

The last 50 years of mineral exploration in Britain

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Abstract: The last 50 years have seen over 100 British and foreign companies and numerous individuals carrying out mineral exploration in Britain, involving the full and expanding range of geological, geochemical and remote sensing techniques. A number of significant copper, nickel, tin, tungsten, fluorite and baryte deposits have been found, some in areas of little previous mineral occurrences, such as Aberfeldy and Gairloch. Several mines have been opened and others are planned. This account also outlines the complex and sometimes opaque legal framework and the varying support of Government as well as the role of the British Geological Survey.

Britain has a splendid history of metal mining, with Cornish engine houses, the Derbyshire Barmote Court (active since 1287), the great opencast at Parys Mountain and the romantic Dolgellau gold mines. Most metalliferous mineral deposits in Britain (excluding iron ores) occur in the older pre-Mesozoic rocks of the north and west of Britain that are relatively less populated; however, these are the areas containing most National Parks and other forms of environmental restriction to development. In spite of this, more than a hundred domestic and international companies have carried out exploration in Britain during the last fifty years, with the development of modern mineral exploration employing geochemical and geophysical techniques unknown to the earlier explorers. The increase in knowledge of how, why and where mineral deposits form has also enabled exploration to move into new areas based on theoretical considerations.

Mineral rights and access to land

Metalliferous mineral exploration commonly requires access to large areas (tens to hundreds of square kilometres) of potentially prospective land chosen on geological grounds. Access to land is generally less of a problem in countries such as Australia and Canada, but the intensely developed nature of Britain means that there may be many landowners, all of whom have to be consulted for agreement to work on their land.

Mineral rights are complicated. Gold and silver are owned by the Crown and licensing is administered by the Crown Mineral Agent. However, all other minerals, apart from coal, oil and gas, are privately owned, and there is no register of mineral rights. This can create a legal and administrative nightmare. In the late 1960s, Exploration Ventures Ltd, carrying out a major nickel exploration programme in Aberdeenshire, is reputed to have spent around half its exploration budget on legal and access fees to gain legal title to mineral rights.

There is also no legal requirement to declare or record any exploration activities apart from those that may require planning permission. The British Geological Survey, under the Minerals Act 1926, requires the location of any drillholes over 30m depth and has the right to request borehole logs and samples. In Northern Ireland the position is different since the Department of

Trade Enterprise and Investment controls exploration through the Mineral Development Act (Northern Ireland) 1969, and issues licences and retains data resulting from exploration activities. A similar act was proposed and almost passed in Britain in 1969, but a change of government led to the bill being dropped.

Government aid for mineral exploration

The Government introduced three programmes of assistance to the mineral exploration industry in the early 1970s to try to mitigate the negative effects of the lack of any sensible mineral rights legislation. All three programmes were funded by the then Department of Trade and Industry, reflecting direct Government support for the minerals industry.

Mineral Exploration and Investment Grants Act

The MEIGA scheme provided for a grant of 35% of allowable expenditure on approved exploration projects for non-ferrous metals, fluorspar, barium minerals and potash. The Act of 1972 was very brief, and the administration of the scheme was through a 22-page document entitled 'A Guide for Industry' but known as 'The Yellow Book'. This laid out the method



Figure 1. Environmental considerations are critical to mining in beautiful landscapes, as over the Coed y Brenin copper mineralisation in Snowdonia National Park.

of application and allowable items which included geological, geochemical and geophysical exploration, rehabilitation of old workings for exploration and testwork for mineral processing. However, general and regional studies, the costs (including legal costs) of acquiring mineral rights and planning permission and any work not related to new exploration (including extending the development of a mineral deposit already being worked) were not eligible for funding. There was also a clause for repayment, with interest, if commercial extraction of any mineral took place within 12 years of last payment. These clauses caused problems of interpretation, and several regional exploration projects were rejected though they would have been very beneficial.

The scheme was initially a great success, with 139 projects proposed in the first three years. There was then a slowdown, with the global downturn in exploration following the collapse of the Australian nickel boom. By the time the scheme closed, 267 projects had been proposed, though not all of them were approved and some withdrawn by the companies before payments were made (Table 1); grants totalled more than £6M. Overall, MEIGA was successful in attracting a wide range of applicants and projects throughout Great Britain (the scheme did not apply to Northern Ireland). It also resulted in a significant amount of exploration data being retained on open file for the nation.

Regional Geochemical Survey Programme

This project started in the late 1960s to develop skills and experience in the newly developed science of geochemical exploration. It was later charged with providing regional geochemical data for a wide variety of elements, to assist the commercial mineral exploration sector and to publish the results as a series of geochemical atlases. It started in Shetland and has now covered Scotland, Wales and much of England with samples at a density of about one per square kilometre. Initially only stream sediments and panned concentrates were collected, but now stream waters and soils have been added, and the emphasis has changed to environmental geochemistry covering more than fifty elements. The project has also evolved into the Geochemical Baseline Survey of the Environment (G-BASE) reflecting this changing emphasis (www.bgs.ac.uk/gbase/home).

Mineral Reconnaissance Programme

Due to the absence of any sensible mineral licensing there was little publicly available mineral exploration data. The lack of information on mineral rights ownership also meant that 'modern' mineral exploration, with the investigation of greenfield areas based on favourable geology, requiring access to large areas for the initial prospecting, was very difficult to carry out. The MRP was intended to provide baseline information to fill this data gap to assist mining companies in their choice of

prospective ground. It was not specifically intended to locate mineral deposits. Although the first published project of the MRP in 1975 was a gravity survey of Cornwall, most of the projects were carried out in areas that had had little exploration by mining companies and often were in 'blue skies' areas. This was a deliberate government policy to encourage exploration in these areas. The early work was reconnaissance, and usually consisted of detailed stream sediment geochemistry accompanied by mineralogy of the panned concentrates. Samples were commonly analysed for twelve or more elements, whereas mining companies then analysed for two or three elements. There were also geophysical projects aimed at proving the utility (or otherwise) of a variety of geophysical techniques in the British environment. Scout drilling was carried out on several projects. A total of 150 projects were completed and published as MRP reports together with 23 Data Releases from smaller or incomplete projects (Colman & Cooper, 2000).

The MRP was intended to cover the whole of western and northern Britain. Publication of the results of the surveys was through a series of Reports that included much of the raw data, including drill logs and with many sketch maps showing the locations of samples and geophysical lines. An early success, which made the reputation of the MRP, was the discovery of the world-class stratiform Aberfeldy baryte deposits, reported in MRP Report no 26 in 1978.

