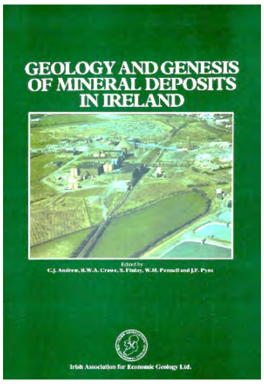

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The Lisglassan-Tullybuck deposit, County Monaghan: Sb-As-Au vein mineralization in Lower Palaeozoic greywackes.

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Abstract

The Lower Palaeozoic greywacke terrain of the Longford-Down inlier is not a part of Ireland well known for its metalliferous mineral deposits; yet it, and its continuation in the Southern Uplands of Scotland, contain a number of vein deposits which have been worked historically, principally for lead. These deposits are concentrated in four groups, two in Ireland, and two in Scotland; three of these groups contain subordinate gold mineralization and all four lie close to a major strike-parallel shear zone. One of the the groups occurs in the Clontibret region of County Monaghan and although dominated by lead mineralization, it also contains subordinate antimony-arsenic-gold. The particular Sb-As-Au deposit described here occurs in Ordovician greywackes just north of Clontibret and was worked historically for antimony. It consists of several NNW-trending lode zones which post-date regional Caledonian metamorphism, and which are congruent with a late stage system of NW- to NE-trending faults. Two principal mineralization episodes are evident, arsenopyrite-pyrite within the zones and disseminated in wallrock adjacent to them, and a subsequent localized stibnite episode. Both mineralization episodes, which also include accessory metallic minerals, are crosscut by minor carbonate ± sphalerite ± chalcopyrite ± galena veinlets.

The arsenopyrite-pyrite mineralization is the principal locus of the gold which occurs mainly as a lattice constituent in arsenopyrite, less abundantly ij pyrite, and very rarely as minute native grains. This association is reflected chemically by a strong positive correlation between As and Au. Prominent wallrock alteration, of phyllic composition adjacent to lode zones and propylitic distally, accompanied this mineralization episode. The alteration is chemically best reflected by progressive K_2O enrichment and Na_2O depletion inwards. Geological evidence suggests that the deposit is Caledonian in age, a conclusion consistent with a recently established K/Ar age (minimum) of 360 Ma.

Introduction

International awareness of Ireland's mineral exploration potential and of its role as a producer of metals has, within the last twenty years, largely stemmed from the search for, and successful exploitation of several carbonate-hosted base metal deposits. The dominating influence exerted by this activity has, however, overshadowed efforts to develop the prospectiveness of non-carbonate terrains for a variety of metallic elements, efforts based either upon the application of modern metallogenic theories or upon the evidence provided by historically worked mineral deposits. The antimony-arsenic-gold deposit described here is but one example of the latter. It occurs in Lower Palaeozoic greywackes cropping out in a deeply incised northerly trending stream valley, between two drumlins, about 1km due north of Clontibret in County Monaghan (Irish National Grid Ref H 755301; Figs. 1 and 2). The stream defines the boundary between the townlands of Lisglassan, to the east, and Tullybuck to the west, after which the two shafts on the deposit are named (Fig. 3).

Mining activity in the Clontibret district, and in the neighbouring Keady district in County Armagh, Northern Ireland, extended over a period of nearly 200 years during the 18th and 19th centuries, and concentrated largely on the development of the numerous lead vein deposits in the region. This group of historically worked deposits is not, however, unique in the Lower Palaeozoic terrain in which it occurs (Fig. 1). Elsewhere in the Longford-Down inlier, a group of lead vein deposits near Newtownards in County Down were worked during the 19th century and in the Southern Uplands, in Scotland, comparable groups of vein deposits were worked during the same period in the Newton Stewart to Burnhead region and in the Leadhills-Wanlockhead area. Both Scottish groups, in common with Clontibret, exhibit an association with gold, though only in the Leadhills area has any commercial development occurred, and that for placer gold during the 16th century (Mackay, 1959). The association of gold with antimony ore at Clontibret was first recognised in 1957 (McCannell, 1957) and resulted in a radical shift in exploration objectives which previously, from the time of the reputed discovery of the deposit in 1774 (Stewart, 1799) to 1957, centred upon its antimony content. Details of the development of the deposit are described elsewhere (Morris, 1984) and are summarized here in Table 1.

Regional and local geology

Greywackes and argillaceous sediments, largely of turbidite origin, dominate the Lower Palaeozoic terrain in which the antimony-gold deposit is located. In the Scottish Southern Uplands these rocks have historically been divided into three strike-parallel belts (Peach and Horne, 1899), Northern, Central and Southern, containing Ordovician (principally), late Ordovician to Silurian, and Silurian age rocks respectively; belts equivalent to the Northern and Central have recently been defined in the Longford-Down inlier (Leggett et al., 1979, Morris, 1983). It is now widely

Table 1. Summary of Lisglassan-Tullybuck deposit development history.

Period	Operator	Developments
c.1975 to the present	Munster Base Metals Ltd.	Surface exploration in Clontibret district, including diamond drilling. Definition of additional *in situ* gold mineralization in the Ballygreany, Carrickaderry and Bryanlitter areas (Fig. 2).
1956-7	Mining Corporation of Ireland	Surface and underground exploration on the Tullybuck-Lisglassan deposit. First record here of *in situ* gold; back sample grades in Tullybuck workings include 7.89 g/t over 1.2m; 34.98 g/t over 1.96m; 21.6 g/t over 2.4m.
1917	R. Espinasse and C. Chator	Surface and (?) underground development and exploration in the vicinity of Tullybuck shaft.
1825-6	Mining Company of Ireland	Tullybuck shaft and underground workings developed; unspecified amount of antimony ore extracted (probably no more than a few tonnes).
early 19th century	Earl of Middleton (?)	Unspecified development work; perhaps development of Lisglassan shaft
1774		Reputed discovery by D. Stewart (Stewart, 1799).

believed that these rocks originally accumulated in a trench along the NW margin of the Lower Palaeozoic Iapetus Ocean and that they were sequentially accreted to the continental foreland, by a series of northward dipping imbricate thrusts, to form a fore arc accretionary prism which cumulatively effected the preservation of the oldest rocks in the Northern Belt and the youngest rocks in the Southern Belt (Mitchell and McKerrow, 1975; Phillips et al., 1976; McKerrow, et al., 1977; Leggett et al., 1979). A number of strike faults, the visible expression of the presumed imbricate thrusts, have been defined in the terrain. Of these, the fault defining the boundary between the Northern and Central Belts (the contact between Ordovician and Silurian in Figure 1) is the most significant as it is marked by a very pronounced stratigraphic discontinuity and, on Slieve Glah, in the SW end of the Longford-Down inlier, by a distinctive mylonitic zone up to 200m wide (Oliver, 1978). To the north of this boundary fault, mid-Ordovician to possibly early Silurian greywackes composed of andesitic mineral and rock detritus, occur in a tract throughout the length of the southern part of the Northern Belt (Leggett et al., 1979; Floyd, 1982; Morris, 1983) whereas early Ordovician argillaceous sediments occur immediately south of the fault in the inlier (Oliver, 1978; Leggett et al., 1979).

Figure 1. Simplified geological map of the Longford-Down inlier, Ireland and the Southern Uplands, Scotland. Igneous intrusions: C=Carlingford; CD=Criffel Dalbeattie; CF=Cairnsmore of Fleet; LD=Loch Doon; MM=Mourne Mountains; N=Newry; SG=Slieve Gullion.

All four mining areas mentioned previously exhibit a striking spatial relationship to this boundary fault, either straddling it or lying in close proximity to it (Fig. 1). At Clontibret, the antimony-gold deposit is located just north of the boundary fault, here termed the Clontibret Shear Zone (Fig. 2), with all but two of the lead vein deposits in the region lying to the south of the fault. Virtually all the greywacke exposed in the area north of the fault, including that in the immediate vicinity of the deposit, characteristically contains andesitic detritus and, although undated, it is correlated with similar composition, largely mid to late Ordovician greywacke elsewhere in the Northern Belt (e.g. Scar Formation, Floyd, 1982; Gowna Group, Morris, 1983) upon the basis of petrographic similarity. SE of the fault, a thick sequence of argillaceous sediments, only a small part of which is exposed in the map area (Fig. 2), contains sporadic greywacke units of felsic composition and two sparse graptolitic faunas of probable early to mid-Llandovery age (graptolite identification by Dr. R. B. Rickards, Univ. of Cambridge).

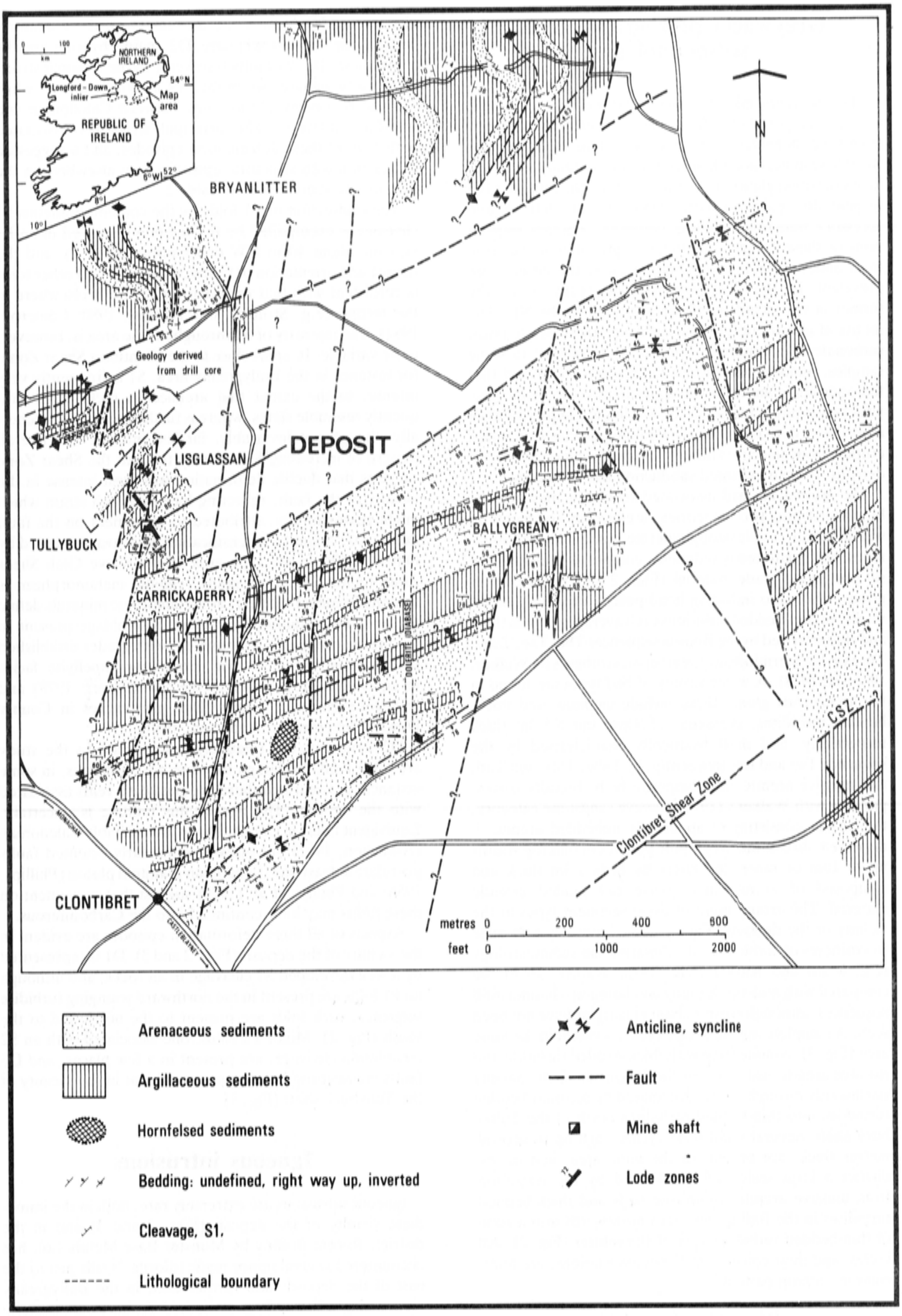


Figure 2. Geological map of the Clontibret district, County Monaghan.

