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GEOLOGY AND EXPLOITATION OF COMPLEX GOLD-BEARING VEINS IN THE GWYNFYNYDD MINE, DOLGELLAU, NORTH WALES, UK.

Simon C. Dominy, Roland F.G. Phelps, M. Andrew Bussell and Clare L. Guard.

Synopsis
The Gwynfynydd Mine, one of two active gold mines in North Wales, is located on the eastern flank of the Harlech Dome within the Coed-y-Brenin Forest and Snowdonia National Park. The mine lies some eight kilometres north of the town of Dolgellau and since 1863 has produced in excess of 1.2 million grammes of gold metal and is currently owned by Welsh Gold Plc. In early 1995, Welsh Gold Plc raised some £1.5M under Rule 4.2 of the London Stock Exchange, thus establishing it with a firm economic base. The company operates the mine as both a gold mine and a high quality tourism facility. The gold extracted is both manufactured into jewellery and retailed by the company. The current extraction rate is 5000 tonnes per annum. With a total resource of approximately 164,000 tonnes of ore located in the Chidlaw Lode, the mine has a potential life of over 30 years. The gold mineralization is dominated by erratic pockets of gold located within structurally complex footwall veins associated with larger, mother vein structures. The definition of ore grade and tonnages is difficult, but guiding of the mining operation is made easier as a good geological model for the deposit is developed.

Introduction
North Wales is arguably the richest gold mining area of the British Isles and has produced in excess of 4.5 million grammes, of metal, mainly from the Gwynfynydd and Clogau St. Davids mines in the Merioneth district. The intensive exploration activities for metalliferous mineralization in Wales during the early 1970s and the financial incentives offered by the Exploration and Investment Grants Act of 1972, fuelled an interest in the Dolgellau Gold Belt. Welsh gold has been sought since Roman times and Celtic royalty wore gold jewellery around their necks as a symbol of power and position. As a result of these romantic and historical ties, and its association with the present Royal Family, Welsh gold currently holds a 200% premium on the international gold bullion price. Successive Welsh gold rushes have come and gone, but within the past few years the Gwynfynydd and Clogau St. Davids mines have reopened to produce gold for jewellery manufacture. In early 1995 Gwynfynydd established itself with a firm economic base following the formation of its parent company Welsh Gold Plc and the successful placing of shares which raised capital of £1.5M.[1] Welsh Gold Plc is the parent to both Gold (Wales) Ltd, which manufactures and retails Welsh gold and silver jewellery, and Gwynfynydd Gold Mine Ltd, which operates the mine and runs an underground tourist facility. The gold deposits of the Dolgellau district have been the subject of previous historical and scientific research, but a detailed understanding of the complex veins and the nature of

gold distribution is still lacking.[2-9] There now exists an opportunity to undertake more detailed geological studies within the mine. This paper reviews current mining activities and geological research in progress.

Historical Basis

The presence of gold in the Dolgellau region has been known for centuries and its historical development has been well documented by Morrison and Hall.[3,6] The reader is referred to these books for a fuller account of the history of the region and, in particular, Hall's description of Gwynfynydd Mine. After the Roman period, no records exist of any mining in North Wales until 1636 when it was reported that gold was worked near Barmouth during the reign of Charles I to supply a mint at Aberystwyth. However, in the charter for Cymer Abbey the monks were given rights to dig for metals and treasures in 1198. The first documented discovery of gold took place in 1836 at Cwm Heisian lead-zinc mine, where although rich vein samples were recovered. Gold mining did not start then, however, and it was not until 1844 that the existence of gold was made known internationally by Arthur Dean in a paper to the British Association. By this time a number of small mines were operational, including the Bedd-y-Coedwr Mine which lies about 350 metres northeast of Gwynfynydd. By the early 1850s prospecting was common in the Dolgellau region, with frequent discoveries and a few of fortunes being made. By 1865, this first "gold rush" was over, because of to poor mining techniques, imprudent speculation and fraudulent activity.

Gwynfynydd Mine first produced gold in about 1863, and from that time to the present it has produced over 1.2 million grammes of gold. Its history is well documented by Hall from which the following account is composed.[6] A small pocket of gold was discovered in 1863 by T.A. Readwin & Co., but the venture ceased during 1865. In 1869, the mine was taken over by Professor William Rickford who formed the Gwynfynydd Gold Mining Company and later the New Gwynfynydd Company. However, his operation failed during the mid-1870s because of technical difficulties in gold processing. The mine was taken over again by Readwin in 1883. Readwin established the Mawddach Gold Mining Company in 1884 and employed the services of Pritchard Morgan to lay tracks and install plant in the mill. However, Readwin disputed the amount of money owed to Morgan and, after arbitration, Readwin was ordered to pay £2,250. Neither the Company nor Readwin could pay Morgan, and so the latter took over the mine in 1887 to settle the debt. Pritchard Morgan, a barrister by training, almost immediately found a very rich pocket of gold. This pocket, the largest ever discovered in the mine, contained over 200,000 grammes of gold and was located on the Chidlaw Lode, No. 1 Level drive west. On the strength of this find, Morgan sold Gwynfynydd Mine to the Morgan Gold Mining Company which attracted a number of notable persons to invest their money. Morgan retained the Directorship of the company, some 70% of the shares, and received some £45,000 in cash. As the mine developed, Morgan required more cash to keep it going, so he refloated the company as the New Morgan Gold Mining Company in 1890 and again in

1894, as British Gold Fields Limited. In 1900, Morgan sold the company to the St. Davids Gold and Copper Mines Ltd, the owners of the nearby Clogau Gold Mine. They ran Gwynfynydd through a subsidiary company, Gwyn Mines (Merioneth) Ltd, until 1913 when Morgan took over the mine again. His new operation raised more ore than before, but the grade of gold was poor and the mine was abandoned in 1917. In 1918, U.K. Mineral Development Ltd investigated the mine, as did Anglo-African Goldfields Ltd in 1933, but neither venture led to mining activity. As late as 1924 the octogenarian Morgan tried to reopen the mine again himself, but without success.

With the rise of the gold price in the 1930s, C.V. Sale formed the Hillside Mining Company which reopened both Gwynfynydd and Clogau Mines. In Gwynfynydd, small pockets of gold were encountered in the Collett Lode, but the mine closed in 1939 following the outbreak of World War II. All activity ceased until 1970 when Geochemical Re-Mining Ltd cleared and re-surveyed the workings on the No.2 Level. In 1976, a joint venture between Frank Freeman and Blackland Exploration Ltd completely re-mapped the mine and evaluated its potential but it was not until 1981 that the mine was truly re-opened, this time with the financial backing of Mark Weinberg, a City of London financier. Further geological studies were undertaken and new development drives and crosscuts put in to locate the Big, Collett and Chidlaw Lodes. The Chidlaw Link Zone was accessed, but it was not until September 1983 that a rich pocket of 6200 grammes was found on the footwall zone of the Chidlaw Lode on No.6 Level. Weinburg pulled out of Gwynfynydd in 1989 and, after a period of abandonment, Gwynfynydd Gold Mine Ltd acquired the property in 1992. In February 1995 it became a wholly owned subsidiary of Welsh Gold Plc under the Managing Directorship of mining engineer Roland Phelps. Since then geological support and research commenced under a collaboration between the company and the University of Greenwich.

