Technical Paper M4
Metals

Cornwall Council
March 2013

1 The geological background of metals in Cornwall

There is a close geographical connection between the granites of Cornwall and the location of the important metalliferous mining districts. The Cornubian granite batholith has a W-E extent of over 250 km beginning from some distance west of the Isles of Scilly to just east of the Dartmoor Granite. Much of the batholith is concealed beneath Devonian and Carboniferous strata.

Relatively recent studies have concluded that the granite magma was essentially derived from partial melting of the lower crust, with a complex history of emplacement between 300 and 270 million years before the present - during and after the period of Variscan earth movements. The batholith varies in width between 40 and 60 km, whilst the thickness is considered to reduce from 20 km in the east to about 10 km in the west: over this interval, the base of the crust is between 25 and 30 km deep. From west to east the larger granite exposures or plutons are those of the Isles of Scilly, Land's End, Carnmenellis, St. Austell (or Hensbarrow) and Bodmin Moor. The smaller bodies include Godolphin/Tregonning, St. Michael's Mount, Carn Marth, Carn Brea, St. Agnes, Cligga Head, Castle-an-Dinas, Belowda, Kit Hill, Hingston Down and Gunnislake.

Fluids escaping along fractures from the cooling granite bodies were responsible for depositing a wide range of minerals including metal ores. This fluid movement was sustained and enhanced by radiogenic heat and led to a complex sequence of mineralising events, with individual veins or `lodes' carrying particular assemblages of minerals. The BGS Report 'Mineral Resource Information for Development Plans' has identified zones of intense hydrothermal vein mineralization and zones of scattered stratiform vein and stratiform mineralization in certain horizons within the slate, sandstone and basic igneous rocks throughout Cornwall that are enriched in metals. These include veins and stratiform deposits that are unrelated to the granites and their thermal influence, which cover broad areas across the County and do not appear give an indication of whether there is a quality of resource of such form quality and quantity that has reasonable prospect for eventual economic extraction. The principal metallic ores extracted in the County have been tin, copper and iron.

The veins within and close to the granites mostly carry tin, in places with tungsten and arsenic. The main stage metalliferous lodes trend east -west and are typically steeply dipping (mostly >70 o) fracture-infill veins. In the rocks immediately around the granites copper and arsenic may be found with tin, while further out tin diminishes and zinc may be present. Veins carrying lead, silver and zinc, together with spar minerals such as fluorite and barite, are to be found at some distance from the granite outcrops. This distinctive set of fractures are commonly referred to as cross-courses as many of these veins trend north-south in contrast to the predominant east-west trend of the main-stage tin-copper-arsenic lodes and were selectively mined as crosscuts into the workings on main-stage lode structures. Cross-course lodes have produced a wide range of metals, including Lead (Pb), Zinc (Zn), Silver (Ag), Barite (Ba) , Antimony (Sb), Cobalt (Co), Nickel (Ni), Iron (Fe) , Manganese (Mn) , Bismuth (Bi) , and Uranium (U) but occur only sporadically. In some districts, for example around Gunnislake, the veins are noted for their polymetallic character. This is the result of a number of mineralising events being superimposed in the same structure and can lead, for example, to tin, tungsten, arsenic, copper, zinc, and fluorite occurring together. In addition to the metals and minerals listed above, Cornwall has yielded manganese and silver as well as small amounts of molybdenum, cadmium, fluorspar and gold.

Metalliferous minerals have been worked by underground methods and (less significantly) from placer deposits; for example in the case of tin ore this has been extracted by tin streaming in the past. Historically, larger tonnages of both copper and iron have been produced and in total, Cornwall has produced more copper than tin but tin has however been the more valuable commodity in terms of price.

2 Current production and reserves of metals in Cornwall

The only current production of metals in Cornwall is at the micro scale Blue Hills Tin Streams near St Agnes. Mine development work is underway at South Crofty Mine, Pool. Planning permission was granted in late 2011 to relocate South Crofty's surface operations and create modern ore processing and mine access facilities in the Tuckingmill Decline Area. Figure 2.1: Geology, currently worked and other permitted metal sites in Cornwall shows permitted metalliferous sites in Cornwall. Table 2.1: Status of permitted metal extraction sites in Cornwall lists those sites with planning permission.

Figure 2.1: Geology, currently worked and other permitted metal sites in Cornwall