Greywacke petrography and sedimentology

The presumed mid-Ordovician greywackes in the map area are composed of andesitic mineral and rock fragments (pyroxene, hornblende, plagioclase and microphyric clasts with these minerals as phenocryst phases), minor blueschist facies detritus (glaucophane mineral and schist fragments), serpentinite, garnet, quartz, felsic igneous detritus and accessory minerals including chromite. Varying proportions of these components define a gradational spectrum from andesitic to felsic-rich greywackes, the latter more prevalent in the Carrickaderry-Ballygreany area, the former in the vicinity of the deposit and to the NE. The matrix of all varieties contains chlorite, albite, white mica, carbonate and saussurite; clinozoisite is present in some samples. Sanders and Morris (1978) have suggested that the andesitic components in equivalent composition greywackes, exposed further to the SW in the Longford-Down inlier, were derived from calc-alkaline pyroclastic material erupted from an active volcanic arc and the blueschist facies detritus from an exhumed subduction zone complex.

The greywackes and associated sediments may broadly be divided into two categories, arenaceous sediments in which arenite ± microconglomerate grade material dominates, and argillaceous sediments composed principally of silt and pelite grade material (Figs. 2 and 3). The latter group, while also including hemi-pelagic deposits, consist mainly of thin-bedded turbidites each averaging 2-6cm thick and characterised by the Bouma sequences Tbe, Tae, Tabe, Tbce or Tce (terminology based upon syntheses by Walker, 1976 and 1978). A wider variety of bed types are found in the arenaceous group; these include medium- and thick-bedded turbidites, averaging 12-50cm and 0.5-3m thick respectively, and most frequently characterised by the sequence Tae and less frequently, by Tabe, Tabc and Tab; and massive arenite and composite beds, broadly corresponding with Walker's (1978) massive sandstone category, the former consisting of apparently unbedded arenite ± dispersed, discontinuous granule patches in outcrop widths up to 10m or more, the latter by beds 1-3m thick and composed of arenite and coarse tail graded granule material. The arrangement of these sediment types in the vicinity of the deposits (Figs. 2 and 3) may, by reference to syntheses of turbidite and submarine fan sedimentology (e.g. Mutti and Ricci Lucchi, 1975; Walker, 1978), be compared with mid-fan thinning and fining-up channel infill sequences, although erosive channel margins have not been seen. A complete medium scale cycle is evident in the mine area (Fig. 3), commencing with thick-bedded turbidite and massive arenite just south of the Lisglassan shaft, passing northwards through a zone dominated by medium-bedded turbidites into thin-bedded turbidites north of the Tullybuck shaft. Several small-scale cycles, each up to several metres thick, are present in the mine area, and in the district a large-scale cycle is defined by the transition from massive arenite, composite beds and thick-bedded turbidites in the Ballygreany area northwards into a zone of thin-bedded turbidites east of Bryanlitter (Fig. 2). All cycles, and their component facies associations, are lenticular in outcrop pattern.

Structural geology

Three phases of deformation are evident in the study area. The first, a ductile phase D1, is represented by folds, cleavage and, probably, by movement on the Clontibret Shear Zone, the second phase, D2, mainly by folds and the third phase, D3, by faults transverse to the regional strike. The first two phases are probably Caledonian in age, while the last is conceivably any age between Caledonian and mid-Carboniferous. The principal structures associated with each of these deformation episodes, and a suggested correlation with structural episodes seen elsewhere in the terrain, are summarised in Table 2.

The transection of F1 folds by the contemporaneous S1 cleavage is exemplified by the relation displayed in an F1 syncline about 400m NW of Clontibret (Fig. 2), and the degree and orientation of transection in this and other folds is consistent with that recorded for D1 folds elsewhere in the terrain (e.g. Stringer and Treagus, 1980; Cameron, 1981). The intensity of S1 throughout the area is, however, quite variable. In areas close to the Clontibret Shear Zone, for instance in the Ballygreany area, S1 is frequently very intense, to the extent that arenaceous rocks might frequently resemble slates, whereas further north, S1 is generally, though not invariably, far less intense. The overall pattern of increasing S1 intensity towards the Shear Zone suggests that ductile deformation was most intense in the vicinity of the fault, reflecting localized high strain which might reasonably be attributed to movement on the fault during D1. A similar intensification of cleavage is noted by Oliver (1978) in the type area of the Slieve Glah Shear Zone to the SW. Low grade regional metamorphism is essentially coeval with D1, as metamorphic minerals define S1, and the metamorphic mineral assemblage present in the greywacke matrix is consistent with grades established elsewhere in the inlier, viz. prehnite-pumpellyite facies in equivalent greywackes to the SW (Oliver, 1978) and anchizone grade in Central Belt greywackes in County Down (Cameron and Anderson, 1980).

D2 structures are relatively unimportant in the study area. D3 faults, although they are not numerous, in some instances crosscut and therefore post-date veins associated with the deposit. The age of this faulting is uncertain. Equivalent faults in County Down are probably Caledonian (Anderson, 1962) but elsewhere similarly oriented faults post-date at least one Caledonian granitoid pluton (Phillips, 1956) and Phillips et al. (1976) suggest that movement on these faults may have continued into the Carboniferous.

Aspects of all three deformation episodes are evident in the vicinity of the deposit (Figs. 2 and 3). D1 is represented by a well developed S1 cleavage in all rocks, and although no F1 folds are present in the northward younging turbidite sequence, such folds are present to the north and to the south (Fig. 2). Minor F2 folds, one associated with an S2 crenulation cleavage, are present in a few places, and D3 faults crosscutting lode zones are evident in the vicinity of the Tullybuck shaft (Fig. 3).

Igneous intrusions

Igneous intrusions are extremely rare, both in the immediate vicinity of the deposit (Figs. 2 and 3) and in the district. Recent drilling by Munster Base Metals Ltd. has encountered several minor mafic (diorite ?) sills just to the east of the deposit, and further east, in the Ballygreany area, a single N-trending, presumed Tertiary age, dolerite dyke crops out. A small area of hornfelsed greywacke is exposed about 2km SE of the deposit, but is not associated with any visible igneous rocks. Comparable hornfels areas are quite common south of the Clontibret Shear Zone,

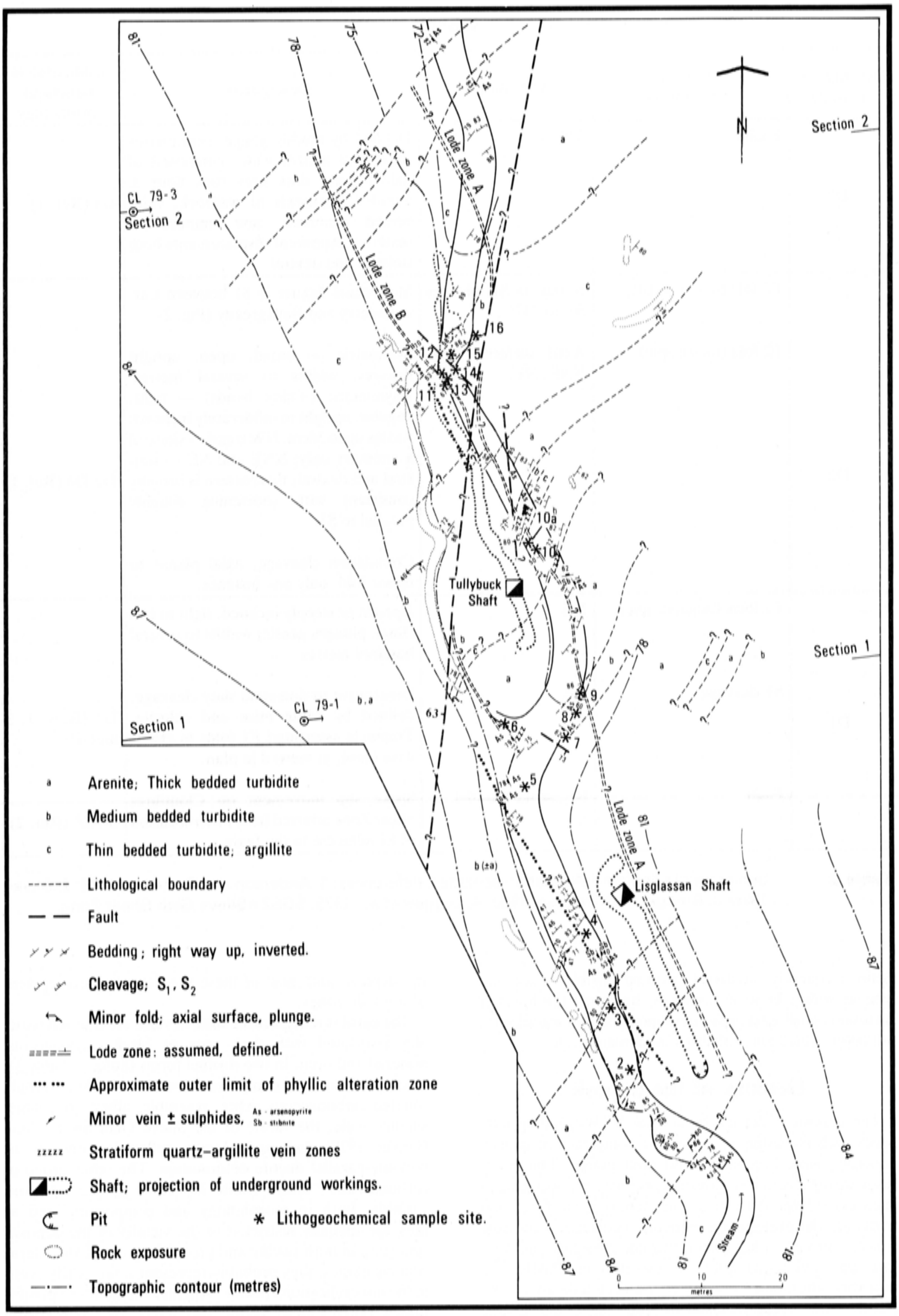


Figure 3. Surface geology in the vicinity of the Lisglassan-Tullybuck Au-Sb-As deposit, County Monaghan.