The MRP continued to explore and publish reports through the 1970s and early 1980s, with a budget of around £2.5 million in the late 1970s and a staff of about 30. Its emphasis changed with time. Initially base metals were the main targets, together with a geophysics and geochemistry research programme to demonstrate the most suitable methods for application to British conditions. The upsurge in interest in strategic metals such as platinum and chromium in the early 1980s led to projects devoted to understanding their possible occurrence in Britain. Gold was also added in the 1980s as cheaper analyses with lower levels of detection became available and the gold price rose. The later years were noted by the development of GIS-based techniques of prospectivity analysis, especially for gold. The MRP was subsumed into the BGS Minerals Programme in 1998, where it has continued to develop prospectivity analysis, and has published short reports on various metals and mineral commodities (freely available at www.mineralsuk.com).

	Scotland	Wales	Southwest England	Northern England	Total
Metals	94	22	69	8	193
Fluorspar				32	32
Baryte	5			5	10
Potash				3	3
Total	99	2	69	48	238

Table 1. MEIGA projects by area and type.

Mineral exploration since 1960

A variety of base and precious metals have been sought in Britain over the past 50 years, including uranium, copper, tin, lead, zinc, gold and platinum (Fig. 2). A number of industrial minerals, include fluorspar and baryte, are commonly grouped with the metalliferous minerals as they occur in similar deposit types and require similar exploration techniques.

Uranium

A uranium reconnaissance programme by the Atomic Energy Division from the 1940s to the 1960s was originally intended to search for domestic and overseas uranium supplies for atomic weapons. The division became the Radiogeology and Rare Minerals Unit (RRMU) in 1965 and started a five year survey of the uranium resources of Britain in 1968. Northern Scotland rapidly emerged as having the most potential. Some minor occurrences of uranium were found in Cornwall (South Terras mine produced 736 tons of uranium ore to 1910) but small narrow vein deposits did not promise large tonnages. The Scottish exploration used car-borne surveys, with an extending mast containing a scintillometer crystal sending data to analysing and recording equipment in the back of a Landrover. This gave an instant indication of increased radiation and hence the possible presence of uranium.

The Orcadian Cuvette proved to be the most interesting area with widespread low-grade uranium (up to 0.1%) in the Middle Devonian Rousay Flags of Orkney and in phosphatic shales of similar age in Caithness. Sporadic higher values of uranium (up to 0.3%) and thorium (up to 0.5%) were found in fish remains. An RMMU drillhole through a mineralised fault breccia near Yesnaby on Orkney intersected 5.5% Pb & 0.1% U over 0.92 m. This was followed up with two additional boreholes by Rio Tinto Zinc Finance and Exploration (RioFinEx) but was then dropped. RioFinEx also investigated radiometric anomalies in the Ousdale area of Caithness; they drilled over 40 shallow percussion holes between 1971-72, finding up to 300 ppm U over 5 metres in fine-grained uraninite associated with hydrocarbon in arkose overlying the Helmsdale Granite (Gallagher et al., 1971).

Nickel

Minor nickel occurrences were already known in Scotland, at Talnotry in the Southern Uplands and near Inverary in western Highlands. However, the Kambalda discovery in Western Australia in 1966 caused a surge in the nickel price and worldwide exploration. Two of the major mining companies in Britain, Consolidated Gold Fields (CGF) and RioFinEx, independently targeted the major Ordovician basic intrusions of Aberdeenshire. RioFinEx geologists' attention was drawn to a Soil Survey memoir which mentioned very high levels of extractable nickel in two areas (Belhelvie north of Aberdeen over an exposed serpentinitised dunite, and an



Figure 2. Notable mineral discoveries in the past 50 years.

area north of Ellon), which caused restricted growth of a number of crops (Rice, 1975). CGF had undertaken a literature review in early 1967 and concluded that the basic masses of Aberdeenshire could be analogous with the known North American layered complexes of Duluth, Sudbury and Stillwater, all of which hosted nickel-copper sulphides. They began a reconnaissance stream sediment sampling programme in August 1968, and soon realised that RTZ were already drilling at Arthra near Ellon where a low-grade deposit containing 17M tonnes at 0.21% Ni and 0.14% Cu was outlined. The CGF team also discovered anomalous soils at Littlemill near Ruthven, north of Huntly, where subsequent drilling indicated a smaller deposit of 3 Mt at 0.52 % Ni and 0.27% Cu. These were both too small and too low-grade to be commercial at the time.

Initially CGF adopted a prospecting approach, without legal agreements, aimed at covering as much ground as possible and eliminating unfavourable areas. This used a simple exclusive permission to prospect and to grant first refusal in any subsequent negotiations in exchange for a small sum of money. However, RioFinEx secured exclusive prospecting rights over the areas on which they were working. This required landowners to consult their solicitors for advice, an approach that was very time-consuming. However, CGF were forced to follow suit and acquire prospecting rights over the remaining 'open' basic masses of Huntly, Inch-Boganclough and Morven-Cabrach,

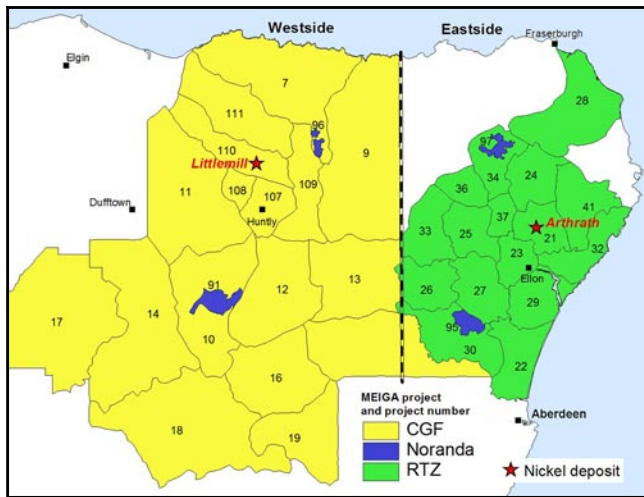


Figure 3. Aberdeenshire nickel exploration.

all of which were in the west of Aberdeenshire. This approach was completely new in Britain as no such wide-ranging basic prospecting had been carried out before. Another major stumbling block was the absence of any publicly available maps of property boundaries and surface ownerships. The geologists had to question hundreds of landowners to persuade them to indicate their boundaries on a map. This again was a very time consuming exercise.