Geology of the Dolgellau Gold-Belt

The Dolgellau Gold-Belt is composed of a series of northeast-southwest-trending, post-metamorphic quartz veins, hosted by Cambrian metasediments. The host rocks have undergone low-grade metamorphism to give an assemblage of chlorite, sericite, quartz and albite, with variable amounts of epidote, calcite, pyrite, magnetite, hematite and potash feldspar.[10] The succession is exposed in the Harlech Dome and consists of the older Harlech Group (Gamlan Formation) overlain by the younger Mawddach Group which is comprised of the Clogau and Vigra Formations (Fig.1). These rocks were intruded by Cambrian and Caradocian intermediate to basic igneous sills, known locally as greenstones, prior to metamorphism and deformation during the Caledonian Orogeny. The Gamlan Formation is composed of thickly bedded, coarse-grained greywackes (or grits), in contrast to the Clogau, and to a lesser extent the Vigra, Formations which are fine-grained, variably carbonaceous shales and bear pyrite.[11,12] These rocks are underlain by the

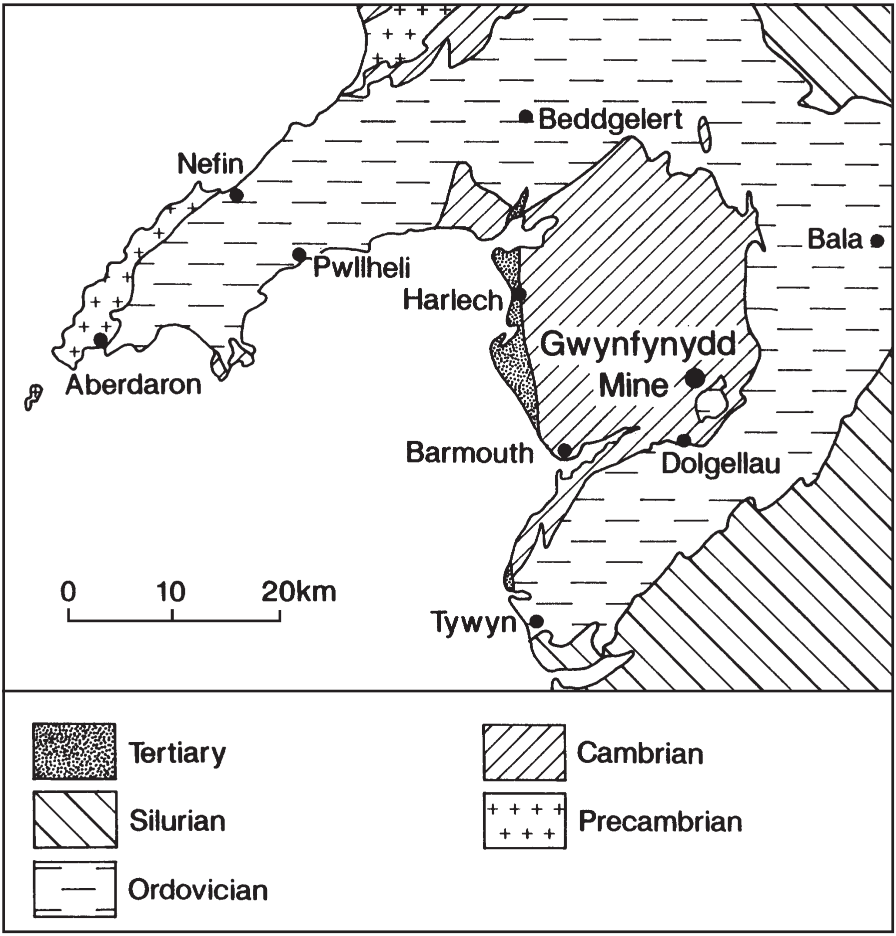

Fig.1. Geological map of North Wales showing the Harlech Dome and the Gwynfynydd Gold Mine. The Cambrian rocks of the Harlech Dome include the Vigra (Maentworg), Clogau and Gamlan Formations.

tuffites and volcanoclastic sandstones of the Bryn-Teg Volcanic Formation, which are not exposed on surface but have been proven in the Geological Survey Bryn-Teg borehole.[13]

The veins occupy normal faults which exhibit some oblique-slip component and are located on the southern and eastern flanks of the Dome. Where the veins cut the Vigra and Clogau Formations they are auriferous, but elsewhere (e.g. the Gamlan grits) they are notably barren of gold. The veins cut the main fold structures and the north-south trending cleavage of the Dome and radiogenic K-Ar ages of 405±6 million years for vein-hosted white micas, demonstrate a post-metamorphic age for mineralization.[14]

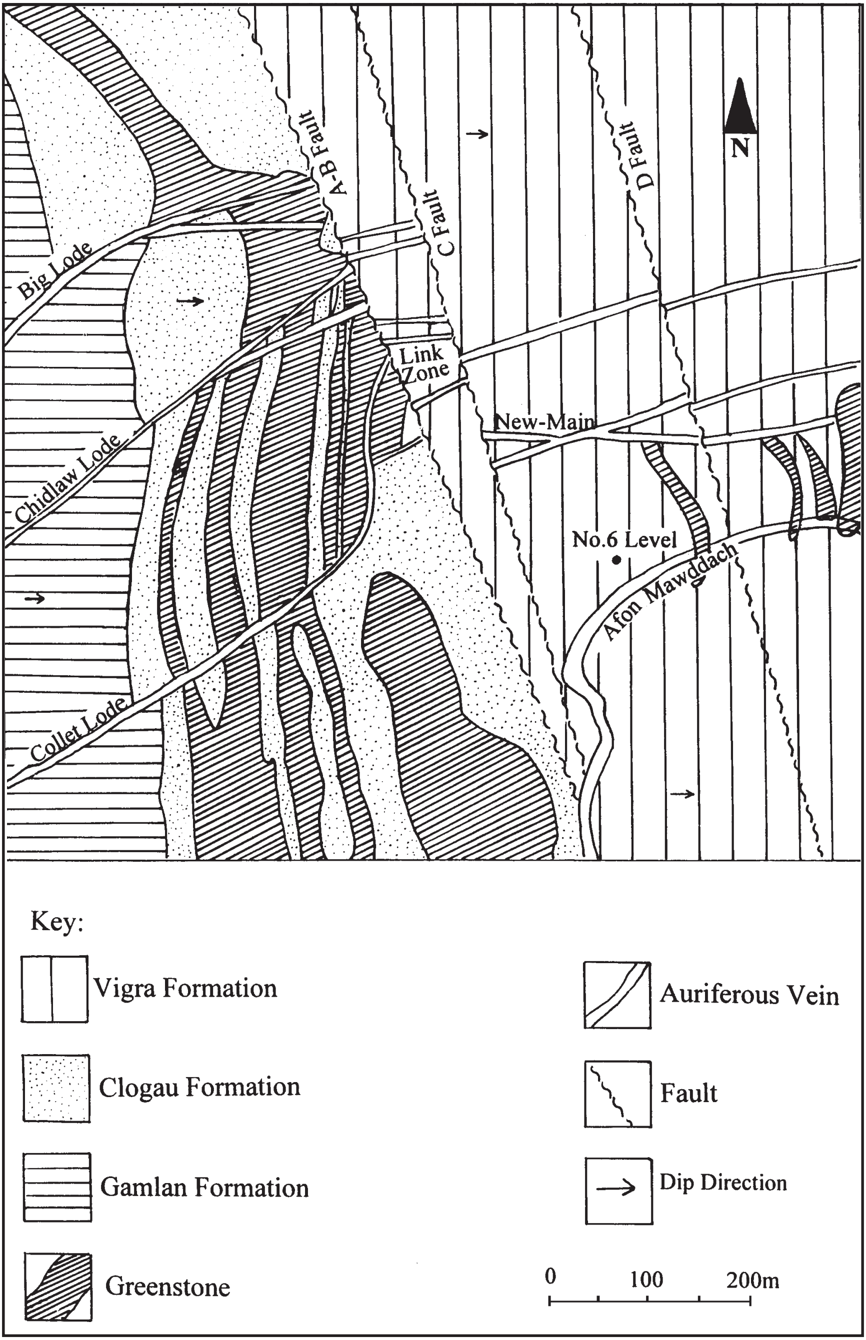

Fig.2. Geological map of the surface area of Gwynfynydd Mine.

