extends over a length of more than 3 miles. Numerous more or less vertical lodes also occur in the area, but their development was regrettably neglected after the discovery of the Flat Lode.

The two principal groups of mines worked in this area were the Basset mines on the E and Grenville United on the W. Both concerns closed down shortly after the first world war consequent upon the acute financial difficulties of the period. By means of highly selective mining, both companies maintained a grade of about 2 per cent of tin ore for many years, the total recorded production of black tin from these mines being over 80 000 tons.

In all these mines, the Flat Lodes ultimately became poor in depth, the deepest workings being in Grenville which reached an inclined depth of about 2400 ft. In view of the declining values in the bottom of their mine the Grenville company decided in 1919 to concentrate on the neglected upper portions of the Flat Lode, but more especially on the so-called 'vertical' lodes to a depth of about 1000 ft from surface. The results of the limited amount of work that it was possible to do in the time available were most encouraging, but the change in policy had been left too late and the concern went into liquidation in the slump in 1920.

In view of the very large extent of ground yet to be developed in these

mines to a depth of, say, 1200 ft, they merit much further attention. Alternatively, it might be better to combine the Grenville and Basset groups as one big unit. If this were done and the aim were to produce a really large output of, say 1 per cent tin ore instead of a relatively small tonnage of 2 per cent material, these mines might again be made a very profitable proposition.

(vii) *The Illogan Area*

On the northern side of the Carn Brea ridge South Crofty, Ltd., is working an extensive series of tin lodes reaching to a depth of more than 2000 ft. There is, however, one important prospect in this famous old district that has not yet been developed though it was discovered as long ago as 1920. The orebody in question is a very large tin/tungsten lode which, where intersected, contained 7 per cent of mixed tin/wolfram values. This discovery is thought to be the eastern continuation of the principal lode of the old East Pool and Agar mines which is also the Main Lode of South Crofty mine, further W. The lode was cut at a depth of 1550 ft in the eastern part of the then East Pool and Agar Company's properties, but it was never developed by reason of the great ground movement which destroyed the shafts of that mine early in 1921. The old part of the property was then abandoned, with the intention of later tackling the great discovery from the new Taylor Shaft, but this was never done. Possibly, at some time South Crofty may extend far enough E to embrace this area.

(viii) *The Scorrier Area*

Immediately E of Redruth is the granite of Carn Marth which is surrounded by a very broad metamorphic aureole and intensive mineralization. The area concerned is that lying immediately N of the granite outcrop and which constitutes the Scorrier mining district. The numerous mines in this area are mostly shallow, very few of them having attained a depth of 1000 ft. Hitherto the production has been principally copper, though a total of over 10 000 tons of black tin has been raised by the various mines in this district, and wolfram in some quantity was making its appearance in some of the deeper workings.

Geologically, the area bears a striking resemblance to that between Redruth and Camborne. In the latter district, greater foresight and greater energy were responsible for the mines being sunk below the copper and into the tin zone, whereas developments in the Scorrier district ceased at what was probably the transitional horizon between copper and tin.

An immense amount of information concerning this area and its mines has been collected by Mr. C. E. Trestrail of Redruth and embodied by him in a series of reports; the information which these contain should be invaluable in any future large-scale planning of mining here. The prospects in this extensive area are, possibly, better than in any other part of Cornwall not at present being worked.

(ix) *The Wheal Kitty and West Wheal Kitty mines, St. Agnes*

The village of St. Agnes on the north coast is surrounded by numerous tin mines which were previously very rich. The principal workings are on very 'flat' lodes (sometimes only 20° from the horizontal). The famous ore-shoot in the bottom of the Wheal and West Kitty mines, still contains good values over a length of 900 ft. Both these mines were closed during or just after the 1914–18 war, but in 1926 they were re-opened and, after some initial disappointments, the ore-shoot was again located on the other side of a major fault. Thereafter, the whole of the development done on this lode in the bottom levels averaged 80·8 lb of black tin per ton over a lode width of 28·4 in. The production of black tin rose to 46 tons per month, but in consequence of the world slump in metals in 1930 mining again ceased. Later, in 1937, an attempt was made to continue the development of this lode by deepening an old shaft at the Polberro mine, nearer to the cliffs. Unfortunately, as a direct consequence of the last war, the company was unable to raise sufficient finance to enable it to complete the necessary developments and, with all the spade work done, the mine had to be closed in March, 1941. Another effort to continue the exploration of this fine lode in depth would seem to be justified by the possibilities of it extending considerably further N under Trevaunance Coombe or even beneath the sea.

(x) *The Perranporth Mines*

Two miles NE of St. Agnes there is a small granite outcrop which forms the 300-ft high cliffs of Cligga Head. The whole mass is traversed by innumerable joints alongside which the granite is greisenized. The joints constitute narrow lodes which contain, among other minerals, cassiterite and wolfram. This stockwork-like mass has been worked from ancient times, but in 1938 mining began on a much larger scale and continued until 1944. This demonstrated that the deposit is not an economic proposition above sea level, but in depth some of the small veins were increasing in size to become well-defined lodes, 12–18 in. wide, containing good tin values and/or massive wolfram and arsenopyrite in a quartz gangue.

Of much greater economic significance, however, than the mineralization of the Cligga granite are the lodes in the metamorphosed sediments to the S and E, which gave rise to the productive copper mines of Perranporth. Mining there came to an end about the middle of the nineteenth century due to heavy pumping costs and a series of disputes leading to litigation between the two principal companies concerned, but it is believed that some reserves of copper remain in these workings. The deepest of the mines is only 700 ft below sea level and it has long been thought that the lodes are likely to become tin-bearing as they approach the granite in depth. Old reports state that the granite was encountered underground at a considerable distance E of the outcrop at Cligga Head and under-sea explorations in Perran Bay might result in important discoveries. From a shaft in the granite of Citligga Head it

would be possible to crosscut under the sea and also landwards to test the downward continuation of the small Cligga lodes and the much more important orebodies of the Perranporth copper mines.

(xi) *Lead Prospects*

S and E of St. Agnes and Perranporth there is an extensive former lead-mining district, approximately 9 miles long by 4 miles wide. Several very productive lead lodes have been mined in the area, but their occurrence has been so sporadic and unpredictable that there seems scope for a further investigation of the whole area by modern methods of prospecting which might well result in other important discoveries being made. In this paper the authors confine themselves to two prospects that seem worthy of examination:

(*a*) An E to W lode that apparently crosses a shallow valley ¾ mile ENE of Mithian Church. The well indicated on the Ordnance Map as 'Silver Well' appears to be on the outcrop of this lode, which was also encountered in draining the marsh at the bottom of the valley. A further discovery of a lead lode on about the same strike was made in a field on the western side of the valley.

(*b*) The eastern and western extensions of the southern lodes of the Shepherds lead mine, near Newlyn East. The southern part of the old mine was worked on E–W lodes about 700 yd S of Shepherds railway station and there are grounds for thinking that the lodes persist further E and W, especially W. On several occasions, when the land has been ploughed W of the old mine, stones of galena have been found.

(xii) *Castle-an-Dinas wolfram lode, St. Columb*

Two miles E of St. Columb Major in mid-Cornwall is the prominent hill of Castle-an-Dinas which is traversed by a N–S quartz/wolfram lode. This has been extensively worked in the Castle-an-Dinas mine over a strike length of 4700 ft and to a maximum depth of about 500 ft. To date this has been the largest producer of wolfram in Britain, but it was closed down in 1957 in consequence of the heavy fall in the price of the mineral. At the extreme northern end of the mine the lode was still productive when work ceased, while surface indications of a wolfram lode about 3000 ft N of the northern end of the existing workings are approximately in line with that worked under the hill.

(xiii) *The St. Austell/Par Mines*

S of the Hensbarrow granite mass, and situated between St. Austell and Par, is an area that was once very productive for both tin and copper. The country rock consists of slate overlying granite, which dips to the S and E. The mines at the western end of the district, and therefore nearest to the granite, yielded tin, those at its southern extremity copper, and the workings to the NE, near St. Blazey station, both copper and tin, though the copper has so far predominated. It is this last group of Par Consols which is now discussed.

Par Consols, the creation of J. T. Treffry, a celebrated nineteenth-century industrialist, was abandoned in 1869, on the advice, so it is reputed, of 'copper' managers who could not see their way to provide the necessary machinery for extending the mines in depth or equipping them with the requisite new milling plant to handle tin ores.

The northern part of Par Consols, known as 'Puckey's North mine', lies closer to the granite than the principal workings further to the S, and it is reported that the tin occurred mostly in these northern parts of the mine; the recorded output of black tin is 3785 tons. In view of the very considerable tin production of the mines further W, and nearer to the granite, Par Consols certainly seems to warrant deeper development.