The two companies eventually formed Exploration Ventures Limited (EVL) in July 1969 for the purpose of systematically investigating the whole area for nickel, copper and other metals. EVL split the area along a north-south line from Banff to Banchory (Fig. 3). RioFinEx took the Eastside, including the Arthra area, while Consolidated Gold Fields took the Westside, including Littlemill. The two companies interchanged all their information while continuing to explore in their separate areas. EVL threw considerable resources into the exploration effort. However, a decision was made in March 1970 to try to locate and obtain legal access and the mineral rights to as much suitable ground as possible, in order to prevent any competitors gaining an advantage. This was partly precipitated by the arrival of Noranda-Kerr, who attempted to sign up landowners in what they thought were the main areas of EVL interest. Only four small areas were obtained by Noranda, in the middle of the EVL area, but it showed the potential for rivals to snap up prospects.

EVL ceased exploration in 1975. The area then lay dormant until the 1990s when nickel prices rose again. Various companies carried out desk studies, but no serious field work. In 2005 a small Irish-based company, Alba Mineral Resources, drilled three holes at Arthra following reinterpretation of the mineralisation using the then newly discovered Voisey's Bay deposit in Canada as a model. However, the holes intersected the same style of mineralisation discovered by EVL.

Other areas investigated during the early 1970s included the Ballantrae ophiolite where Selection Trust drilled a number of holes but only found minor amounts

of nickeliferous marcasite, and the Unst ophiolite in Shetland where Noranda carried out superficial exploration. Around Loch Fyne in Argyll, Consolidated Gold Fields investigated the old Craignure and Coille Bhragad mines for strata-bound Cu-Ni in mineralisation in Dalradian psammities associated with metabasic rocks.

Platinum Group Metals

Platinum, palladium, rhodium, ruthenium, iridium and osmium (all metals of the Platinum Group) have never been worked in Britain. Their presence was not detected until low-cost, low-detection-level analyses were developed in the 1970s. In the early 1980s, the MRP investigated the Unst ophiolite and found high levels (up to 50 ppm) of platinum and palladium (Gunn et al, 1985). Esso Minerals drilled a number of shallow holes in the 1990s, without finding a significant deposit. Occasional grains of platinum group minerals have been found associated with basic or ultrabasic rocks in Aberdeenshire and in the Palaeogene Volcanic districts of western Scotland (Pirrie et al, 2000).

Copper

The last 50 years have seen a number of areas investigated for copper. No significant new deposits have been found in southwest England which was formerly the major producer.

Parys Mountain

Underground mines and large open pits at Parys Mountain, on Anglesey, produced about 130,000 tonnes of copper metal in the years after 1768 (Fig. 4). After lying dormant since the late 19th century, the area has been continuously explored since 1955 by a number of companies (Table 2) and has almost reached a production stage several times. The deposit was considered to be a series of semi-vertical epigenetic 'lodes' in a steeply dipping overturned syncline formed in Ordovician and Silurian rocks (Greenly, 1919). Ordovician shales are overlain by Ordovician rhyolites with Silurian shales at the top of the sequence. Later folding and thrusting has produced a complex faulted syncline (Fig. 5).



Figure 4. The great open pit of Parys Mountain.

year	company	holes	metres
1961-62	Anglesey Mining Exploration	11	3,554
1966-70	Canadian Industrial Gas and Oil	54	14,604
1971-72	Intermine and Noranda	24	5,380
1973-81	Cominco	53	17,338
1985	Anglesey Mining	10	5,925
1988-91	Anglesey Mining (surface holes)	12	2,443
	(underground holes)	125	10,500
1997-98	Anglesey Mining	5	2,200
2005-07	Anglesey Mining	5	2,750
	Total	299	64,694

Table 2. The recent drilling history at Parys Mountain.

Initial drilling was directed at the ‘Northern Copper Zone’ that consists of series of chalcopyrite veinlets within silicified shales. A resource of 30M tonnes at 0.7% Cu was identified by Canadian Industrial Oil and Gas. British Titan Products also drilled short holes to investigate the area for pyrite for sulphuric acid production. In the early 1970s, other Canadian companies identified the deposit as a member of the volcanogenic massive sulphide class. Significantly, this type of deposit is generally formed almost synchronously with the host rocks and can occur as a series of small to large deposits at a particular horizon. Drilling was therefore directed at the volcanic/shale contact and made significant intersections of ‘bluestone’ (the local name for a fine-grained mixture of copper lead and zinc sulphides). This was impossible for the earlier miners to separate into the different minerals and so they had largely ignored it, but it commonly forms a significant part of many deposits of this type. However, correlation between drillholes in the steeply dipping and faulted rocks, proved very difficult.

Cominco then took over, and found a new zone of high-grade copper-lead-zinc mineralisation (the Engine Zone) that appeared to be more coherent, but relinquished the site in 1982 after drilling over 50 holes to depths of over 500 m. A retired Cominco exploration manager, Hugh Morris, then formed Anglesey Mining and drilled further holes to demonstrate a resource of 4.8 Mt at 1.5% Cu, 3.0% Pb, 6.0% Zn, 57 g/t Ag and 0.4 g/t Au. A share issue raised over £5 million to fund a major project from 1990 to 1992, including sinking a shaft to 300m and over a kilometre of underground development to produce over 2000 tonnes of ore from the Engine Zone, which was processed in a pilot plant on site. Unfortunately depressed metal prices prevented commercial development. Anglesey Mining carried out further drilling campaigns and used geochemistry to elucidate the volcanic stratigraphy of the deposit (Barrett et al, 2001). There were at least four distinct rhyolite episodes in the Lower Silurian, similar in age to the Skomer volcanic rocks. Only one volcanic episode and a silica sinter known as the White Rock was associated with significant mineralisation (Fig. 5). Other companies have since shown interest in Parys Mountain, but it remains undeveloped.

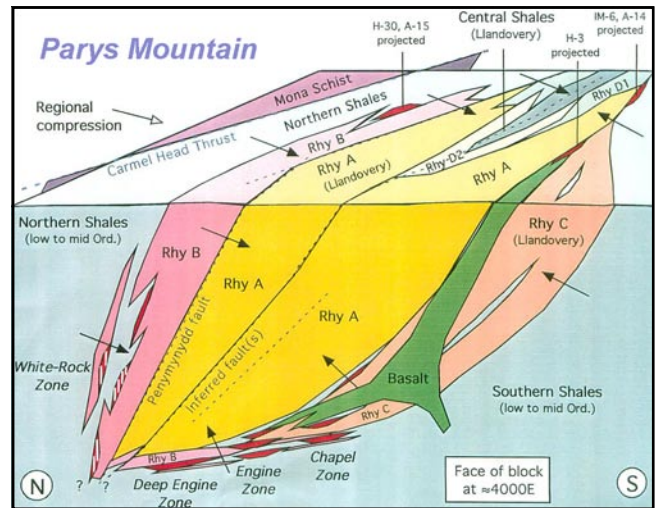


Figure 5. Inferred geological structure of Parys Mountain; arrows show younging (by Anglesey Mining, 1999).

