

Mineral Resources
Consultative Committee

Mineral Dossier No 25

Silver

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Titles in the series

- No 1 Fluorspar
- No 2 Barium Minerals
- No 3 Fuller's Earth
- No 4 Sand and Gravel
- No 5 Tungsten
- No 6 Celestite
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PREFACE

The Mineral Resources Consultative Committee consisted of representatives of interested Government Departments, and specialist advisers. It was set up in 1967 to keep present and future requirements for minerals under review and to identify problems associated with the availability, exploitation and use of mineral resources, both inland and offshore, having regard to competing demands on land use and other relevant factors.

Widespread and increasing interest in the mineral resources of the United Kingdom led the Committee to undertake the collation of the factual information available about those minerals (other than fossil fuels) which were being worked or which might be worked in this country. The Committee produced a series of dossiers, each of which was circulated in draft to the relevant sectors of the minerals industry. They bring together in a convenient form, in respect of each of the minerals, data which had previously been scattered and not always readily available. These dossiers in updated form are now being published for general information.

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Metric units are employed throughout this document except where otherwise stated. In most cases this has necessitated the conversion of originally non-metric data. The units and conversion factors used are as follows:

millimetres (mm)	= inches \times 25.4
metres (m)	= feet \times 0.3048
kilometres (km)	= miles \times 1.609344
hectares (ha)	= acres \times 0.404686
kilogrammes (kg)	= pounds \times 0.45359237
tonnes (1,000 kg)	= long tons \times 1.01605
grams (g)	= Troy ounces \times 31.1035
gm/tonne (ppm)	= Troy ounces/long ton \times 30.614
gm/tonne (ppm)	= Troy ounces/short ton \times 34.285

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SUMMARY

Silver, a heavy, soft, white metal with exceptionally high conductivity and reflectivity, was apparently known to man as long ago as 4000 B.C. It has been used in coinage in England since Saxon times and until the beginning of the 19th century was the basis of the English monetary system. At present 90% of silver is used for industrial, that is, non-monetary, purposes, with photographic products accounting for half of that figure. World silver supply is derived from both primary and secondary sources, and during the 1970s "above-ground" supplies of silver (waste, scrap, demonetised coin, etc) accounted on average for 40% of world total requirements. About 75% of world mine production of silver is obtained as a by-product or co-product of base metal mining, from ores frequently containing less than 35 g of silver per tonne, although in argentiferous tetrahedrite ores, which are mined primarily for their silver content, grades of 860 g per tonne are not uncommon. Mexico, Canada, Peru, USA and Australia together account for 75% of Western World primary silver production, while the EEC countries together account for about 8%. The shortfall between consumption and new, "under the ground" production (mine production) of silver is made up mainly from scrap, releases from private and government stocks and demonetized coin.

Silver has been mined in Britain since the Roman era. During the period 1851-1950 over 800 tonnes were extracted, about a quarter of which was raised between 1861 and 1870. Present mine production in the UK is extremely small (as a by-product of base metal mining), but there is a large silver recovery and refining industry based on imported crude silver bullion, lead bullion, blister copper and lead and zinc concentrates, as well as scrap materials. The UK is also a major silver exporter, re-exporting large quantities of secondary silver refined in the UK. Consumption of silver for industrial uses in the UK amounted to about 622 tonnes in 1982 (20.0 million oz) as compared with 653 tonnes in 1981.

In the United Kingdom, silver in ore in the ground is the property of the Crown. Royalty on the production of silver as a byproduct of base metal mining is payable to the Crown Estate Commission, except in Cornwall and Devon where it is payable to the Duchy of Cornwall. Hallmarking legislation in England, the earliest form of consumer protection, dates from 1238 and makes it possible to date a silver object with considerable precision.