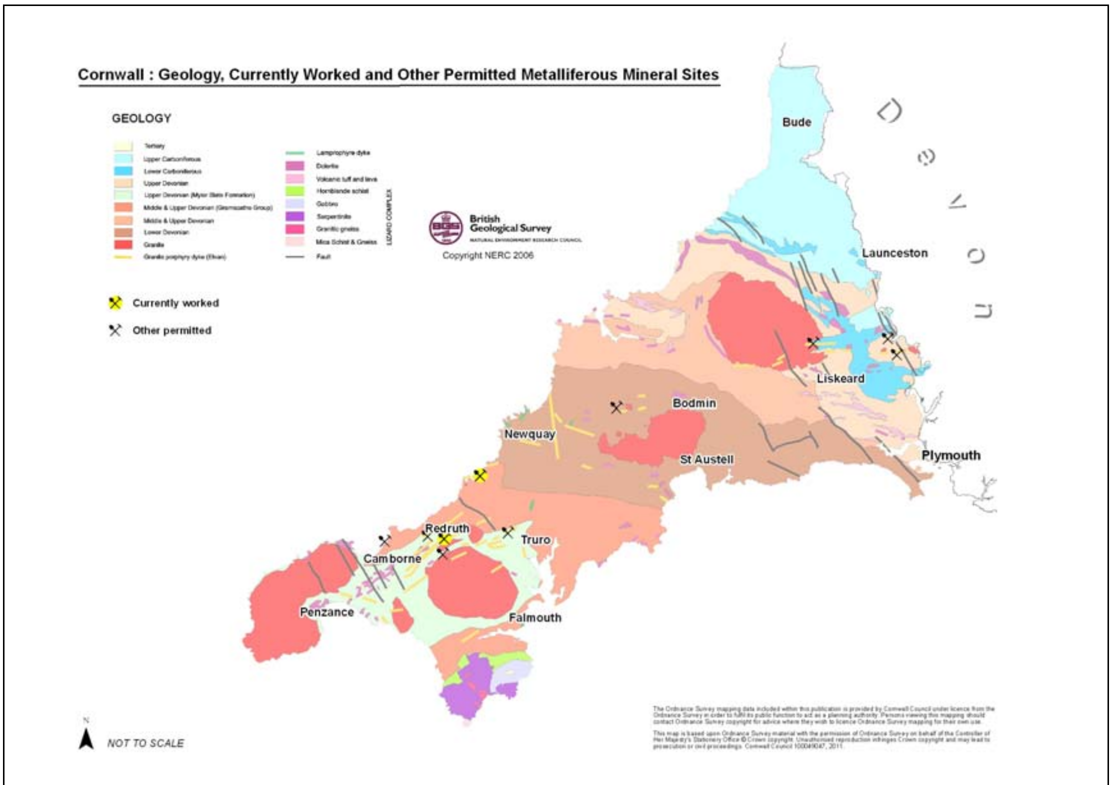


Table 2.1: Status of permitted metal extraction sites in Cornwall

Site	Status
Blue Hills Tin Streams	Active (currently working)
Castle-an-Dinas Mine	Dormant
Cotts Farm Mine	Dormant
Dolcoath Tin Streams	Dormant (restored)
New Consols Mine	Dormant
Prince of Wales Mine,	Dormant
Rosewarne Mill/Tehidy Hill/Reskadinnick	Dormant
South Crofty Mine, Pool	Active (currently working – undertaking mine development)
Tin Sand, Gwithian Beach	Dormant
Wheal Jane Mine, Baldhu	Active (no mining operations - only used for deposition of mine water sludge on tailings dam)

It has recently been reported (October 2012) that inferred resources at South Crofty Mine are estimated to be around 2.47 million tonnes at 0.68% tin equivalent.

3 Markets, transport and use of metals in Cornwall

Generally, primary refining of metal ores is undertaken at, or close to, the mine, thus reducing the weight and volume of the material to be transported to secondary refining facilities and markets (which tend to be global). Large scale smelting facilities for many metals are specialised and consequently there may be a need to export materials to smelters outside the UK or Europe. The proximity of mines to coastal export facilities may therefore be advantageous.

Section 8 below includes detailed information on markets and use of various metals.

4 Government planning policy and guidance for metals

4.1 National Planning Policy Framework (CLG, July 2011)

In March 2012 the Government published the National Planning Policy Framework (NPPF), which replaced existing national planning policy. This includes a section on minerals and makes specific reference to the sustainable use of important minerals and also to defining Mineral Safeguarding Areas for minerals of national and local importance. Mineral Planning Statements and Mineral Planning Guidance notes were replaced by the NPPF and are no longer extant.

The NPPF requires local planning authorities to include policies for local and nationally important mineral resources and to safeguard those resources. Great weight should be given to the benefits of mineral extraction including to the economy.

The NPPF also clarifies the status of existing plans with full weight given to policies adopted since 2004 until March 2013. In all other cases and from March

2013 due weight should be given to relevant policies in existing plans according to their degree of consistency with the NPPF (the closer the policies in the plan to the policies in the Framework, the greater the weight that may be given).

The NPPF is accompanied by a technical guidance document which provides guidance on the implementation of policies contained in the NPPF. This mainly relates to amenity issues, dust, noise, stability and restoration.

In addition, the Localism Act received Royal Assent in November 2011. The aims of the new legislation include decentralising and strengthening local democracy, empowering communities and the introduction of neighbourhood planning. Information on the Localism Act can be viewed at http://www.communities.gov.uk/localgovernment/decentralisation/localismbill/

5 History of local planning policy in Cornwall for metals

5.2 Cornwall Minerals Local Plan

The Minerals Local Plan provides the policy context within which mineral development applications can be assessed to the year 2011 and is the current adopted minerals planning policy. This was published in March 1998 and seeks to ensure the long term production of the Cornish minerals industry to provide an adequate and stable supply of minerals in a sustainable manner. The policies within this document have been 'saved' until the adoption of the Local Plan - Core Strategy.

5.3 Cornwall Structure Plan 2004

The policies of the Cornwall Structure Plan 2004 have been saved and will remain extant until replaced by Cornwall Local Plan. Structure Plan Policy 5 Minerals states that *"Mineral resources should be conserved and managed to provide a steady supply of minerals to meet the needs subject to environmental and special considerations and the need for high standards in restoration and aftercare. Development should ensure:*

- *The conservation of mineral resources;*
- *A steady supple if minerals is available;*
- *Impacts on the environment are minimised and encouragement given to the use of secondary or recycled aggregates;*
- *An increased use in non road based transport;*
- *The improvement of operational standards in all mineral workings;*
- *The high standards of restoration and aftercare are secured on a progressive basis;*
- *That adequate overall capacity for mineral waste arisings in Cornwall is provided for during the Plan period."*

5.4 Cornwall and West Devon Mining Landscape World Heritage Site

Parts of the orefield in Cornwall have been inscribed as a UNESCO World Heritage Site since July 2006 (http://www.cornish-mining.org.uk/). There are ten areas in the inscribed Site whose landscapes represent former mining districts, ancillary industrial concentrations and associated settlements: St Just Mining District; Port of Hayle; Tregonning and Trewavas Mining District; Wendron Mining District; The Camborne-Redruth Mining District; Gwennap Mining District, Kennall

Vale and Perran Foundry; St Agnes Mining District; Luxulyan Valley & Charlestown; Caradon Mining District; Tamar Valley & Tavistock.

5.5 Cornwall Minerals Development Framework

Since the reform of the planning system (as required by the Planning and Compulsory Purchase Act 2004), work has been undertaken to replace the Cornwall Minerals Local Plan. Initially, Cornwall County Council was working towards the production of a Cornwall Minerals Development Framework. However, since the amalgamation of the former County and District/Borough Councils for Cornwall to form the unitary Cornwall Council minerals policy for Cornwall is now to be included in the Cornwall Local Plan see section 5.6 below.

To progress this work consultations / stakeholder participation has been undertaken to date on the following publications:

- Cornwall Minerals Development Framework: Report on Issues and Options October 2004
- Cornwall Minerals Development Framework: Report on Preferred Options November/December 2006
- Cornwall Minerals Development Framework: Core Strategy Revised Report on Preferred Options May 2008

These documents can be viewed on Cornwall Council's website http://www.cornwall.gov.uk/Default.aspx?page=22887. Th2006 and 2008 documents indicated that there is no presumption against mining within the World Heritage Site and included a positive policy indicating that development within the World Heritage Site should maintain and enhance the outstanding universal value and setting of the World Heritage Site. The Cornwall Minerals Development Framework also reviewed the mineral safeguarding areas for metalliferous mining.