The current genetic model for gold mineralization, based on fluid inclusion geochemistry, provides an account for the overall location of pockets within the Clogau Formation.[7-9,15] However, the model is of restricted use to the mining geologist who seeks to predict the location of pay-shoots and pockets in order to guide the mining operation. The model involves the introduction of an externally derived gold-bearing fluid into the Clogau shales and its reaction with the shales to deposit the gold. The veins which host the gold are thought to have formed as a result of dewatering of Cambrian sediments during post-metamorphic uplift at the close of the Caledonian Orogeny.[10,15] The source of the gold is attributed to the Bryn-Teg Volcanics which lie some 1600-2000 metres below the Clogau shales.

Gwynfynydd Gold Mine

Gwynfynydd Mine is located on the eastern flank of the Harlech Dome, some eight kilometres north of Dolgellau (Figs.1 & 2). The workings lie on the western bank of the Afon Mawddach where the mine is cut by a major fault into three sections; the western section containing the Big, Little, White Lady, Collett and Chidlaw Lodes, the central section containing the Link Zone and the eastern section containing the New-Main Lodes. Access is via the No.6 or Main Adit Level whose portal lies some 13.2 metres above the Afon Mawddach. In the western section, the old Nos.2, 3, 4 and 5 Levels are currently not used for production, but are all accessible from within the mine. On the western section, the 30, 60 and 120 (feet) Levels are partially accessible.

Ten men are employed at the mine, though this is seasonally adjusted to cater for tourism activities. The current annual extraction rate is 5,000 tonnes of ore, using an overhand shrinkage stoping method. The production area in the Chidlaw Link Zone contains 10,000 tonnes of *proved mineral reserve*, 14,000 tonnes of *probable mineral reserve* and a further *indicated mineral resource* of 140,000 tonnes of ore, classified using the IMM (1991) terminology. These reserves/resources are quoted at an estimated grade of 15.2 grammes per tonne, which is based on the historical production figures for the Chidlaw Lode over the last 100 years.[1,16] This figure takes into account the fact that it is possible to have a much lower grade for unquantifiable periods of time until a gold-rich pocket is encountered which will increase the grade accordingly. A further four lode structures are accessible from the mine which classify as *mineral potential*, and for which grades and tonnages are not currently available.

Mine Geology

A number of east-north-east-trending, quartz-dominated veins are accessible in the mine, but only the Chidlaw Lode is currently productive. The veins occupy normal faults, with their strike, dip and width varying according to the host rock type. Within the greenstones, vein refraction and/or termination is reported, and brittle-shear failure dominates. Vein dips are generally greater than 65° and widths are usually in excess of one metre. In the less competent

Clogau and Vigra Formations, semi-ductile failure is more common, and the veins have dips which are often less than 45° with widths of less than 10 centimetres have been reported. *Book and ribbon* and *pinch and swell* structures combine to give the veins a complex, and often anastomosing, geometry.

Vein mineralogy is dominated by quartz, which shows some local variations in colour. A blue-grey type is observed, containing micro-inclusions of sulphides (e.g. pyrite) and wallrock whereas, the common milky white variety contains fewer mineral inclusions. The former variety is reputed to be a good indicator of gold occurrence, but this has yet to be substantiated by this study. Ore minerals present include sphalerite, galena, pyrite and chalcopyrite, with lesser quantities of arsenopyrite and marcasite. Gold is always present as the native metal and is often associated with sphalerite and lesser amounts of argentiferous galena. Electron probe micro-analysis shows that galena may contain up to 20 wt. % silver (Dominy, unpublished data). Paragenetic studies of the vein reveal that gold occurs coevally with sphalerite and galena, and generally post-dates the deposition of quartz, calcite and pyrite. The latest stage of deposition is characterised by marcasite, siderite, dolomite and chlorite and is related to vein reactivation during dip-slip faulting.

Vein wallrock alteration in the Clogau shales is poorly developed, though narrow zones (<10 centimetres wide) of sericitization are sometimes evident. The development of carbonate minerals (carbonitization) is locally common where vein-parallel faults cut the Clogau shales, resulting in the development of blebs and veinlets of pink dolomite and/or white/creamy calcite. Extreme silicification of both Clogau Shale and greenstone is observed where lenses/horses of these rocks are included within the vein interior. Alteration within greenstone wallrocks is far more widespread, with silicification and sericitization being common. In the case of silicification, masses of quartz appear to have replaced the groundmass. Similarly with sericitization white mica replaces the groundmass and any remaining feldspars.

The mine is transected by the major north-west-trending Trawsfynydd Fault Zone (TFZ), which shows evidence of movement and reactivation from the Ordovician to the Mesozoic.[9] The TFZ is seen underground as the A-B, C and D faults, which cut and displace the gold-bearing veins. Movements on the fault zone have isolated and down-faulted a large section of the Chidlaw Lode (the Chidlaw Link Zone) by about 65 metres between the A-B and C faults, which themselves are composed of a number of separate fault strands (Figs.2 & 3).[17]