GEOCHEMISTRY AND MINERALOGY

Silver, Ag, is a white, chalcophile, metallic element in Group 1B of the Periodic Table; it is heavy, soft, extremely ductile and malleable, capable of a high degree of polish and occurs as a rare but widely-dispersed element in a variety of geological environments. It exhibits geochemical affinity with many heavier metals and chalcophile elements, occurring commonly as a sulphide or sulphosalt, but also as arsenides, halides, selenides and tellurides. Because of its atomic configuration and properties, silver is more closely associated with gold than with any other element, although economically its associations with lead and copper are more important.

Natural abundance of silver

The cosmic abundance of silver has been estimated at 0.00052 ppm and the average silver content of iron meteorites is 0.2 ppm. The crustal abundance is about 0.1 ppm. In natural waters silver may occur in a number of more or less soluble forms and colloids, the most important being various chloride complexes with sodium and potassium, soluble organic compounds and complex hydrosulphides. The average silver content of all types of fresh waters is 0.2 ppb. Spring waters (especially from mineral springs) are preferentially enriched in silver compared with river or lake waters, as apparently are acid compared with neutral or alkaline waters. Sea water normally contains between 0.15 and 2.9 ppb, abundance increasing with depth in areas of high phosphate and high organic activity. The highest concentrations in natural waters occur in the metalliferous brines of the Red Sea deeps (60 ppb average) and the brines from wells in the Salton Sea geothermal area, California (800 ppb-2ppm).

Silver is a microconstituent of practically all plants. Lichens in the Orijärvi mining district of Finland, for example, contain up to 10 ppm and some mosses growing over serpentine masses contain even more. Up to 500 ppm has been found in mushrooms. Some marine algae are reported to precipitate silver from thermal waters. The Upper Cambrian *Dictyonema* shales of Scandinavia contain more than 2 ppm Ag. The enrichment factor for silver in seaweeds as compared with sea water is about 2,500 while that in respect of some marine animals is over 22,000. Coal ashes with up to 10 ppm Ag have been reported and ash from some crude oils produced in the USA and the USSR has been found to contain up to 100 ppm.

Silver is not an essential or major constituent of any rock-forming mineral, but occurs in minor or trace amounts in a great variety of minerals. It occurs in nearly all silicates, which rarely contain more than 500 ppb, but in slightly greater quantity in albite, sodalite and other sodium rich silicates. Amphibole, biotite, garnet and chlorite have very variable silver contents, containing on average between 660 and 5,000 ppb. The behaviour of silver during magmatic differentiation is largely unknown, although there is a tendency for it to become enriched in the later magmatic fraction and to precipitate out with the sulphide minerals. Silver occurs in amounts from 50 to 100 ppb in common igneous rocks.

The behaviour of silver during weathering and its mobility and fixation in soils are strongly affected by the acidity of the environment. Silver salts are generally thought to be more soluble and mobile in an acid environment; the element is relatively immobile in soils where the pH is greater than 4. Under alkaline conditions the oxide or hydroxide may be precipitated directly or the silver may be affected by the behaviour of iron, manganese, aluminium and organic matter. Humic substances adsorb silver, leading to enrichment of the element in the A horizon of soils as well as in peats and other organic-rich materials. Silver also tends to become concentrated with gold in eluvial lateritic 'banket' deposits representing the detritus from weathered precious metal deposits. Silver is present in sediments and sedimentary rocks in very small quantities, generally less than 1 ppm, but when associated with carbonaceous matter or very fine-grained sulphides in, for example, black shales, sulphidic schists, alum shales and phosphorites, may occur in concentrations of up to 10 ppm. Some of the silver in sedimentary rocks may also be associated with potassium-rich clay minerals and hydrated iron and manganese oxides.

Data on the concentration of silver in metamorphic rocks are few but, as a chalcophile element, it probably behaves like sulphur, arsenic, antimony, lead and zinc, during regional and contact metamorphism. The silver appears to be concentrated in any copper or iron sulphides and in ferromagnesian minerals; it also tends to concentrate with arsenic in the form of sulpharsenides, notably arsenopyrite.