The Minerals Development Framework will no longer be progressed, strategic mineral policies are included in the Cornwall Local Plan – Strategic Policies

5.6 Cornwall Local Plan

Following creation of the unitary authority for Cornwall in April 2009, minerals planning policy is now being prepared for inclusion in the Cornwall Local Plan, although it is anticipated that a specific Minerals Plan will be prepared following adoption of the Local Plan.

A consultation document, "Options and Preferred Options for Minerals, Waste and Energy" was prepared in January 2012 and detailed options and preferred options for minerals. With reference to metals, the preferred options include:

- Support metal extraction in response to market demand, including working within the AONB and WHS.

The pre-submission Local Plan – Strategic Policies March 2013 sets out the Council's proposed strategic mineral policies. These aim to support appropriately scaled metal mineral development throughout Cornwall. Proposed policy also seeks to safeguard metal resources and reserves.

6 Projected demand and future supply

BGS Metals Factsheet[1] states that *"SW England remains prospective for discovery of high grade tin and copper vein deposits. However, extensive and intensive historical workings make exploration for new deposits difficult. It is likely that new discoveries would be at considerable depth which would require a substantial exploration investment. Recent metalliferous extraction operations have been relatively small scale operations, often based on historical mines. Such locations may become of importance in the future*". The price of metals is a major factor controlling the viability of developing new mines as will be illustrated by the monitoring of the viability of South Crofty mine, which aims to develop as a polymetallic mine.

7 Key considerations issues for planning policy development for metals

Consideration 1 Safeguarding issues, largely dealt with in conjunction with the Cornwall Chamber of Mines and Minerals, have been addressed by safeguarding secondary and important access shafts by means of a 50 m radius safeguarding area. Where appropriate, safeguarding areas around identified Primary shafts will relate to physical features on the ground (e.g. roads and field boundaries) which would be of sufficient size and shape as to allow for required surface structures for any future mining development. In principle, if developers put forward new mining areas, further access shafts could be safeguarded.

Consideration 2 Present day lithium needs are mostly met from overseas high-grade deposits and it is unlikely that the Cornish lithium resource will be exploited in the foreseeable future; it may be appropriate to safeguard mica dams in the china clay areas as potential mineral resources for the future.

Consideration 3 The distribution and grade of minerals containing rare earth elements in Cornwall is poorly identified and there is a slight possibility that there could be important strategic deposits for the future.

Consideration 4 The legacy of contaminated land left as a result of mineral extraction and processing is of interest: Information such as geochemistry surveys in areas of mining-related contaminated land in the proximity of past mining areas if available could be used for future identification of resources.

[1] http://www.bgs.ac.uk/mineralsuk/planning/mineralPlanningFactsheets.html

Appendix
8 Information on individual metals

8.7 Arsenic

In the early years of Cornwall's mining history, arsenic minerals were regarded as an undesirable waste material in the tin and copper lodes. Just before 1870 a demand for arsenic in the chemical industry led to the extraction and refining of arsenic as a by-product at a number of Cornish mines. Dines (1956) states that ‘In the later years of the 19th century a relatively small number of mines around Callington in East Cornwall and Tavistock in West Devon were producing about half of the world's output. Between 1870 and 1902 the annual output of arsenic oxide varied between 4,000 and 8,000 tons. Subsequently production declined with an annual production in excess of 2,000 tons exceeded only between 1914 and 1926. After 1936, the output declined to less than 100 tons, and there is no output at the present day.

The principal arsenic mineral is arsenopyrite (FeAsS) also known as mispickel or "white mundic". Arsenic also occurs in lollingite ($FeAs_2$) and in other sulphides and secondary arsenates. As noted above it also occurs in veins together with tin and copper minerals, and in minor amounts with lead, zinc and antimony ores.

In the past, some mines sold arsenic ore in the natural state but it was more usual for the material to be roasted (calcined) and the resulting vapours passed through flues where arsenic oxide precipitated as a grey sooty powder. The arsenic soot containing 80-90% of arsenious oxide was the form in which a material was usually sold, but at some places refined arsenic containing 99.5% of the oxide was produced. At many localities the roasted ores were treated to remove any tin and copper that may have been present. The production of arsenic from the mines of Cornwall has left a considerable legacy of pollution stemming from waste dumps, and from the effects of former refining operations.

8.7.1 Current production & reserves

There is no current arsenic production in Cornwall.

8.7.2 Markets and uses

A former chief use of arsenic oxide was as the main ingredient of various insecticides. Much of the refined arsenic was used in the production of insecticides to combat the American Boll Weevil. Demand is small at the present day: small amounts are used in glassmaking, in the manufacture of electronic components and as a timber preservative.

8.8 Copper

Copper is the second most important metal worked from the Cornish veins and was extensively worked in the 18th & 19th centuries but was abandoned as large-scale open pit deposits were discovered overseas.

It is probable that the total production has been in the region of 2 million tonnes of metal, though records are incomplete. There is little information about the production of copper in early times and systematic mining of the metal does not appear to have commenced before the 16th Century. In the first half of the 19th

Century, production increased considerably and more than 40% of the world's output was obtained from Cornwall and Devon. The highest production was reached about 1860 with an annual output of more than 15 thousand tonnes of metal. After this period the production declined dramatically, and by the beginning of the 20th century the output was negligible.

The principal ore of copper is chalcopyrite ($CuFeS_2$), a sulphide of copper and iron, though it is also extracted from other copper iron sulphides such as bornite (Cu_5FeS_4) and the copper sulphide chalcocite (Cu_2S). Carbonates, oxides and native copper have also been found in the upper parts of the veins. Copper occurs together with tin and arsenic in many districts and the waste ('gangue') minerals in the veins are most commonly quartz with tourmaline, chlorite, fluorite and carbonates. It is not uncommon for veins situated close to the boundaries of granite bodies to have a copper-tin-arsenic association, while those farther into the country rock bear copper with zinc. Small tonnages of copper ores have in places been worked from lead-zinc-silver veins.

In the past copper ores were concentrated by hand picking of the coarser material and gravity separation of the finer fractions. In the present century the small production of copper has mostly involved flotation, and this process has also been used to remove traces of copper and other sulphides from the tin ores. At a number of localities, copper has been produced by precipitation on scrap iron using either copper-rich mine drainage waters or leachate from dumps and low-grade tailings.