(xiv) *The Prince of Wales Area*

Near the eastern border of Cornwall granite appears in the two small outcrops of Kit Hill, and Hingston Down. The metamorphic aureole bridging these two outcrops is suggestive that they are connected at no great depth thus forming an intrusive ridge at least 4 miles long. On the southern side of this ridge, and lying parallel to it, are numerous lodes which have yielded copper, arsenic, tin, tungsten, pyrite and, lesser amounts of lead and silver. At approximately the centre of this mineralization is situated the Prince of Wales mine, standing just N of Harrowbarrow. This property has been worked to a depth of about 1100 ft, primarily for copper, pyrite and arsenic, but from the deeper levels over 1000 tons of black tin have been raised. There are still possibilities latent in further sinking and lateral development of the main lode, quite apart from the development of the numerous other lodes in the area which have as yet been only imperfectly explored.

Mining at Prince of Wales ceased about 1914; it was continually hampered by a lack of adequate finance and in consequence the operations were always conducted on a 'hand-to-mouth' basis. It may reasonably be said that the property has never yet been given a fair trial and that the existing workings are little more than the nucleus of the development necessary for opening up such an extensive and promising belt of land.

In the light of the evidence at present available the foregoing areas appear to offer the best prospects for future mining enterprise in Cornwall. Nevertheless, the authors are aware of the existence of other favourable propositions, and many more might be discovered if there were the same incentives to prospect in Britain that exist elsewhere in the world.

REFERENCES

DEWEY, H. South-West England, 2nd ed. *Brit. reg. Geol.*, 1948, 50.

DINES, H. G. The metalliferous mining region of South-West England. *Mem. geol. Surv. U.K.* 1956. 2 vols.

HOSKING, K. F. G. Fissure systems and mineralisation in Cornwall. *Trans. R. geol. Soc. Cornwall*, **18**, 1949, 9–49

JOINT DISCUSSION

Dr. K. F. G. Hosking, introducing the paper on the mineral potential of Cornwall, said that as it was virtually impossible to make an adequate assessment of the Cornish mineral potential within the space of a few pages, Mr. Trounson and he had decided to limit their observations to three topics. They had elected first to state, without elaboration, the fundamental distribution — and other major — characteristics of the Cornish orebodies, and from those they had sought to determine the factors controlling the distribution and nature of the lodes, in particular those containing cassiterite and wolframite.

They had largely neglected the mesothermal lodes but some had been discussed by Mr. Vipan; and the Cornish uranium lodes had not been mentioned as they were being investigated by the Atomic Energy Branch of the Geological Survey.*

Alluvial deposits, also, had been omitted, although the stanniferous beach-sands of the Hayle/Godrevy area were certainly not without potential and would probably be worked on a large scale were they, for example, in Malaya or Siam.

Secondly, they had noted certain difficulties associated with the investigation of mineral deposits, and of old mines, in Cornwall; and finally they had briefly described a few areas, which, from the evidence at present available, appeared to them to have some potential.

Dr. Hosking then said that he wished to emphasize the following facts which must be constantly borne in mind when considering the merits of any Cornish area:

(i) Pegmatites were few and small, and although some contained cassiterite and wolframite they were of no great economic value. A few had been worked, particularly where they were associated with 'normal' lodes. They did not always fit into the primary zone pattern of the hypothermal lodes.

(ii) The narrow, greisen-bordered, cassiterite/wolframite veins, which were characteristically associated with the apices of granite cusps (as at Hemerdon, Cligga, St. Michael's Mount, etc.), were of marginal economic importance. They did not appear to coalesce in depth and were quite distinct from the important tin-bearing lodes of the South Crofty type. Economically important 'normal' lodes often occurred near such mineralized cusps, and, therefore, the latter should be used as pointers to areas worthy of examination.

(iii) In any limited area most of the early lodes and dykes possessed the same general strike and many lode/dyke streams were apparent on Fig. 1 (Plate I) of the paper. It was to be noted that those streams were not confined to the junctions of the killas and the major granite outcrops, and that many of those junctions were quite devoid of lodes.

Following Emmons' teachings they believed that the early lodes and dykes were associated with granite ridges with undulating crest-lines,

* See p. 483.

and that in any given area the strikes of the majority of the lodes and dykes were approximately parallel to that of the associated ridge. A ridge might be still partly hidden by killas or, as a result of differential erosion, it might be a quite prominent feature of the landscape. In some instances parts of ridges had been largely obliterated.

Certain lodes with anomalous strikes might occupy pre-granite faults, or faults developed during the emplacement of the granite.

(iv) Centres of mineralization — Dines's emanative centres — were somewhat irregularly distributed, but, in the speaker's opinion, they were associated with the original 'high spots' — cusps — on the granite ridges. Typical examples of cusp/emanative-centre association occurred at St. Agnes, Carn Brea, Kit Hill and Hingston Downs.

(v) The most intense early mineralization occurred within the St. Agnes/Carn Marth/Carn Brea/Godolphin quadrangle. The intensity of the mineralization decreased progressively to the northeast and southwest.

(vi) The early tin/tungsten lodes of major economic importance owed their development to the ascent of mineralizing agents along fissures which were often repeatedly reopened by faulting. Usually the faults were of the normal type, but on occasion lateral movement was prominent. The lodes were developed by deposition within open spaces and by intense replacement of the wall-rock.

(vii) Because the major phase of lode development was of comparatively short duration, and also because the nature of the lode-forming agents was changing fairly quickly, the minerals were deposited in zones — the first to be deposited being nearest the source. Those primary zones — which had been investigated at length by Dines — were often flatter than the associated granite/killas contacts, and later zones were more extensive in plan than earlier, deeper ones. Thus, tin was only likely to be found in economic amounts beneath copper near the centres of mineralization.

Within the lodes a certain amount of telescoping was sometimes apparent, and the mesothermal phase of mineralization was locally so prolonged that lead, zinc, silver, etc., were deposited in the original tin zone, but usually in a completely different set of fissures.

In some areas the economic limits of the tin zone could only be determined very approximately. At South Crofty mine, for example, the upper and lower limits of the productive tin zone were far from being straight lines when plotted on transverse sections.

(viii) As a result of erosion, mines in the granite, and well inside the granite/killas junction, were likely to be shallow and to contain only the narrow roots of lodes which were usually characterized by containing fine, and, therefore, not easily recovered, cassiterite.

(ix) Mining the earlier lodes was rendered somewhat difficult because they were displaced by mesothermal lodes and barren crosscourses. Furthermore, the rapid, and often quite unpredictable, changes in the width and value of a particular lode within short distances also added to the difficulties of mining, evaluation and prospection (particularly by diamond-drilling).

As the authors believed that tin lodes of importance occurred in the vicinity of granite cusps they entirely agreed with Dines's suggestion that the ground below the sea in the vicinity of St. Agnes was well worth while examining, and they also thought the same applied to the submarine area near Cligga and, to a lesser extent, to certain other similar areas.

They believed that geophysicists would be doing a great service to Cornwall — and to a number of similar foreign areas — were they to develop a method — if one did not exist — for locating concealed granite cusps.

In concluding, they wished to acknowledge the fact that the skeletal geologic structure shown in Fig. 2 (p. 360) was based on Plate XXIV of Hendricks's work* and to state that the indicated form of the batholith — which was postulated a decade ago by one of them (K. H.) — agreed, in essence, with that arrived at by Dr. Bott (of the University of Durham) and his co-workers as a result of comparatively recent geophysical investigations. So far as they were aware Dr. Bott's work had not been published but they hoped that Professor Dunham would comment on it.

Mr. J. H. Trounson recalled that Mr. Anton Gray had pointed out in his lecture that, whatever might be said of the other base metals, there was indeed a very close association between the occurrence of tin and the presence of granite, though that rock might be hidden. Dr. Hosking had therefore rightly emphasized the importance of determining the form of the West of England batholith as a means of locating further economic tin lodes.

While he did not wish to suggest that Cornwall could produce a tin mine comparable with Avoca as a copper producer, he was confident that there were still excellent chances of making important discoveries in Cornwall. The Duchy was frequently spoken of as being an exhausted field but the same had been said of Ireland and they now knew that that was far from being the case. If they took a sane and balanced view of the prospects in Cornwall and used their brains to avoid the mistakes of the past there was good reason for thinking that a lot of successful mining would yet take place there.

On the previous day mention had been made of an excellently equipped and well managed lead mine in the north. He could but wish that all those present were able to visit the Geevor mine in Cornwall which was a splendid example of a successful tin mine. When considering such properties, however, they did well to remember that they had been opened up and equipped at a time when taxation was far less onerous; indeed it was now practically impossible to create such mines in Britain. He felt, therefore, that if there were to be any future for metalliferous mining in the country they had to convince Government

* HENDRICKS, E. M. L. Rock succession and structure in South Cornwall: A revision. With notes of the central European facies and variscan folding there present. *Quart. J. geol. Soc. Lond.*, **93**, 1937, 322–67.

of the imperative need to co-operate with private enterprise as the Irish Government had done recently with very fruitful results.

Dr. Hosking had drawn attention to the possibility of new discoveries or even entirely new mining areas being found in Cornwall. Dr. Hosking was a geologist whereas he (Mr. Trounson) was a miner, but he entirely agreed with him in the matter. Having been in the business for 35 years he had seen too much of it to indulge in any facile optimism, but he was confident that there were still considerable possibilities latent in Cornwall. In contributing their joint paper, Dr. Hosking and he had endeavoured to indicate some of the areas, both old and new, that appeared to offer the best prospects for investigation.