Coed y Brenin

The 1963 discovery of the major porphyry copper deposit on Bougainville, New Guinea, (by a subsidiary of RTZ) generated worldwide interest as it showed that these major granite-hosted copper deposits could be found outside the Americas. RioFinEx carried out a literature search in Britain and found a note on the Turf copper deposit near Dolgellau in Wales: *Andrew Ramsay (1881) stated that it was in this country, more than half a mile west of Dol-y-frwynog, that the once famous Turf Copper Mine was situated in the heart of the talcose schist, which almost everywhere contains much iron-pyrites in small crystals, scattered through the rock, together with specks of yellow sulphide of copper. Very small veins of this ore also intersect the mass. A peat bog occupied the greater part of the bottom of the valley. The turf was pared off the surface and burned in kilns, and being partly saturated with some compound of copper a large residue of valuable copper was left in the ashes. Many thousand pounds' worth were thus extracted.* (Dewey & Eastwood, 1925).



Figure 6. Typical veinlet mineralisation at Coed y Brenin.

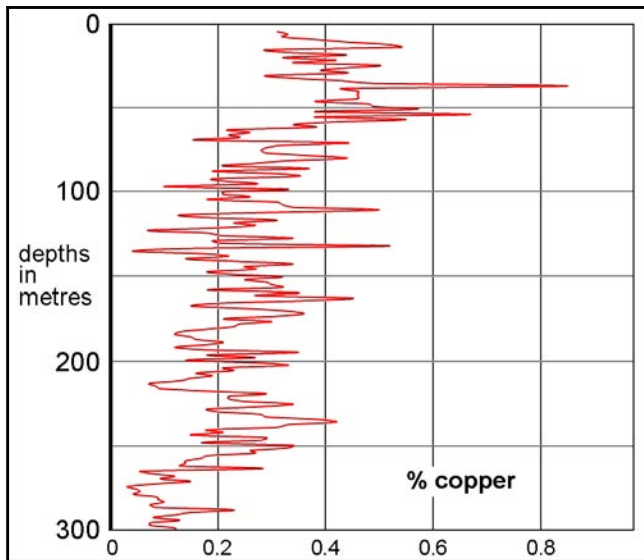


Figure 7. Copper values in borehole CB40 at Coed y Brenin.

RioFinEx carried out a stream sediment survey in 1966 and found a large area with elevated copper content underlain by a late Cambrian granite intrusion with sulphide veinlets (Fig. 6). They acquired the mineral rights and drilled more than 100 holes to depths of 300m, to indicate a deposit of about 200 Mt at 0.3% Cu (Fig. 7). Unfortunately the deposit is entirely within the Snowdonia National Park, and its proposed development rapidly became a cause célèbre with the environmental movement (Smith, 1975). In April 1973 RioFinEx announced that it was doubtful that a mining operation would be economic in the foreseeable future, and dropped the project. Certainly the size is small and the grade is low; Bougainville has 900 Mt at 0.48% Cu and 0.55 g/t Au. During the early 1970s virtually all Scottish granites were prospected for porphyry copper mineralisation. Only one significant area was found, at Kilmelfort near Loch Melfort, but drilling found only low copper values (Ellis et al, 1977).

Gairloch

Remote and sparsely populated following the Highland clearances, the northwest coast of Scotland shelters the small fishing port of Gairloch. Its Lewisian rocks were first mapped by Ben Peach, John Horne and co-workers to produce their classic 1907 Geological Survey memoir with a meticulous lithological description of the rocks (though they lacked modern knowledge of tectonics for their interpretation). They did observe and record a copper-bearing limestone with the words: *a much contorted brown-weathering limestone crops out. It is mixed with talcose streaks and siliceous layers which contain a good deal of pyrite and some chalcocopyrite. Its apparent thickness is ten feet but the calcareous portions of the band are probably less than those of the other constituents taken together. None of the pyritous layers exceeds two or three inches in thickness* (Peach et al, 1907). This text became the key to the discovery of the Gairloch deposit over 70 years later.

The area became famous from the late 1950s onwards with the meticulous unravelling of the complex geological history (Park, 1964) to show that there were multiple episodes of sedimentation and volcanism, and at least five periods of metamorphism and structural disruption. Critical to future mineral exploration was the recognition of basaltic volcanic rocks (now amphibolites) overlying the earlier Lewisian basement. However, these structural geologists were not concerned with mineral deposits, and may have actually avoided the conspicuous outcrop by the side of the old track from Kerrysdale to Gairloch. It looked altered, was iron-stained and lacked bedding or schistosity of structural interest (Fig. 8). A Geologists' Association guide mentions a thin marble band within hornblende schists and banded-iron-formation of quartz-magnetite schist in its Gairloch itinerary (Park, 1978).

In the late 1970s Liz Jones, an exploration geologist working for Consolidated Gold Fields, decided to investigate possibilities in the Lewisian rocks. There were few reports of mineralisation in the area and no old workings or trials were known. Initial outcrop sampling showed up to 9% copper, 0.6% zinc, 8.4 ppm gold and 27 ppm silver, but further surface exploration was difficult as no more sulphide-bearing outcrops were visible in the peat-covered terrain. Ten short holes were drilled in 1978, of which six intersected mineralisation at depth. A further 86 holes were then to a maximum depth of 835 m (Jones et al, 1987).

This showed that the mineralisation was within a 4m thick unit of quartz and carbonate, with pyrite, pyrrhotite, chalcocopyrite, magnetite and sphalerite giving an overall grade of about 1% copper, 0.5% Zn, 1 ppm gold and associated silver. Total resources were never stated but are probably less than a million tonnes, and there is currently no prospect of further development of the deposit. The surface mineralisation in the discovery outcrop lies in a shallow syncline cut off by a thrust fault. Patient interpretation of the early drilling results traced its downdip extension as a near-vertical horizon plunging to the northwest at about 30°. This appeared to have a distinctively altered and



Figure 8. The discovery gossan at Gairloch.