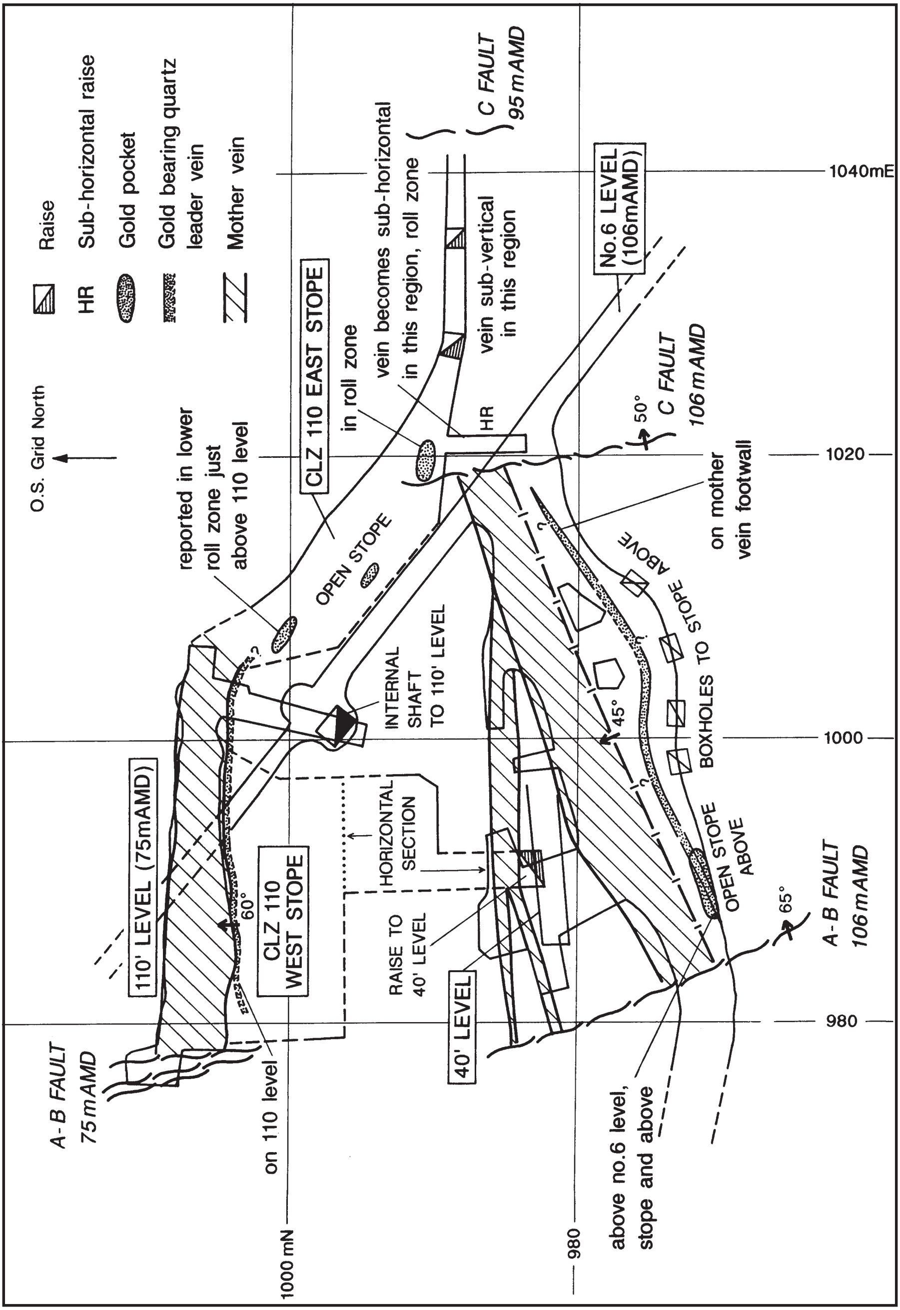

Fig.3. Plan of the Chidlaw Link Zone showing the positions of the A-B and C faults and the mother and footwall quartz leader veins in relation to the mine workings.

Nature of Gold Pay-Shoots and Pockets

Since the 1850s the Dolgellau gold-belt has produced over 4.5 million grammes of gold from vein deposits and an unspecified amount from alluvial sources.[6] The veins show extremely erratic gold distribution (nugget effect) and as a consequence, the accurate determination of tonnage and grade in particular blocks is difficult. Diamond drilling programmes at best confirm the location of potentially gold-bearing structures and the only accurate way to determine gold grade is to mine the block and calculate it retrospectively, though minima may be assigned with a lower degree of accuracy.[18]

Within Gwynfynydd, gold occurs as the native metal, commonly as coarse or granular aggregates which rarely show crystalline faces. Investigations of gold occurrence in the Chidlaw Link Zone show that it occurs in rich pockets, located within moderately dipping, easterly pay-shoot zones.[18-20] This feature has also been recently observed following a re-evaluation of production data from the New-Main Lode. There is some evidence to suggest that these zones coincide with the vein-bedding intersection, but this needs to be substantiated further in the light of the complexity of vein geometry. An individual pocket may contain thousands of grammes of visible native gold and yield grades well in excess of 500 grammes per tonne in its core. At its extremities, grades may drop to below 30 grammes per tonne until no further gold is seen, but an anomalous geochemical halo of gold may be present. A pocket located in early 1989, just below the 40 Level in the CLZ, was reported to contain over 20,000 grammes of gold.[21] These pockets are highly localized and, in the simplest cases, may occur at vein intersections, within vein footwall zones

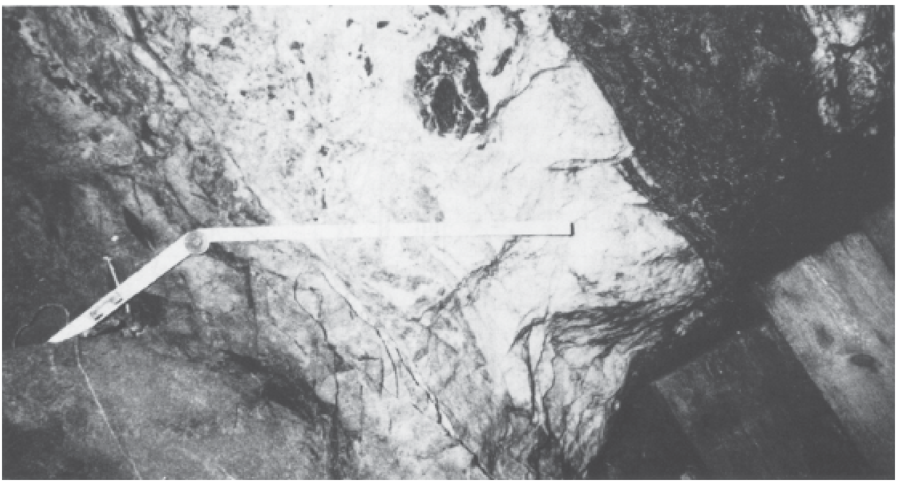

PLATE 1. Gold-bearing footwall quartz leader vein within the CLZ on the 60 Level. At this point the vein is about 0.5 metre wide and dips about 60°N. Its footwall (under scale hinge) is a large greenstone mass that can be traced above and below the 60. (S.C. Dominy, May 1996).

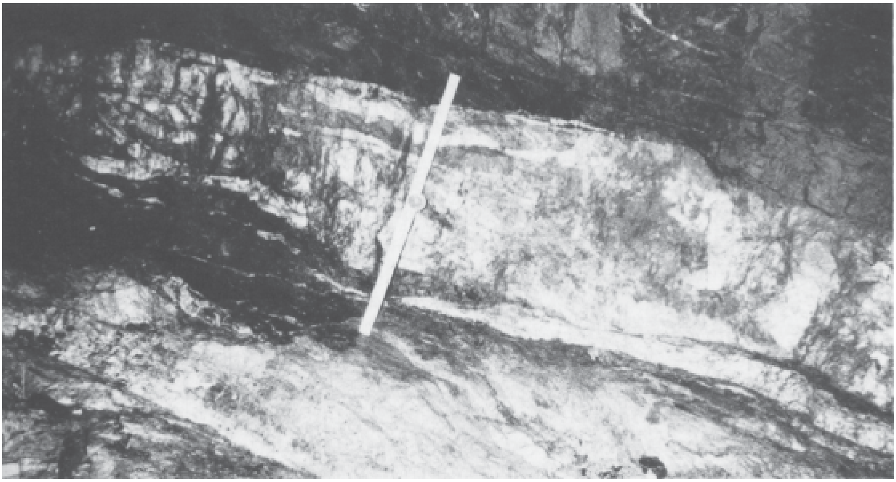

PLATE 2. Gold-bearing footwall quartz leader vein within the CLZ 110 West stope. At this point the vein attains sub-horizontal attitude (dip about 20°N). The footwall is greenstone and its hangingwall Clogau Shale. (S.C. Dominy, May 1996).

and with variations in vein attitude and/or geometry. As noted previously for the regional gold distribution, these features only produce gold where the veins are hosted in either the Vigra or the Clogau Shales. Elsewhere they are notably barren (e.g. in the Gamlan Grits). Since 1983 the CLZ has produced in excess of 62,000 grammes of gold.

Previous pockets in the CLZ have variably contained 25-35% gold as grains, and veinlets up to 10 milimetres in size are scattered through quartz with up to 10% mixed sulphides.[21] The gold is reported to usually be intergrown with massive pale yellow-brown sphalerite, and this has been confirmed following the study of rich specimens. Recent work within the CLZ has revealed that the rich gold pockets are related to a narrow, quartz leader vein, which is hosted in the footwall zone of the mother vein (Figs.3 & 4; Plates 1, 2 & 3). Recoverable “background shows” of gold are observed which contain up to 25 grammes of metal associated with the quartz leader vein (Plate 3) and/or where the quartz leader and mother veins coincide.