In several of the papers that had been discussed the fact emerged that, in order to investigate the extension of known orebodies or to develop entirely new ones, old mines would sometimes have to be reopened. That applied to Cornwall as well as to other parts of the country and the speaker had therefore written the second paper in the hope that it might prove useful to other engineers faced with that sort of problem in future.

Whatever possibilities might be latent in some of the old West Country mines, he could not too strongly deprecate indiscriminate reopening of such properties. Far too much of that sort of thing had been done in the past and in consequence Cornwall had gained a bad reputation. He agreed with a previous speaker who had said that the old men rarely left anything of value in sight. They were very good miners and whatever the price of metal they usually completely cleaned out all the ore that they had discovered.

Nevertheless, it was still necessary at times to deal with an old mine. In doing so, the first essential was to be very clear as to the objectives of the reopening. If the intention was to sink further, the bottom of the mine should be reached as quickly as possible and the temptation to turn aside on the way down in order to investigate old workings should be sternly resisted. Likewise, if the object of the reopening was lateral exploration, old levels that were stoped and crushed should be avoided like the plague and new levels and crosscuts driven instead.

In his paper he had tried to deal briefly with the importance of adits, the interconnexion of mines, with the metals adopted for handling corrosive water, with particular reference to the unusual conditions prevailing at the South Crofty mine, and also with the means of estimating the amount of water to be dealt with in Cornish mines. The paper contained notes on the typically small West Country shafts, their dimensions and equipment, and discussed the question of vertical distance between levels. It concluded with a brief section on the availability of mining records in Cornwall.

Professor K. C. Dunham, responding to the Chairman's invitation for comments upon the papers presented by Dr. Hosking and Mr. Trounson, said Dr. Hosking had mentioned the recent gravity survey of South-West England. It was unfortunate that his paper should have come out quite so soon because very shortly the Royal Society was to

publish the results obtained by Dr. M. H. P. Bott and his collaborators on the form of the Cornish batholith (emphasizing that it was singular, not plural) as determined by gravimetric measurements on the surface. As Dr. Hosking had said, it was a remarkable fact that the form deduced from the distribution of mineral bodies was almost precisely confirmed by the form deduced from completely different lines of evidence — from observation of the variation of the force of gravity and of the magnetic field. He believed they could have no more striking proof than that of the positive relationship which existed between a group of mineral veins and an underlying batholith.

The fact remained that for the delimitation of the cusps of granite which had not yet been explored underground, further gravity and magnetic work was required, both on land and off the Cornish coast; and nowadays such work was perfectly feasible. Offshore work was, of course, expensive to undertake, for ships and special equipment were needed; but having regard to the convincing results obtained on the land, the work would be of real service to the Cornish industry and the development of the undersea areas.

Mr. F. B. Michell* said while he had nothing to add to the comments of Dr. Hosking and Mr. Trounson on the appraisal of certain areas, he did wish to speak on the paper which dealt with the difficulties likely to be encountered when assessing the mineral potential of certain Cornish areas.

In considering the recorded value of any particular lode as well as the production figures of any mine as given in old reports, one was faced with a number of problems about which little seemed to have been written; but he did not believe the task was as hopeless or the figures as entirely valueless as Dr. Hosking and Mr. Trounson appeared to imply on page 363.

It was necessary, however, to make an assessment involving at least four factors: (1) the units employed, (2) the grade of the concentrate, when the value was expressed as the quantity of mineral concentrate, (3) the loss incurred at the time in making such a concentrate, and (4) the accuracy of the determination of metal content.

Furthermore, it should be clearly understood that many of the output figures should be taken with considerable reserve. (Indeed, figures given in old numbers of the *Mining Journal* carried an editorial note to that effect.) An official figure indicating a very low output for one year was no real guide, as sometimes concentrate was taken elsewhere or ore was stamped on an adjoining property. In other words, those figures must be weighed with other evidence. The subject was too big to be dealt with adequately in a contribution to the discussion, but he hoped very shortly to prepare a paper covering the field more fully.

Considering, first, the units employed, in very old records tin ore output was given in sacks as it was customary to buy and sell by

* Mining and mineral dressing engineer; Vice-Principal, Camborne School of Metalliferous Mining.

measure, the sack containing from 8 to 18 gallons beer measure (of 282 cu. in.). Usually the 'sack' contained 11 or 12 gallons.

Later the tin produced was given in statute tons but for many years it was customary to report the amount of 'ore' stamped in terms of a 21-cwt ton. He believed that was the custom up to 1890. An examination of old records would show that the output of mines was sometimes stated in terms of 'black tin' sold and at other times in pounds sterling. The position, therefore, was difficult, but certain guides existed in making a valuation.

For example, in the year 1884 the black tin produced by the mines had an average produce of 66 per cent, while from stream-works it amounted to only 53 per cent. Some idea of associated minerals also often gave a clue to the possible grade.

The value of a lode *in situ*, however, was usually found to be expressed either in terms of the amount of concentrate produced or the sterling value per square fathom, but unfortunately, many old records did not give the lode width.

The percentage grade of copper ore was also expressed as 'produce' being determined by fire assay, and the ore was sold by a 21-cwt ton, dry weight.

As one might expect, the 'produce' varied considerably as there were many copper minerals with a wide variation in copper content, while pyrite frequently diluted the concentrate. In Cornwall, however, the variation in 'produce' was not great, being between $5\frac{1}{2}$ and $7\frac{3}{8}$ in 1856; but in Wales and Ireland the produce varied from 8 to 17. In cases where the 'produce' was not known, however, it was possible to obtain it, knowing the tonnage, the value received and the 'standard' or price of copper metal at the time.

Lead ores were also sold by a 21-cwt ton and the grade of concentrate varied fairly widely but on an average appeared to have been between 67 per cent and 76 per cent.

He concluded by pointing out that the value of tin ores was based on 'vanning' estimates* and that prior to 1850–60 the 'vanning' was carried out with a measured sample, using a half-noggin wine measure.

---

* Vanning is the term given to a hand-washing procedure employed for estimating the value of tin ores which usually also involves roasting to oxidize sulphides and sulparsenides and magnetic separation to remove any magnetic iron oxide.

An experienced operator will obtain consistent results on one type of ore, but with any considerable change in the character of the ore he may find it difficult to maintain consistency. It is easy to produce a slightly lower-grade concentrate and equally as easy to lose some of the cassiterite by attempting to make too clean a concentrate, by taking insufficient care with extremely fine cassiterite or by failing to grind the middling sufficiently.

The method is most valuable as a means of assessing the amount of recoverable mineral, in fact, one can say it represents a very simple recovery test and as such it is obvious that the liberation size and the degree of grinding will influence the result.

Being a simple operation, vanning is also an excellent means of providing day-to-day valuations, provided results are checked periodically by chemical analysis. The use of a chemical assay only for the valuation of an ore can be equally misleading as an inaccurate vanning result, however, as it gives no indication of the recoverable cassiterite.—F. B. MICHELL.

taken place there had been entirely due to the change in the Government's policy towards mining and there would have to be a similar change in Great Britain before any really costly exploration could take place. That point should be underlined by all who might speak on the subject.

The Chairman said he wished, before calling upon the next speaker, to emphasize his complete agreement with what had been said by Mr. Gill. There would be an opportunity later for discussing the question of taxation in relation to mining but he was personally perfectly satisfied that before they could expect to see any major developments in regard to the mineral potential, the right fiscal climate would have to be created.

They had to create the position in which a prospector could reasonably expect a high rate of interest and could hope to get his money — whatever capital he might invest — back over the life of the mine.

Until those two conditions had been achieved he could foresee no very great development of minerals in Britain.

Major Brian Llewellyn said he felt hardly qualified to comment upon the excellent combined paper but he thought Mr. Trounson was to be congratulated on having the courage to bring up the subject of level intervals in Cornish mines, to which he had referred on page 381.

On grounds of economy in main and subsidiary development the tendency had been to increase intervals without proper regard to subsequent stoping difficulties, which in shrinkage stoping were inevitable with flucany hanging-walls. He could not agree with the author, however, that the reclamation of a single shaft was sufficient. He considered that two were necessary for ventilation purposes, especially in a deep mine.

In regard to pumping figures, many members might be interested to know that most of them were also published by H. T. De La Beche.*

Professor W. R. Jones said there had been some use that morning of the terms 'black tin' and 'block tin'. They owed to Cornwall many good mining terms but surely the use of those two expressions should now be discarded. A printer had only to change the letter 'a' to an 'o' (as had been done inadvertently some years ago in a prospectus) to effect what no mining engineer had ever been able to do — a sudden increase of 25 per cent in the value of a property!

He suggested that instead of the term 'black tin' they should use 'tin concentrate'; and instead of 'block tin', 'tin metal'. That would be in keeping with modern practice and would avoid confusion.