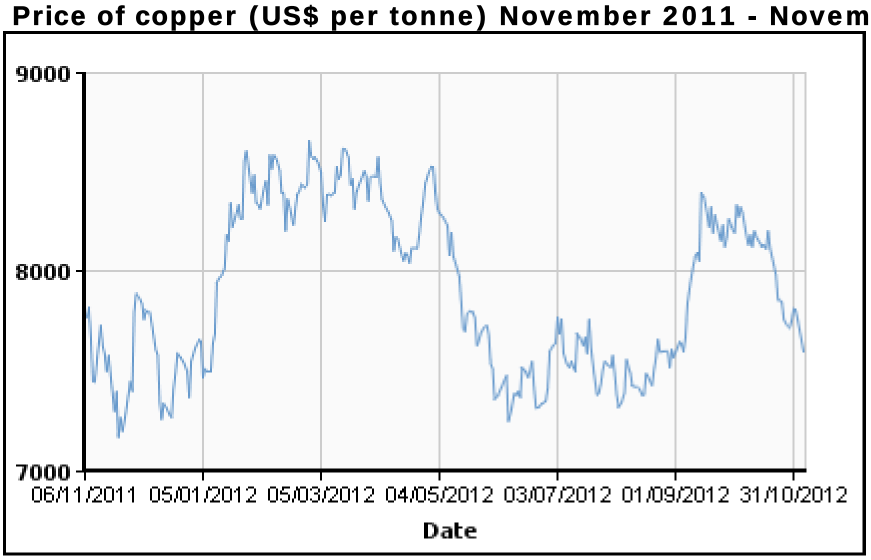
8.8.1 Current production & reserves.

There is currently no copper production in Cornwall.

8.8.2 Markets and uses

The current cash buyer price for copper quoted on the London metal exchange is 7,600 US$/tonne (5th November 2012). Figure 8.1 Price of copper (US$ per tonne) November 2011 - November 2012 below indicates the copper price as quoted by the London Metal Exchange from November 2011 to November 2012.

Figure 8.1 Price of copper (US$ per tonne) November 2011 - November 2012[2]



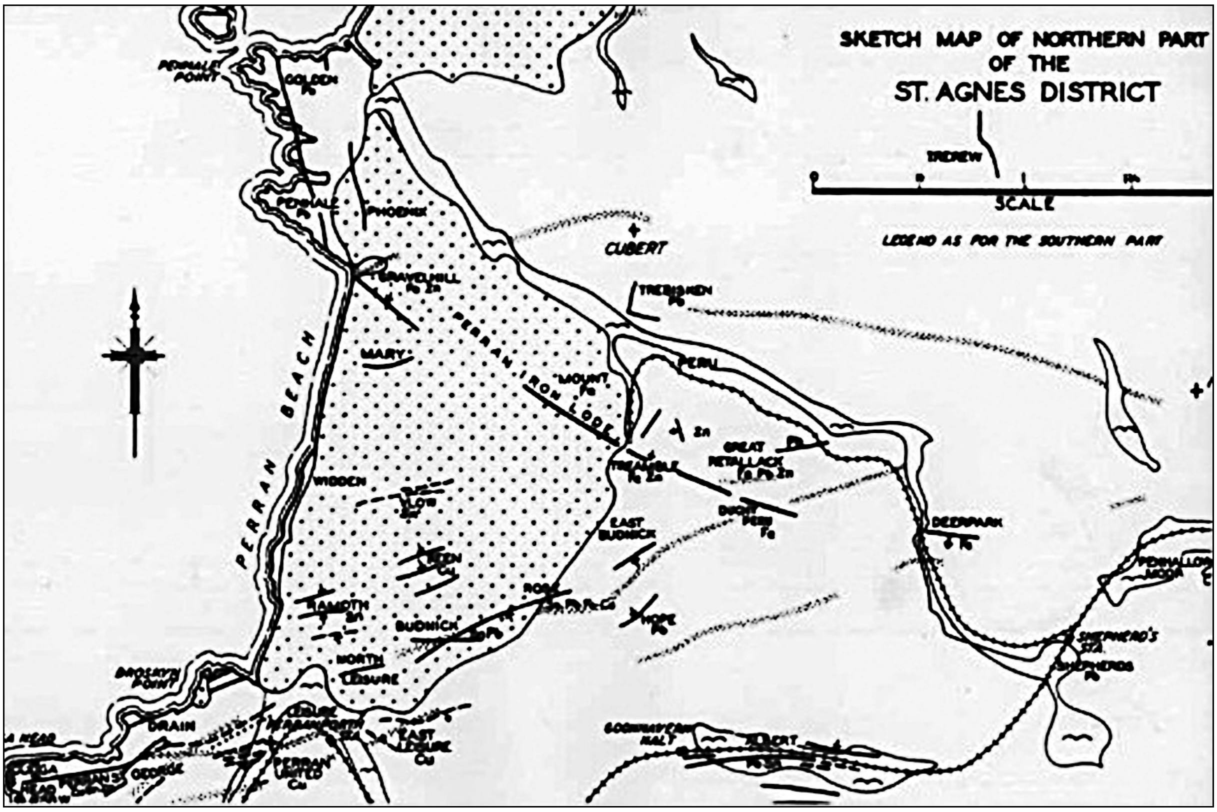
[2] http://www.lme.com/copper.asp

Copper is used for the fabrication of metal parts which depend on its high electrical conductivity and ductility; these include wire and pipes. It is widely used in alloys, particularly with zinc or tin to give brass and bronze respectively. Copper compounds also find application in the chemical industry and are used in the manufacture of wood preservatives and fungicides.

8.9 Iron

The Great Perran Iron Lode, forms a linear feature extending from Gravel Hill Mine, at the northern end of Perran Bay, south-eastwards for at least 6 km (Reid and Scrivenor, 1906; Dines, 1956). The Perran Iron Lode varies in width from 1-30 m and typically includes brecciated slate with siderite, quartz and black sphalerite. In places the lode is cut by late, low temperature N-S trending cross-course veins containing pyrite, sphalerite and argentiferous galena. Oxidation of the siderite to depths of 60 m or more below surface has produced oxides and hydrated oxides of iron (hematite, goethite and limonite), which were formerly worked by opencast and underground development. The mines are Gravel Hill Mine, Mount Mine, Treamble Mine, Duchy Peru and Deerpark Mine, and these are shown in Figure 8.2 Nature and origin of the Great Perran Iron Lode, Perranporth area, Cornwall below. Output figures are only available for the last working, when it produced about 8000 tons of iron ore, and 30 tons of zinc ore.