Table 2.

Deformation episode	Principal structure(s)	Orientation	Description	Comparative structural chronology
D3	Faults	330°-020°	Defined by muddy gouge, centimetres to several metres wide, composed of pale to very dark grey rock flour ± abraded fragments of wallrock, vein, veined wallrock and mineralized material. Apparent displacements both sinistral and dextral.	D5 (Ref. 1)
D2	F2 fold (macroscopic)	B axis, in S1, plunges 50° to 247°	Monoclinal flexure in S1 between Carrickaderry and Ballygreany (Fig. 2)	D2-D4 (Ref. 1)
	F2 fold (mesocopic)	Axial surfaces: NW, NNE, NE.	Symmetric — broad, open, upright flexures; widths to several metres. Asymmetric (+kink bands) — tight, angular, upright to moderately inclined; widths up to 30cm. NW trend—sinistral asymmetry only; NNE and NE — sinistral and dextral; this pattern is broadly consistent with shortening roughly parallel to S1.	
			Crenulation cleavage, axial planar to minor fold: only one instance.	
D1	F1 folds (macroscopic)	NE	Upright or steeply inclined, tight to isoclinal, plunges gentle; widths to several hundred metres.	D1 (Refs. 1, 3 and 4)
	S1 cleavage	NE	Penetrative to domainal slaty cleavage, defined by white mica and chlorite. Transects associated F1 folds in clockwise sense, as viewed in plan.	
	Fault	NE, strike parallel	Strike slip movement on Clontibret Shear Zone inferred from intensification of S1 adjacent to the fault.	SGSZ (Ref. 2).

Table 2. Summary of principle deformation episodes. References: 1, Anderson and Cameron, 1979; 2, Oliver, 1978; 3, Stringer and Treagus, 1980; 4, Leggett et al., 1979. SGSZ=Slieve Glah Shear Zone.

again frequently occurring without visible associated igneous rocks. In some instances, however, the hornfels surrounds small intermediate composition (?monzodiorite) intrusions which are probably Caledonian in age.

Geology of the deposit

The deposit is defined by several NNW-trending lode zones each consisting of polyphase complexes of quartz-ankerite veins, brecciation and fault gouge. The zones range up to 0.5m in width and have been traced over lengths in excess of 100m. Stibnite and auriferous arsenopyrite and pyrite are the principal ore minerals associated with these zones, although other minor metallic minerals and very rare grains of native gold are also present. Phyllic and propylitic alteration haloes surround each lode zone. The phyllic shells occur proximal to lode zones, and include abundant disseminated arsenopyrite and pyrite in the immediate lode zone wallrock. More extensive propylitic shells occur distally. Suites of other minor, generally barren, veins are present only in the immediate vicinity of the deposit, and most of these pre-date the development of the lode zones.

The earliest recognizable suite of veins are characteristically associated with dark grey or black carbonaceous material and occur in two distinct forms (Suite 1, Table 3). The stratiform vein complexes, contained within strongly foliated carbonaceous pelite, resemble, albeit on a much smaller scale, the fabric of the Slieve Glah Shear Zone (Oliver 1978) and undoubtedly reflect an episode of bedding-parallel ductile deformation. The other group of carbonaceous "veins" (Suite lb, Table 3) are far more variable, both in morphology and composition and as they are spatially restricted to the vicinity of the deposit, occurring in both phyllic and propylitic parts of the alteration envelopes, they probably represent a very early event in the mineralization episode. Angular fragments of pyrobitumen, ranging up to 200 microns in size, are a noteworthy and frequently common component in this vein assemblage (Suite lb).

The subsequent veins of Suite 2 are all morphologically similar and range from very irregular forms through podi-

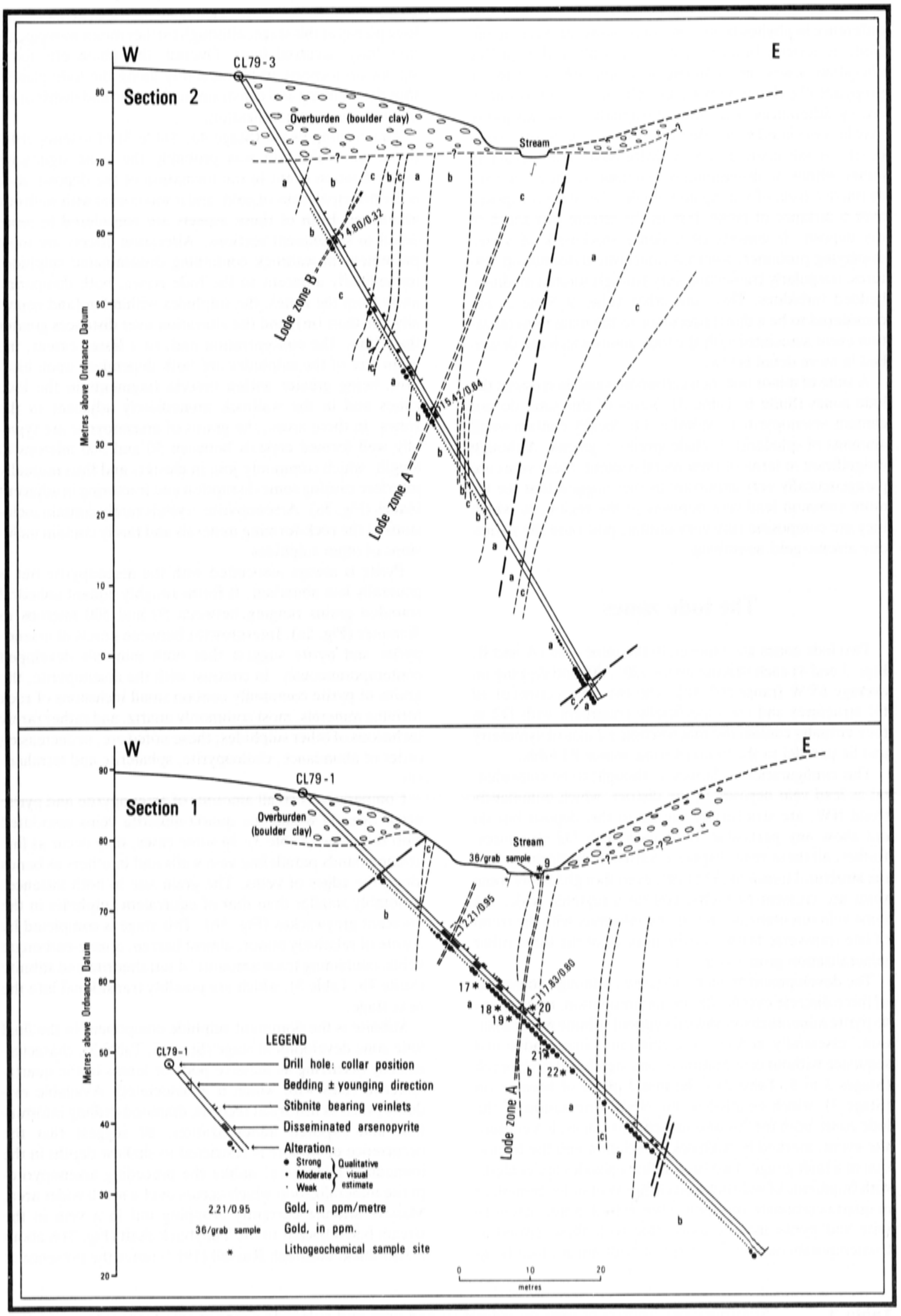


Figure 4. Drill hole sections through the Lisglassan-Tullybuck Au-Sb-As deposit. Section locations indicated in Figure 3. Symbols as per Figure 3.

form to tabular. Vein orientations are very variable. The difference in phyllosilicate content is, however, very significant, as sericite bearing veins occur only within phyllic alteration zones, and chlorite is found only in veins in propylitically altered greywacke. This distinction is mirrored by differences in associated sulphides; whereas pyrite may be associated with either type of vein, accessory arsenopyrite is only associated with phyllic zone veins, occurring either within or disseminated marginal to them. A very distinctive form of veining and phyllic alteration is exposed over a distance of about 15m in the stream just south of the deposit. It consists of a dense stockwork of veins, displaying prominent internal cataclastic deformation textures, irregularly transecting very strongly altered medium-bedded turbidites. This, and other veins of Suite 2, are considered to be a direct precursor to the main mineralization event associated with the lode zones which are described in more detail below.

A suite of minor iron-rich carbonate veinlets crosscut the lode zones (Suite 6, Table 3). Veins of this suite do not contain arsenopyrite or stibnite, but locally contain small amounts of sphalerite ± chalcopyrite ± galena. Although insignificant in terms of their metal content, these veins are paragenetically very important as they suggest that the far more common lead vein deposits in the region, to which they are compositionally very similar, post-date the antimony-arsenic-gold assemblage.

The lode zones

Two lode zones are exposed in the mine area (A and B, Figs. 3 and 4) each striking about 320°-330° and dipping on average 65°W (range 50°-90°). The two zones crosscut all D1 structures and are superficially congruent with D2 as they virtually contain the macroscopic F2 axis of symmetry and lie parallel to the trend of some minor F2 folds.

This configuration is, however, thought to be coincidental as lead vein deposits in the district, which dominantly trend NW, are structurally similar to this deposit but do not show any particular association with D2 structures. Rather, all these veins display a consistent conformity with the structural trends of D3 faults, even though locally some veins are crosscut by faults, and on a regional scale, the same vein orientations, and their conformity with the trend of late transverse faults, is evident in all of the three other mineralization groups (Fig. 1).