Reverting to Mr. Gill's comment that somebody had banged the table in Ireland and that had led to the developments at Avoca, he said in fact there was no table-banging. He himself had been consulted at the time and had sat round a table with the Cabinet of the Dail Eireann

* De La Beche, *Sir* H. T. *Report on the geology of Cornwall, Devon, and West Somerset* (London: H.M.S.O., 1839).

whose members had patiently and willingly considered his recommendations. It was that kind of approach that had led to the financing of the great enterprise at Avoca.

Mr. L. G. Brown* apologized for speaking at all in view of the fact that three representatives of his Association were already on the platform; but, being there, they were not really in a position to speak, as he could, on behalf of the Association.

He said the Cornish Mining Development Association welcomed the opportunity to take part in the Symposium for many reasons but chiefly perhaps for the sake of the resultant publicity which it should arouse for the policy their Association had been advocating for ten years. In those years it had dealt at some length with (*a*) the technical aspects of the case (he referred his hearers to the Memorandum on the Mineral Areas in Cornwall Worthy of Investigation, December 1950, a copy of which had been submitted to the Symposium Committee); (*b*) the fiscal aspects of the case (his Association had published a Memorandum of Taxation Policy and another on the Incidence of Development Charges, copies of which had also been submitted); and (*c*) the question of the supply of metals for world consumption, which had an important bearing on their case for the revival of mining in Britain. He referred his hearers to the address given by the chairman to the Truro Conference with Cornish Members of Parliament.

During that time, also, they had attempted to work through Parliamentary channels by various means — staging conferences with local M.P.s, getting at least two Parliamentary Questions asked each Session, initiating delegations and personal contacts between their members and the Ministers of the various Departments concerned, up to and including the Chancellor of the Exchequer; and also by inducing M.P.s from time to time to sponsor Motions before the House on the Finance Bill.

In all this they had had excellent co-operation from their local M.P.s, regardless of their political affiliations, but their efforts had been of no positive avail. He was proud to see Mr. Douglas Marshall there and greatly appreciated his presence. He hoped they would all benefit as a result.

At the time of the formation of the Cornish Mining Development Association a Labour Government had been in power. That had given way to a Conservative administration in 1951. That had involved reorientating their attack on a different set of Ministers who had since been constantly changing. So far they had not succeeded in persuading either political party that any action was required. Fundamentally, it was the permanent officials at the Treasury who had to be 'converted'.

In the course of the past ten years the Association had also been in touch with the County Planning Office, the Central Land Board, local Chambers of Commerce, the Registry of Mining Records and the County Archives, the South-West Regional Board of Trade, the Organisation for European Economic Co-operation of the United

* Mining engineer, English Clays, Lovering, Pochin and Co., Ltd.; Honorary General Secretary of the Cornish Mining Development Association

Nations, the Federation of British Industries, the local Tin Producers' Association (with regard to health and safety precautions, foreign labour, etc.) and the Federation of Chambers of Commerce and Trade Associations of Cornwall.

Nevertheless in the past two or three years and despite all this activity, they had been forced to the conclusion that they were getting nowhere. The creation of U.K.M.M.A. and the conjunction of that body with the I.M.M. in the calling of the Symposium had raised their hopes that at last forces of considerable magnitude and influence were being gathered together, that would have the power to demand attention to their legitimate aims. They had been working for the benefit, primarily, of their own county or region; but they realized that every argument they had used and every theme of policy pursued could be applied to the United Kingdom as a whole, and with a better chance of being heard by a wider audience. It was in that spirit, and with those hopes, that they participated in the Symposium.

They had been asked not to dwell on either the geological or historical aspects of Cornish mining, as it was felt that those matters were well-known throughout the mining profession as a whole, and thus to those present. While agreeing with that in principle and realizing that the time of the Symposium was strictly limited, he wished to point out that the deliberations of the Symposium surely were intended for a much wider audience still most lamentably ignorant of the glorious past of British metal mining, and of its potential importance in the near future.

A rough estimate made after a quick perusal of the pre-prints of the score or more papers showed that two-fifths of the space was devoted to geology and about one-fifth to history; so it was obvious that other areas agreed with them on the importance of those aspects. For that reason they could not be ignored. Geologically, they were content to rest their case on the substance of their memorandum on the Mineral Areas in Cornwall Worthy of Investigation.

Looking to the historical side, tin production started in pre-history and had continued throughout the historical period to a peak of some 10 000 tons per annum for the period 1870–90 and had since fallen back to about 1200 tons per annum from two mines only. Copper mining had started later than tin — much later — had reached a peak of some 12 000 tons per annum between 1830 and 1860 and had then fallen to vanishing point before the end of the century.

Lead was produced to the amount of over 300 000 tons in the latter half of the nineteenth century, from which were extracted some 7 000 000 oz of silver. Other metals in great variety but small quantities appeared in the records, such as tungsten, zinc, iron, arsenic, manganese, nickel, uranium and others. At its peak the mining industry employed some 30 000 persons, working over 300 mines.

It was not expected that copper mining would ever again feature greatly in the metal production from Cornwall, but no one had ever suggested that the tin ore there was exhausted. On the contrary, the weight of expert opinion was that there was far more tin still in the

ground than had ever come out of it during recorded history. He referred those present to Major Llewellyn's paper of 1946.*

Further there were available to-day ore-dressing processes which had been absolutely unknown in the nineteenth century. There was no reason why a tin mine should not produce to-day, as a series of by-products, other metals such as copper, lead, zinc, arsenic and iron, as well as other substances such as sulphur, fluorspar and barytes.

In some of the papers which had been submitted it had been implied that the need to re-assess the mineral resources of the United Kingdom had arisen only in the last few years; but that was not so. They themselves had been at it for ten years but ever since the first world war various leading personalities of the industry had been hammering away at the subject. Three Presidents of the Institution had used the theme, in one form or another, for their Presidential Addresses. A dozen or more papers had been presented to the Institution. The theme had been supported by the technical publications of the industry. But he submitted that all this was insufficient unless it reached the general public and held their interest to such an extent that their political masters were forced to take the matter seriously.

It was to be hoped that full arrangements had been made by the convenors of the Symposium for this wider publicity by Press, radio and even, he hoped, television. If the only result of the Symposium was that they had merely been once more talking over the subject between themselves, he was afraid it must be counted as a failure, however pleasant it may have been as a social occasion and re-union.

The Chairman commented that the word 'politics' had been mentioned. He was most anxious that no one should run away with the idea that there was any party political feeling in regard to support for British metal mining.

A year or two ago he had asked an old friend of his, the late Earl Jowitt (Lord Chancellor in the last Socialist Government), to speak in the House of Lords on the subject and advocate an alteration in the system of taxing metal mines, which he had done, but Lord Jowitt had been met with the reply that the Treasury did not see any reason to alter the existing system of taxation.

To-day another champion of Cornish mining and of the case for alteration of the system of taxation — Mr. Douglas Marshall — was with them. He was the Conservative Member of Parliament for South-East Cornwall. As Chairman he hoped that in asking Mr. Marshall to speak he would not be deemed to be putting him forward in any political sense.

Mr. Douglas Marshall, M.P.,† said though he felt some anxiety in addressing an assembly of such wide technical knowledge he was glad to have been invited to speak because he had been greatly interested in

* A survey of the deeper tin zones in a part of the Carn Brea area, Cornwall. *Trans. Instn Min. Metall., Lond.*, **55**, 1945–46, 505–523.

† Member of Parliament for Bodmin, Cornwall.

everything that had been said. He had noted that Mr. Trounson had said those who were optimistic about the mineral wealth of Cornwall were regarded as irresponsible. If that were so he saw no reason why one should not be optimistic, particularly when one reflected what were the feelings of the nation at the time of Dunkirk and such feelings led to victory.

The only way to get things moving was to have real faith in what they were doing and at the same time to be optimistic in regard to that faith. 'Re-capping' briefly what had been said from the platform, and what had no doubt been going through the minds of many of those present: technically they believed there was every reason to assume there was mineral wealth in Cornwall not yet developed and which could be commercially profitable. The thought which followed was that they were stopped from pursuing it by what seemed to be the national decision that, at this moment, the taxation impact could not be altered. If the first be true then the second was ridiculous not to have altered.

He suggested that by their own faith they had to make that impact, not only by talking to each other on technical subjects which they understood, but by realizing that to achieve their dreams they had to make possible the political concept. There had been mention of the necessity for a change in the economic climate; but in fact there had been such a change. It was for them to take advantage of the change.

They must not run away with the idea that a Budget which came out in April was framed in February. As in any great business, that began its conception round about the autumn. He had found no difficulty in approaching Cabinets or Chancellors of the Exchequer or anyone else. It was for them to make the impact felt immediately.

For his own part, he had faith in the project. He did not go towards it in any mood of emotional sentimentalism, but rather with the thought that, first, they must create the possibility of development and then, having succeeded in drawing upon the wealth which God had given this country, after three to five years of production, by the normal process of taxation, the nation gained, the Chancellor of the Exchequer gained and the people of Britain gained — and they would have proved their faith.