Figure 8.2 Nature and origin of the Great Perran Iron Lode, Perranporth area, Cornwall[3]



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3 Scrivener, R.C., Grant, J.B., Hollick, L.M. and Smith, C.W. 2006. *Geoscience in south-west England*, 11, 255-256

8.9.1 Current production & reserves.
Iron is not currently produced in Cornwall

8.9.2 Markets and uses
The natural magnetic properties of iron make it suitable for both permanent magnets and electromagnets. Alloys of cobalt and iron (both magnetic materials themselves) can be used in the manufacture of very powerful permanent magnets. It is also used in the production of various types of dyes and inks, and in the manufacture of abrasives.

Alloyed with other metals, iron is the most widely used of all metallic elements. Steel is a general term used to describe iron alloyed with carbon and, in some cases, with other elements such as small amounts of phosphorus sulphor, chromium, manganese, molybdenum, nickel, silicon, vanadium, nickel, and manganese. Steel is widely used in many types of construction. It has at least six times the strength of concrete, and about three times the strength of special forms of high-strength concrete. Steel reinforced concrete, is one of the strongest of all building materials available to architects.. It has also been used in the manufacture of car bodies, ship hulls, and heavy machinery and machine parts.

Steels that contain the element niobium have unusually great strength and have been used, among other places, in the construction of nuclear reactors. Tungsten steels are also very strong and have been used in the production of high-speed metal cutting tools and drills. The alloying of aluminum with iron produces a material that can be used in AC magnetic circuits since it can gain and lose magnetism very quickly.

8.10 Lead
Lead is a dense, soft, malleable and ductile metal with a low tensile strength and poor electrical conductivity. It is included in the heavy metals group. Lead is the end product of radioactive decay and can cause lead poisoning. It has a lustrous silver-blue appearance when freshly cut, but when exposed to moist air darkens to a dull grayish colour due to the formation of an oxide film that protects the metal from further oxidation or corrosion. The primary lead mineral is galena (PbS), containing 86.6% lead. Other lead minerals include anglesite ($PbSO_4$) and cerussite ($PbCO_3$).

East Lead was found in East Wheal Rose Mine in St. Newlyn in 1812, and there was also a silver content in the lead ore (galena). West Chiverton Mine, along with Cargol and Ludcot, emerged in the 1860s as lead producers. http://www.cornwall-calling.co.uk/mines/north-cornwall-perranzabuloe/west-chiverton.htm

8.10.1 Current production & reserves.
Lead is currently not being produced in Cornwall

8.10.2 Markets and uses
The current cash buyer price for lead quoted on the London metal exchange is 2,096 US$/tonne (5th November 2012). Figure 8.3 Price of lead (US$ per tonne) November 2011 - November 2012 indicates the lead price as quoted by the

London Metal Exchange.

Figure 8.3 Price of lead (US$ per tonne) November 2011 - November 2012[4]

Some of the many uses of lead are as follows:

- sheathing material in high voltage power cables
- worked in the past for the manufacture of sulphuric acid
- roofing and cladding, to prevent water penetration.
- lead acid batteries e.g. car batteries.
- red and yellow colouring elements in paints and ceramic glazes.
- projectiles and firearms, bullets and shot
- glazing bars for stained glass windows.
- used in polyvinyl chloride (PVC) plastic
- lining of chemical treatment baths, acid plants and storage vessels.
- dense lead sheet is used for sound insulation and radiation shielding.
- molten lead is utilized as a coolant for lead cooled fast reactors.
- keels of sailboats, scuba diving belts, fishing sinkers and lead weights
- lead is the base metal used for organ pipes
- used in soldering and as electrodes in the process of electrolysis.
- statues, sculptures, decorative motifs, leaded bronze ornaments
- lead based semiconductors - used in photovoltaic (solar energy) cells and infrared detectors.

8.11 Tin

Tin orebodies in Cornwall are variable in form and width along their lateral extent with occasional rich pods of ore termed ‘carbonas’. ‘Tin floors’ are layers in which cassiterite (tin) is associated with silicates. The mineralisation of the Cligga Head system is a greisen-bordered sheeted-vein complex. Tin, tungsten and arsenic mineralisation extends out into fractures within the surrounding sedimentary rocks at both the northern and southern contact zones.
Tin has been produced for centuries in Cornwall by tin streamers working alluvial sands and gravel downstream from other existing mines on the beaches and valley floors.

[4] http://www.lme.com/lead.asp

8.11.1 Current production & reserves.

The only site currently producing tin is Blue Hills Tin Streams, which is situated at the seaward end of the Trevellas Valley near St Agnes on the north coast of Cornwall. This is a small scale working producing tin by traditional methods for decorative uses. The workshop employs traditional, small-scale 'tin streaming' methods to extract tin from local waste dumps and beach sand (under licence from Duchy of Cornwall). It lies within the St Agnes Mining District of the World Heritage site.

8.11.2 South Crofty Mine

South Crofty Mine is situated mid-way between Camborne and Redruth at Pool. South Crofty is the only underground tin mine with extant permission to extract and process the ore. The modern mine was worked for tin, arsenic and tungsten during the early 20th century, but by the 1960's tin was the sole product. The workings eventually reached almost 500 fathoms or 3000 feet in depth (1 fathom = 6 feet and 1.83 m) and approximately 200,000 tonnes of tin ore a year were extracted producing approximately 2000 tonnes of tin metal per year. The mine ceased production in 1998 when the tin price fell and the mine is now flooded to adit level, still reportedly possessing significant reserves.

Baseresult Holdings Ltd, bought South Crofty in 2001 and was the majority shareholder, along with Cassiterite LP, an investment vehicle that was acting for, amongst others, Galena Asset Management, a subsidiary of global commodity trader Trafigura Beheer. Western United Mines Limited (WUM) was launched in November 2007 and is a joint venture between BHL and Cassiterite LP. Western United Mines Limited (WUM) now owns and operates the mine. An estimated £50 million is needed to bring the mine back into production. Some of the money is needed to complete a 1.6 km decline to access previously unexploited areas. It is believed that WUM plans to focus on developing the poly-metallic nature of the deposit so that South Crofty would not be solely reliant on tin.

The existence of shafts and associated infrastructure give an indication of where historically important deposits have been exploited. The main former tin mining areas in Cornwall are around St Just, Zennor, Camborne, Redruth and Illogan, St Agnes, Wendron, Gwennap, Carnon Valley, A large area bounded by St Austell, and Wadebridge to Bodmin, Callington in the east and an area in North Cornwall.

