Precious and base metal selenide mineralization at Hope's Nose, Torquay, Devon

C. J. STANLEY AND A. J. CRIDDLE
Department of Mineralogy, British Museum (Natural History), Cromwell Road, London SW7 5BD
AND
D. LLOYD
Ashburton, Devon

Abstract

Precious and base metal selenide minerals have been identified in gold-bearing carbonate veins cutting Middle Devonian limestones of the Torquay Limestone Group at Hope's Nose, Torquay. The selenide assemblage consists of clausthalite (PbSe), tiemannite (HgSe), klockmannite (CuSe), umangite (Cu_3Se_2), tyrrellite ($(Cu,Co,Ni)_3Se_4$), trustedtite (Ni_3Se_4), penroseite ($NiSe_2$), naumannite (Ag_2Se), eucairite (AgCuSe) and fischesserite (Ag_3AuSe_2), only clausthalite having previously been reported from Britain. They are associated with palladian gold, gold, hematite, and accessory pyrite and chalcopyrite in a gangue consisting predominantly of calcite; alteration products include cerussite, malachite, aragonite and goethite.

The relative abundance of Au, Ag, Hg and Se is a characteristic feature in the uppermost parts of some precious metal 'epithermal' systems. The occurrence at Hope's Nose is related to both structural and lithological factors: a deep-seated NW–SE structural lineament, the Lundy–Sticklepath–Lustleigh–Torquay fault; local thrusting, and to an association of basic–intermediate igneous rocks with a sedimentary sequence including carbonaceous shales and limestones. The mineralization is considered to be post-Variscan, probably Permo–Triassic in age.

KEYWORDS: selenides, gold, Hope's Nose, Devon, U.K.

Introduction and general geology

HOPE'S Nose is a promontory on the northern side of Tor Bay, Devon, England. It forms a steeply sloping, grass covered headland bounded by low cliffs, some 3 km east of the centre of Torquay.

The geology of this part of Devon is complex and, because there are few inland exposures, poorly understood. Torquay lies in a roughly east–west tectonic belt which extends from north Cornwall to southeast Devon. This belt incorporates the Bodmin Moor and Dartmoor granites in a Devonian to Lower Carboniferous sedimentary succession, typified by marine shales and sandstones together with interbedded lavas and tuffs. This largely sedimentary succession was deformed during the Variscan (Hercynian) orogeny, and the belt has been referred to as 'thrust and nappe terrane' (Chandler and Isaac, 1982). In south Devon, during the Middle to Upper Devonian, extensive carbonate platforms developed within a predominantly marine sequence and the Tor Bay reef complex, of which the limestones at Hope's Nose are a part, formed on the eastern margin of one of these platforms.

Today, a variably developed wave-cut platform provides most of the coastal exposure in the northern part of Hope's Nose. In these exposures, and in a small disused quarry in the headland (Fig. 1), massively bedded, hard and fossiliferous limestones are overlain, apparently disconformably, by a thin to poorly bedded, dark grey and shaley limestone containing interbedded tuff horizons. This sequence has been assigned to the Daddyhole Limestone of Eifelian Age, the earliest of the three formations of the Middle-Devonian Torquay Limestone Group (Scrutton, 1978; Goodger *et al.*, 1984). There has been much discussion as to whether or not the sequence at Hope's Nose is inverted (see Ussher, 1903); current thinking is that it is not (Coward and McClay, 1983), and that only minor imbricate thrusting (as seen at the quarry) has occurred. To the west of