Geology of the Working Area

The mother and footwall quartz leader veins are currently exposed in the west block shrink stope above the 110 Level (CLZ 110 West Stope). Elsewhere, the veins are also exposed on No.6 Level Lode Drive and on the 110 Level Lode Drive West (Fig.3).

No. 6 Level, Lode Drive

On the No.6 Level (elevation 106 metres AMD), the vein structure is exposed for 40 metres along strike, bounded by the A-B and C faults (Fig. 3). Within

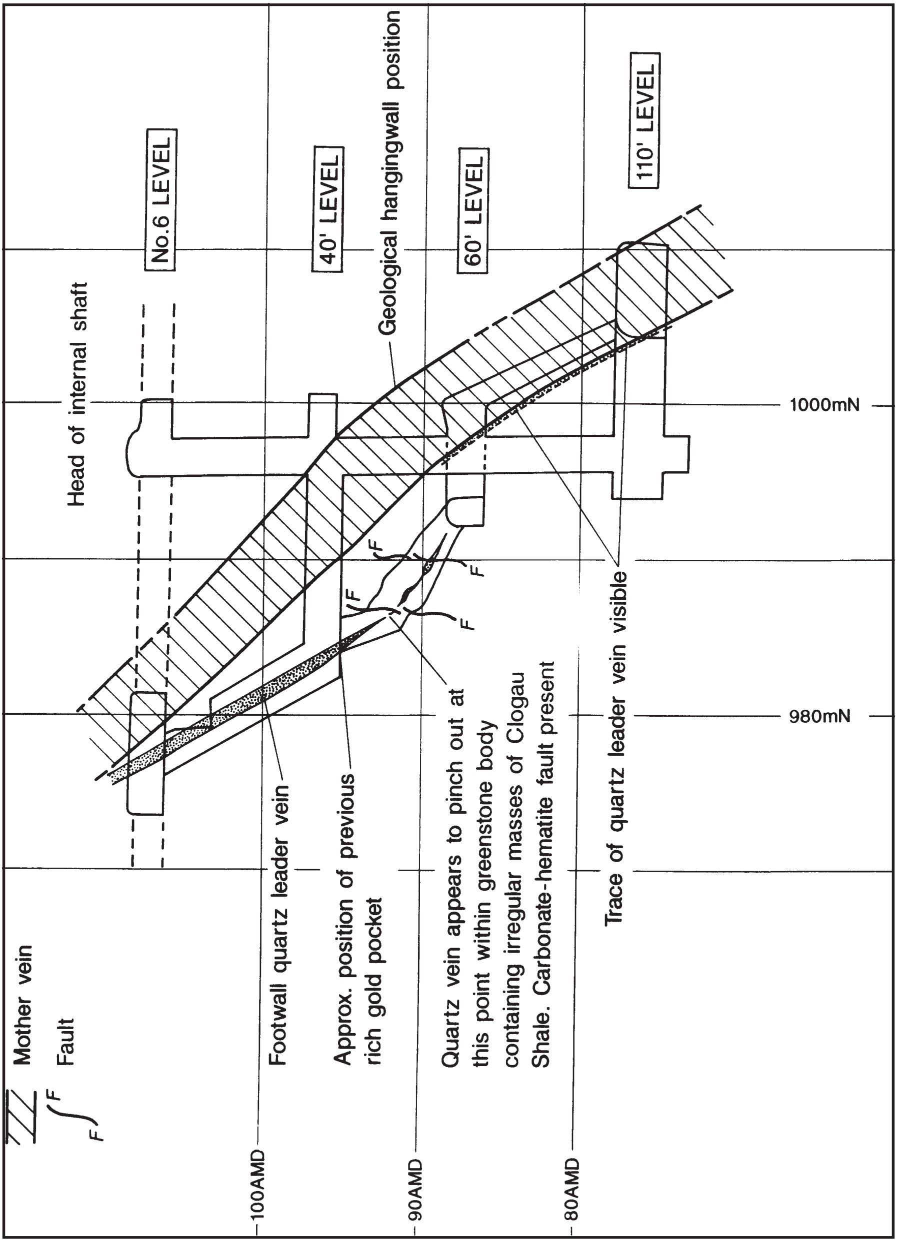

Fig.4. Cross-section on CLZ grid easting 1000 metres looking west through the Internal Shaft. The position of the Mother and Footwall Quartz Leader Veins are shown.

this region, the total vein thickness varies from 5 up to 11 metres. The 2-3 metres wide footwall zone is marked by a massive greenstone body, which is pervasively silicified closest to the vein and contains a number of impersistent quartz veinlets. A pocket of gold containing over 15,000 grammes which was recovered from this region, having been hosted by the footwall quartz leader vein about 1.5-2.0 metres below the footwall of the mother vein (Fig.3). Shale lenses are included within the mother vein and give rise to a typical book and ribbon texture. The central 2-5 metres wide portion is composed of altered lenses of shale and greenstone, set in quartz carrying sphalerite, galena, pyrite and chalcopyrite. The hangingwall zone, some 1-4 metres wide, contains massive quartz with narrow ribbons of shale and traces of sphalerite, galena and calcite/dolomite.

110 West Block, Stope Sub-Level

Mapping of the 110 West block stope (CLZ 110 West) roof shows a complex composite structure, transected by a series of steeply-dipping, dip-slip intra- and cross-vein faults. Access to the stope sub-level is via the raise which links the 60 Level with the 110 Level (Fig. 3).

Within the stope sub-level (Fig. 5), a persistent intra-vein fault follows the mother vein and is characterised by a narrow, variably carbonate-marcasite-bearing structure (Fig. 5). The fault plane is highly persistent and displays local variations in dip, strike and width. Localized bends on the fault plane contain well developed vuggy dolomite vein(s) which contain euhedral

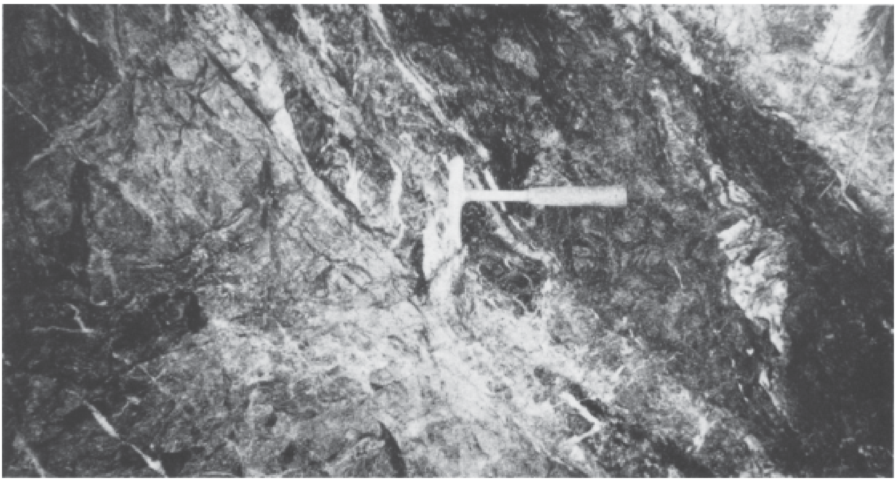

PLATE 3. Gold-bearing footwall quartz leader vein within the CLZ 110 West stope. This section is about 10 metres up-stope from Plate 2 and represents of zone of rapid increase in attitude from horizontal to 65°N. The vein is thinner and less well defined than seen in the previous plates. A small show of gold was found in the region of the hammer head. (S.C. Dominy, May 1996).

calcite and marcasite. The footwall zone comprises a massive greenstone body which is strongly silicified along its contact with the footwall quartz leader vein. The hangingwall of the leader vein is marked by a fault plane along its contact with the mother vein. The greenstone along the contact contains isolated blebs and veinlets of galena and/or sphalerite and localized vein networks of calcite which cut through the contact zone.