The development of each lode zone, although consisting of three discrete events, viz. initial brecciation, arsenopyrite-pyrite mineralization and subsequent stibnite mineralization, essentially reflects a continuous, intergradational sequence without connotation of any significant time break (Stages 3 to 5, Table 3). The initial phase of brecciation (Stage 3), which established the NNW orientation of the lode zones both for this and subsequent stages, is a composite event, marked by wallrock brecciation and the formation of a fault gouge. Two brecciation episodes are evident, with fragments of wallrock and earlier vein suites cemented in quartz-carbonate and then rebrecciated. Some arsenopyrite and pyrite may be associated with these episodes. Contemporaneous development of fault gouge, locally up to 75cm thick, indicates significant movement along the lode planes at this stage, although further minor movements may have occurred later. Overall, this phase effected a significant increase in permeability along the lode planes, thus determining and constraining the form and distribution of subsequent mineralization.

The ensuing phase (Stage 4a, Table 3) of arsenopyrite-pyrite mineralization was probably the most significant mineralization event in the formation of the deposit, as it is the principal locus of gold, and it was coeval with wallrock alteration. Both of these aspects are considered in more detail in subsequent sections. Alteration effects are most prominent in wallrock containing disseminated sulphides immediately adjacent to the lode zones, both dissipating away from the zones, the sulphides within 5m (and generally less than 1m), and the alteration over distances greater than 10m. The concentration and, to a lesser extent, the grain size of the sulphides are both dependent upon location, being greater within breccia fragments in the lode zones and in the wallrock immediately adjacent to the zones. In these areas, the grains of arsenopyrite are typically well formed crystals between 50 and 500 microns in length, which commonly join in clusters and thus mutually interfere causing some disruption and fracturing in adjacent blades (Fig. 5a). Arsenopyrite crystals rarely contain inclusions of the rock-forming minerals and rarely contain inclusions of other sulphides.

Pyrite is always associated with the arsenopyrite but is generally less abundant. It forms roughly equant anhedral rounded grains ranging between 50 and 500 microns in diameter (Fig. 5a). Intergrowths between grains of arsenopyrite and pyrite suggest that both minerals developed contemporaneously. In contrast with the arsenopyrite, the grains of pyrite commonly contain small inclusions of rock forming minerals, most commonly quartz, and rather rarely inclusions of other sulphides; those noted are, in decreasing order of abundance, chalcopyrite, sphalerite and tetrahedrite.

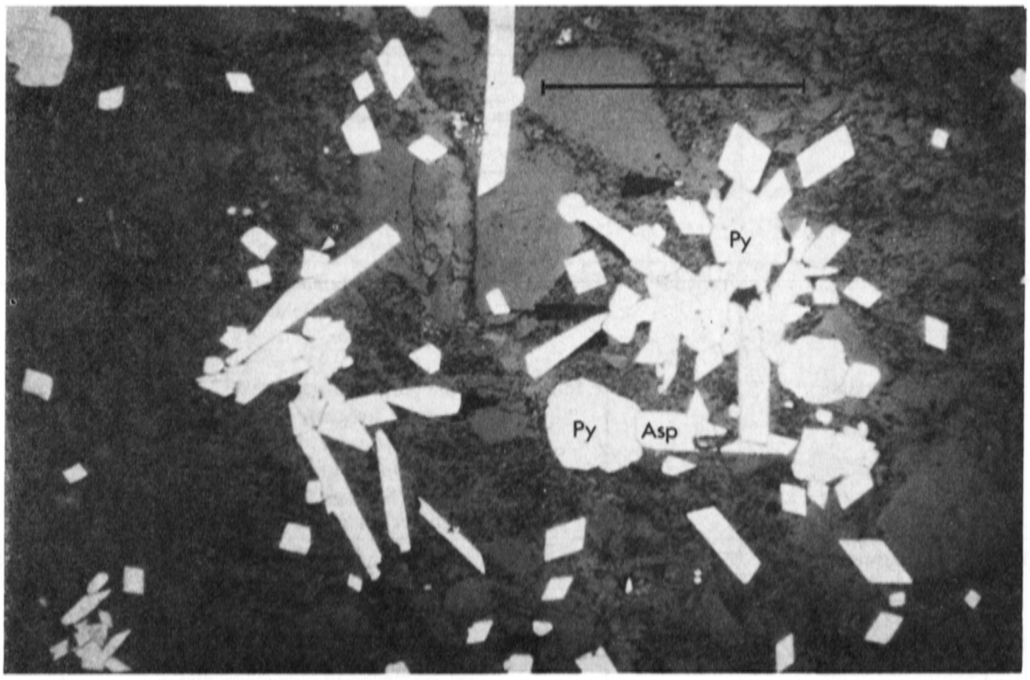
Comparatively small amounts of arsenopyrite and pyrite occur directly within the quartz-ankerite veins associated with this stage (Table 3). In some cases, they occur as fine grained bands paralleling vein walls and in others as bands along the edges of veins. The grain size in both instances is notably smaller than that of equivalent sulphides in the adjacent greywackes (Fig. 5b). This stage is completed by a suite of relatively minor, almost barren, quartz-carbonate veins, containing trace amounts of tetrahedrite and stibnite (Suite 4b, Table 3), which are possibly transitional into the next stage.

Stibnite is the dominant sulphide component in the final lode zone development stage (Stage 5, Table 3), characteristically occurring as massive pods or lenses in the quartz-ankerite veins with which it is associated. Available evidence, such as historical records, diamond drilling information and exposed mineralization, all suggest that the occurrence of stibnite is restricted to shallow depths in the immediate mine area, unlike the preceding arsenopyrite-pyrite mineralization which occurs over a much wider area. Massive stibnite currently cropping out in a vein in the stream bed adjacent to the Tullybuck shaft (Fig. 3) is about 5-7cm thick, although Russell (1917) notes the presence of

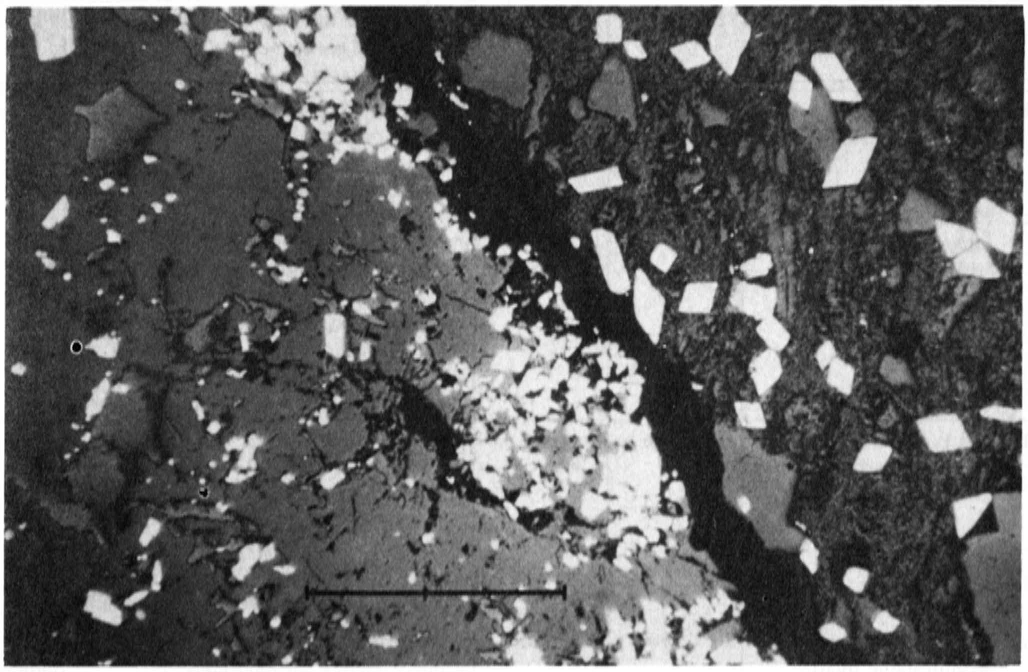
Table 3. Summary description of vein morphology and vein and sulphide paragenesis (oldest to youngest, 1 to 6 respectively). No paragenetic implication is attached to the arrangement of subgroups within stages 1, 2 and 5. (Asp = arsenopyrite; Py = pyrite; Sb = stibnite; Sp = sphalerite; Gn = galena; Thd = tetrahadrite; Mar = marcasite; Boul = boulangerite; Cpy = chalcopyrite).

Table 3.

Stage or vein suite	Composition	Orientation	Thickness	Morphological description	Associated metallic minerals	
					Principal	Minor
6	Ankerite and/or siderite	Uncertain	Few mm	Thin anastomosing or tabular veinlets. Only seen in drill core; very minor vein phase.		Sph, Cpy, Gn
(b)	Carbonate	Irregular	Hairline	Very thin carbonates veinlets, with accessory sulphides, mainly stibnite.		Sb, Sp, Mar
5 (a)	Quartz-carbonate	320°-330°	c.10-30cm	Pale grey semi-translucent quartz + irregular patches of white carbonate locally gradational into stibnite-rich lenses. No vugs. No discernible wallrock alteration.	Sb	Boul, Sph, Gn
(b)	Quartz-carbonate	320°-330° to cross cutting	Few cm	Single veins, random intergrowth of quartz and carbonate.		Sb, Thd (rare)
4 (a)	Sulphides Quartz-carbonate		Veins 10cm	Sulphides (aspy, py) disseminated in lode zones and in phyllic altered greywacke adjoining lode zones.		
			Dissemination zones: few cm	Extensive wallrock alteration. Veins = concordant to lode zone, locally cross-cutting; granular to finely banded textures (frequently carbonate-rich margins) ± banded fine-grained sulphides	Asp. Py (Au)	Cpy, Sph, Thd
3	Fault gouge + breccia	320°-330°	1m	Multi-episode breccias of wallrock and earlier vein suites + rock flour gouge.		? Py, Asp
(b)	Quartz-carbonate ± sericite gradational to sericite rich	Irregular	1cm to c.20cm	Quartz, pale greyish white or white, the dominant component, but with gradations to carbonate rich veins. Random intergrowth textures predominant, though with increasing phyllosilicate content, layering more frequent. Minor silicification defined by irregular quartz segregations in wallrock adjacent to lode zones. No vugs.		± Asp, Py
2 (a)	Quartz-carbonate ± chlorite gradational to chlorite-rich					
(b)	Carbonaceous material ± quartz ± carbonate	Stratiform to irregular	Few mm to c.30cm	Dark grey carbonaceous veins and veinlets ± dark grey quartz with or without carbonate infilled transverse fractures, variable to irregular diffuse carbonaceous replacement in greywacke.		± Py euhedra, Pyrobitumen
1 (a)	Carbonaceous material ± conformable quartz-carbonate	Stratiform	To 30cm	Bedding parallel zones of strongly foliated carbonaceous material containing stratiform lenticular, podiform and occasionally sigmoidally folded quartz-carbonate veins resembling, in appearance, those of suite 2.		± Py euhedra and/or fine grained stratiform or transverse veinlets and patches.