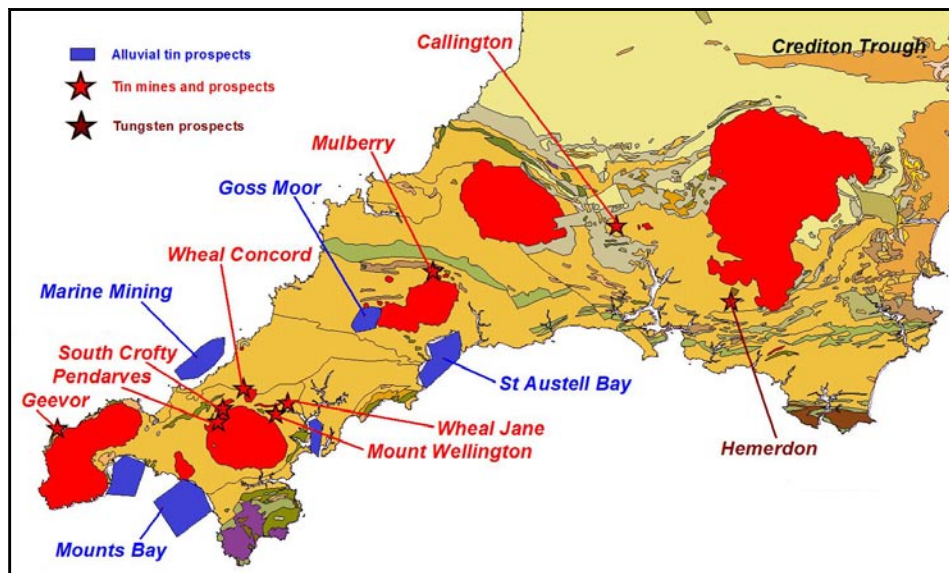


Figure 9. Locations of recent developments in extraction of tin and tungsten in southwest England.

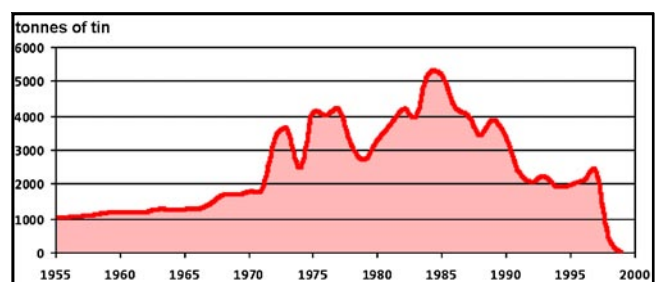
chloritised massive hornblende schist footwall and a more diverse metasedimentary schist hanging wall. It was interpreted to have occurred at the end of a tectonic cycle during an exhalative, fumarolic phase, before renewed volcanism brought fresh lava and pyroclastic debris to the area. The closest analogue to the Gairloch deposit is the Besshi-type Cu-Zn deposit, which forms stratiform lenses in sediments associated with basaltic volcanics. Most of these, including the Japanese Besshi deposit itself, are much younger than Gairloch, which, together with the Outukumpu deposit in Finland, is one of the oldest Besshi deposits in the world.

Another small Besshi-style deposit was found during the early stages of the MRP in Dalradian rocks at Vidlin, near Sullom Voe on Shetland. Drilling a sulphide horizon associated with metabasic rocks revealed low-grade intersections up to 10m with up to 1.2% Cu and 1.1% Zn. Though the sulphide zone appeared to increase in thickness and grade northwards beneath the sea, no further work has been carried out.

Tin and Tungsten

The only area in Britain prospective for tin is southwest England, where cassiterite occurs in fissure veins associated with the Variscan granites (Fig. 9). The area has numerous abandoned tin and copper mines, but by 1960 only South Crofty and Geevor were producing. During the next few years around fourteen companies entered the area as the tin price rose. Exploration was largely restricted to drilling around old mines and opening old workings. Consolidated Gold Fields opened the Wheal Jane mine in 1969. It worked a complex lode with fine-grained cassiterite and sphalerite in pyrite, which had formerly been impossible to separate economically. The opening of Wheal Jane was followed by Wheal Pendarves in 1970 and Mount Wellington in 1976 leading to a considerable increase in tin output (Fig. 10). These deposits were all developed by drilling around old mines from surface, instead of the earlier practice of underground exploration by driving along

Figure 10. Cornish tin production 1955 – 1998 (after BGS Mineral Statistics).



veins. Between 1967 and 1984 Marine Mining, an American funded company, tried to develop economic recovery of fine-grained cassiterite (that had been released from the old mines) by dredging from the sea bed off Cornwall's north coast

By 1984 the tin price had risen to \$10,000 per tonne, encouraged more companies to investigate southwest England. Geevor Tin Mines, as well as developing their own mine, looked at greisen veins on Cligga Head, a mineralised elvan dyke at Goonzion Downs and alluvial tin at Withybrook Marsh near Bodmin Moor. Consolidated Gold Fields carried out extensive soil geochemistry and shallow drilling around Chasewater, and investigated alluvial tin at Red and Breney Moors. Billiton was actively exploring alluvial prospects in the Carnon River valley, including its estuary at Restronguet Creek, and also over Goss Moor near Bodmin where they found that the 'tin streamers' of the past had extracted almost all the tin. Billiton searched for coarse-grained tin in the floors of the rias (drowned rivers valleys) in St Austell Bay and Mounts Bay. South West Consolidated Minerals raised over £2.5M for exploration around the Callington area centred on the old Redmoor tin mine. They initially drilled the Redmoor veins, before finding a sheeted vein complex similar to the Hemerdon tin-tungsten mineralisation. A series of 30 drill holes totalling over 8000m tested the vein complex to depths of 700m and indicated a 40 Mt low-grade resource at about 0.2% tin.

A small group attempted to develop the Wheal Concord tin mine from 1982-1985 by the traditional



Figure 11 (Left).
Kaolinised granite streaked with dark mineral veins exposed in the small open pit in the orebody of tungsten and tin at Hemerdon.



Figure 12 (Right).
Cores of mineralised and unmineralised granite from beneath the kaolinised zone at Hemerdon.

method of crosscutting from an old shaft to find additional lodes. Modern geochemical and geophysical methods can be problematic in Cornwall because of the widespread old workings and non-responsive nature of the mineralisation. They used MEIGA assistance and soon found a promising lode that was mined, but they were unable to withstand the tin price crash of 1985, when tin prices dropped from £10,000 per tonne to £4000. Within 5 years only South Crofty and Wheal Jane remained in operation. Wheal Jane closed and was reopened by RTZ who later amalgamated it with South Crofty, before closing again in 1991. South Crofty followed in 1998, but since 2001 Western United Mines has been attempting to redevelop it as a more mechanised mine.