Mineralogical Magazine, September 1990, Vol. 54, pp. 485–493

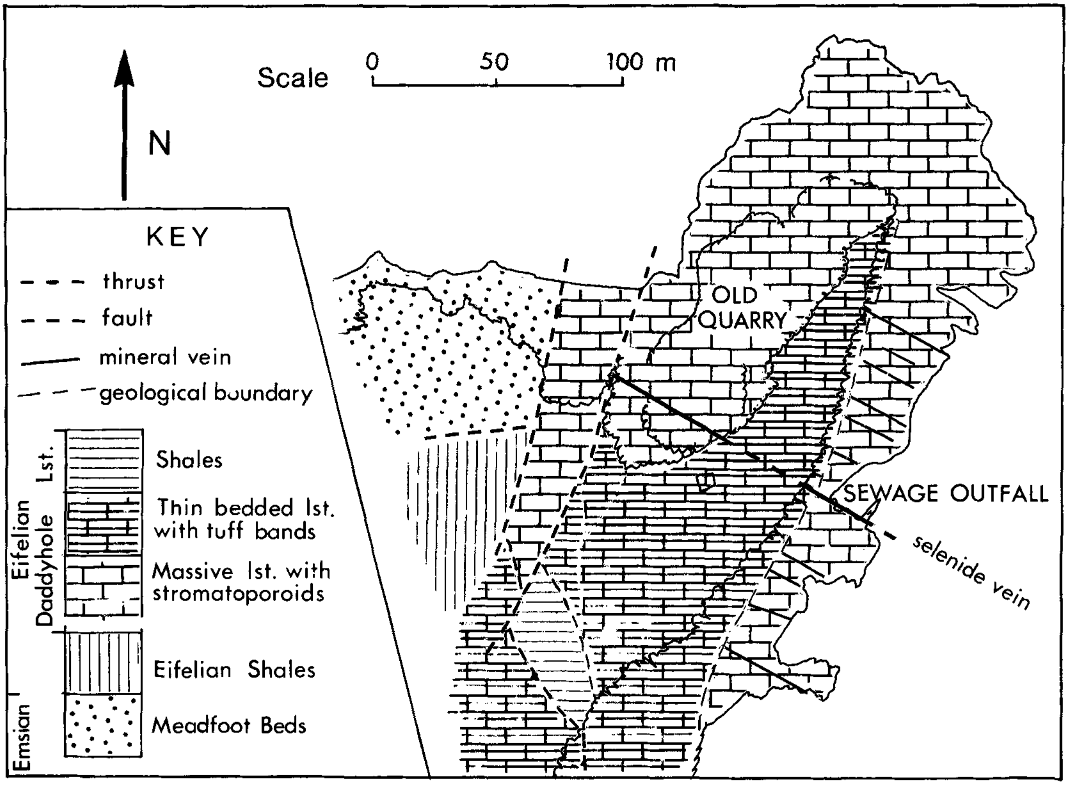

FIG. 1. Sketch geological map of Hope's Nose with location of the selenide vein.

Hope's Nose, thrusting and recumbent folding is attributed to Variscan earth movements (Goodger *et al.*, 1984).

The massive limestone at Hope's Nose is cut by a number of calcite veins and stringers in the vicinity of the sewage outfall (Fig. 1) and for some 50 m to the northeast and southwest of it. The veins are steeply dipping and trend roughly N70°W. Some of them are slickensided and most have been subject to faulting, both normal and reverse, but with little vertical displacement (up to 17 cm according to Scrivener *et al.*, 1982). Wall-rock alteration around the veins is restricted to patchily developed hematitization, the intensity of which seems to be directly related to the concentration of calcite veins: at its most intense (in an area to the northeast of the sewage outfall), it is developed for 0.5 m from the vein plexus. Gold was first found in these calcite veins by Gordon (1922) and more fully described by Russell (1929), although gold had previously been reported from Daddy Hole Plain (some 1.5 km east of Hope's Nose) by Ussher (1903) 'traces of gold were met with in the calc-spar of the fault rock on the south side of the quarry, on the east side of Daddy Hole, but the gold fever this discovery produced was speedily allayed by a small dose of unremunerative prospecting'. Interest in the Hope's Nose locality was renewed in the early 1980s when more specimens of gold were found. Subsequent analysis of the gold showed the presence of up to 5.7 wt.% palladium (Criddle and Stanley, 1986; QDF 2.142) with up to 16 wt.% Pd reported by Scrivener *et al.* (1982). The rare minerals isomertieite and mertieite II were associated with the palladian gold (Clark and Criddle, 1982). More recently, the site has been extensively and crudely excavated by mineral dealers and collectors. It is a designated SSSI (Site of Special Scientific Interest) of the Nature Conservancy Council with full legal protection.

A few years ago one of us (DL) collected a few specimens from a single thin vein (<3cm) situated close to the metal grille over the sewage outfall on the southeastern side of Hope's Nose. Polished sections made from some of these specimens, examined in reflected light, and analysed by electron microprobe, revealed a remarkable assemblage of precious and base metal selenides, the identities of which were confirmed by X-ray diffraction. This led to further examination of the locality and a vein was found on the western side of the disused quarry which also contained selenides. This vein directly follows the westerly trend of the selenide-bearing vein first discovered. It cannot be confirmed that it is the same vein, however, since it is not possible to trace it in the overlying thin-bedded shale limestone.

Mineralogy

The gangue mineralogy of the selenide vein differs little from that of the other gold-bearing veins at Hope's Nose described by Clark and Criddle (1982), except that no quartz was found.

In hand specimen, reddened, partially hematitized, limestone wall rock is commonly separated from the vein calcite by an extremely thin muscovite selvedge. At the vein margin, the calcite is massive, barren, and white to pale pink. It rapidly grades into a well-crystallized, vughy, calcite. Here, the pinkish to reddish colour of the crystals (characteristically, scalenohedral) is caused by inclusions of fine-grained platelets of hematite. This, hematite-bearing calcite is typically 5–20 mm thick. Some of the scalenohedra are fractured, and the fractures are filled by selenides which have also grown along zone boundaries in the calcite. Occasionally, individual crystals are also overgrown or encrusted by the selenides. Towards the centre of the vein, white calcite occurs together with a buff ferroan dolomite which contains goethite and 'limonite' pseudomorphs after chalcopyrite and pyrite. In the centre of the vein, calcite is intergrown with the selenide minerals forming areas up to 10 mm across. Cavities within the vein are common (up to 5 mm across) and are lined with aragonite, cerussite or partly altered dolomite. In other veins within the immediate vicinity of the selenide-bearing vein, lustrous, white and spherulitic masses of dickite occupy these cavities.

Four polished sections were made from fragments collected from exposures of the selenide-bearing vein on the sewage outfall side of Hope's Nose and one section from material from the disused quarry. The selenides identified are: clausthalite (PbSe), tiemannite (HgSe), umangite (Cu_3Se_2), klockmannite (CuSe), penroseite (Ni,Co,Cu)Se_2, trustedtite (Ni_3Se_4), tyrrellite (Cu,Co,Ni)$_3Se_4$, eucairite (CuAgSe), naumannite (Ag_2Se), and fischesserite (Ag_3AuSe_2). Optical and other characteristic data for the following Hope's Nose species appear in the Quantitative Data File for Ore Minerals (Criddle and Stanley, 1986): clausthalite (QDF 2.70), eucairite (QDF 2.114), fischesserite (QDF 2.155), penroseite (QDF 2.272), tiemannite (QDF 2.382) and tyrrellite (QDF 2.391).