Variable, and often high, concentrations of silver are present in sulphide minerals, notably argentiferous galena. The silver may occur as admixed intergrowths and exsolution bodies either as native silver or as sulphide, or argentiferous sulphides may be optically and structurally homogenous, the silver substituting for such elements as copper and lead in the crystal lattice. Most of the silver formerly mined in the United Kingdom was associated with galena which rarely contained more than 0.5%. However, as much as 5% or more silver may be present in this important lead mineral in other areas, (Ag_2S has a maximum solubility in PbS of about 0.4 mol %). Some of the silver is contained in associated tetrahedrite.

Many argentiferous galenas contain microscopic intergrowths or exsolution bodies of the silver minerals acanthite, matildite or miargyrite, and extensive solid solution occurs between silver minerals and galena at higher temperatures. The presence of bismuth greatly increases the solubility of silver in galena even at low temperatures, and silver, bismuth and antimony commonly occur together in galena, so that the presence of significant amounts of antimony is often a useful guide to the discovery of highly argentiferous varieties. Another sulphide mineral, sphalerite (ZnS), which often occurs associated with galena, may contain up to 1.5% silver, while pyrite (FeS_2), invariably contains traces of the metal. Silver may substitute for copper in chalcopyrite (CuFeS_2) which may contain up to 3,300 ppm Ag. In pyrite, silver may substitute for both iron in the structure and, because it is a chalcophile element, for sulphur in the interstitial spaces. Silver may also be present in high concentrations in native elements, for example, up to 4% in native copper and up to 20% in native gold in unlimited solid solution, and in native tellurium and antimony.

Silver minerals

More than sixty silver minerals have been recognised, containing very variable amounts of the metal. Commercially the most important are as follows:—

Mineral	Formula	Silver content %	Specific Gravity
native silver	Ag	100.0	10
acanthite (argentite)	Ag ₂ S	87.0	7
proustite	Ag ₃ AsS ₃	65.4	5.6
pyrargyrite	Ag ₃ SbS ₃	59.8	5.8
polybasite	Ag ₁₆ Sb ₂ S ₁₁	75.5	6
cerargyrite	AgCl	75.0	5.5-5.6
tetrahedrite-tennantite	(Cu, Fe, Ag) ₁₂ – (Sb, As) ₄ S ₁₃	up to 30.0	4.4-5.1
stephanite	Ag ₅ SbS ₄	68.5	6.3

Native silver seldom occurs in the pure state, but usually contains variable amounts of gold, mercury or other elements. Silver and gold form a continuous series of alloys, from pure silver through aurian silver to argentine gold (electrum with more than 20% silver) and gold. Native silver has been recorded in the United Kingdom at a number of localities notably at Alva (Central Region, Scotland) and Hilderstone (Lothian, Scotland), as well as at various mines in Cornwall and Devon. Silver amalgam, also known as 'arquerite', contains up to 20% mercury and is also known to occur in some Canadian ore deposits.

Simple silver sulphide occurs as two distinct minerals, *acanthite*, $\beta\text{Ag}_2\text{S}$, the stable monoclinic form, and *argentite*, $\alpha\text{Ag}_2\text{S}$, which is cubic and unstable below 173°C; natural silver sulphide is thus always acanthite though it is commonly and erroneously referred to as argentite.