Mr. Trounson, in reply to Major Llewellyn, said that he quite agreed that ventilation had to be watched very carefully and, where necessary, a second shaft might have to be cleared in order to secure adequate ventilation. What he was opposed to, however, was the spending of great sums of money on the reconditioning and equipment of several shafts where one might be quite adequate for the proving of the mine.

As far as the control of broken ore in stopes was concerned, and its relationship to the length of the lift, that was a thorny problem and one that was giving a great deal of trouble at the South Crofty mine at the present time.

Dr. Hosking also made a brief acknowledgement of speakers' contributions.

WRITTEN CONTRIBUTION

on *The Mineral Potential of Cornwall*

Mr. Brian Llewellyn: Mineralization is closely related to tectonic movement and regional metamorphism, and so miners recognized long ago that an area of complex faulting generally yielded the richest ore. They also sensed what has been so ably epitomized by the authors in this paper, namely that there was some connexion between mineral deposits and mountain ridges (of igneous rock?), for Agricola* says: 'The miner should not dig in those solitary mountains, dispersed through the plains and open regions, but only in those which are connected and joined with others.'

In this respect Cornwall has the unique advantage of being plentifully endowed with such dislocations and, indeed, it seems possible that ground movements are still taking place, although they may no longer be cataclysmic. While it is as difficult to predict with any degree of certainty the mineral potential of Cornwall as it is in some cases that of a particular tin mine, no matter how carefully the selection has been made, it can be stated with confidence that the general conditions are so favourable that the earlier miners were induced to win tin ore in what would nowadays be considered almost fantastic circumstances.

The writer has long held the view that the earliest orogeny, that of West Cornwall, was connected with the Caledonian movement (late Silurian–early Devonian) and that much of the fissuring and jointing took place at that time, while other structural strains were imposed. It seems doubtful whether this movement extended as far eastward as East Cornwall and West Devon. The later Armorican movement, with East–West folding, extended throughout the whole area and was responsible for both the mineralization and the formation of the N–S crosscourses. The details presented in Fig. 2 (p. 360) seem to confirm this hypothesis.

The answer to the mineralization or otherwise of the crosscourses would appear to lie in the characteristics of their formation: dynamic due to thrust or rotation, which might be expected to give rise to mineral injection, or simple strain relief, which would not provide the appropriate channels for ore deposition. As many crosscourses persist in strike for several miles, it seems probable that these characteristics vary along their course and I should like to ask the authors if they have investigated this subject, which is of cogent application to some classes of deposit and particularly to those of lead-zinc-silver.

There is no doubt that the temperature-pressure relationship has considerable bearing on tin deposition. This bearing, being bound up with such unknown variables as dynamic metamorphism, weight of superincumbent rock, penetrability of the feeder channel and even conductivity of the enclosing rock, greenstone extrusives, etc., is so

* AGRICOLA, GEORGIUS. *De re metallica.* Hoover translation of the first Latin edition of 1556 (London: *Mining Magazine*). Section relating to Book II, p. 30.

Every pennyweight recovered from one gill was taken as equal to 160 lb per 100 sacks. A calculation showed that a pennyweight per gill should be equal to 240 lb not 160 lb. and the difference was allowed for loss in dressing. From the present-day point of view that is considerable and should be taken into account.

The practice of measuring samples persisted at least until 1859 and probably there were variations of 20–30 per cent because of variation in measures, specific gravity and other factors. There was also the fact that the vanning results (and this applied to vanning results at the present time, for the practice was still in force) could mean very little unless the grade of concentrate produced was known.

Vanning estimates were valuable as giving some estimate of the recoverable cassiterite but it had to be understood that the results should always be considered with the chemical assay. Likewise, a chemical assay alone was misleading and in some cases valueless because there was no indication of what might be recovered. With a simple ore one might recover, with a very coarse dissemination, as much as 95 per cent of the amount shown by chemical assay (although usually it was about 80 per cent), whereas with a very fine dissemination the recovery might be under 50 per cent.

It should always be remembered, therefore, that while vanning was a very useful method, it gave results which should be treated with care and if possible considered in conjunction with chemical assays.

Mr. D. Gill* said it appeared that the authors believed very strongly in the potential of Cornwall for the future production of tin. He entirely agreed with them. They had mentioned fourteen sub-areas or specially favourable places, and there again he was in general agreement with them. The real question was: How was that potential to be realized?

It appeared that there was a vicious circle which must be broken. The cost of developing any one of the fourteen areas mentioned was going to be very high. What mining group to-day would put up several hundred thousand pounds to cover the cost of investigating one of the areas unless the fiscal climate was changed?

On the other hand, the present attitude of the Government appeared to be that they would not change that climate unless somebody demonstrated that there were large orebodies which could be exploited. That vicious circle must be broken. Someone, at some time, had jogged the Government and banged the table in Ireland and a more favourable financial atmosphere was created. To-day the result was to be seen in the development at Avoca and elsewhere.

The problem for Great Britain, and especially for Cornwall, was thus a purely political one — the task of effecting a similar change in outlook. Who, some fifteen years ago, would have prophesied the developments that they had seen taking place in Ireland? He did not believe anybody would have done so. The developments which had

* Consulting mining engineer.

complex that it is beyond the scope of this concise paper, on which I congratulate the authors.

Finally, the extent of erosion of the granite batholiths is of the greatest importance, when it is considered that the surface level at the time of maximum ore deposition would be between 9000 and 15 000 ft higher than it is at the present day.

AUTHORS' WRITTEN REPLY

Dr. Hosking and Mr. Trounson: We are grateful to Mr. Brian Llewellyn for his most valuable comments.

We agree that the mineralization phenomena of the Cornish crosscourses are both extremely interesting and economically important, and had not a limit been put on the length of the paper we would have dealt with this topic in some detail. Briefly, however, we are of the opinion that the degree, etc., of mineralization of any crosscourse depends on when it was developed and opened. Early crosscourses contain Cu, Co, Ni, U, etc., while those which came into being somewhat later contain Pb, Zn, Ag and Fe. Crosscourses which were not opened until the last phase of mineralization hold little more than barren quartz, while the distinctly post-mineralization faults are filled solely with fault-clay and breccia.

It is, perhaps, pertinent to record that one of the writers (K. H.) is at present investigating the antimony-bearing lodes of N.E. Cornwall. Are these bodies genetically related to the granite—as is commonly believed—or are they essentially the products of differentiation of the magma from which the spilites formed? Some of the antimony lodes—at least—are spatially closely related to the spilites.

JOINT DISCUSSION

Dr. K. F. G. Hosking, introducing the paper on the mineral potential of Cornwall, said that as it was virtually impossible to make an adequate assessment of the Cornish mineral potential within the space of a few pages, Mr. Trounson and he had decided to limit their observations to three topics. They had elected first to state, without elaboration, the fundamental distribution — and other major — characteristics of the Cornish orebodies, and from those they had sought to determine the factors controlling the distribution and nature of the lodes, in particular those containing cassiterite and wolframite.

They had largely neglected the mesothermal lodes but some had been discussed by Mr. Vipan; and the Cornish uranium lodes had not been mentioned as they were being investigated by the Atomic Energy Branch of the Geological Survey.*

Alluvial deposits, also, had been omitted, although the stanniferous beach-sands of the Hayle/Godrevy area were certainly not without potential and would probably be worked on a large scale were they, for example, in Malaya or Siam.

Secondly, they had noted certain difficulties associated with the investigation of mineral deposits, and of old mines, in Cornwall; and finally they had briefly described a few areas, which, from the evidence at present available, appeared to them to have some potential.

Dr. Hosking then said that he wished to emphasize the following facts which must be constantly borne in mind when considering the merits of any Cornish area:

(i) Pegmatites were few and small, and although some contained cassiterite and wolframite they were of no great economic value. A few had been worked, particularly where they were associated with 'normal' lodes. They did not always fit into the primary zone pattern of the hypothermal lodes.

(ii) The narrow, greisen-bordered, cassiterite/wolframite veins, which were characteristically associated with the apices of granite cusps (as at Hemerdon, Cligga, St. Michael's Mount, etc.), were of marginal economic importance. They did not appear to coalesce in depth and were quite distinct from the important tin-bearing lodes of the South Crofty type. Economically important 'normal' lodes often occurred near such mineralized cusps, and, therefore, the latter should be used as pointers to areas worthy of examination.

(iii) In any limited area most of the early lodes and dykes possessed the same general strike and many lode/dyke streams were apparent on Fig. 1 (Plate I) of the paper. It was to be noted that those streams were not confined to the junctions of the killas and the major granite outcrops, and that many of those junctions were quite devoid of lodes.

Following Emmons' teachings they believed that the early lodes and dykes were associated with granite ridges with undulating crest-lines,

* See p. 483.

and that in any given area the strikes of the majority of the lodes and dykes were approximately parallel to that of the associated ridge. A ridge might be still partly hidden by killas or, as a result of differential erosion, it might be a quite prominent feature of the landscape. In some instances parts of ridges had been largely obliterated.