8.11.3 Markets and uses

The price of tin has more than doubled since South Crofty closed in 1998 when the price dropped to below US$6000/tonne. Price for cash buyers on 5th November 2012 was 20,170 US$/tonne and fluctuations are shown in Figure 8.4 Price of tin (US$ per tonne) November 2011 - November 2012 below.

Figure 8.4 Price of tin (US$ per tonne) November 2011 - November 2012[5]

[5] http://www.lme.com/tin.asp

World resources, principally in western Africa, south-eastern Asia, Australia, Bolivia, Brazil, China, and Russia, are sufficient to sustain recent annual production rates well into the 21st century. There is continued strong demand fuelled by the growing economic giants of India and China. As far as extraction in the future is concerned this is highly dependent on global metal price and is difficult to predict. In addition, metals can be recycled successfully without loss of quality and legislation is increasingly demanding that recycling opportunities are built into the manufacturing process. This could reduce the demand for primary materials.

Tin is used in the production of bronze, pewter and die-casting alloys, for tin plating (tin cans) and to make tungsten more machineable. Minor applications of tin compounds are in the ceramics industry (the oxide is used as an opacifier), and as a mordant in dyeing cloth; organic tin compounds were formerly much used as fungicides and insecticides, though these applications are in decline due to the toxicity of the products. The following are substitutes for tin: Aluminium, glass, paper, plastic, or tin-free steel substitute for tin in cans and containers. Other materials that substitute for tin are epoxy resins for solder; aluminium alloys, copper-base alloys, and plastics for bronze; plastics for bearing metals that contain tin; and compounds of lead and sodium for some tin chemicals.

8.12 Tungsten

The tungsten bearing ore bodies are mostly close to granite outcrops which are associated with greisening in which the granite adjacent to discontinuities is replaced by a dark grey mass of mica, tourmaline and quartz as a result of Boron/fluorine-rich fluids which circulated through fractures in the granite. Wolframite ($(Fe,Mn)WO_4$ iron/manganese tungstate) is the principal ore of tungsten in Cornwall where it can also be associated with tin. Scheelite, another ore of tungsten has also been identified.

Tungsten ore occurs in sheeted vein complexes, at St Michaels Mount, near Penzance and Cligga Head near Perranporth which was worked for tungsten during the Second World War. In the Gunnislake district, the ores may be found in classical fissure veins. A lode at Castle-an-Dinas Mine, near St Austell in Cornwall, was mined from 1917 until 1958 and the mine became Cornwall's premier wolfram producer. A soil survey over Devonian slates to the south of

Castle-an-Dinas wolfram mine produced anomalies indicative of at least two sub-parallel zones of tungsten veining and a broad area of anomalously high tin values. After a fluctuating start, Castle-an-Dinas Mine reportedly obtained a steady production of about 200 tons of concentrates per annum up to the closure of the mine in 1958. According to Beer et al., the ore potential south of the old workings can be estimated at about 1000 tonnes of recoverable tungsten. To the north the strike length of possible mineralisation is less predictable, but there is little doubt that this area offers the better target for exploration (Mineral investigations near Bodmin, Cornwall. Part 5 - The Castle-an-Dinas Wolfram Lode K E Beer, T K Ball and M J Bennett (1986))

Tin/tungsten deposits were discovered at Red Moor mine in 1981 by South West Consolidated Minerals. These are sheeted vein deposits in Devonian sediments associated with Variscan Granite. Around the fringe of the Bodmin Moor Granite near the contact are small areas of sheeted greisen veins with cassiterite and wolframite, sometimes altering to scheelite. At Hawks Wood mine these were exploited by adit mining. The tungsten rich eluvial/alluvial deposits had been exploited by placer mining.
http://projects.exeter.ac.uk/geomincentre/01East%20Cornwall%20and%20South%20Devon2.pdf

8.12.1 Current production and reserves

There is currently no tungsten production in Cornwall.

In Devon, emerdon mine, near Plympton is a large tungsten and tin resource and is set to re-open, possibly in the next three years. Ore is currently accessed by an open pit which, if mining restarts, could be up to 850 m long, 540 m wide and 200 m deep. The mine life is expected to be 15-19 years and will provide 200 new full-time jobs. Wolf Minerals anticipates producing 3000 tonnes of tungsten each year.

8.12.2 Markets and uses

Price quoted at just over 51US$/Kg in August 2012. China controls about 75 per cent of the world's production of tungsten.

The value of tungsten for hardening steel was not understood until the late 1800's. The high temperature properties as well as the high density are responsible for the use of tungsten in various tungsten-based alloys. Elemental tungsten is used in many high-temperature applications such as cathiode ray tubes and vacuum tube filaments and heating elements. Tungsten carbides are an important component in steels, stellites, superalloys and diamond tools and in powdered form as abrasives. Tungsten is also used in Cemented Carbides (Hardmetals).

8.13 Uranium

Uranium is widely distributed throughout Cornwall. Uranium minerals occur mainly in cross courses with low temperature minerals such as those of iron, cobalt, nickel and bismuth. Resource assessment undertaken by the United Kingdom Atomic Energy Authority after World War II demonstrated very small reserves.

In the past Trenwith Mine, above St Ives, produced 694 tons of pitchblende and other ores over the period 1911 to 1917. Radium, discovered by Marie Curie, was first isolated by her from pitchblende from Trenwith Mine. South Terras Mine lay between the villages of St. Stephen and Grampound Road on the upper reaches of the Fal river and was mined from 1870 to 1930 for a number of metals, including radium for Marie Curie's research. (http://www.cornwallinfocus.co.uk/history/trenwith.php). Formerly known as Union Mine, South Terras mine was originally worked for iron in an opencast pit extracting iron and magnetite from ochre. One major uranium lode trending southwest to north east was discovered in 1873 and was up to four feet wide. This is the only mine where uranium was the main metal mined, the primary ore being uraninite or pitchblende, a variable oxide of uranium. The bulk of the ore, mainly pitchblende, was worked out by 1903. Principal shafts: Jem, New Adit, Old Pump and Gossan shafts. Total of 736 tons of ore was produced, including 286 tons from the dumps. Pitchblende is said to have occurred in the Botallack area of West Penwith at Wheal Edward there were limited amounts of pitchblende and uranium produced with production ceasing in 1893. Wheal Owles lodes carried some bismuth and uranium ores associated with argentiferous galena in cross-veins. The other mines of the Botallack Group include The Crowns, Wheal Owles, Wheals Cock, Carnyorth, Botallack and Parknoweth. (http://www.cornwallinfocus.co.uk/history/mining.php).