The geological hangingwall of the mother vein is exposed in the first 2-3 metres of the sub-level, near to the stope raise, where it is marked by a fault-hosted carbonate-marcasite vein with earthy hematite along its centre and margins (Fig. 5). The hangingwall portion of the mother vein, about 1.5-2.0 metres in width, passes out of the sub-level wall after 3.5 metres. The bulk of the rest of the mother vein consists of quartz with lenses of shale and masses of highly quartz-veined shale. Pyrite, galena, sphalerite and chalcopyrite are sporadically distributed throughout the whole of the structure.

Visible gold was observed on the footwall 7.5 metres along the stope (Fig. 5), in the form of bright yellow sub-milimetre specks, hosted within the quartz leader vein and silicified greenstone. At this point the quartz leader vein is sandwiched between the mother vein footwall and a large greenstone body. A number of specks of pyrite, galena and sphalerite were also observed, but these are not intimately related to the gold. This show reaffirms that the occurrence of gold is often along the footwall zone of the mother vein.[6] The occurrence is concentrated within no more than 0.4 cubic metres of rock and contains about 10-15 grammes of gold, but it is believed to represent a background value which probably occurs throughout the vein system. Because of their small size, the background gold occurrences are not always observed or exposed after blasting, but they nevertheless represent a significant addition to recoverable metal.

The footwall greenstone body and associated quartz leader vein (0.1-0.2 metres in width) passes out of the stope footwall after about 10.5 metres, thus diverging from the mother vein (Fig. 5). At this location the quartz leader vein dips approximately 60° towards the northwest, with its hinge zone plunging towards the east.

The carbonate-marcasite fault plane continues along the stope, exposing massive quartz, which is part of the hangingwall portion of the mother vein. A number of narrow, sub-vertical, hematitic fractures cross the mother vein, but do not appear to displace it. The whole mother vein structure is truncated by the A-B fault at the end of the stope (Fig. 5).

The stope has been developed between 87 and 90 metres AMD and mine grid lines 990 mE and 995 mE (Fig. 3). A raise was initially driven on the footwall quartz leader vein, which was seen to flatten above 86 metres AMD (Plate 2) and rise steeply at 88 metres AMD (Plate 3). A second raise has been driven on the steepening section of the leader to link the top of the stope with the 40

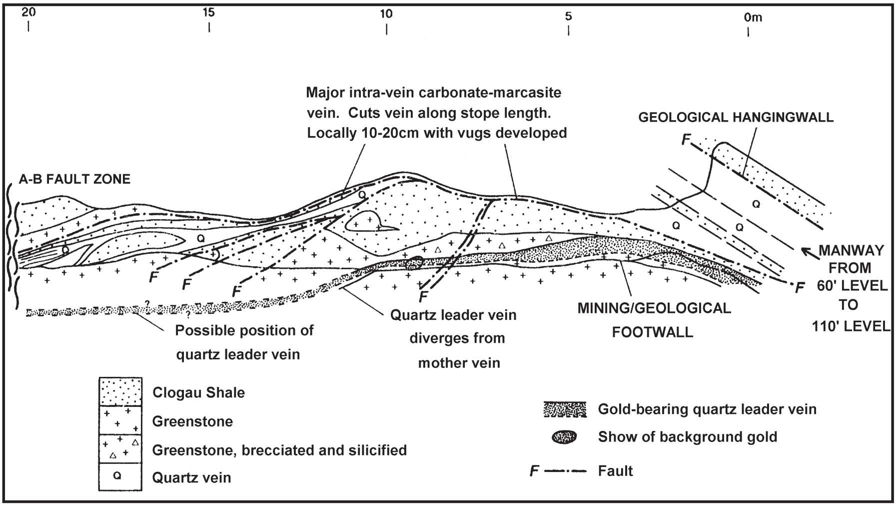

Fig.5. Geological plan of the 110 West Stope sub-level at an elevation of 80 metres AMD. The Quartz Leader Vein is well exposed until it passes out of the stope footwall at about 10 m. The stope hangingwall is marked by a prominent fault plane which is variably filled with carbonate, marcasite and hematite.

Level at 94 metres AMD. This type of structure has previously yielded gold pockets and the area is currently being mined out. A show of gold, containing about 15 grammes, was found at the bottom of the second raise (Plate 3). The gold was in the form of bright yellow, sub-milimetre specks, associated with highly silicified greenstone and quartz veinlets containing traces of sphalerite and pyrite. This show represents the occurrence of a background value.

110 Lode Drive West

The West Lode Drive (73 metres AMD) lies down-dip from the 110 West Stope and the mother vein is exposed for some 25 metres, with both the hangingwall and footwall zones generally visible (Fig. 3). Throughout this section, the mother vein is dominated by massive, milky-white quartz vein sections with included fragments of shale and greenstone. Book and ribbon textures are common throughout the vein seen this drive. The footwall zone is marked by a pervasively silicified greenstone body and the down-dip continuation of the quartz leader vein. The leader vein passes out of the drive wall after about 21 metres, thus corresponding to the divergence noted in the stope above. The mother vein hangingwall zone is generally marked by the lower extension of the intra-vein carbonate-marcasite vein seen in the stope.

110 Lode Drive East and 110 East Block Stope

The 110 Lode drive east is partially accessible and contains a highly complex footwall zone comprising greenstone and included lenses of Clogau Shale.

The footwall has been strongly faulted, giving rise to a complex relationship between the greenstone and shale. The mother vein hangingwall is also exposed and is comprised of quartz with sulphides.

Before ore removal, the upper part of the 110 East block stope (CLZ 110 East) was accessible and the mother vein footwall zone is exposed for about 25 metres in the roof and hangingwall of the stope, which lies about 98 metres above mine datum (AMD). The footwall throughout the upper part of the stope is composed of silicified greenstone with localized areas enriched in galena, sphalerite and chalcopyrite and is also exposed within two sub-vertical raises, located at 1027E and 1035E (Fig.3). In the stope hangingwall, a variable, 0.5 metre wide, quartz-sulphide (galena-sphalerite-chalcopyrite) vein is exposed. This represents the central part of the mother vein that had a total thickness of about 4-5 metres. At the eastern end of the stope (Fig.3; 1042E), the footwall quartz leader vein is sub-vertical (dip >70°), but attains an almost a horizontal attitude around the 1021E raise (Fig.3). Below this level (98 metres AMD), it steepens but is reported to flatten again before reaching the 50 metre long 110 East Drive which is currently filled with previously blasted ore. Both flattened areas, known locally as “rolls”, contained gold pockets. Finally, the stope passes into the 110 East Drive, since no pillars were established and the lode was mined overhand directly onto the level. The stope and drive are cut halfway along by a strand of the major C-fault, but the displacement appears small.