Certain lodes with anomalous strikes might occupy pre-granite faults, or faults developed during the emplacement of the granite.

(iv) Centres of mineralization — Dines's emanative centres — were somewhat irregularly distributed, but, in the speaker's opinion, they were associated with the original 'high spots' — cusps — on the granite ridges. Typical examples of cusp/emanative-centre association occurred at St. Agnes, Carn Brea, Kit Hill and Hingston Downs.

(v) The most intense early mineralization occurred within the St. Agnes/Carn Marth/Carn Brea/Godolphin quadrangle. The intensity of the mineralization decreased progressively to the northeast and southwest.

(vi) The early tin/tungsten lodes of major economic importance owed their development to the ascent of mineralizing agents along fissures which were often repeatedly reopened by faulting. Usually the faults were of the normal type, but on occasion lateral movement was prominent. The lodes were developed by deposition within open spaces and by intense replacement of the wall-rock.

(vii) Because the major phase of lode development was of comparatively short duration, and also because the nature of the lode-forming agents was changing fairly quickly, the minerals were deposited in zones — the first to be deposited being nearest the source. Those primary zones — which had been investigated at length by Dines — were often flatter than the associated granite/killas contacts, and later zones were more extensive in plan than earlier, deeper ones. Thus, tin was only likely to be found in economic amounts beneath copper near the centres of mineralization.

Within the lodes a certain amount of telescoping was sometimes apparent, and the mesothermal phase of mineralization was locally so prolonged that lead, zinc, silver, etc., were deposited in the original tin zone, but usually in a completely different set of fissures.

In some areas the economic limits of the tin zone could only be determined very approximately. At South Crofty mine, for example, the upper and lower limits of the productive tin zone were far from being straight lines when plotted on transverse sections.

(viii) As a result of erosion, mines in the granite, and well inside the granite/killas junction, were likely to be shallow and to contain only the narrow roots of lodes which were usually characterized by containing fine, and, therefore, not easily recovered, cassiterite.

(ix) Mining the earlier lodes was rendered somewhat difficult because they were displaced by mesothermal lodes and barren crosscourses. Furthermore, the rapid, and often quite unpredictable, changes in the width and value of a particular lode within short distances also added to the difficulties of mining, evaluation and prospection (particularly by diamond-drilling).

As the authors believed that tin lodes of importance occurred in the vicinity of granite cusps they entirely agreed with Dines's suggestion that the ground below the sea in the vicinity of St. Agnes was well worth while examining, and they also thought the same applied to the submarine area near Cligga and, to a lesser extent, to certain other similar areas.

They believed that geophysicists would be doing a great service to Cornwall — and to a number of similar foreign areas — were they to develop a method — if one did not exist — for locating concealed granite cusps.

In concluding, they wished to acknowledge the fact that the skeletal geologic structure shown in Fig. 2 (p. 360) was based on Plate XXIV of Hendricks's work* and to state that the indicated form of the batholith — which was postulated a decade ago by one of them (K. H.) — agreed, in essence, with that arrived at by Dr. Bott (of the University of Durham) and his co-workers as a result of comparatively recent geophysical investigations. So far as they were aware Dr. Bott's work had not been published but they hoped that Professor Dunham would comment on it.

Mr. J. H. Trounson recalled that Mr. Anton Gray had pointed out in his lecture that, whatever might be said of the other base metals, there was indeed a very close association between the occurrence of tin and the presence of granite, though that rock might be hidden. Dr. Hosking had therefore rightly emphasized the importance of determining the form of the West of England batholith as a means of locating further economic tin lodes.

While he did not wish to suggest that Cornwall could produce a tin mine comparable with Avoca as a copper producer, he was confident that there were still excellent chances of making important discoveries in Cornwall. The Duchy was frequently spoken of as being an exhausted field but the same had been said of Ireland and they now knew that that was far from being the case. If they took a sane and balanced view of the prospects in Cornwall and used their brains to avoid the mistakes of the past there was good reason for thinking that a lot of successful mining would yet take place there.

On the previous day mention had been made of an excellently equipped and well managed lead mine in the north. He could but wish that all those present were able to visit the Geevor mine in Cornwall which was a splendid example of a successful tin mine. When considering such properties, however, they did well to remember that they had been opened up and equipped at a time when taxation was far less onerous; indeed it was now practically impossible to create such mines in Britain. He felt, therefore, that if there were to be any future for metalliferous mining in the country they had to convince Government

* HENDRICKS, E. M. L. Rock succession and structure in South Cornwall: A revision. With notes of the central European facies and variscan folding there present. *Quart. J. geol. Soc. Lond.*, **93**, 1937, 322–67.

of the imperative need to co-operate with private enterprise as the Irish Government had done recently with very fruitful results.

Dr. Hosking had drawn attention to the possibility of new discoveries or even entirely new mining areas being found in Cornwall. Dr. Hosking was a geologist whereas he (Mr. Trounson) was a miner, but he entirely agreed with him in the matter. Having been in the business for 35 years he had seen too much of it to indulge in any facile optimism, but he was confident that there were still considerable possibilities latent in Cornwall. In contributing their joint paper, Dr. Hosking and he had endeavoured to indicate some of the areas, both old and new, that appeared to offer the best prospects for investigation.

In several of the papers that had been discussed the fact emerged that, in order to investigate the extension of known orebodies or to develop entirely new ones, old mines would sometimes have to be reopened. That applied to Cornwall as well as to other parts of the country and the speaker had therefore written the second paper in the hope that it might prove useful to other engineers faced with that sort of problem in future.

Whatever possibilities might be latent in some of the old West Country mines, he could not too strongly deprecate indiscriminate reopening of such properties. Far too much of that sort of thing had been done in the past and in consequence Cornwall had gained a bad reputation. He agreed with a previous speaker who had said that the old men rarely left anything of value in sight. They were very good miners and whatever the price of metal they usually completely cleaned out all the ore that they had discovered.

Nevertheless, it was still necessary at times to deal with an old mine. In doing so, the first essential was to be very clear as to the objectives of the reopening. If the intention was to sink further, the bottom of the mine should be reached as quickly as possible and the temptation to turn aside on the way down in order to investigate old workings should be sternly resisted. Likewise, if the object of the reopening was lateral exploration, old levels that were stoped and crushed should be avoided like the plague and new levels and crosscuts driven instead.

In his paper he had tried to deal briefly with the importance of adits, the interconnexion of mines, with the metals adopted for handling corrosive water, with particular reference to the unusual conditions prevailing at the South Crofty mine, and also with the means of estimating the amount of water to be dealt with in Cornish mines. The paper contained notes on the typically small West Country shafts, their dimensions and equipment, and discussed the question of vertical distance between levels. It concluded with a brief section on the availability of mining records in Cornwall.

Professor K. C. Dunham, responding to the Chairman's invitation for comments upon the papers presented by Dr. Hosking and Mr. Trounson, said Dr. Hosking had mentioned the recent gravity survey of South-West England. It was unfortunate that his paper should have come out quite so soon because very shortly the Royal Society was to

measure, the sack containing from 8 to 18 gallons beer measure (of 282 cu. in.). Usually the 'sack' contained 11 or 12 gallons.

Later the tin produced was given in statute tons but for many years it was customary to report the amount of 'ore' stamped in terms of a 21-cwt ton. He believed that was the custom up to 1890. An examination of old records would show that the output of mines was sometimes stated in terms of 'black tin' sold and at other times in pounds sterling. The position, therefore, was difficult, but certain guides existed in making a valuation.

For example, in the year 1884 the black tin produced by the mines had an average produce of 66 per cent, while from stream-works it amounted to only 53 per cent. Some idea of associated minerals also often gave a clue to the possible grade.

The value of a lode *in situ*, however, was usually found to be expressed either in terms of the amount of concentrate produced or the sterling value per square fathom, but unfortunately, many old records did not give the lode width.

The percentage grade of copper ore was also expressed as 'produce' being determined by fire assay, and the ore was sold by a 21-cwt ton, dry weight.

As one might expect, the 'produce' varied considerably as there were many copper minerals with a wide variation in copper content, while pyrite frequently diluted the concentrate. In Cornwall, however, the variation in 'produce' was not great, being between $5\frac{1}{2}$ and $7\frac{3}{8}$ in 1856; but in Wales and Ireland the produce varied from 8 to 17. In cases where the 'produce' was not known, however, it was possible to obtain it, knowing the tonnage, the value received and the 'standard' or price of copper metal at the time.

Lead ores were also sold by a 21-cwt ton and the grade of concentrate varied fairly widely but on an average appeared to have been between 67 per cent and 76 per cent.

He concluded by pointing out that the value of tin ores was based on 'vanning' estimates* and that prior to 1850–60 the 'vanning' was carried out with a measured sample, using a half-noggin wine measure.

---

* Vanning is the term given to a hand-washing procedure employed for estimating the value of tin ores which usually also involves roasting to oxidize sulphides and sulparsenides and magnetic separation to remove any magnetic iron oxide.