8.13.1 Current production & reserves.

There is currently no production of uranium in Cornwall.

8.13.2 Markets and uses

One significant commercial use for uranium is to fuel nuclear reactors for the generation of electricity. Reportedly roughly half of the uranium mined today is used to produce nuclear weapons. Depleted uranium is used for armour piercing shells and missiles, and as ballast in yachts and aircraft. Unlike most metals, uranium is traded in most cases through contracts negotiated directly between a buyer and a seller.

8.14 Zinc

The principal ore of zinc is the sulphide sphalerite (ZnS), also known as blende or "black jack". Other zinc minerals such as the carbonate calamine also occur but only in minor amounts. Sphalerite occurs in association with lead and copper ores and is particularly common in north-south cross-course veins. Impurities in the zinc ores include lead and the very toxic element cadmium. Cadmium anomalies may occur around sites of former zinc mining or the treatment of its ores.

Until the early 19th Century zinc ores were commonly discarded, as there was only a limited requirement of zinc ores for use in the production of brass. Subsequently zinc concentrates were produced, with a peak between 1850 and 1885, much of it from veins in the St Agnes district. In former times zinc concentrates were produced by hand picking and gravity concentration. More recent production such as that at Wheal Jane was from flotation.

8.14.1 Current production & reserves.

In recent years, zinc concentrates have been produced from the polymetallic ores at Wheal Jane; prior to closure in 1991 some 5500 tonnes of zinc metal in concentrates were produced annually. The possibility of extracting zinc from the ores extracted from South Crofty is being considered.

8.14.2 Markets and uses

Zinc price for cash buyers on 5th November 2012 as reported by the London Metal Exchange was 1,814 US$/tonne and fluctuations are shown in Figure 8.5 Price of zinc (US$ per tonne) November 2011 - November 2012 below.

Figure 8.5 Price of zinc (US$ per tonne) November 2011 - November 2012

Much of the world production of zinc is used in the metallic form, for example in brass, rolled zinc sheet, and as a protective coating on galvanised iron and steel. Zinc dust and some zinc compounds, such as the oxide, are widely used in the manufacture of pigments. Zinc compounds are in widespread uses for a range of applications including fungicides, preservatives, phosphors and lubricants.

8.15 Antimony

Antimony-bearing minerals include the sulphides antimonite, jamesonite and bournonite. These minerals usually occur in association with the sulphides of lead and zinc. There has been some production of antimony from cross-course veins, mostly in the Wadebridge district of north Cornwall. In North Cornwall near Portquin, narrow quartz veins, trending mostly N-S, include a variety of sulphide minerals notably lead and antimony. Treore Mine produced antimony ores from north Cornwall. There is reportedly antimony content in the mica dams produced as a result of china clay extraction in the western part of the St. Austell granite.

Antimony metal is used to harden lead, as a component of low melting point alloys, and in the production of type metal in the printing industry. There is also a range of applications for antimony compounds including use as a flame retarder for fabrics.

According to Dines (1956) the recorded output of antimony did not much exceed 300 tons in the 19th century, but records are incomplete. There is no current antimony production in Cornwall.

8.16 Gold

The Mineral Reconnaisance Programme of the British Geological survey indicates anomalous high levels of gold in Carboniferous and Devonian volcanic strata, slates and black shale in Cornwall. The levels are below economic mining grade but may be viewed as an indicator of the possibility of higher grade mineralistion elsewhere. Stratiform gold enrichment has been reported from the Wadebridge area [6].

Gold has also been found within vein deposits. The gold is associated with sulphide minerals such as pyrite, and chalcopyrite for example in the Levant Mine, near St Just and from mines in the Falmouth district. In North Cornwall near Portquin, narrow quartz veins, trending mostly N-S, include a variety of sulphide minerals and gold occurs as microscopic grains[6]. It is unlikely that this type of mineralisation by itself would be of any great economic value, although it may indicate the presence of potentially more economic orebodies of different type.

Traces of native gold have also been found in alluvial gravels. Reportedly, the river gravel at Carnon has yielded native gold. Manaccan lies on the south of the Helford River, between St Martin's and St. Anthony. Titanium, or macannanite, as it was then called, was discovered in this parish in 1791 by the Rev. William Gregor. Small quantities of gold also exists in the black sand which yields manaccanite. http://www.genuki.org.uk/big/eng/Cornwall/Manaccan/index.html.

Gold is also present in the antimony ores of north Cornwall, notably at Treore Mine. In recent years traces of gold have been found in the Middle Devonian to Lower Carboniferous rocks of east and north Cornwall and these were explored under licences granted by the Crown Estates Commissioners. Traces of gold have also been reported from Lower Devonian volcanic rocks in east Cornwall.
Gold is currently not produced in Cornwall

8.17 Lithium

Lithium is the lightest of the metals and is one of the most reactive as it has the greatest electrochemical potential. It reacts violently with water and can ignite into flame.. There are two major types of lithium deposit: a hard silicate mineral called Spodumene; and Brine Lake or Salt Pan deposits that contain Lithium Chloride. These latter deposits are currently the only economically and energetically viable source for LiIon batteries.

The St. Austell Granite hosts a considerable, although low-grade, lithium resource which is present in lithium-bearing micas containing up to 2.5% lithium metal. Goonvean Ltd micaceous residues amount to approximately 100,000 tonnes/year. Kernick Dam also holds historical residues from Goonvean pits plus others in the lithium granite area.

Some of the hydrothermal brines at depth in old mine workings contain lithium e.g. Historical reports in the United Mines area concerning the hot lode indicate that ‘the hot water issuing in great quantities at these depths is rich in lithia’.

[6] ‘Gold in Cornwall’ British Geological Survey

There is currently no lithium produced in Cornwall.

8.17.1 Lithium Supply and Markets

The main producers of Lithium minerals are Chile, the USA, Argentina, China, Australia and Russia. South America holds 75% of the known global Lithium Reserve Base. The lithium salt deposits at Salar de Atacama in Northern Chile are the biggest producer in the world, with production of about 40,000 tonnes of lithium carbonate per year. Other Producers: Western Lithium Corp (hectorite) USA, Canadian Lithium Corp (spodumene and brine) Serbia (jadarite,) and China. New exploration in Canada and USA, brines in Bolivia and Argentina.