Tetrahedrite and *tennantite* are cubic-tetragonal minerals representing antimony-rich and arsenic-rich varieties respectively and exhibiting a wide range of substitution of metals. They normally contain up to 20% silver, while the name *freibergite* is used for tetrahedrites with more than 20% of the metal. The hexagonal ruby silver ores *proustite* and *pyrargyrite* form a complete solid solution series down to 300°C and in the UK occur, for example, in several parts of Cornwall. *Stephanite* is an orthorhombic mineral, rarer than other silver sulphosalts, but occurring at Wheal Ludcott in Cornwall and in many classic silver deposits in Mexico and Canada. Monoclinic *polybasite* accompanies native silver, acanthite and ruby silvers in many deposits; it occurs in Cornwall and is common in European and Mexican silver deposits. *Cerargyrite* is a soft, waxy, cubic mineral which occurs in the gossan or upper parts of silver veins, forming extremely rich but small deposits. It occurs in veins in the Newquay district of north Cornwall and, for example, in Chile, Bolivia and the USA. Other ore minerals of silver are the tellurides, *stromeyerite*, $(\text{Ag,Cu})_2\text{S}$, common in copper-rich silver deposits, for example, in Canada, and *pearceite* $(\text{Ag,Cu})_{16}\text{AsS}_{11}$, an arsenical variety of polybasite. Almost all selenides and tellurides contain some silver; *hessite*, Ag_2Te , which may contain up to 63% silver and 8% gold, and *sylvanite*, $(\text{Au,Ag})\text{Te}_4$, containing up to 13% silver and 24% gold, occur in Rumania, Chile, Mexico, Australia and the USA.

SILVER ORE DEPOSITS AND THEIR ASSOCIATIONS

Silver ore deposits occur in a wide range of sedimentary, igneous and metamorphic host rocks, usually as fracture and cavity fillings or as replacements. At one time, most deposits were regarded as being of magmatic hydrothermal origin but, in recent years, weathering and biochemical processes have come to be recognised as important in the mobilization and concentration of silver. World silver production has largely been derived from deposits where the metal occurs as a constituent of base metal ores, mainly those of copper, lead and zinc. Ore deposits exploited primarily for their silver metal content account for perhaps only 25% of all mined silver. Several classifications have been proposed for silver-bearing ore deposits but each has its imperfections due mainly to the varied and complex ways in which silver occurs. The following classification is based on work by Beunderman (1980) and emphasises the nature of the host rock which, in most cases, is a good indicator of the type of silver ore to be encountered, the silver content to be expected, and the mining and processing methods used:

Magmatic segregation Ni-Cu-Co sulphide deposits.

Classic examples of this type of ore deposit are associated with the Sudbury irruptive in Ontario, Canada, where small amounts of silver and other precious metals occur in nickel and copper ores. The irruptive is intruded as a complex ring dyke mass between a sequence of sediments occupying the centre of a complex basin and old basement rocks of Archaean and Huronian (Proterozoic) age. Several types of orebodies are present. Sulphides occur at the base of mafic norite, in quartz diorite offset dykes, along faults and in brecciated footwall rock, and as blebs, pods and disseminations in granite breccia. Dominant sulphide minerals are pyrrhotite, pentlandite and chalcopyrite with many minor and accessory minerals, including galena and hessite.

Forming a sub-group are massive Ni-Co sulphides associated with basic to ultrabasic volcanic suites rather than plutonic assemblages. The ores at Kambalda in Western Australia are an example, occurring mostly at the base of ultramafic Archaean rocks that lie between two metabasalts, and are both massive and disseminated. Primary mineralization consists of pyrrhotite – pentlandite with subordinate cobaltiferous pyrite and chalcopyrite. Supergene and gossan ores also occur. Ore deposition has been explained as the result of gravity separation after high temperature emplacement of an ultramafic crystal mush. As at Sudbury, the silver content is extremely low (figures not officially released, but thought to be approximately 10 ppm Ag per tonne of ore). Deposits of this type probably account for only about 1% of Western World primary silver production.

Vein deposits containing Ag-Bi-Ni-Co-As-(U), associated with basic igneous rocks.

An example of this type of orebody occurs in the famous Cobalt District, Ontario, Canada, where the silver-cobalt ore currently mined grades from 120 g Ag per tonne (opencast) to 685 g Ag per tonne (underground). Average run-of-mill grade is between 130 and 230 g per tonne. These are among the richest silver ores in North America and veins carrying masses of native silver weighing up to 726 kg have been exposed on the surface. Production from this once-flourishing field has now greatly declined.