Low-magnification examination of these polished sections show that the textural relationships between selenides and carbonate matrix may be summarized as: (*i*) the selenides form a fine interconnecting network defining calcite grain boundaries; the individual calcite grains are partially rounded and there is evidence for widespread calcite recrystallization after the selenide mineralization; (*ii*) isolated, mostly euhedral, inclusions occur within calcite grains; (*iii*) skeletal or dendritic selenide overgrowths on early hematite-bearing calcite, or inclusions along growth zones in later calcite; (*iv*) larger areas where calcite appears to have undergone replacement and the selenides occupy solution cavities.

The ore mineralogy of the selenide vein is described below in its suggested paragenetic sequence (Fig. 2). Unless otherwise stated, the descriptions are for specimens collected from near the sewage outfall.

Native gold occurs in three apparently distinct associations. Firstly, and typical of the association described by Clark and Criddle (1982), it occurs as skeletal or dendritic growths in a buff coloured calcite, which we interpret as earlier than the white calcite. Here, the gold is zoned, alloyed with palladium, and is sometimes coated with euhedral grains of the palladium arsenide–antimonide, *isomertieite*. In the second association, the gold is argentian (Table 1.1, and cf. Clark and Criddle, 1982). It forms discrete (5–20 μm) grains in white calcite and irregular (50–100 μm) inclusions in clausthalite and tiemannite which are, themselves, concentrated at calcite grain boundaries. Although the palladian and argentian gold co-exist within the same vein, the absence of palladium in the argentian gold and in the selenide assemblage, and the absence of selenium in the palladium-bearing/isomertieite assemblage, strongly suggests that they crystallized at different times from different mineralizing fluids. In the third association, extremely small (<5 μm) grains of gold are interpreted as having formed from the breakdown, or replacement, of fischesserite.

Minute amounts of *pyrite* and *chalcopyrite*, heavily altered to goethite and 'limonite', form inclusions in ferroan dolomite but their relationship with gold and the selenide minerals is unclear.

Tiemannite (Table 1,2–3) is commonly not intergrown with the other selenides. In the quarry

Table 1. Electron microprobe data - Hope's Nose selenides

		Co	Ni	Cu	Ag	Au	Hg	Pb	Se	TOTAL
1	gold			0.2	5.8	92.4			2.1	100.5
2	tiemannite	0.1					70.6		29.6	100.3
3		0.1					70.1		29.6	100.3
4	trustedtite	0.3	36.1	0.1					63.3	99.8
5	penroseite	7.1	13.0	7.5					73.1	100.7
6		8.8	12.1	6.3					72.3	99.5
7		3.0	16.8	7.3					73.1	100.2
8	tyrrellite	13.3	13.4	10.2					62.8	99.7
9		10.0	12.8	13.0					63.1	98.9
10	naumannite			0.9	70.8				28.1	99.7
11				2.2	71.5				26.2	99.9
12	eucairite			24.5	44.4				32.1	101.0
13				24.3	44.0				32.5	100.8
14	fischesserite			0.9	52.3	23.4			22.8	99.4
15				0.7	48.9	26.4			22.9	98.9
16	umangite			55.2					45.3	100.5
17				54.3					45.6	99.9
18	klockmannite			43.3	1.5				55.3	100.1
19				43.9	0.3				55.6	99.8
20	clausthalite		0.1	0.1				71.4	27.5	99.1
21			0.1	0.1				72.4	27.7	100.3

Cambridge Instruments Microscan IX, operated at 20kV.
Standards: PbSe, Ga_2Se_3, Au, Ag, FeS, Co, Ni, HgS
Radiations: FeKα, CoKα, NiKα, CuKα, AgLα, AuMα, HgLα, PbMα, SeKα, S Kα