Mining and Mineral Processing

The mining techniques traditionally employed in the Dolgellau gold-belt were based on overhand stoping methods. The majority of stoping was carried out by hand labour, using hammer and drill steels, until the introduction of the pneumatic rock drill in about 1880. Overhand shrinkage stoping is currently used at Gwynfynydd. This allows a strong degree of control and selectivity in the narrow and complex vein systems.[22] The method is a vertical, overhand technique, whereby most of the broken ore remains in the stope to form a working floor for the miners. Stopes are mined upward in horizontal slices, allowing the blasted ore to fall to the floor, and the technique is labour intensive with little scope for mechanization. The volume of broken ore is some 35-40% higher than solid rock, so some rock is drawn off via boxholes throughout the mining process. This broken ore is taken to the internal shaft on the CLZ 110 or 160 Levels, hoisted to No. 6 Level (Plate 6) and then trammed to the underground mill (Plate 4).

Early extraction methods in the Dolgellau area employed either Britten or Berden Pans in a combined crushing-mercury amalgamation operation.[6] The feed to these systems was often hand sorted and very rich in gold. Fine gold was liberated by crushing, using either stamps or a steam hammer. Gold extraction was carried out using equipment such as blanket strakes, amalgamation plates and shaking tables. It is likely that these early operations were highly inefficient, the most important problem being the variation in gold particle size within the veins. This is the single most important characteristic, which continues to cause problems to the present day. Owing to its malleability, the behaviour of gold grains during the grinding process is unlike that of brittle minerals (e.g. quartz, pyrite etc.). The liberated particles of gold become progressively flattened with grinding, yielding flakes which are difficult to recover by gravity concentration processes.

Gwynfynydd extracts gold in an environmentally friendly way, based on crushing, grinding and density separation (Fig.6; Plate 4). The ore is first passed into a two-stage crushing operation, comprising of a jaw and then a gyratory crusher. The crushed ore is ground in a rod mill and discharged into the gravity concentration circuit, comprising two Knelson Hydrostatic Concentrators and a half-size Wilfley Table. The Knelson Concentrator separates materials based on differential specific gravity in an enhanced gravity field (Plate 5) and the mill feed passes firstly into the 12" Knelson, where high specific gravity particles (e.g. >6 gcm^{-3}) of galena and gold are trapped in the bowl mechanism and are washed out as a concentrate.[23] The tailings are then passed through the smaller 7.5" Knelson to ensure maximum gold recovery. The remaining gold and galena concentrates are treated on the Wilfley table, the underflow concentrate from which is smelted on-site. The mill has a daily capacity of about 20 tonnes. The smelted gold is refined on-site to greater than 99.5% purity prior to alloying to make 9, 18 or 22 ct. gold for jewellery manufacture.

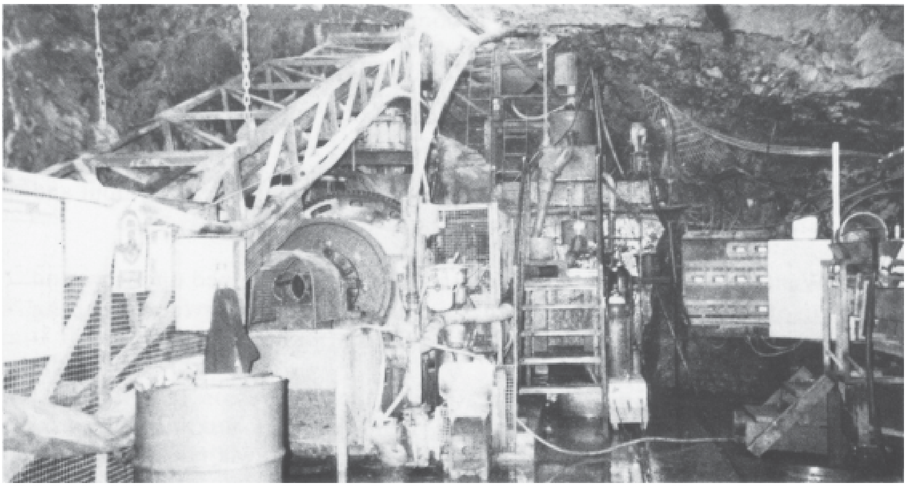

PLATE 4. View of the underground mill. The principal features are (1) conveyor from jaw crusher, (2) gyratory crusher, (3) rod mill, (4) screen, (5) 12" Knelson concentrator, (6) 7.5" Knelson concentrator and (6) Wilfrey table. (S.C. Dominy, May 1996).

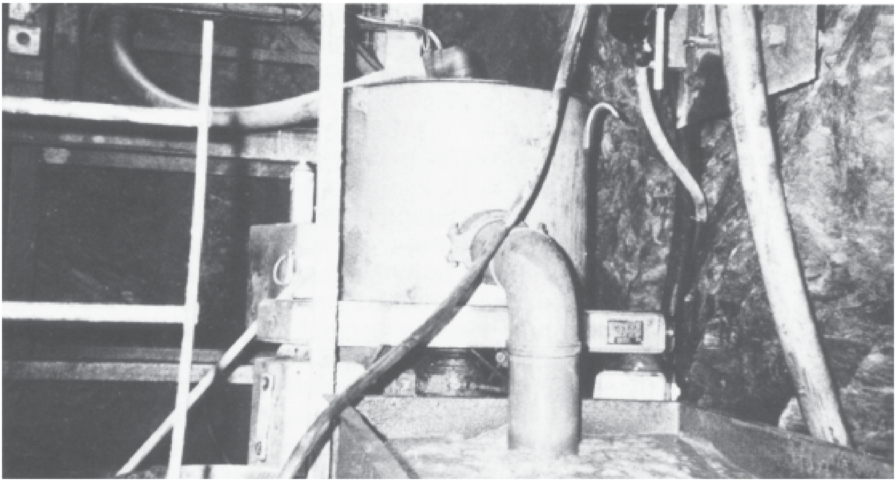

PLATE 5. Close-up of the 12" Knelson Concentrator. The mill feed enters through the small upper pipe, with the gold-bearing outflow passing through the large bottom pipe into a gold trap prior to tabling. (S.C. Dominy, May 1996).

Environmental Control

Gwynfynydd Mine is located within the Snowdonia National Park and on the banks of the Afon Mawddach. The area is without doubt one of outstanding natural beauty offering notable features of flora and fauna, geology and leisure facilities. Welsh Gold Plc is committed to operating in a way which will not threaten the environment and the environment around the mine is continuously monitored to ensure the lowest possible impact.[24] A number of key points have been implemented which will ensure continued protection, as follows:

1) Most extraction methods used in the mill have no chemical input and are based solely on physical separation methods.

2) Waste rock/slimes from the mine and mill are dumped underground in old stopes so that, while the company does have surface dumping rights, surface dumping is kept to a minimum.

3) Settling tanks and a lime treatment plant have been installed to ensure that the water pumped out from the mine and mill is treated to reduce acidity and concentrations of metallic salts before being returned to the river. This treated water actually improves the water quality in the river, which suffers from high natural acidity because of the peaty soil and acid rain in the area.

Future Development and Mine Planning

Current production is based in the CLZ 110 East and West stope blocks. To facilitate access to the down-dip extensions of the vein, the internal shaft has recently been furnished with a new headgear and winder (Plate 6), and deepened to the 160 Level (58 metres AMD). A 30 metre crosscut has been driven northwards from the shaft and this has intersected a four metre wide vein which is the down-dip extension of the structure on the 110 Level. An East Lode Drive has been established and a raise and sub-level to prove the nature of the vein prior to stoping has commenced (June 1996; Figs. 3 & 4). The shaft will be deepened to establish the 210 Level (43 metres AMD) and stopes on the CLZ 210 East and West blocks. Ultimately the shaft will be sunk to its maximum depth with the establishment of the 260 Level (28 metres AMD) and the CLZ 260 East and West Blocks. These blocks within the CLZ account for 24,000 tonnes of reserves. Access to the easterly down-faulted section of the Chidlaw Lode (indicated mineral resource of 140,000 tonnes) will be via a new decline from the 210 Level.