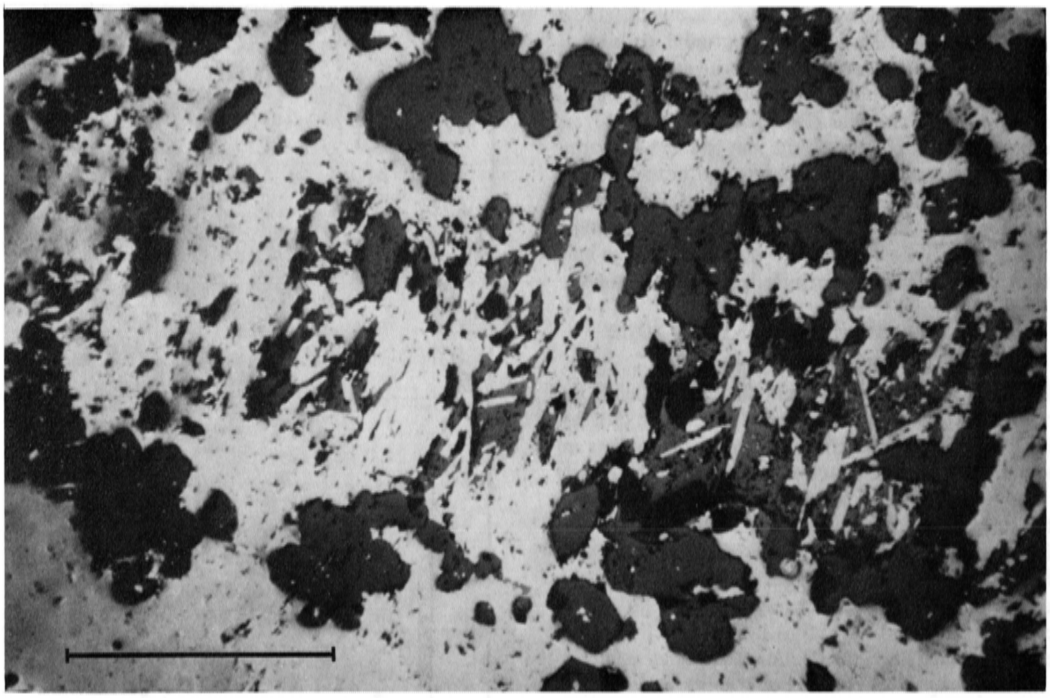


(a) Disseminated arsenopyrite (Asp) and pyrite (Py) in greywacke.

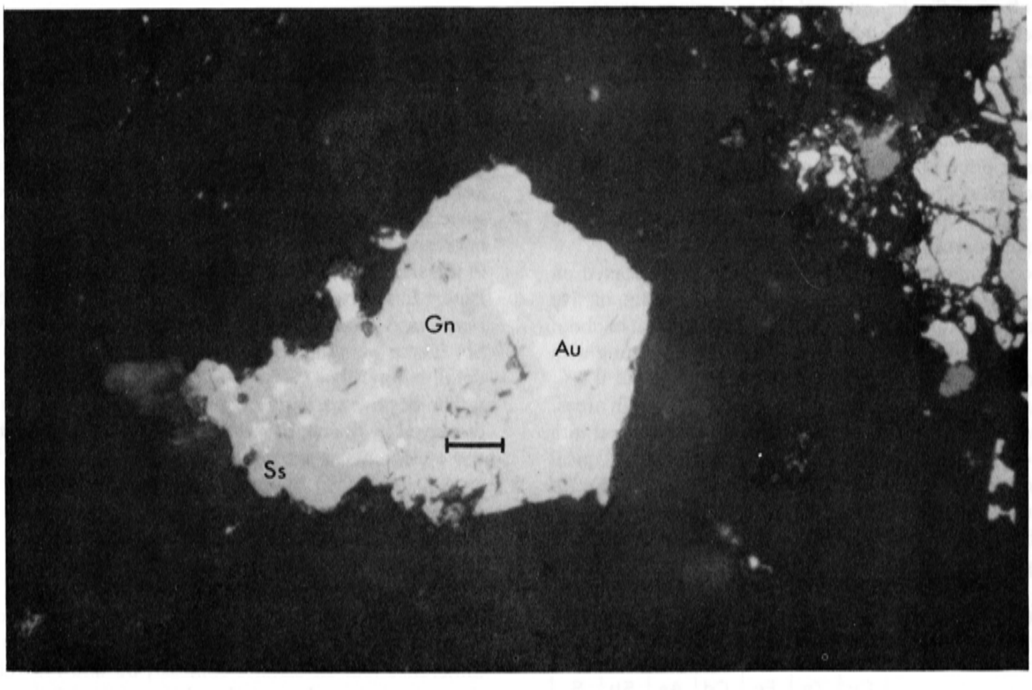


(b) Arsenopyrite (principally) disseminated in greywacke (right), and in quartz-ankerite vein (left); note difference in grain size.

Figure 5. Ore photomicrographs: Bar scales: a, b, c=500 microns; d=10 microns.



(c) Massive stibnite ophitically enclosing sub/euhedral quartz and anhedral ankerite.



(d) Native grains of gold (Au) enclosed in a galena (Gn) -sulphosalt (Ss) complex grain.

four such veins, individually ranging up to 6cm thick, across total widths of about 1.3m in the underground workings.

The stibnite, with accessory boulangerite and sphalerite, predominantly occurs within quartz-ankerite veins, in some instances replacing ankerite (Fig. 5c). Where, however, concentrations are high, the stibnite may locally be disseminated in greywacke breccia fragments and in the country rock up to 1m from lode zones. Minor stibnite, with accessory sphalerite and marcasite, is also present in a succeeding suite (5b, Table 3) of hairline carbonate veinlets which may occur in either phyllic or propylitically altered greywacke.

Chemistry of vein and lode zone minerals

Microscopic studies suggest that the earliest veins are quartz-rich in contrast to later veins which contain progressively more carbonate. In some veins these components are crudely zoned, but more commonly the two are irregularly and finely intergrown. Probe analyses of carbonate in a limited number of samples from various vein suites does not indicate any substantial variation in composition until the final stage (6, Table 3). The carbonate associated with both principal mineralization stages (4 and 5, Table 3) is ankerite containing about 5.5% iron and 0.15% manganese. Ankerite is again the dominant carbonate composition in the youngest vein suite, but is somewhat richer in iron, containing about 6.5% iron, and it is associated with subordinate siderite.

Currently available whole rock analyses of both mineralized and unmineralized surface and diamond drill hole samples (Figs. 2, 3 and 4) indicate that, relative to unmineralized material, arsenopyrite- and pyrite-bearing samples are enriched in Au, Bi and, to a lesser extent, Ni, Co, Cu, Zn and possibly Cr, and stibnite-bearing material is enriched in Pb and Zn. These associations reflect the known mineralogy of the deposit, with Bi as a minor constituent in arsenopyrite, Co and Ni as lattice constituents in pyrite and, to a minor degree, in arsenopyrite, and Cu and Zn reflecting the presence of rare inclusions of chalcopyrite, tetrahedrite and sphalerite in pyrite. The possible enrichment of Cr in these samples is unusual and is discussed in the description of the alteration envelope. In the stibnite-rich samples, Pb reflects the presence of boulangerite and rare galena, and associated sphalerite represents an adequate source for the Zn content.

Electron microprobe analyses have been conducted on a range of selected sulphide minerals. Analyses of five arsenopyrite grains indicate an average Sb content of about 0.2% and analyses of fifteen pyrite grains coexisting with arsenopyrite shown a typical As content of about 0.9%, although ranging as high as 7.5% in small sub-grain areas. Two tetrahedrite grains, accessory minerals associated with stage 4 mineralization (Table 3), have yielded fairly typical compositions, but with a surprising variability in the Fe:Zn ratio (Table 4). Analyses of two stage 5 sphalerite grains associated with stibnite indicate low Fe concentrations and average Cd contents (Table 4).

Table 4: Microprobe analyses of sphalerite and tetrahedite grains. All analyses in weight per cent.

	Cu	Zn	Fe	Cd	As	Sb	S
Tetrahedrite grains	38.1	1.1	6.3	0.1	1.5	27.0	26.6
	40.1	6.6	1.5	0.1	0.6	27.8	24.6
Sphalerite grains	—	68.0	0.6	0.5	—	—	—
	—	67.5	0.9	0.4	—	—	—

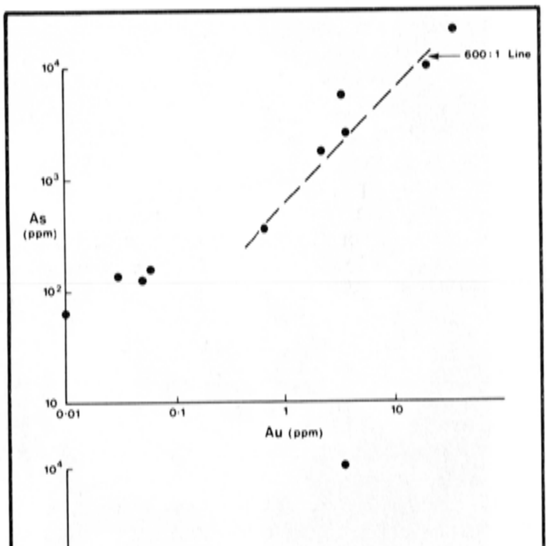


Figure 6. Element variation diagrams: As vs. Au (top) and Sb vs. Au (bottom).

Gold mineralization: form and distribution

Modern exploration interest in the Clontibret region has focussed exclusively upon its potential for gold mineralization, a potential based almost solely upon analytical results, since grains of visible gold have only ever been observed microscopically and no alluvial gold has ever been recorded in the area. Analytical results, obtained mainly by Munster Base Metals Ltd., indicate a broadly positive correlation between As and Au, but little correlation between Au and Sb. These general relationships are considered in more detail below.

The positive correlation between As and Au is strikingly displayed by the nearly perfect linear relationship between these elements as shown in Figure 6, which is based upon analytical results obtained from greywacke samples containing disseminated arsenopyrite and pyrite. For Au values greater than about 0.5ppm, the results indicate a fairly consistent As:Au ratio of about 600:1. This ratio is generally supported by many other analytical results of lesser precision, though these also suggest that ratio values may be somewhat variable along the known strike length of the mineralization. In distinct contrast, Sb and Au values in the same greywacke samples show no correlation, either positive or negative (Fig. 6). These results clearly indicate that gold is associated with arsenic-rich mineralized material.