An experienced operator will obtain consistent results on one type of ore, but with any considerable change in the character of the ore he may find it difficult to maintain consistency. It is easy to produce a slightly lower-grade concentrate and equally as easy to lose some of the cassiterite by attempting to make too clean a concentrate, by taking insufficient care with extremely fine cassiterite or by failing to grind the middling sufficiently.

The method is most valuable as a means of assessing the amount of recoverable mineral, in fact, one can say it represents a very simple recovery test and as such it is obvious that the liberation size and the degree of grinding will influence the result.

Being a simple operation, vanning is also an excellent means of providing day-to-day valuations, provided results are checked periodically by chemical analysis. The use of a chemical assay only for the valuation of an ore can be equally misleading as an inaccurate vanning result, however, as it gives no indication of the recoverable cassiterite.—F. B. MICHELL.

Every pennyweight recovered from one gill was taken as equal to 160 lb per 100 sacks. A calculation showed that a pennyweight per gill should be equal to 240 lb not 160 lb. and the difference was allowed for loss in dressing. From the present-day point of view that is considerable and should be taken into account.

The practice of measuring samples persisted at least until 1859 and probably there were variations of 20–30 per cent because of variation in measures, specific gravity and other factors. There was also the fact that the vanning results (and this applied to vanning results at the present time, for the practice was still in force) could mean very little unless the grade of concentrate produced was known.

Vanning estimates were valuable as giving some estimate of the recoverable cassiterite but it had to be understood that the results should always be considered with the chemical assay. Likewise, a chemical assay alone was misleading and in some cases valueless because there was no indication of what might be recovered. With a simple ore one might recover, with a very coarse dissemination, as much as 95 per cent of the amount shown by chemical assay (although usually it was about 80 per cent), whereas with a very fine dissemination the recovery might be under 50 per cent.

It should always be remembered, therefore, that while vanning was a very useful method, it gave results which should be treated with care and if possible considered in conjunction with chemical assays.

Mr. D. Gill* said it appeared that the authors believed very strongly in the potential of Cornwall for the future production of tin. He entirely agreed with them. They had mentioned fourteen sub-areas or specially favourable places, and there again he was in general agreement with them. The real question was: How was that potential to be realized?

It appeared that there was a vicious circle which must be broken. The cost of developing any one of the fourteen areas mentioned was going to be very high. What mining group to-day would put up several hundred thousand pounds to cover the cost of investigating one of the areas unless the fiscal climate was changed?

On the other hand, the present attitude of the Government appeared to be that they would not change that climate unless somebody demonstrated that there were large orebodies which could be exploited. That vicious circle must be broken. Someone, at some time, had jogged the Government and banged the table in Ireland and a more favourable financial atmosphere was created. To-day the result was to be seen in the development at Avoca and elsewhere.

The problem for Great Britain, and especially for Cornwall, was thus a purely political one — the task of effecting a similar change in outlook. Who, some fifteen years ago, would have prophesied the developments that they had seen taking place in Ireland? He did not believe anybody would have done so. The developments which had

* Consulting mining engineer.

taken place there had been entirely due to the change in the Government's policy towards mining and there would have to be a similar change in Great Britain before any really costly exploration could take place. That point should be underlined by all who might speak on the subject.

The Chairman said he wished, before calling upon the next speaker, to emphasize his complete agreement with what had been said by Mr. Gill. There would be an opportunity later for discussing the question of taxation in relation to mining but he was personally perfectly satisfied that before they could expect to see any major developments in regard to the mineral potential, the right fiscal climate would have to be created.

They had to create the position in which a prospector could reasonably expect a high rate of interest and could hope to get his money — whatever capital he might invest — back over the life of the mine.

Until those two conditions had been achieved he could foresee no very great development of minerals in Britain.

Major Brian Llewellyn said he felt hardly qualified to comment upon the excellent combined paper but he thought Mr. Trounson was to be congratulated on having the courage to bring up the subject of level intervals in Cornish mines, to which he had referred on page 381.

On grounds of economy in main and subsidiary development the tendency had been to increase intervals without proper regard to subsequent stoping difficulties, which in shrinkage stoping were inevitable with flucany hanging-walls. He could not agree with the author, however, that the reclamation of a single shaft was sufficient. He considered that two were necessary for ventilation purposes, especially in a deep mine.

In regard to pumping figures, many members might be interested to know that most of them were also published by H. T. De La Beche.*

Professor W. R. Jones said there had been some use that morning of the terms 'black tin' and 'block tin'. They owed to Cornwall many good mining terms but surely the use of those two expressions should now be discarded. A printer had only to change the letter 'a' to an 'o' (as had been done inadvertently some years ago in a prospectus) to effect what no mining engineer had ever been able to do — a sudden increase of 25 per cent in the value of a property!

He suggested that instead of the term 'black tin' they should use 'tin concentrate'; and instead of 'block tin', 'tin metal'. That would be in keeping with modern practice and would avoid confusion.

Reverting to Mr. Gill's comment that somebody had banged the table in Ireland and that had led to the developments at Avoca, he said in fact there was no table-banging. He himself had been consulted at the time and had sat round a table with the Cabinet of the Dail Eireann

* De La Beche, *Sir* H. T. *Report on the geology of Cornwall, Devon, and West Somerset* (London: H.M.S.O., 1839).

whose members had patiently and willingly considered his recommendations. It was that kind of approach that had led to the financing of the great enterprise at Avoca.

Mr. L. G. Brown* apologized for speaking at all in view of the fact that three representatives of his Association were already on the platform; but, being there, they were not really in a position to speak, as he could, on behalf of the Association.

He said the Cornish Mining Development Association welcomed the opportunity to take part in the Symposium for many reasons but chiefly perhaps for the sake of the resultant publicity which it should arouse for the policy their Association had been advocating for ten years. In those years it had dealt at some length with (*a*) the technical aspects of the case (he referred his hearers to the Memorandum on the Mineral Areas in Cornwall Worthy of Investigation, December 1950, a copy of which had been submitted to the Symposium Committee); (*b*) the fiscal aspects of the case (his Association had published a Memorandum of Taxation Policy and another on the Incidence of Development Charges, copies of which had also been submitted); and (*c*) the question of the supply of metals for world consumption, which had an important bearing on their case for the revival of mining in Britain. He referred his hearers to the address given by the chairman to the Truro Conference with Cornish Members of Parliament.

During that time, also, they had attempted to work through Parliamentary channels by various means — staging conferences with local M.P.s, getting at least two Parliamentary Questions asked each Session, initiating delegations and personal contacts between their members and the Ministers of the various Departments concerned, up to and including the Chancellor of the Exchequer; and also by inducing M.P.s from time to time to sponsor Motions before the House on the Finance Bill.

In all this they had had excellent co-operation from their local M.P.s, regardless of their political affiliations, but their efforts had been of no positive avail. He was proud to see Mr. Douglas Marshall there and greatly appreciated his presence. He hoped they would all benefit as a result.

At the time of the formation of the Cornish Mining Development Association a Labour Government had been in power. That had given way to a Conservative administration in 1951. That had involved reorientating their attack on a different set of Ministers who had since been constantly changing. So far they had not succeeded in persuading either political party that any action was required. Fundamentally, it was the permanent officials at the Treasury who had to be 'converted'.

In the course of the past ten years the Association had also been in touch with the County Planning Office, the Central Land Board, local Chambers of Commerce, the Registry of Mining Records and the County Archives, the South-West Regional Board of Trade, the Organisation for European Economic Co-operation of the United

* Mining engineer, English Clays, Lovering, Pochin and Co., Ltd.; Honorary General Secretary of the Cornish Mining Development Association

Nations, the Federation of British Industries, the local Tin Producers' Association (with regard to health and safety precautions, foreign labour, etc.) and the Federation of Chambers of Commerce and Trade Associations of Cornwall.

Nevertheless in the past two or three years and despite all this activity, they had been forced to the conclusion that they were getting nowhere. The creation of U.K.M.M.A. and the conjunction of that body with the I.M.M. in the calling of the Symposium had raised their hopes that at last forces of considerable magnitude and influence were being gathered together, that would have the power to demand attention to their legitimate aims. They had been working for the benefit, primarily, of their own county or region; but they realized that every argument they had used and every theme of policy pursued could be applied to the United Kingdom as a whole, and with a better chance of being heard by a wider audience. It was in that spirit, and with those hopes, that they participated in the Symposium.

They had been asked not to dwell on either the geological or historical aspects of Cornish mining, as it was felt that those matters were well-known throughout the mining profession as a whole, and thus to those present. While agreeing with that in principle and realizing that the time of the Symposium was strictly limited, he wished to point out that the deliberations of the Symposium surely were intended for a much wider audience still most lamentably ignorant of the glorious past of British metal mining, and of its potential importance in the near future.

A rough estimate made after a quick perusal of the pre-prints of the score or more papers showed that two-fifths of the space was devoted to geology and about one-fifth to history; so it was obvious that other areas agreed with them on the importance of those aspects. For that reason they could not be ignored. Geologically, they were content to rest their case on the substance of their memorandum on the Mineral Areas in Cornwall Worthy of Investigation.