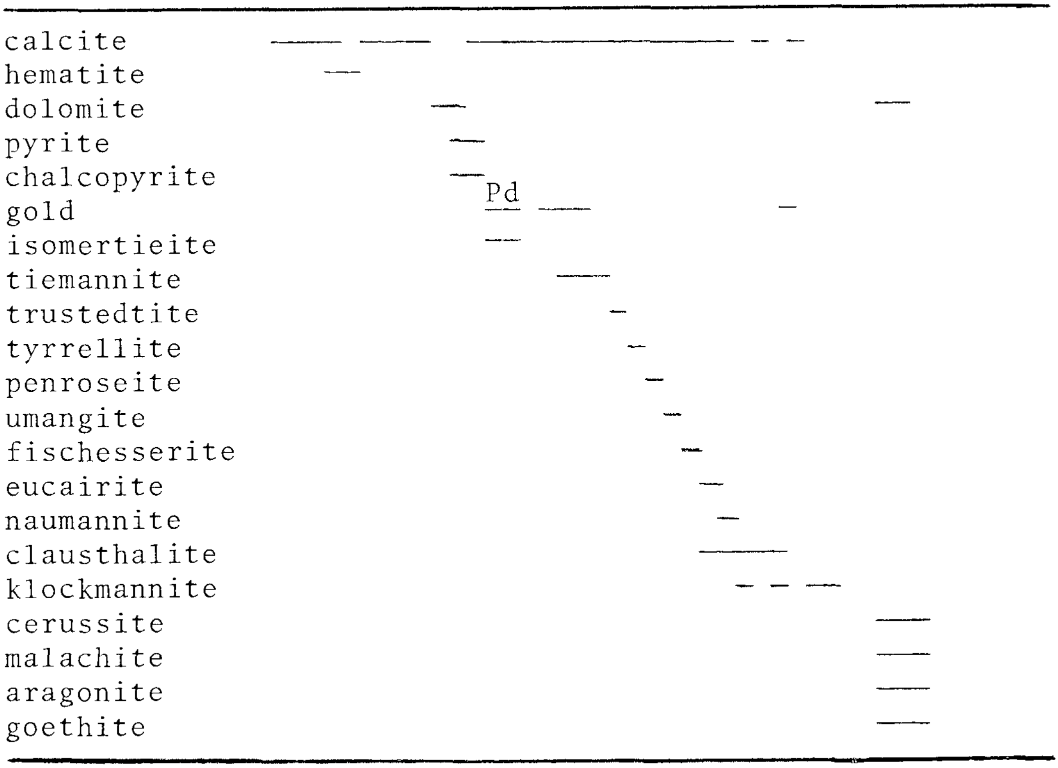

FIG. 2. Paragenetic diagram.

exposure it is by far the most abundant selenide and forms thin rims (up to 50 μm) which overgrow early hematitic calcite. Tiemannite replaces later white calcite at grain boundaries and develops into skeletal or dendritic growths which are overgrown and enclosed by a subsequent calcite generation. Here, it also forms aggregates up to 3 mm across, intergrown with calcite and, rarely, ferroan dolomite rhombs, and contains minute (up to 5 μm) inclusions of penroseite, clausthalite and native gold. In specimens from the exposure near the sewage outfall, tiemannite is less abundant and occurs as small anhedral grains (up to 50 μm) and skeletal growths (up to 100 μm in length) in calcite (Fig. 3C). It commonly contains inclusions of native gold and is found in association with umangite, or as inclusions (up to 50 μm) in clausthalite.

The nickel- and cobalt-bearing selenides are, typically, intergrown. The earliest is *trustedtite* (Table 1,4) which occurs as irregular to lath-like relicts (5–50 μm) in tyrrellite. *Tyrrellite* (Table 1,8–9) is common as anhedral, partially replaced, inclusions (50–100 μm) in clausthalite and penroseite, also as euhedral inclusions in klockmannite, umangite, and clausthalite. Where host clausthalite has been replaced by cerussite, tyrrellite (together with its inclusions of trustedtite) is replaced in preference to penroseite. *Penroseite* (Table 1,5–7) is abundant as inclusions in clausthalite, either in the form of irregular grains (up to 100–200 μmm) or as apparently pseudo-myrmekitic intergrowths (grains up to 50 μm) (Fig. 3A). Together with gold, it is resistant to replacement by later cerussite.

Umangite (Table 1,16) is included in clausthalite as anhedral (up to 200μm) grains. It also occurs as larger areas in calcite where it contains inclusions of euhedral tyrrellite, and is replaced by, and always associated with, klockmannite (Fig. 3B).

The silver- and gold-bearing selenides, naumannite, eucairite and fischesserite are all associated with clausthalite, or occur as discrete inclusions in calcite, but appear to have no close association with the Ni/Co or Hg selenides. *Naumannite* is moderately common as isolated grains (up to 100 μm) in calcite or clausthalite and is extensively replaced by klockmannite at naumannite/eucairite grain boundaries. *Eucairite* (Table 1,12–13) forms large (up to 300 μm), equant, anhedral grains mostly at, or along, calcite grain boundaries. It also forms skeletal to dendritic grains which appear to have grown from these grain boundaries. The least common mineral of this group is *fischesserite* which occurs as anhedral grains (up to 200 μm) associated, but not intergrown, with naumannite and eucairite. It is replaced by naumannite, eucairite and klockmannite. In addition, finely disseminated gold (up to 5 μm) appears to have formed at replaced fischesserite grain boundaries.

Clausthalite is the main selenide mineral in specimens collected from the sewage outfall locality. It is coarse grained and generally occurs as irregular patches (1–2 mm across, but with calcite inclusions to 10 mm across) in calcite which it partially replaces along calcite grain boundaries. Clausthalite contains inclusions of penroseite and tyrrellite, and is extensively replaced by klockmannite and cerussite.

Of those minerals involved in selenide replacement, klockmannite and cerussite are the most common. *Klockmannite* (Table 1,18–19) is coarse-grained where it replaces umangite, but fine grained where replacing fischesserite, naumannite and clausthalite. It is itself replaced by malachite. *Cerussite* replaces clausthalite extensively, often entirely, when the only evidence that clausthalite was once present is the unaltered inclusions of penroseite and native gold now residing in a granular cerussite groundmass (Fig. 3D).