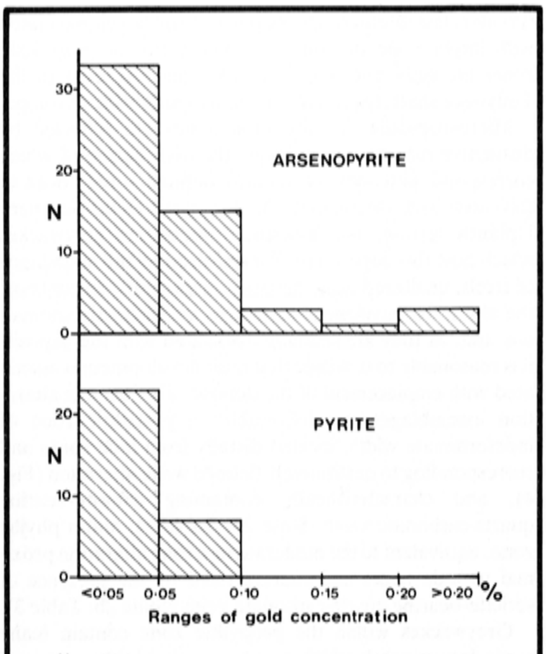
Detailed microscopic examination of numerous samples of diverse types of ore material revealed only very rare grains of particulate gold. These grains rarely exceed 10 microns in size and occur as inclusions either in quartz or in pyrite; no equivalent inclusions have been observed in arsenopyrite or stibnite. Particles of gold larger than 10 microns are exceedingly rare. The most spectacular such example is illustrated in Figure 5d in which gold grains up to about 20 microns in diameter occur within a multi-mineral complex particle. Probe analyses of this complex indicate the presence of galena and lesser amounts of boulangerite and bournonite, and that the native gold contains an average of about 11% silver. The paragenetic association of this complex grain is uncertain, but the presence of galena and boulangerite suggest comparison with the stibnite phase of mineralization (Stage 5, Table 31), thereby indicating that gold, albeit in rare and perhaps very erratic amounts, may be associated with this stage, in addition to its primary locus in stage 4.

In any comparable investigation of a gold ore based upon microscopic studies, even semiquantitative estimates of gold concentrations are fraught with difficulty. Even so, the amount of visible gold in the samples studied appears insufficient to account for the known relatively high gold values, ranging up to about 36g/t (Fig. 4 and Table 1). This discrepancy suggests that a considerable proportion of the gold occurs either as submicroscopic particles or as lattice constituents within arsenopyrite and associated pyrite, a possibility examined by study of mineralized samples from near Lode Zone A at a depth of about 55m in diamond drill hole CL79-3 (Fig. 4). Heavy and light mineral concentrate fractions prepared from this material with the use of tetrabromoethane, were each analysed for Au and As, with the following results:

	As (ppm)	Au (ppm)	As:Au
Untreated ore (selected sample)	15,700	35	449
Heavy concentrate	55,500	124	447
Light concentrate	4,500	10	450

These values clearly indicate that gold is concentrated in the heavy mineral, arsenopyrite-pyrite rich fraction and the virtual absence of microscopically visible gold in sulphide samples from this fraction effectively confirms its presence in submicroscopic form. Probe analyses of this and four other auriferous arsenopyrite-pyrite samples failed, however, to detect any submicroscopic native gold particles, suggesting that the gold content is even more finely dispersed within the sulphides, possibly as a lattice constituent. Subsequent probe analyses for As and Au in 30 pyrite and 55 arsenopyrite grains, the analyses limited only by an Au detection limit of 500ppm, indicate that arsenopyrite is the principal gold host mineral, and pyrite is a subsidiary host (Fig. 7). In both cases, however, the gold tenor is quite variable, ranging from a gold content less than the detection limit in many grains, to a maximum of 2,500ppm recorded in one arsenopyrite grain. There is some evidence to suggest that the highest gold values in pyrite occur in grains with a higher than normal As content, although this conclusion is only tentative as gold content is, in most pyrite grains, below the detection limit and barely detectable in the remainder.

These results allow approximate estimates to be made of overall gold distribution. A reasonable average of about 500ppm gold in arsenopyrite is indicated and in pyrite, the average gold content is unlikely to be greater than about 250ppm. These figures imply that, in the samples from hole CL79-3, some 20ppm of the overall gold content is present as a lattice constituent in arsenopyrite and perhaps up to 10ppm in pyrite. Even allowing for imprecision in these figures, it is clear that a very substantial proportion of the total gold, about 30ppm, is present in sulphide lattices, rather than as native particles, and, by extrapolation, a similar conclusion may be applied to the gold content of the remainder of the deposit. It may be noted that in a mineralogically similar antimony-arsenic deposit at Glendinning, in the Central Belt of the Southern Uplands, gold contents of up to 3,000ppm have recently been recorded in arsenopyrite (P. Duller, pers. comm.), although the overall gold content is extremely low as indicated by one analysis of 0.1ppm (Gallagher et al., 1983).



N = Number of electron-probe determinations

Figure 7. Histograms of gold concentration in arsenopyrite and pyrite.

Wallrock alteration: mineralogy and chemistry

Wallrock alteration, in the form of haloes surrounding lode zones, has been referred to previously. Both in surface outcrops and in drill core, alteration is characterized by a progressively more intense bleaching towards lode zones; this is marked by a transition from medium green coloured greywacke, grading through pale green or greyish green (weak to moderate alteration, Fig. 4) into pale grey and ultimately into pale greyish white (moderate to strong, Fig. 4) immediately adjacent to the zones. The widths of the moderately to strongly altered zones is very variable and depends upon the scale of the lode zone or veins to which it is spatially related, ranging from single margin widths of a few centimetres adjacent to minor veins, up to about 10m (most typically 1m to 6m) adjacent to substantial lode zones, such as Zone A (Figs. 3 and 4). Composite alteration envelopes are present either where small veins associated with narrow, but strongly altered, envelopes occur within broader, less intensely altered parts of envelopes associated with larger scale structures, or where two or more lode zones are sufficiently close, for example just south of the Tullybuck shaft, to produce an anomalously wide envelope.

Microscopically the alteration zones are reflected by distinctive mineral assemblages, the distribution of which correspond well with the visually defined zones. Both in this area and throughout the Longford-Down/Southern Uplands terrain, the andesitic composition greywackes which host this deposit are characterized by the abundance of fresh, unaltered mafic detrital components. In contrast, the alteration envelope assemblages are distinctly anomalous and, as they are spatially associated with the deposit, it is reasonable to conclude that their development is associated with emplacement of the deposit. Two distinct alteration assemblages are discernible: a propylitic zone of indeterminate width, located distally from lode zones and corresponding to qualitatively defined weak alteration (Fig. 4), and characteristically containing chlorite-bearing quartz-carbonate veins (Suite 2a, Table 3); and a phyllic zone, equivalent to the moderate to strong alteration proximal to lode zones and characterized by the presence of sericite-bearing quartz-carbonate veins (Suite 2b, Table 3).

Greywackes within the propylitic zone contain many secondary minerals which are also present in the matrix of regionally unaltered greywackes. However, in the alteration zone these minerals are more pervasively developed and overprint all but quartz and felsic igneous fragments. Sericite is prominent throughout the matrix and feldspathic detritus and all mafic fragments are totally replaced by oxychlorite and/or saussurite. Interstitial patches of pale green chlorite are present in variable amounts and microcrystalline carbonate veinlets and patches are very common, overgrowing fragments and matrix. The relict detrital chromite grains are well preserved and almost invariably surrounded by chlorite/oxychlorite.

A gradual transition from the propylitic into the phyllic zones is defined by elimination of interstitial chlorite and by an increasing abundance of sericite and carbonate. The latter minerals occur in approximately equal proportions in the same mode as in the propylitic zone but vary in grain size from microscrystalline to fine-grained. Detrital mafic minerals are also pseudomorphed by the same minerals as in the propylitic zone, although incipient or partial replacement of oxychlorite by sericite is quite frequent. Pyrite and arsenopyrite are common accessory minerals in the prominently altered greywacke adjacent to lode zones. The detrital chromite grains are, in this zone, characteristically surrounded by narrow, bright green haloes which are composed of mica. The colour of this mica, together with the presence of marginal corrosion textures on many chromite grains, indicates at least a partial redistribution of Cr, and suggests that it is a Cr-rich variety.

The chemical expression of wallrock alteration is illustrated by reference to a suite of samples collected both on surface (Fig. 3) and from drill hole CL79-1 (Fig. 4) which were analysed for all major and a range of minor and trace elements. These analyses indicate that the most significant chemical expression of alteration is defined by progressive increase in K_2O and decrease in Na_2O contents with increasing proximity to a lode zone. This pattern, expressed as a K_2O/Na_2O ratio, is exemplified by the profile adjacent to lode zone A (Fig. 8). The increase in K_2O content undoubtedly reflects the increasing abundance of sericite and white mica, largely accompanied by more pervasive alteration of plagioclase with, presumably, a consequential loss in Na_2O. Other elements showing progressive inward

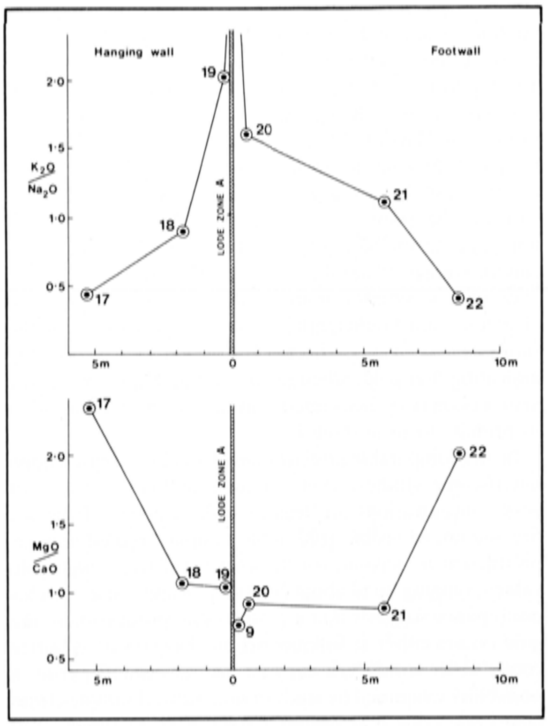


Figure 8. K_2O/Na_2O and MgO/CaO ratio profiles adjacent to Lode Zone A. Sample points correspond to sample locations shown in Figures 3 and 4.