The major Hemerdon tungsten deposit, which had been worked in the Second World War, was taken up by Hemerdon Mining and Smelting in the late 1960s (Fig. 11). This was run by Bill Richardson, a maverick Canadian entrepreneur who delighted in controversy and whose correspondence regarding other entrepreneurs was robust to say the least: *These fantastic master thieves steal 100% more from the public than the Mafia ever dreamed of*, is one statement in a letter. He sold

a controlling interest to AMAX, at that time a major American mining company with its flagship Henderson and Climax molybdenum mines in Colorado. AMAX carried out a programme of intensive drilling and underground bulk sampling at Hemerdon from 1978 to 1982, assisted by substantial MEIGA funding. The ore consists of a sheeted vein complex in greisenised granite intruded into Devonian metasediments known as killas (Fig. 12). AMAX proved a resource of 42 Mt at 0.18% tungsten and 0.02% tin (Fig. 13), and won planning permission for an open pit mine in 1985, before abandoning the project due to low metal prices and changed priorities. The Hemerdon deposit was taken over by an Australian company, Wolf Minerals, in 2007. They carried out some confirmation drilling and sampling, and announced resource figures of 70.92 Mt at the same grades of tungsten and tin, worth £4500 million at prevailing metal prices. In January 2011, Wolf received updated planning permission to open the mine, and is raising finance to commence operations.

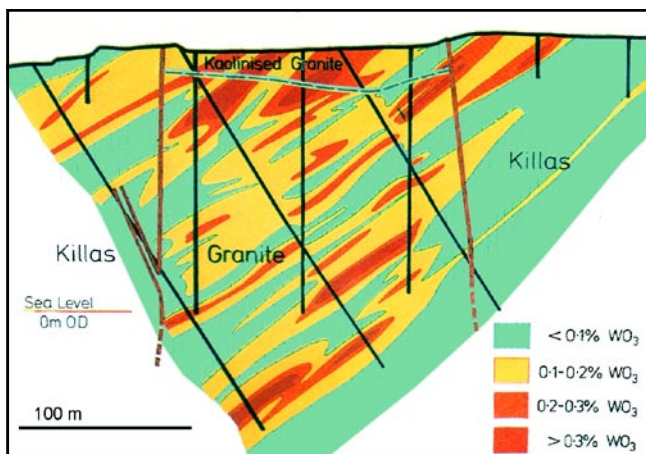


Figure 13. Drill holes and tungsten grades through the Hemerdon orebody (after Mining Magazine).

Lead and Zinc

Attempts at developing lead mines at Leadhills, Nenthead and Matlock all failed in the 1950s. A decade later, Cominco investigated the Carboniferous Limestone adjacent to the Middle Craven Faults west of Malham, in Yorkshire, for replacement deposits similar to those at Pine Point in Canada, but only a few short low-grade intersections were made. In the early 1970s, Central Mining Finance (an offshoot of Selection Trust of London) attempted to drill for deep extensions (at 700-800m) of the major Minera vein in North Wales, but geological and drilling problems prevented the target zone being successfully tested. Discoveries of major lead and zinc deposits in the Carboniferous Limestone of Ireland at Tynagh, Silvermines and Navan encouraged exploration in similar rocks in Britain. The BGS searched for 'Irish-style' mineralisation around Clitheroe in Lancashire for 'Irish-style' mineralisation, but found only low-grade zones of lead and zinc. They

were followed by BP Minerals in the early 1980s in the Marl Hill and Brennand areas. Additional discoveries of low-grade mineralisation were made, before BP was taken over by RTZ and the project was dropped. BP and RTZ were also then active in southwest England, where extensive, roadside, deep-overburden sampling explored the Palaeozoic shales for possible sedimentary-exhalative deposits like those in similar rocks at Meggan and Rammelsberg in Germany. RTZ discovered a small deposit with up to 2% combined lead and zinc over 1–2 metres in black shales at Egloskerry near Launceston.

The major baryte deposits near Aberfeldy in Scotland also contain scattered lenses of lead and zinc with up to 10% Pb/Zn. This prompted a major regional airborne survey of the Dalradian belt (already outlined by the MRP) by Exxon in 1983–84, but the project ended before many of the prospects could be properly evaluated. In 1983, a small Canadian company, Domego Resources, investigated the Dalradian limestone area on Islay for replacement mineralisation, but without success.