Discussion

Age of mineralization

There are no radiometric dates for the mineralization at Hope's Nose, nor is there any direct or indirect geological evidence to place it in any of the periods of mineralization which have been ascribed to the SW England metallogenic province. Clearly, the mineralization post-dates the Devonian sequence in which it is emplaced, and it may be Variscan: the earliest, or 'main stage', polymetallic Cu–Sn–W mineralization within the region has been dated at 270 Ma (Darbyshire and Shepherd, 1985) and this stage was followed by Pb–Zn, Sb, Fe and U mineralizations. The most recent mineralization (U), is associated with Tertiary faulting, and has been dated at *c.* 45 Ma (Darnley *et al.*, 1965). Evidence for pre-Variscan mineralizing events is scanty (Scrivener *et al.*, 1989), and is represented in S Devon by exhalative pyrite and ankerite associated with highly altered mid-Devonian tuffs (Leake *et al.*, 1985).

Conditions of formation

Fluid inclusion work (Scrivener *et al.*, 1982) on calcite and quartz from the Hope's Nose gold-bearing veins gave a range of homogenization temperatures (T_h) of 65–120°C. The fluids were rich in $CaCl_2$ with total gross salinities of 20–23 equiv. wt.%NaCl and a $CaCl_2$:NaCl ratio probably a minimum of 3:1. Such salinities are within the ranges found for some of the SW England Pb–Zn–F mineralization, although the temperatures are slightly lower at Hope's Nose. Alderton (1975) reported T_h of 122–159°C and 21–26 equiv. wt.% NaCl for a variety of Pb–Zn (±F) veins, while Shepherd and Scrivener (1987) found evidence of a high-salinity (19–27 equiv. wt.% NaCl; approx. $CaCl_2$:NaCl ratio 1:1), low-temperature (T_h 110–170°C), fluid involved in mineralization in the Tamar valley area.

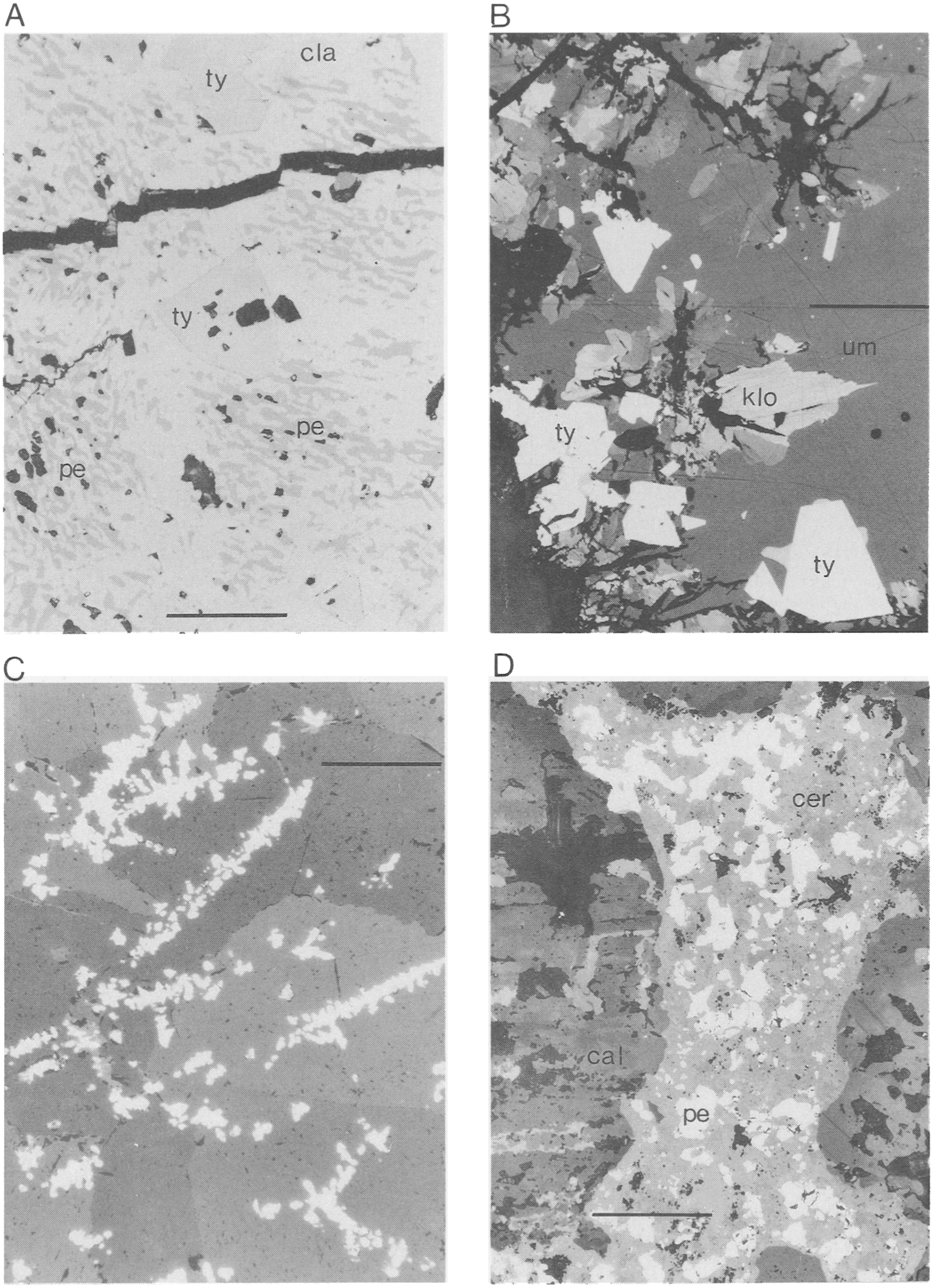

FIG. 3. Reflected light photomicrographs. A. Early euhedral tyrrellite (ty) and pseudomyrmekitic penroseite (pe) inclusions in clausthalite (cla). Scale Bar 100 μm. B. Euhedral tyrrellite (ty) in umangite (μm) the latter partially altered to klockmannite (klo). Scale bar 100 μm. C. Skeletal tiemannite in calcite. Scale bar 200 μm. D. Cerussite (cer) has entirely replaced clausthalite leaving relict anhedral penroseite (pe) and gold grains (Au). Gangue mineral is calcite. Scale bar 200 μm.