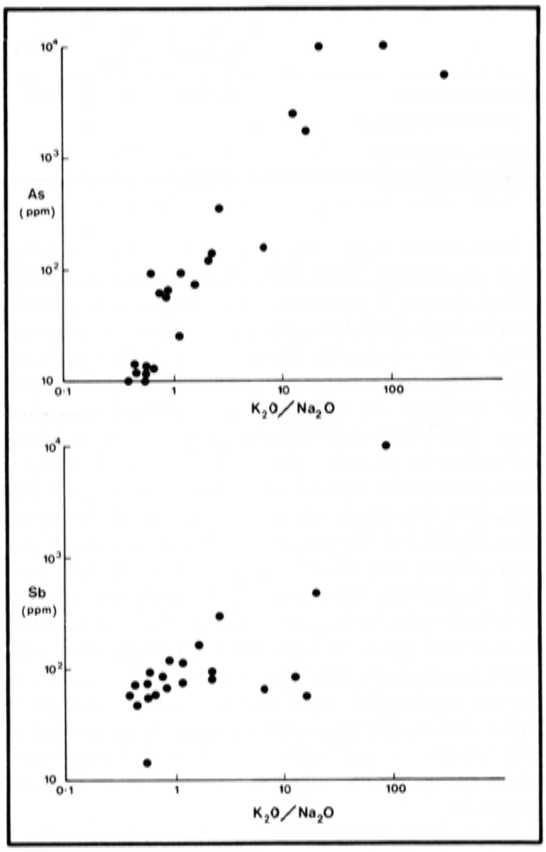


Figure 9. Chemical variation diagrams: As vs. K_2O/Na_2O (top) and Sb vs. K_2O/Na_2O (bottom).

trends include CaO, which increases slightly, and MgO which diminishes quite sharply. Expressed as a ratio, MgO:CaO is relatively constant near the lode zone and increases rather abruptly outward into areas of essentially propylitic alteration (Fig. 8). This variation may reasonably be attributed to a combination of greater abundance of carbonate adjacent to the lode zone and replacement of chlorite and mafic and feldspar components. The overall loss of MgO and also total iron, which exhibits variation trends parallel to those of MgO, is unusual, in view of the abundance of ankeritic carbonate in and adjacent to the lode zones. The ultimate fate of these excess components is speculative, but it is at least conceivable that they may have contributed to the development of late stage ankerite-siderite veins (Suite 6, Table 3). Rb and, to a lesser extent, Cr also show systematic trends, both increasing inwards. The Rb variation parallels that of potassium, as indicated by a near constant K/Rb ratio regardless of distance from the lode zone, and presumably reflects its presence as a phyllosilicate lattice constituent. The Cr pattern is considerably more erratic, but given the textural evidence of limited Cr mobility, it is possible that minor, perhaps locallized, enrichment may be present.

Ore mineralogical studies suggest that the most intensive, and presumably the highest temperature, phase of mineralization is represented by the auriferous arsenopyrite-pyrite assemblage. This is reflected by, and is consistent with, its spatial association with the most prominent wallrock alteration. This relationship is underlined by the close correlation between As and the best indicator of alteration, the K_2O:Na_2O ratio (Fig. 9). In contrast, the stibnite phase is much more localized, probably formed at lower temperatures and is not accompanied by any discernible wallrock alteration. As a consequence, the correlation between Sb and K_2O:Na_2O is poor (Fig. 9), although some degree of correlation is to be expected as both As and Sb mineralization phases occupy the same lode structures. It has been previously shown that As and Au values show excellent correlation and therefore, as As content is sympathetically related to degree of alteration, so too is that of Au.

Discussion

The metallogenesis of this and the lead vein deposits in the Clontibret-Castleblayney district is the subject of a detailed study (by GMS, JHM and others) currently in progress and hence definitive statements would, at this stage, be premature. Nevertheless there are several factors bearing upon the age and origin of the deposit which may be mentioned here.

Mineralization comparable to that characterizing this deposit occurs in various parts of the Southern Uplands of Scotland, in several instances associated directly with Caledonian igneous intrusions. In the Glenhead Burn area at the south end of the Loch Doon pluton (Fig. 1), a very striking mineralogical and morphological analogy with this deposit is provided by a system of N- trending quartz veins and stockwork systems containing abundant arsenopyrite, lesser amounts of pyrite and minor gold which have yielded analyses of up to 3.5% As and 8.8ppm Au (Leake et al., 1981). Individual veins may range up to 30cm wide and all are enclosed by sericitic alteration envelopes which frequently contain abundant disseminated arsenopyrite. These veins crosscut all rock types in the district including both the principal intrusive units of the pluton and an earlier suite of minor monzonitic intrusions. The marginal zones of many of the latter intrusions contain disseminated pyrrhotite, arsenopyrite and pyrite. Arsenopyrite also occurs disseminated in adjacent hornfelsed metasediments. Analyses of up to 3,000ppm As and 0.16ppm Au have been determined from this form of mineralization which may occur in zones up to 18m wide and which Leake et al. (1981) believe to be the bedrock source of many As soil anomalies in the district. A similar association is evident in the Clontibret district, where several soil As anomalies correspond to the outcrop of some (?) monzodioritic intrusions mentioned previously. Minor carbonate-base metal veins, similar to those at Clontibret, are also present in the Glenhead deposit and were apparently emplaced relatively late. Leake et al. (1981) clearly consider that the arsenic-gold mineralization is directly related to Caledonian igneous activity, an association underlined by the occurrence of arsenopyrite in the tonalitic facies of the Burnhead intrusion just to the east of the Loch Doon pluton, and by the spatial association of significant alluvial arsenic and gold anomalies with minor igneous intrusions both at the northeastern end of the Cairnsmore of Fleet pluton (Fig. 1) and at the southeastern end of the Carsphairn granitoid body (Dawson et al., 1977; Leake et al., 1981).

Antimony occurs in minor amounts at some of these localities, but its association with arsenic and gold is more prominent in two other deposits, at Black Stockarton Moor and at Glendinning. The former is principally a porphyry copper-type deposit centred on a subvolcanic complex of mafic to intermediate composition intrusions, most of which pre-dates emplacement of the nearby Criffell-Dalbeattie pluton (Fig. 1; Browne et al., 1979). Gold, antimony and arsenic are minor constituents in this deposit (maxima; Au 0.06ppm, As c.300ppm, Sb c.200ppm), and correlate positively with each other, but not with Cu. The Glendinning deposit occurs about 45km along strike to the NE from the Criffell pluton and like Lisglassan-Tullybuck, it was worked historically for antimony (Gallagher et al., 1983). The antimony occurs principally as stibnite in NNE-trending veins but, unlike Clontibret and the other Scottish deposits, its arsenic content primarily reflects stratiform, apparently synsedimentary, arsenopyrite rather than vein arsenopyrite which, although present, is of minor importance (Gallagher et al., 1983). A further contrast, at least with the Scottish deposits, is provided by the complete absence of igneous intrusions anywhere in the vicinity of the deposit, other than for Tertiary dolerite dykes cropping out 2.5km to the SW.

The geological evidence provided by the Scottish deposits clearly suggests a spatial and genetic relation to Caledonian igneous activity, and, at Glendinning, with perhaps even earlier hydrothermal events. By comparison, particularly with the Glenhead Burn mineralization, a similar age and origin may be inferred for the Lisglassan-Tullybuck deposit. This inference is consistent with a K/Ar age of 360±7Ma derived from clay minerals associated with the stibnite phase of mineralization at Lisglassan-Tullybuck (Halliday and Mitchell, 1983), and as this can only be regarded as a minimum age, it suggests that the deposit was emplaced prior to the end of the Devonian. In contrast, K/Ar ages derived from various samples from two lead vein deposits in the Clontibret district range from 329Ma to 293Ma, and Halliday and Mitchell (1983) consider that these results indicate emplacement or isotopic resetting of these deposits during the Hercynian orogeny.

All known instances of antimony-arsenic-gold mineralization in the Clontibret district occur only within andesitic composition greywacke and it may be more than coincidental that some of the Scottish arsenic-gold deposits also appear to occur within the strike continuation the same type of greywacke, viz. Glenhead Burn, Burnhead, and perhaps the area SE of the Carsphairn intrusion. The Leadhills-Wanlockhead mining district, with which placer gold and auriferous quartz-pyrite-muscovite veins are associated (Temple, 1955), also occurs within the same andesitic composition greywacke. South of the boundary fault between the Northern and Central Belts, the gold-arsenic association noted at the northeastern end of the Cairnsmore of Fleet pluton occurs within the outcrop of greywacke, some of which contains appreciable amounts of augite and other mafic igneous detritus (Craignell Formation; Cook and Weir, 1980). Such detritus is, however, not present in the greywackes which host the Glendinning deposit.

It is conjectural how the spatial coincidence between arsenic-gold (-antimony) deposits and mafic composition greywackes may be interpreted, but it is a pattern which is at least comparable to, for example, the association of Archaean lode gold deposits with mafic igneous rocks (Hutchinson, 1976). The association might indicate that either the greywackes were, at least in part, a source of metals or, being composed of chemically reactive detrital components, that vein mineralization was localized in them as a consequence of chemical interaction between the wallrock and hydrothermal fluids bearing metals derived from elsewhere.

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References

ANDERSON, T. B. 1962. The stratigraphy, sedimentology and structure of the Silurian rocks of the Ards Peninsula, County Down. Unpubl. Ph.D. thesis, Univ. of Liverpool, 244pp.

ANDERSON, T. B. and CAMERON, T. D. J. 1979. A structural profile of Caledonian deformation in Down. *In:* Harris, A. L., Holland, C. H. and Leake, B. E. (eds.). *The Caledonides of the British Isles — reviewed.* Scottish Academic Press, Edinb., 263-267.

BROWN, M. J., LEAKE, R. C., PARKER, M. E. and FORTEY, N. J. 1979. Porphyry style copper mineralisation at Black Stockarton Moor, south-west Scotland. *Mineral Reconnaissance Programme Rep. Inst. Geol. Sci.*, No. 30, 87pp.

CAMERON T. D. J. 1981. The History of Caledonian Deformation in East Lecale, County Down. *J. Earth Sci. R. Dublin Soc.*, 4, 53-74.

CAMERON, T. D. J. and ANDERSON, T. B. 1980. Silurian metabentonites in County Down, Northern Ireland. *Geol. J.*, 15, 59-75.

COOK, D. R. and WEIR, J. A. 1980. The stratigraphical setting of the Cairnsmore of Fleet Pluton, Galloway. *Scott. J. Geol.* 16, 125-141.

DAWSON, J. and others. 1977. A mineral reconnaissance survey of the Doon-Glenkens area, south-west Scotland. *Mineral Reconnaissance Programme Rep. Inst. Geol. Sci.*, No. 18.

FLOYD, J. D. 1982. Stratigraphy of a flysch succession: the Ordovician of W. Nithsdale, SW Scotland. *Trans. R. Soc. Edinburgh,* 73, 1-9.

GALLAGHER, M. J. and others. 1983. Stratabound arsenic and vein antimony mineralisation in Silurian greywackes at Glendinning, south Scotland. *Mineral Reconnaissance Programme Rep. Inst. Geol. Sci.*, No. 59, 81pp.