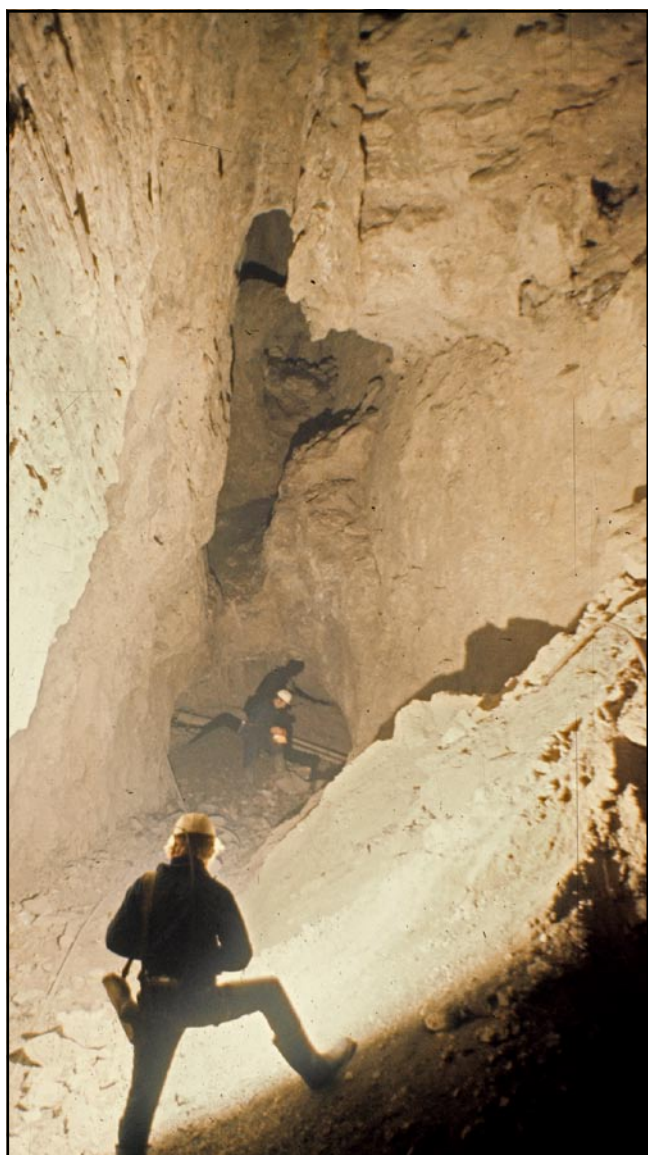


Figure 14. *Stope on a fluorspar vein in Ladywash Mine.*

Fluorspar

In 1960 galena and fluorspar were being produced at Redburn Mine at Rookhope in the northern Pennines by Weardale Lead, and in Derbyshire by Laporte Minerals at Ladywash Mine near Eyam (Fig. 14). In 1965 Laporte opened their Cavendish Mill near Stoney Middleton to process ore from its Ladywash and Sallet Hole mines, as well as from various small tributary operations, with an annual capacity of 70,000 tonnes of acid-grade fluorspar, 18,000 tonnes of baryte and 3850 tonnes of lead concentrates. Interest in fluorspar increased in the late 1960s and early 1970s with the development of three new aluminium works in Britain, increased demand from a major expansion of steelmaking and new fluorine-containing chemicals such as fluorocarbons (Smith, 2003). Production peaked at over 235,000 tonnes in 1975 (Fig. 15). In the northern Pennines Blanchland Fluor Mines (a subsidiary of Colvilles Steel) extended its plant at Whiteheaps Mine and also processed ore from Groverake Mine. In 1974 Dresser Minerals opened an acid-grade fluorspar processing plant at Hopton in Derbyshire, taking ore from several open-pit operations including the Raper Pit on Long Rake, near Youlgreave. The Italian group Guillini Minerals operated several open-pits feeding ore to Cavendish Mill, and the Clay Cross Company worked open-pits at Milltown and Fall Gate, at Ashover.

There were a number of MEIGA applications in the early 1970s for fluorspar exploration within the northern and southern Pennine orefields. Between 1973 and 1982, Swiss Aluminium had eleven projects, mainly small-scale attempts at rehabilitating and investigating old lead mines to see if any fluorspar had been missed, or drilling along extensions of known veins. Their most important mine was Cambokeels (also known as Cammock Eals) which exploited the major Slitt Vein near Westgate in Weardale. They also bought Weardale Lead from ICI in 1977, and opened a new processing plant at Broadwood, near Frosterley, in 1979. But the fluorspar market declined, and their operations were sold to Minworth in 1982, which collapsed in 1991. Mines on the Groverake and Frazer's Hush near Rookhope continued until final closure in 1998, and so ended mining in the northern Pennines.

Laporte closed Derbyshire's Ladywash Mine in 1979, but continued operations at Cavendish Mill,

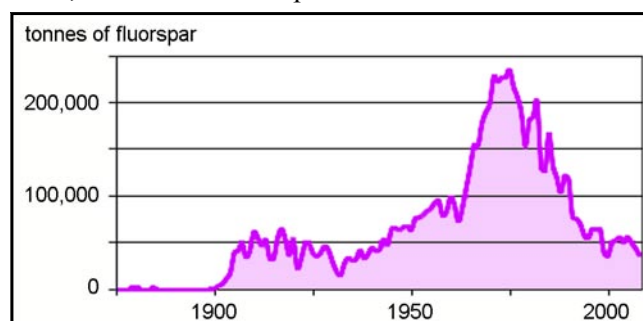


Figure 15. *Fluorspar production in Britain 1875 – 2008 (after BGS Mineral Statistics).*

sourcing ore from Sallet Hole Mine and numerous tributors. A large replacement body, containing several hundred thousand tonnes of ore, was discovered adjacent to Dirlow Rake near Castleton in 1984 (Butcher & Hedges, 1987). The limestone had been partly dissolved by acidic mineralising fluids that moved upwards leading to collapse of large blocks of limestone and their partial replacement by fluor spar. Laporte accessed the old Milldam mine on Longstone Edge at the end of the 1980s, but the ore proved unexpectedly siliceous, leading to recovery problems in the processing plant. Glebe Mines took over the Laporte operations in 1999, but ceased production at the end of 2010. With the closure of Cavendish Mill, any small tributors have no domestic outlet for their ore, so this probably marks the end of fluor spar mining in Britain.

Baryte

In 1960 there were baryte mines at Muirshiels and Gasswater in southern Scotland, Settlingstones and Cow Green in the northern Pennines and at Ladywash in the southern Pennines. By 1970, all except Ladywash had been exhausted, in spite of rising demand for baryte in drilling mud in North Sea oil and gas exploration.

In 1975 the government MRP was investigating the 'Pyrite Belt', a pyrite-enriched member (with minor copper) of the Dalradian Supergroup in the upper part of the Ben Lawers Schist (Stephenson & Gould, 1995). Stream sediment surveys indicated enrichment in lead, zinc and especially barium in an area north of Aberfeldy underlain by the Ben Eagach Schist. Checking the area revealed a thick bed of massive baryte with considerable strike length and economic potential. In the 1970s it is unlikely that company exploration techniques would have included barium as an element to be analysed, so the MRP analysis of a wider range of elements was instrumental in discovering the deposit. Eight short boreholes proved the thickness and grade of the deposit



Figure 16. Folding in massive baryte in Foss Mine. (Photo: BGS OpenGeoscience).

(Coats et al., 1978). The baryte mineralisation was shown to be of the sedimentary exhalative (SEDEX) class, based upon a model whereby warm mineralising solutions are circulated within subsiding sedimentary basins and then expelled onto the sea floor along marginal basin-controlling faults. The dense fluid then settles in depressions in the sea bed to form lenses of baryte or massive sulphides (usually lead and zinc).