Looking to the historical side, tin production started in pre-history and had continued throughout the historical period to a peak of some 10 000 tons per annum for the period 1870–90 and had since fallen back to about 1200 tons per annum from two mines only. Copper mining had started later than tin — much later — had reached a peak of some 12 000 tons per annum between 1830 and 1860 and had then fallen to vanishing point before the end of the century.

Lead was produced to the amount of over 300 000 tons in the latter half of the nineteenth century, from which were extracted some 7 000 000 oz of silver. Other metals in great variety but small quantities appeared in the records, such as tungsten, zinc, iron, arsenic, manganese, nickel, uranium and others. At its peak the mining industry employed some 30 000 persons, working over 300 mines.

It was not expected that copper mining would ever again feature greatly in the metal production from Cornwall, but no one had ever suggested that the tin ore there was exhausted. On the contrary, the weight of expert opinion was that there was far more tin still in the

ground than had ever come out of it during recorded history. He referred those present to Major Llewellyn's paper of 1946.*

Further there were available to-day ore-dressing processes which had been absolutely unknown in the nineteenth century. There was no reason why a tin mine should not produce to-day, as a series of by-products, other metals such as copper, lead, zinc, arsenic and iron, as well as other substances such as sulphur, fluorspar and barytes.

In some of the papers which had been submitted it had been implied that the need to re-assess the mineral resources of the United Kingdom had arisen only in the last few years; but that was not so. They themselves had been at it for ten years but ever since the first world war various leading personalities of the industry had been hammering away at the subject. Three Presidents of the Institution had used the theme, in one form or another, for their Presidential Addresses. A dozen or more papers had been presented to the Institution. The theme had been supported by the technical publications of the industry. But he submitted that all this was insufficient unless it reached the general public and held their interest to such an extent that their political masters were forced to take the matter seriously.

It was to be hoped that full arrangements had been made by the convenors of the Symposium for this wider publicity by Press, radio and even, he hoped, television. If the only result of the Symposium was that they had merely been once more talking over the subject between themselves, he was afraid it must be counted as a failure, however pleasant it may have been as a social occasion and re-union.

The Chairman commented that the word 'politics' had been mentioned. He was most anxious that no one should run away with the idea that there was any party political feeling in regard to support for British metal mining.

A year or two ago he had asked an old friend of his, the late Earl Jowitt (Lord Chancellor in the last Socialist Government), to speak in the House of Lords on the subject and advocate an alteration in the system of taxing metal mines, which he had done, but Lord Jowitt had been met with the reply that the Treasury did not see any reason to alter the existing system of taxation.

To-day another champion of Cornish mining and of the case for alteration of the system of taxation — Mr. Douglas Marshall — was with them. He was the Conservative Member of Parliament for South-East Cornwall. As Chairman he hoped that in asking Mr. Marshall to speak he would not be deemed to be putting him forward in any political sense.

Mr. Douglas Marshall, M.P.,† said though he felt some anxiety in addressing an assembly of such wide technical knowledge he was glad to have been invited to speak because he had been greatly interested in

* A survey of the deeper tin zones in a part of the Carn Brea area, Cornwall. *Trans. Instn Min. Metall., Lond.*, **55**, 1945–46, 505–523.

† Member of Parliament for Bodmin, Cornwall.

everything that had been said. He had noted that Mr. Trounson had said those who were optimistic about the mineral wealth of Cornwall were regarded as irresponsible. If that were so he saw no reason why one should not be optimistic, particularly when one reflected what were the feelings of the nation at the time of Dunkirk and such feelings led to victory.

The only way to get things moving was to have real faith in what they were doing and at the same time to be optimistic in regard to that faith. 'Re-capping' briefly what had been said from the platform, and what had no doubt been going through the minds of many of those present: technically they believed there was every reason to assume there was mineral wealth in Cornwall not yet developed and which could be commercially profitable. The thought which followed was that they were stopped from pursuing it by what seemed to be the national decision that, at this moment, the taxation impact could not be altered. If the first be true then the second was ridiculous not to have altered.

He suggested that by their own faith they had to make that impact, not only by talking to each other on technical subjects which they understood, but by realizing that to achieve their dreams they had to make possible the political concept. There had been mention of the necessity for a change in the economic climate; but in fact there had been such a change. It was for them to take advantage of the change.

They must not run away with the idea that a Budget which came out in April was framed in February. As in any great business, that began its conception round about the autumn. He had found no difficulty in approaching Cabinets or Chancellors of the Exchequer or anyone else. It was for them to make the impact felt immediately.

For his own part, he had faith in the project. He did not go towards it in any mood of emotional sentimentalism, but rather with the thought that, first, they must create the possibility of development and then, having succeeded in drawing upon the wealth which God had given this country, after three to five years of production, by the normal process of taxation, the nation gained, the Chancellor of the Exchequer gained and the people of Britain gained — and they would have proved their faith.

Mr. Trounson, in reply to Major Llewellyn, said that he quite agreed that ventilation had to be watched very carefully and, where necessary, a second shaft might have to be cleared in order to secure adequate ventilation. What he was opposed to, however, was the spending of great sums of money on the reconditioning and equipment of several shafts where one might be quite adequate for the proving of the mine.

As far as the control of broken ore in stopes was concerned, and its relationship to the length of the lift, that was a thorny problem and one that was giving a great deal of trouble at the South Crofty mine at the present time.

Dr. Hosking also made a brief acknowledgement of speakers' contributions.

WRITTEN CONTRIBUTION

on *The Mineral Potential of Cornwall*

Mr. Brian Llewellyn: Mineralization is closely related to tectonic movement and regional metamorphism, and so miners recognized long ago that an area of complex faulting generally yielded the richest ore. They also sensed what has been so ably epitomized by the authors in this paper, namely that there was some connexion between mineral deposits and mountain ridges (of igneous rock?), for Agricola* says: 'The miner should not dig in those solitary mountains, dispersed through the plains and open regions, but only in those which are connected and joined with others.'

In this respect Cornwall has the unique advantage of being plentifully endowed with such dislocations and, indeed, it seems possible that ground movements are still taking place, although they may no longer be cataclysmic. While it is as difficult to predict with any degree of certainty the mineral potential of Cornwall as it is in some cases that of a particular tin mine, no matter how carefully the selection has been made, it can be stated with confidence that the general conditions are so favourable that the earlier miners were induced to win tin ore in what would nowadays be considered almost fantastic circumstances.

The writer has long held the view that the earliest orogeny, that of West Cornwall, was connected with the Caledonian movement (late Silurian–early Devonian) and that much of the fissuring and jointing took place at that time, while other structural strains were imposed. It seems doubtful whether this movement extended as far eastward as East Cornwall and West Devon. The later Armorican movement, with East–West folding, extended throughout the whole area and was responsible for both the mineralization and the formation of the N–S crosscourses. The details presented in Fig. 2 (p. 360) seem to confirm this hypothesis.

The answer to the mineralization or otherwise of the crosscourses would appear to lie in the characteristics of their formation: dynamic due to thrust or rotation, which might be expected to give rise to mineral injection, or simple strain relief, which would not provide the appropriate channels for ore deposition. As many crosscourses persist in strike for several miles, it seems probable that these characteristics vary along their course and I should like to ask the authors if they have investigated this subject, which is of cogent application to some classes of deposit and particularly to those of lead-zinc-silver.

There is no doubt that the temperature-pressure relationship has considerable bearing on tin deposition. This bearing, being bound up with such unknown variables as dynamic metamorphism, weight of superincumbent rock, penetrability of the feeder channel and even conductivity of the enclosing rock, greenstone extrusives, etc., is so

* AGRICOLA, GEORGIUS. *De re metallica.* Hoover translation of the first Latin edition of 1556 (London: *Mining Magazine*). Section relating to Book II, p. 30.

complex that it is beyond the scope of this concise paper, on which I congratulate the authors.

Finally, the extent of erosion of the granite batholiths is of the greatest importance, when it is considered that the surface level at the time of maximum ore deposition would be between 9000 and 15 000 ft higher than it is at the present day.

AUTHORS' WRITTEN REPLY

Dr. Hosking and Mr. Trounson: We are grateful to Mr. Brian Llewellyn for his most valuable comments.

We agree that the mineralization phenomena of the Cornish crosscourses are both extremely interesting and economically important, and had not a limit been put on the length of the paper we would have dealt with this topic in some detail. Briefly, however, we are of the opinion that the degree, etc., of mineralization of any crosscourse depends on when it was developed and opened. Early crosscourses contain Cu, Co, Ni, U, etc., while those which came into being somewhat later contain Pb, Zn, Ag and Fe. Crosscourses which were not opened until the last phase of mineralization hold little more than barren quartz, while the distinctly post-mineralization faults are filled solely with fault-clay and breccia.

It is, perhaps, pertinent to record that one of the writers (K. H.) is at present investigating the antimony-bearing lodes of N.E. Cornwall. Are these bodies genetically related to the granite—as is commonly believed—or are they essentially the products of differentiation of the magma from which the spilites formed? Some of the antimony lodes—at least—are spatially closely related to the spilites.