HALLIDAY, A. N. and MITCHELL, J. G. 1983. K-Ar ages of clay concentrates from Irish orebodies and their bearing on the timing of mineralisation. *Trans. R. Soc. Edinb.*, 74, 1-14.

HUTCHINSON, R. W. 1976. Lode gold deposits: the case for volcanogenic derivation. *In: Proc. Vol. Pac. Northw. Min. Metals Conf., Portland, Oreg., 1975.* Oreg. Dep. Geol. Mineral. Ind., 64-105.

LEAKE, R. C. and others. 1981. Gold mineralisation at the southern margin of the Loch Doon granitoid complex, south-west Scotland. *Mineral Reconnaissance Programme Rep. Inst. Geol. Sci.*, No. 46, 41pp.

LEGGETT, J. K., McKERROW, W. S., MORRIS, J. H., OLIVER, G. J. and PHILLIPS, W. E. A., 1979. The North-western Margin of the Iapetus Ocean. *In:* Harris, A. L., Holland, C. H. and Leake, B. E. (Eds.). *The Caledonides of the British Isles —reviewed.* Scottish Academic Press, Edinburgh, 499-512.

MACKAY, R. A. 1959. The Leadhills-Wanlockhead Mining District. *In: Symposium on the future of non-ferrous mining in Great Britain and Ireland.* Inst. Min. Metall.

McCANNELL, J. D. 1957. Gold in Ireland. Press Release, January 29th, 1957, on behalf of Can-Erin Mines Ltd.

McKERROW, W. S., LEGGETT, J. K. and EALES, M. H. 1977. Imbricate thrust model of the Southern Uplands of Scotland. *Nature.* London, 267, 237-239.

MITCHELL, A. H. G. and McKERROW, W. S. 1975. Analagous evolution of the Burma orogen and the Scottish Caledonides. *Bull. Geol. Soc. Am.*, B6, 305-315.

MORRIS, J. H. 1983. The stratigraphy of the Lower Palaeozoic rocks in the western end of the Longford-Down inlier, Ireland. *J. Earth Sci. R. Dublin Soc.*, 5, 201-218.

MORRIS, J. H. 1984. The metallic mineral deposits of the Lower Palaeozoic Longford-Down inlier in the Republic of Ireland. *Geol. Surv. Ire. Rep. Series,* RS84/1, 72pp.

MUTTI, E. and RICCI LUCCHI, F. 1975. Turbidite facies and facies association. *In: Examples of Turbidite Facies and Facies Associations from selected Formations of the Northern Apennines (Field trip excursion guide)* (by E. Mutti, G. C. Parea, F. Ricci Lucchi, M. Sagri, G. Zanzucchi, G. Ghibaudo, and S. Jaccarino), IXth Int. Congr. Sedim: Nice — 75, Field Trip All, 21-36.

OLIVER, G. J. H. 1978. Prehnite-pumpellyite facies metamorphism in County Cavan, Ireland. *Nature,* London, 274, 242-243.

PEACH, B. N. and HORNE, J. 1889. The Silurian rocks of Britain; 1, Scotland. *Mem. geol. Surv. Scotland,* 749pp.

PHILLIPS, W. E. A., STILLMAN, C. J. and MURPHY, T. 1976. A Caledonian plate tectonic model. *J. geol. Soc. London,* 132, 579-609.

PHILLIPS, W. J. 1956. The Criffell-Dalbeattie Granodiorite Complex. *Q. Jl. geol. Soc. Lond.,* 112, 221-239.

RUSSELL, A. 1917. Report on the Clontibret Antimony Mine, Castleblayney, Co. Monaghan. Unpublished report to the Ministry of Munitions.

SANDERS, I. S. and MORRIS, J. H. 1978. Evidence for Caledonian subduction from greywacke detritus in the Longford-Down inlier. *J. Earth Sci. R. Dubl. Soc.,* 1, 53-62.

STEWART, D. 1799. The Report of Donald Stewart, Itinerant Mineralogist to the Dublin Society. *Trans. Dublin Soc.,* 1, 142pp.

STRINGER, P. and TREAGUS, J. E. 1980. Non-axial planar S1 cleavage in the Hawick Rocks of the Galloway area, Southern Uplands, Scotland. *J. Struc. Geol.,* 2, 317-331.

TEMPLE, A. K. 1955. The Leadhills-Wanlockhead Lead and Zinc Deposits. *Trans. R. Soc. Edinburgh,* 63, 85-113.

WALKER, R. G. 1978. Deep-Water Sandstone Facies and Ancient Submarine Fans: Models for Exploration for Stratigraphic Traps. *Am. Assoc. Pet. Geol. Bull.,* 62, 932-966.

Discussion

MARK BENNETT (Leeds University) asked the following questions:

1. Is there any relation between high gold values and detailed wallrock lithology, as the presence of pyrite in some deposits may have provided the sulphur necessary to "fix" metals as sulphides together with associated gold? 2. Is there any evidence of pyritization of iron minerals where high gold values occur? This relation can be demonstrated in western Australia and has obvious economic implications. 3. Is the disseminated pyrite which is associated with the Au-Sb-As mineralization a secondary alteration product, or is it a primary (sedimentary) constituent of the country rocks, and does this pyrite occur adjacent to veins that do not contain significant gold values? 4. Are the veins associated with any intrusive rocks? If not, do you consider they may be the result of metamorphic "sweating" and leaching, as is believed to be the case in the Archaean Greenstone terrain of western Australia? 5. You have suggested that the lithic (andesitic) greywackes may be the source of the metals in these veins. Surely any metals leached would have been removed from the immediate vicinity and deposited elsewhere under different physical and chemical conditions. Is it not more likely that the association of metalliferous veins with these rocks is a result of their chemical reactivity and their consequent major influence on ore deposition?

REPLY:

The first three questions posed by Bennett focus primarily upon any potential relation between pyrite and the locus of gold mineralization and may be considered together. Pyrite, of presumably diagenetic origin, is an ubiquitous accessory mineral in greywackes of variable composition throughout the Longford-Down inlier, and there is no evidence to suggest that such primary pyrite, or other sulphides, occurred in sufficient concentrations in the vicinity of the deposit to have played any significant part in the "fixing" of gold or other metals, Rather, the anomalous concentrations of pyrite which are present in the deposit occur only within the immediate vicinity of the lode zones, and are undoubtedly of epigenetic origin. Iron minerals other than pyrite are not present in greywackes outside the mineralized area, and it is therefore unlikely that such minerals were present, and then subsequently pyritized, in proximity to the gold mineralization.

Although there is no apparent relation between high gold values and wallrock composition in detail, a general relation between mineralization and wallrock lithology is evident. Lode zones and veins are best developed, and disseminated mineralization is most extensive, in coarse-grained rocks (greywacke) rather than in argillaceous rocks or thin-bedded turbidites composed principally of silt and clay grade material. This, on a larger scale, is reflected by lode zones being most prominent in the arenaceous portions of the medium scale thinning and fining-up cycles in the mine area.

Turning to the question concerning any association between igneous intrusions or regional metamorphism and the deposit, the available structural evidence suggests that the lode zones were emplaced in fractures/fault zones generated at some considerable time after the peak of regional metamorphism. The time gap between metamorphism and lode zone emplacement encompassed the development of at least one intervening period of deformation in this district and three periods further NE in County Down (Anderson and Cameron, 1979). Further details concerning the structural chronology have been discussed in the text. The hiatus between metamorphism and mineralization effectively precludes a "metamorphic sweating" origin for the deposit, especially as the intervening deformation structures are unmineralized. Moreover, if the mineralization was emplaced during regional metamorphism, then it would be reasonable to expect that, on a regional scale, it would be more evenly and widely developed than it is. Instead, the very obvious mineralization clustering pattern, described in the text, suggests development in response to localized, rather than regional, heat sources. Igneous manifestation of a localized heat source is readily apparent adjacent to the Glenhead Burn-Newton Stewart-Burnhead group of deposits, but in all other instances, including Leadhills, Glendinning and Clontibret, such igneous expression is absent or poorly represented at present erosion levels. At Clontibret some very minor intrusions (described in the text) occur to the E of the deposit, but more significantly, areas of hornfelsed sediments, some of which are associated with visible intrusions, occur to the S of the deposit and suggest the presence of concealed intrusions over a widespread area.

We agree with the comments which Bennett expresses in his final question, but would suggest that any intimation that the wallrock — mineralization relationship exclusively reflects scavenging of the latter from the former is due to a misunderstanding. Our opinions on this relationship are expressed in the final paragraph of the text.

FRIEDRICH GUNTHER (Technical University, Aachen) asked:

Could the authors provide some information about the rocks underlying the greywackes, and whether there was a possibility that gold, arsenic etc. might have been mobilized from these rocks?

REPLY:

Various stratigraphic syntheses (see for example McKerrow et al., 1977, and Leggett et al., 1979) indicate that the turbiditic sequences of the Northern Belt of the Southern Uplands and Longford-Down inlier, within which this deposit occurs, are underlain by mafic volcanic rocks. These rocks are widely believed to be remnants of Iapetus oceanic crust accreted, along with overlying pelagic and turbiditic sediments, onto the continental (Laurentian) foreland to the NW of the ocean. However, an alternative interpretation (Morris, 1979); see also discussion in Leggett et al., 1979) suggests that the Northern Belt represents the remnants of an Ordovician marginal ocean basin, and that the andesitic composition greywackes which host this deposit were derived from a volcanic arc to the south or southeast.

References

As for the text, except

MORRIS, J. H. 1979. The geology of the western end of the Lower Palaeozoic Longford-Down inlier, Ireland. Unpubl. Ph.D. Thesis, Univ. of Dublin, 200pp.

PAUL DULLER (University of Strathclyde, Glasgow) asked:

In comparison with the probable cogenetic vein system at Glendinning in Southern Scotland, is it possible to infer a zone depletion envelope associated with both phyllic and propylitic wallrock alteration at Clontibret?

REPLY:

The distribution pattern of Zn in alteration envelopes at Clontibret, based upon currently available chemical data, is rather erratic. A depletion pattern ranging from 62ppm Zn is sample 16 (Fig. 3) to 14ppm in sample 12 is evident in the footwall of Lode Zone B, and depletion from 61ppm to 14ppm is evident between samples 22 and 20 respectively in the footwall of Lode Zone A (Fig. 4). However, in the hanging wall of Lode Zone A, a converse pattern is apparent, as Zn content drops from 1,693ppm Zn in sample 9 to between 53 and 59ppm Zn in samples 5 to 8 (Fig. 3). these patterns, along with those of other elements, are in the process of being examined further by more detailed lithogeochemical sampling.