This discovery created intense interest, and a number of companies investigated the deposit before Dresser (UK) bought the mineral rights and developed the Foss Mine in 1979, first as a small open pit and then as an underground operation (Fig. 16). The Foss Mine produced its millionth tonne of baryte in 2009. Another, much larger, deposit was found by Dresser in the early 1980s at Duntanlich, a few kilometres east of Foss. This is at the same horizon as the Foss deposit, with intersections of massive baryte exceeding ten metres. Drilling over 30 boreholes proved more than 5 Mt of almost pure baryte. This deposit could have satisfied the demand for baryte drilling mud for the following 30 years, at a rate of 200,000 t/y, saving an annual £10M for imported material. However, planning permission was refused because of the scenic beauty of the area and potential traffic problems. Subsequent appeals with modified proposals have also been rejected by the planning authorities. The MRP found similar, though not economic, deposits at Loch Kandar 40 km northeast of Aberfeldy, and in Glen Lyon 40 km to the southeast. The whole Dalradian belt, from Islay in the southwest to Portsoy in the northeast, is now of interest for the discovery of baryte and lead-zinc mineralisation.

Other areas investigated for baryte include Strontian in western Scotland where Minworth attempted to reopen the historic Strontian lead mines in the early 1980s but were unable to maintain an adequate feed of suitable ore for a profitable operation. And in Cheshire, N L Baroid drilled some shallow holes in 1980 to test a baryte-enriched area of the Sherwood Sandstone Formation at Gallantry Bank near Nantwich.

Gold

Exploration for gold was not considered until the 1970s when the fixed price of \$35/oz was removed. The rise to over \$800/oz by 1980 encouraged several companies to take out Crown exploration licences. The Australian-backed Caernarvon Gold floated in 1982 and raised £2.5 million to investigate additional potentially mineralised structures around the old Clogau St Davids gold mine near Dolgellau in North Wales. The nearby Gwynfynydd mine was reopened in 1981 as a private venture, and produced around 2000 oz of gold before final closure in 1998.

BP Minerals carried out a major programme over a number of Scottish granites from 1981-84. They were initially interested in the Loch Melfort area where they identified intensive alteration or 'silica flooding' of the granite and country rock associated with elevated gold



Figure 17. Gold-bearing quartz-sulphide vein along the roof of the 1985 adit in the Curraghinalt prospect.

and base metal values. BP, and later RTZ, drilled 37 holes for a total of 6400m on the Lagalochan prospect and found sporadic zones of gold enrichment of several metres exceeding 1 g/t of gold, but were unable to establish a coherent deposit. They also investigated a number of areas in the Southern Uplands around Leadhills and Moffat where the MRP had reported panned gold in a number of streams. These also produced sporadic, low-grade intersections of gold mineralisation. In Cornwall, Britcan (a subsidiary of European Mining Finance) drilled a number of holes in Devonian killas close to the Bodmin granite at Tregear near Launceston in the late 1990s but without success.

In 1983 the Irish-based Ennex found potentially commercial deposits of the mesothermal quartz-vein type in the Sperrin Mountains at Curraghinalt, near Omagh Co Tyrone in 1983 and at Cononish, near Tyndrum in Scotland in 1984. Curraghinalt, which consists of multiple auriferous quartz-pyrite veins (Fig. 17), was investigated by drilling and an adit (Colman, 2010). The project has recently been acquired by Dalradian Resources, who are continuing drilling to expand the resource.

RioFinEx had been interested in the Tyrone area since the 1960s, and found another mesothermal quartz vein at Cavanacaw, southwest of Omagh in 1985. Drilling showed that this was a complex, brecciated structure up to 5 m wide with some galena as well as gold and pyrite (Cliff and Wolfenden, 1992; Colman, 2010). The prevailing gold price delayed development until 2007, when Galantas Gold Corporation started a small open pit mine with a current annual production of about 5500 oz of gold, 150,000 oz of silver and 250 tonnes of lead. This is currently Britain's only operating metal mine.

Cononish was also explored by an adit and drilling in the mid 1980s along a single vein (Fig. 18); its gold resources exceed 150,000 oz (Colman, 2010). Planning permission for a mine was gained in 1996, but work was held back with the gold price at only around \$350/oz. In 2007, following the sustained rise in the gold price and a new feasibility study, the Australian company Scotgold Resources sought planning permission from the Loch Lomond and Trossachs National Park to mine at the rate of 20,000 oz per year, but this was turned down in August 2010 on environmental grounds. Scotgold are currently considering reapplying with a modified proposal. They are also exploring a number of other prospects on their 370-square-mile Crown licence, most of which is outside the park.



Figure 18. Mineralised quartz vein against a dolerite dyke in the roof of the Cononish adit (photo: Gus Gunn).

A different style of gold mineralisation was found by the MRP in the late 1980s in the Crediton Trough in Devon, which is underlain by Permian sandstones and basalts (Leake et al. 1991; Colman, 2010). Panned gold grains contain platinum and palladium, in a most unusual combination. This is similar to the isolated occurrence at Hope's Nose near Torquay where it is hosted in Devonian limestone. Commercial exploration was carried out by Crediton Minerals, a subsidiary of MinMet (now Aventine Resources), who drilled short holes at a series of locations kept spuriously secret thereby garnering considerable local publicity. Minor intersections of around 2-3 ppm gold were found, associated with carbonate veining in basalt, but no substantial discovery was made, and Minmet dropped their options in the late 1990s.

In the Ochil Hills of Scotland, the MRP also discovered concentrations of gold grains that were traced back to extrusive Devonian volcanic rocks in Boreland Glen. Drilling showed sub-economic (<1 ppm) levels of gold in highly altered basalts and andesites that are indicative of a major epithermal system. Major gold deposits are found in similar high-level volcanic settings elsewhere, mainly in Tertiary rocks that have not been subject to deep erosion. Subsequently a small Irish company, Navan Resources, carried out test alluvial working in the area but did not proceed to commercial mining. A similar setting was found at Rhynie, near Huntly, in Aberdeenshire, when the Devonian Rhynie chert (world famous for its exquisitely preserved early plant fossils) was found to contain anomalous levels of gold arsenic and antimony (Rice et al, 1995). Drilling proved an auriferous epithermal system in unexposed Devonian andesites, but it was not economic.

Into the Future

Fifty years of exploration have discovered a number of mineral deposits; some of which are potentially economic. Furthermore, several styles of mineralisation hitherto unknown in Britain have been found. These include the SEDEX baryte at Aberfeldy, Besshi-style copper at Gairloch and red-bed gold at Crediton. The total value of mineral in the ground of all the significant discoveries, excluding all mining processing and other costs, is estimated to be in the range of £10-15 billion at current metal prices. Much of this, such as the copper at Coed y Brenin, may remain in the ground because of a combination of economic and planning considerations. However, it is probable that several discoveries, notably Hemerdon and Parys Mountain, as well as a number of small gold deposits, will be mined in the near future.

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