Elsewhere within the mine, other areas of potential gold mineralization have been identified and are currently undergoing further investigation. To the west of the A-B fault on No.6 Level, the lower part of the Collett Lode within the Gamlan Formation has been intersected by two raises. These are being continued so as to access the lode within the payable Clogau Formation. Above No.8 Level, the Collett Lode has produced significant quantities of gold and represents a further reserve of more than 5000 tonnes above the No.6 Level. Within the CLZ a section of the Collett Lode is also isolated by the A-B and C faults south-east of the current working area. In the eastern

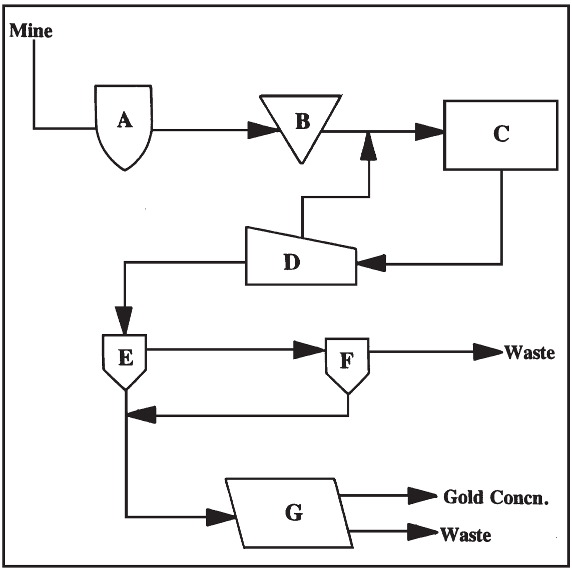

Fig.6. Gwynfynydd Mine mill flow chart. Gyratory crusher [A], jaw crusher [B], rod mill [C], screen [D], Knelson concentrators 12" [E] & 7" [F] and Wilfey table [G]. From [G] the gold concentrate is smelted and refined prior to final alloying into jewellery grade karats (22, 18, & 9).

section of the mine, the offset part of New-Main Lode, cut by the D-fault, has been intersected by boreholes and will be a site for further investigation.

DISCUSSION

Gwynfynydd Mine is a small operation, extracting high-grade gold ore from narrow and complex veins hosted by black shales. The mining and processing methods employed are well suited to the complex structural and mineralogical nature of the veins which provide a challenging geological and engineering environment in which to work. The tourism facility provides members of the public with a highly informative experience, which includes viewing the working underground mill and an overview of early and modern mining techniques. It is thus a valuable educational and scientific resource.

Geologically the mine is highly complex, illustrating a multi-stage history of shearing, fracture dilation, fluid flow and mineral deposition. Early tectonic activity resulted in the shear failure of the rocks (e.g. Clogau Shales) and the formation of wide (>1 metre) fault zones, composed of elongate fragments of shale, shear planes and fault gouge in-fill. Continued activity and high fluid flow led to the development of quartz veins orientated parallel to the pre-existing fault zones. Many of the veins of Gwynfynydd, especially the Chidlaw Lode, show book and ribbon style textures which developed as a result of repeated fracture dilation. Late-stage structural activity resulted in the undeterminable displacement of the vein by intra-vein, dominantly dip-slip faulting and minor cross-vein faulting with negligible displacement.

Like many mineralized fracture systems, the veins show lateral and vertical changes in strike, dip, width and composition which pose challenging geological problems during mining. These variations were controlled by the interaction of mechanical energy with host rock-type and mineralizing fluid. A detailed geological understanding of these features is thus crucial for effective mining and exploration for further reserves.[19,20,25,26]

In the current working area, two rock types are observed. These are greenstones, which are prone to brittle deformation, and shales, which are prone to ductile deformation. A hangingwall and footwall of shale, or a hangingwall of shale and footwall of greenstone are typically observed. There is evidence to show that the location of the mother vein structure was controlled by an original shale and greenstone body contact. It has also been noted that the presence of greenstone bodies may affect the persistence of the veins and/or their attitude and geometry. The important conclusion from this is that the host rock type(s) and any variation associated with them, may lead to geometrical complexities within the orebody.

Occurrences of gold-bearing pockets, which may contain thousands of grammes of metal, are generally observed within the complex footwall zone of the mother vein. Greenstone bodies are often observed in close association with the footwall and may have aided preferential fracture dilation by their

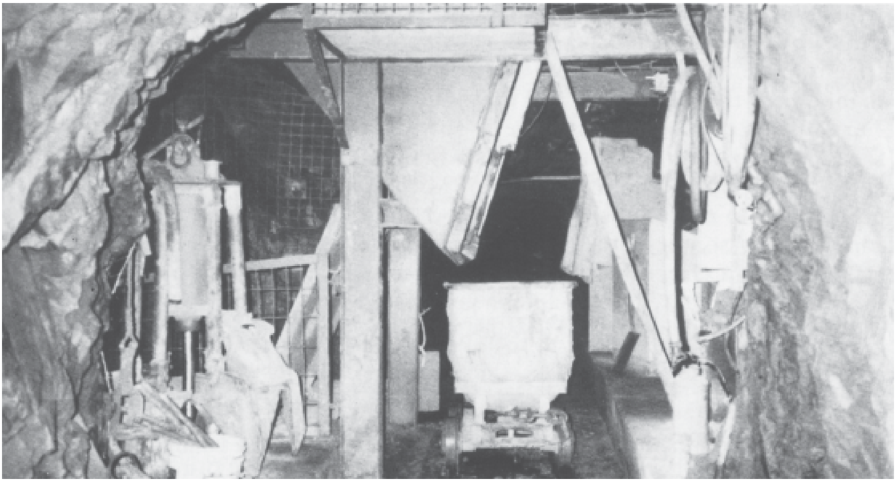

PLATE 6. New headgear and loading pocket at the head of the internal shaft on No. 6 Level. The shaft collar lies behind the cactus grab used for shaft sinking to the left of the 1 tonne waggon. (S.C. Dominy, May 1996).

brittle behaviour. These gold pockets are erratically distributed (therefore a high nugget effect) but current work shows that they appear to be located within a moderately dipping pay-shoot zone. Continuing exploration and development activities are thus aimed at locating the pay-zones and then extracting them to find the gold-bearing pockets. Recent mining activity within the CLZ has revealed a narrow footwall quartz leader vein which exhibits marked changes in dip, strike, width and structural complexity. The exposed quartz leader vein is associated with a large greenstone body that lies within the footwall zone of the mother vein (Figs.3 & 4). This leader vein has previously produced significant gold pockets and shows background gold at locations within a recognised pay-shoot zone. It is thus vital that the nature of the footwall zone, and in particular the leader vein, is established to enable the mining operation to be effectively guided. Careful geological observation and interpretation is, therefore, a key feature of day-to-day activities.[22,26]

The mine has reserves in the Chidlaw Lode to give it a life of in excess of 30 years. Further veins are accessible from the workings which, pending further investigation, have the potential to increase the overall resource and extend the mine life. Current studies aim to further our understanding of the nature and controls on gold mineralization and will ultimately increase confidence in the resource and its exploitation.

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S.C. Dominy, M.A. Bussell & C.L. Guard
Mining Geology Group
School of Earth Sciences
University of Greenwich
Medway Campus
Chatham Maritime
Kent
ME4 4AW UK

R.F.G. Phelps
Welsh Gold Plc
Marian Mawr
Dolgellau
Gwynedd
LL40 1UU UK