Comparison with other deposits

SW England. The Hope's Nose deposit appears to be unique in SW England and, indeed, in Britain. However, concentrations of some (but not all) of the elements and minerals found here occur in other areas of SW England. In the Permo-Triassic red beds at Budleigh Salterton, clausthalite has been reported in vanadiferous nodules (unpublished notes, pers. comm., P. H. A. Nancarrow) which also contain U, Ni, Co, Cu, As and Ag minerals (Harrison, 1975). This mineralization has been interpreted as originating from hot springs (ibid.). The only other occurrence of selenium in SW England, that of a selenium-bearing chalcopyrite from a uranium vein in the Bodmin area of Cornwall, was noted, without further comment, by Ball *et al.* (1979). Of the precious metals, grains of palladian gold, and a single dendritic grain of potarite (PdHg) were found by Leake *et al.* (1988) in panned overburden concentrates at a locality some 30 km SW of Hope's Nose. An indication, perhaps, that the Hope's Nose style of mineralization is more widespread in the area, but is hidden by a lack of surface exposure. Other gold occurrences, though non-palladian, are found in the same 'thrust and nappe' belt of Devonian to Lower Carboniferous sediments as that which is host to Hope's Nose. These vein deposits, in which the gold is associated with Pb–Sb–Ag sulphosalts, are found in E Central Cornwall, at Port Isaac in N Cornwall and in S Devon, at Loddiswell. All share a spatial association with lavas, tuffs and dolerite ('greenstone') intrusions first recognized by De la Beche (1839) who noted that the ores 'appear chiefly to be obtained in those portions of the greywacke of the district which are closely associated with trap rocks', and all are also believed to be associated with NW–SE shear zones or subsidiary fractures and local thrusting (Stanley *et al.*, 1990).

Worldwide selenide occurrences. Selenium is a strongly chalcophile element which substitutes for sulphur in minor amounts (ppm) in most sulphides. However, discrete selenide minerals are mostly restricted to hydrothermal vein deposits and to organic deposits such as burning coal waste dumps (e.g. Dunn *et al.*, 1986). It is from the former category that comparisons with Hope's Nose must be drawn. Three major hydrothermal associations are known:

(*a*) epithermal volcanic-related deposits associated with hot spring activity;

(*b*) in association with uranium in sandstone-hosted, and unconformity related vein deposits;

(*c*) in Fe-rich oxidation zones where selenite $(SeO_3)^{2-}$ ions are adsorbed on iron hydroxide minerals having first been mobilized from Se-bearing and selenium minerals under oxidizing conditions.

Although the mineral association at Hope's Nose is unusual it is not unique. There are distinct similarities between it and the classic selenide deposits in the Harz Mountains (West and East Germany) at Clausthal, Lerbach, Tilkerode, Trogtal and Zorge (Tischendorf, 1959), the now exhausted Pacajake mine, Colquechaca, Bolivia (Ahlfeld, 1954) and the recently described El Dragon mine, Bolivia (Grundmann *et al.*, 1990). In these areas, the selenides occur in veins or veinlets in association with carbonate gangue, hematite, gold and the platinum-group elements (PGE), notably palladium.

Other deposits where gold is associated with selenides in calcite veins include Corbach, West Germany (Ramdohr, 1932) and a number of deposits in the western USA (Sindeeva, 1964). In some, but not all of these deposits the host rocks are similar to those at Hope's Nose and there is a common association with shales, shaly sandstones or limestones, small laccolithic-type intrusions of diabase, dolerite, or 'greenstone', and 'eruptive' igneous rocks variously described as keratophyre or porphyry, trachyte, andesite, and tuff.

It is unclear why no concerted effort has been made to thoroughly examine the geology and mineralogy of these apparently related deposits, but it may be due to the fact that unless they are gold- or PGE-bearing and of reasonable size, they are not economic to mine.

Origin, transport and deposition

Genetic interpretations of selenide deposits generally favour a low-temperature 'late stage' hydrothermal mineralization. For the Tilkerode and other Harz selenide deposits, Tischendorf (1968) suggested that the metal and selenium contents had been leached from black carbonaceous shale host rocks, an interpretation based on a comparative study of the altered and unaltered wall rocks. He further proposed that solutions from a deeper source, possibly residual fluids from a relatively basic magma, contributed Fe, Ca, Mn and Mg.