The last and biggest untapped reserve of Lithium salt in the world is in the Salar de Uyuni salt pans of Bolivia, the remains of an ancient inland sea. Bolivia is estimated by the USGS to contain Lithium resources of 5,400,000 tonnes or nearly 50% of the global Lithium metal reserve base and an even higher percentage of the Lithium salt reserves. Another estimate has put the Bolivian resource as high as 9MT." from 'The Trouble with Lithium - Implications of Future PHEV Production for Lithium Demand.' William Tahil, Research Director, Meridian International Research

"The Greenbushes Mine in Australia and the Lac du Bonnet mine in Canada are both primarily tantalum operations. Spodumene is only a secondary resource and sales of this mineral for ceramics are a minor secondary operation at both of these mines."

8.17.2 Uses of Lithium

Rechargeable lithium batteries are fast replacing Nickel Metal Hydride cells as the preferred power in mobile phones and are used a wide range of consumer products including cameras, camcorders, electric razors, toothbrushes, calculators, medical equipment, communications equipment, instruments, portable radios and TVs, pagers and PDA's. Laptop computers almost exclusively use Lithium batteries. Lithium has the potential to achieve very high energy and power densities (up to 1000 Amp hours capacity and more). High power versions of lithium batteries can be used in traction applications in electric and hybrid vehicles as well as for standby power. Solid state chemistry can be printed on to ceramic or flexible substrates to form thin film batteries for specialist applications such as implantable medical devices, non-volatile memory backup and sensors, powering smart cards and radio frequency identification (RFID) tags.

8.18 Rare earth metals

The rare earth elements (REEs) are a group of 17 elements including Scandium (Sc, 21), yttrium (Y, 39), and the lanthanides:lanthanum (La, 57), cerium (Ce, 58), praseodymium (Pr, 59), neodymium (Nd,60), promethium (Pm, 61)samarium (Sm, 62), europium (Eu, 63), gadolineum (Gd, 64), terbium (Tb, 65), dysprosium (Dy, 66), holmium (Ho, 67), erbium (Er, 68), thulium (Tm, 69), ytterbium (Yb, 70) and lutetium (Lu, 71).

Rare earths are usually incorporated into other minerals as mere traces with far too low concentrations to be used as ores. The principal economic sources of rare earths are the minerals bastnasite, monazite, and loparite and the lateritic ion-adsorption clays. Except for one primary mine in the United States, essentially all

rare earths are produced as by-product during processing for titanium and zirconium minerals, iron minerals, or the tin mineral cassiterite.
http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/stat/

Granites from Cornwall reportedly contain rare earth elements and there are accounts of the occurrence of the mineral Agardite at Wheal Alfred, Phillack, Cornwall (Nd-rich - (La, Ca)Cu6(AsO4)3(OH)6 3H2O);
http://www.handbookofmineralogy.org/pdfs/agarditela.pdf

Rhabdophane has been found in Mine dumps of Fowey Consuls (Wheals Treasure, Fortune, Chance Polharmon and Lanescot), Tywardreath, Par Cornwall.
http://www.mindat.org/loc-1206.html

Reportedly, albitized riebeckite granites are economically interesting for Zr, Nb and REE. See "Fluorine in granitic rocks and melts: A review" J. C. Bailey
http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V5Y-4888J9P-2N&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=3977e2e4b1535553f03bf8ff265c3a00

REE's are used in glass polishing, lasers and ceramics, automotive catalytic converters, computer monitors, lighting, televisions and pharmaceuticals. Neodymium, one of the most common rare earths, is a key part of neodymium-iron-boron magnets used in hyper-efficient motors and generators. Around two tonnes of neodymium are needed for each wind turbine. Lanthanum is a major ingredient for hybrid car batteries, while terbium is used in low-energy light bulbs and cerium is used in catalytic converters. The nuclear industry and speciality alloys are other industries in which rare earth elements are used. Failure to secure long-term sources of rare earth elements (REEs) would affect the manufacturing and development of low-carbon technology, which relies on the unique properties of the 17 metals to mass-produce eco-friendly innovations such as wind turbines and low-energy lightbulbs. China has had the monopoly on the global production- reportedly 97% of global supplies, and produced 139,000 metric tons of material in 2008.
http://www.independent.co.uk/news/world/asia/concern-as-china-clamps-down-on-rare-earth-exports-1855387.html

Greenland Minerals reserves in Ilimaussaq, Greenland reportedly could change the dynamics of rare earth metal usage worldwide by hugely increasing the global supply. Studies of the site show that the Ilimaussaq reserves would comfortably meet at least 25 per cent of global rare earth demand for the next half century. The cost of extracting the rare earths will be offset by the profits from extracting uranium from the same site
http://business.timesonline.co.uk/tol/business/industry_sectors/natural_resources/article6860901.ece

8.19 Manganese

Only a little manganese was produced in Cornwall. Treburland Mine, Altarnun, recorded 470 tons in 1887 - 1890. The most important producer was Ruthers, or Ruthvose, St. Columb Major, with over 1,000 tons between 1874 and 1891. In 1880, it produced 722 tons and was briefly one of Britain's largest producers. This was the mine that William Borlase described in 1758 (Natural History of

Cornwall) as 'lately discovered near Tregoss Moor. The lode was 20 feet [6 m] wide, and so near the surface that one ton may be raised for one shilling and six-pence'

8.20 Silver

Lead ores from Cornwall may contain varying amounts of silver, ranging up to 180 oz per ton of lead metal. The silver is present as mineral inclusions in galena and as small individual concentrations of silver minerals, commonly sulphides. The silver present in lead ores has been the main source of that metal in South-West England but there has been production from copper and zinc concentrates and also from true silver ores which contain minerals such as native silver, pyrargyrite and rare silver chloride minerals such as cerargyrite. The copper-antimony sulphide mineral, tetrahedrite, also contains silver. The occurrence of silver is as for lead; in addition there is a common association with the ores of bismuth, cobalt, nickel and antimony. There are sparse records of early production of silver from Cornwall with the bulk of production occurring during the 19th century.

8.21 Molybdenite

Molybdenite is a very soft metallic mineral which can be easily confused with graphite. Molybdenum occurs as the sulphide molybdenite at several localities including the Prince of Wales mine and there was a small production from Drakewalls Mine near Callington. Also samples from from Wheal Gorland, St Day United Mines (Poldice Mines), Gwennap area, Camborne - Redruth - St Day
Niobium is a silvery coloured metal (atomic number 41) that is very resistant to corrosion and is added in small amounts to improve stainless steels
Niobium is used in the aviation industry.

Other ores with minor production included bismuth, cobalt and nickel. In the 1980s investigations by the BGS for 'strategic' minerals were concerned principally with the platinum-group elements (PGE).