More information is available concerning a related group of deposits, the hydrothermal uranium deposits. Here, selenides are interpreted as late-stage components, sometimes associated with pitchblende, arsenides and sulphides (e.g. at Beaverlodge, Canada) and sometimes with uraninite and sulphides in carbonate veins (e.g. the U–deposits of western Moravia, Czechoslovakia). Uranium has been interpreted (Kucha, 1982) as the concentrating element (through catalytic auto-oxidation) of a range of elements Ni, Co, Pt, Pd, Ir, Se, Hg, Mo, Re, Au, As, Bi in the genesis of Zechstein noble-metal-bearing shales in Poland. Here, a thin black shale horizon is host to an extensive mineral assemblage including gold and many of the known palladium arsenides. Their origin is interpreted by Kucha (ibid.) as evaporitic brines which, percolating through basement rocks, scavenged the metals and transported them as organometallic complexes, the shale horizon providing a boundary between oxic and anoxic conditions, and with uranium and organic matter promoting this auto-oxidation. This has subsequently been modified by Mountain and Wood (1988) in a model which requires no auto-oxidation; the metal-bearing solutions encounter an organic-rich layer and are here fixed by adsorption, 'complexation' and reduction by the organic matter.

In terms of chemistry the ions Pd^{2+}, Au^{+}, Ag^{+} and Hg^{2+} tend to form complexes with ligands that give a predominantly covalent interaction (Mountain and Wood, 1988) and require saline, acidic and highly oxidizing conditions for chloride complexing and transport, and reducing conditions for deposition. As noted earlier, these are also requirements for selenium transport and deposition. At Hope's Nose, the high salinities in fluid inclusions, their high Ca:Na ratios (possibly from dissolution of the host limestones), and the widespread hematitization of the limestone adjacent to the veins, suggest that conditions for such complexing could have been present. However, the mechanism for deposition is less certain. The Daddyhole Limestone is not notably bituminous and it may be that the fluids simply ponded against the overlying thinly bedded shaly limestone, were neutralized by reaction *in situ* and could no longer hold their trace element content.

Conclusions

It is clear that further work is necessary on the geochemistry of the local igneous and sedimentary rocks; nevertheless some tentative conclusions can be drawn concerning the Hope's Nose selenide mineralization.

1. The low fluid-inclusion homogenization temperatures, high salinities, and the element association Hg, Au, Ag, Cu, Pb, Sb, As, Se, S, are typical of the class of deposits known as 'epithermal' (Lindgren, 1928) and in Lindgren's classification would fall in the 'gold-selenide' category. In the classification systems of Ferguson (1924) and Nolan (1933) it would undoubtedly be of gold–silver (i.e. gold dominant over silver) type.
2. Nolan (ibid.) noted that these gold–silver ores are irregular in distribution and commonly occur within, or close to, shallow intrusive bodies. One such small igneous body may exist beneath Hope's Nose. To the north of Hope's Nose, a small laccolith-like outcrop of altered dolerite occurs (Busz, 1896) neither the extent nor the trace element geochemistry of which is known. At Hope's Nose itself there is a significant positive gravity anomaly which may indicate the presence of a small basic or ultrabasic intrusion, although Leake *et al.* (1988) interpret it to represent relatively near surface crystalline basement. If there are basic or ultrabasic rocks nearby, they may have contributed Pd, Au, Co and Ni to the epithermal system. This may have occurred during carbonatization (Haynes, in press), in which case the metal-bearing fluids would be rich in CO_2 and Ca and would readily precipitate in a carbonate environment. Comparison with other selenide deposits suggests that local sedimentary rocks, particularly greywackes, carbonaceous shales (the Eifelian shales at Hope's Nose) and limestones (the Daddyhole limestone) are important in addition to local extrusive, dominantly alkaline volcanic activity, either as metal sources or in controlling reduction and deposition.
3. The high salinities and epithermal nature of the Hope's Nose fluids suggests an analogy with the Pb–Zn–Ba–F mineralization of the Teign and Tamar valleys in SW England and with similar post-Variscan deposits in the Harz Mountains which may have been derived in part from Mesozoic basinal evaporitic brines (Shepherd and Scrivener, 1987); similar basins developed around Hope's Nose.
4. The fracture system into which the fluids were drawn may have been controlled by movements along the major NNW–SSE lineament, the Sticklepath–Lustleigh–Torquay fault. Local thrusting may also have been important in localizing the deposit (Stanley *et al.*, 1990).
5. The low temperatures and small amount of silica in the veins might indicate a relatively shallow and restricted circulatory system since chemically active fluids would be expected to react readily with any siliceous wall rocks.

Acknowledgements

We thank Roger Harding, Bob Symes, Paul Henderson and two anonymous referees for their comments on the manuscript.

References

Ahlfeld, F. (1954) *Las especies minerales de Bolivia*, 3rd ed. Bilbao, Banco Minero de Bolivia.

Alderton, D. H. M. (1975) Fluid inclusion studies in SW England. *Proc. Ussher. Soc.* **3,** 214–7.

Ball, T. K., Basham, I. R. and Michie, U. McL. (1979) *Uraniferous vein occurrences of South West England-Paragenesis and genesis.* [Unpubl. Open file Report no. 337, 48 pp. Institute of Geological Sciences.]

Busz, K. H. E. G. (1896) Ueber einige Eruptivgesteine aus Devonshire in England. *Neues Jahrb. Mineral.* Bd 1, 57–78.

Chandler, C. and Isaac, K. P. (1982) The geological setting, geochemistry and significance of L. Carboniferous basic volcanic rocks in Central South-west England. *Proc. Ussher. Soc.* **5,** 279–88.

Clark, A. M. and Criddle, A. J. (1982) Palladium minerals from Hope's Nose, Torquay, Devon. *Mineral. Mag.* **46,** 371–7.

Coward, M. P. and McClay, K. R. (1983) Thrust tectonics of S. Devon. *J. Geol. Soc. London,* **140,** 215–38.

Criddle, A. J. and Stanley, C. J. (eds) (1986) *The Quantitative Data File for Ore Minerals.* 471 pp. British Museum (Natural History) and International Mineralogical Association.

Darbyshire, D. P. F. and Shepherd, T. J. (1985) Chronology of granite magmatism and associated mineralization, SW England. *J. Geol. Soc. London,* **142,** 1159–77.

Darnley, A. G., English, T. H., Sprake, O., Preele, E. R. and Avery, D. (1965) Ages of uraninite and coffinite from southwest England. *Mineral. Mag.* **34,** 159–76.

De La Beche, H. T. (1839) *Report on the geology of Cornwall, Devon and West Somerset.* Mem. Geol. Surv. London. 648 pp.

Dunn, P. J., Peacor, D. R., Criddle, A. J. and Finkelman, R. B. (1986) Laphamite, an arsenic selenide analogue of orpiment from burning anthracite deposits in Pennsylvania. *Mineral. Mag.* **50,** 279–82.

Ferguson, H. G. (1929) The mining districts of Nevada. *Econ. Geol.* **24,** 131–41.

Goodger, K. B., Buglass, A. and Scrutton, C. T. (1984) Sequence of coralline faunas and depositional environments in the Middle Devonian Daddyhole Limestone formation stratotype section, Torquay, Devon. *Proc. Ussher. Soc.* **6,** 13–24.

Gordon, W. T. (1922) Native gold at Torquay, Devonshire. *Nature,* **109,** 583.

Grundmann, G., Lehrberger, G. and Schnorrer-Köhler, G. (1990) The El Dragon mine, Potosi, Bolivia. *Mineral. Record,* **21,** 133–46.

Harrison, R. K. (1975) Concretionary concentrations of the rare elements in Permo–Triassic red beds of south-west England. *Bulletin Geol. Surv. G.B.* **52,** 1–26.

Kucha, H. (1982) Platinum-group metals in the Zechstein copper deposits, Poland. *Econ. Geol.* **77,** 1578–91.

Leake, R. C., Brown, M. J., Smith, K., Rollin, K. E., Kimbell, G. S., Cameron, D. E., Roberts, P. D. and Beddoe-Stephens, B. W. (1985) *Volcangenic and exhalative mineralization within Devonian rocks of the South Hams district of Devon.* Min. Rec. Prog. Rep. No. 79, British Geological Survey.

—— Cameron, D. G., Bland, D. J., Styles, M. T. and Rollin, K. E. (1988) *Exploration for gold between Hams district of Devon.* Ibid. No. 98. British Geological Survey.

Lindgren, W. (1928) *Mineral Deposits,* 3rd ed. McGraw Hill, New York. 1049 pp.

Mountain, B. W. and Wood, S. A. (1988) Chemical controls on the solubility, transport, and deposition of platinum and palladium in hydrothermal solutions: A thermodynamic approach. *Econ. Geol.* **83,** 492–510.

Nolan, T. B. (1933) Epithermal precious-metal deposits in ore deposits of the Western States. *Amer. Inst. Min. Metall. Engineers, New York,* 623–40.

Ramdohr, P. (1932) Die Goldlager Stätte des Eisenbergs bei Corbach. *Abh. z. prakt. Geol. und Bergwirtschaftslehre,* **21,** 1–39.

Russell, A. (1929) On the occurrence of native gold at Hope's Nose, Torquay, Devonshire. *Mineral. Mag.* **22,** 159–62.

Scrivener, R. C., Cooper, B. V., George, M. C. and Shepherd, T. J. (1982) Gold-bearing carbonate veins in the Middle Devonian Limestone of Hope's Nose, Torquay. *Proc. Ussher. Soc.* **5,** 393.

—— *et al.* (1989) *Terra Abstracts.*

Scrutton, C. T. (1978) Eastern South Devon. In *A field guide to selected areas of the Devonian of south-west England* (Scrutton, C. T., ed.). International Symposium on the Devonian System (P.A.D.S. 1978). The Palaeontological Association, London.

Shepherd, T. J. and Scrivener, R. C. (1987) Role of basinal brines in the genesis of polymetallic vein deposits, Kit Hill–Gunnislake area, SW England. *Proc. Ussher. Soc.* **6,** 491–7.

Sindeeva, N. D. (1964) *Mineralogy and types of deposits of selenium and tellurium.* Interscience, New York. 363 pp.

Stanley, C. J., Halls, C., Camm, G. S. and James, J. (1990) Gold–antimony mineralization at Loddiswell, Devon, UK. *Terra Nova,* **2,** 224–31.

Tischendorf, G. (1959) Formation of selenium enrichments in deposits in German. *Neue Huette,* **4,** 19–21.

—— (1968) Sources of elements in selenide mineralization near Tilkerode (Harz). *Int. Geol Rev.* **11,** 1298–301 [original article in *Geol. Rudn. Mest.* 1968, No. 4, 79–82] Istochnik: elementov v selenidoy mineralizatskii okolo Til'kerode (Garts).

Ussher, W. A. E. (1903) *The Geology of the Country around Torquay.* Mem. Geol. Surv. of England and Wales.

[*Manuscript received 20 October 1989; revised 1 February 1990*]