The host rocks consist of Keewatin greenstones overlain by Cobalt Conglomerate (Middle Proterozoic) and intruded by a diabase sill 300 m thick. The ore occurs in steep joint-and fault-fissure veins in the conglomerate beneath the sill. The mineral assemblage is rather unusual, consisting primarily of native silver, with dyscrasite (Ag₃ Sb), argentite, tetrahedrite, stromeyerite, polybasite, stephanite, and ruby silver minerals. Arsenopyrite, bismuth, galena, pyrite, chalcopyrite, pyrrhotite and sphalerite also occur, as well as a unique group of nickel and cobalt arsenides. The ores are generally thought to be cavity fillings with minor replacement formed by low-temperature hydrothermal solutions which originated from the same source as the diabase intrusion. Similar deposits are known from Annaberg and Scheeberg in Saxony, Germany F.R., and at Gowganda, Ontario.

Epithermal¹ and telethermal² Pb-Zn-Cu-Au-Ag veins, pipes and mantos³, associated with calc-alkaline igneous suites.

At La Encantada, in northern Coahuila, Mexico, two major and several minor high grade silver-lead orebodies are mined. The host rocks form part of a major anticline of Lower Cretaceous limestones, deeply fractured and cross-cut by dykes. Numerous folds and brecciated zones of fractured limestone cemented by calcite occur in the mineralized area, as well as alteration to marble of some zones in the limestone country rock. The deposits occur in various forms, as mantos, chimneys and veins, and in tabular form along limestone-skarn (tactite) contacts. La Encantada ores are characterized by complex mineral assemblages, including abundant iron oxides. The two most important orebodies, the Prieta chimney and the 660 tabular deposit, contain, respectively, abundant hematite, cerussite, mimetite, acanthite, argentite and native silver, and abundant goethite, smithsonite, cerussite, argentite, anglesite, lead jarosite, native silver, sphalerite, hemimorphite, various copper minerals, and argentojarosite. Silver values are very variable, up to 1,000 g Ag per tonne in the Prieta chimney and 60 g per tonne in the Prieta limestone 'halo', but grades generally exceed 360 g Ag per tonne. Lead values may exceed 10%. The mineralization has been ascribed to igneous activity during the Laramide (Alpine) orogeny; an intrusion domed the overlying limestone and facilitated the introduction of hydrothermal solutions, producing the tabular orebodies on the flanks of the dome and the chimney. Lead and silver sulphides were introduced by a late mesothermal phase and were followed by a period of oxidation (weathering).

The Casapalca Ag-Pb-Zn-Cu vein system in Peru is probably of the same type with three distinct vein filling stages including a late sulphide-sulfosalt stage. It represents a fracture zone mineralized over a horizontal distance of 5 km and a vertical distance of 2,000 m during early Tertiary times. Average silver grade is about 120 g per tonne.

Tin-silver ores of the Bolivian Tin Province.

These ores, representing perhaps 1-2% of total world mine production of silver, are complex and do not fit easily into any single ore type.

1 Products of deposition from hydrothermal solutions at shallow depths and low temperatures.

2 Produced at or near the surface from ascending low temperature hydrothermal solutions in the terminal phase of their activity.

3 Flat, bedded, blanket-like replacement ore bodies, often confined within a single stratigraphic horizon.

Production of both tin and silver has come largely from vein systems within, or peripheral to, late Tertiary high-level stocks of intermediate composition in the central and southern parts of the province. Several of these stocks, including those at Potosi and Oruro, contain stockwork, disseminated and breccia-filling mineralization and other characteristics normally typical of porphyry copper deposits. The Potosi district is famous as having been the richest silver mining area in history. It is said to have produced at least 30,000 tonnes of silver since its discovery in 1544. The Cerro Rico granitic stock has intruded anticlinal Ordovician sediments and overlying Upper Tertiary tuffs and volcanic conglomerate. The region in general contains widespread Tertiary calc-alkaline flows and pyroclastics. Many steeply-dipping veins, up to 4 m in width and converging at depth, cut both volcanics and sediments. The xenothermal¹ silver-rich ores are late-stage, post-dating both stock alteration and stockwork tin mineralization. The oxidized ores were very rich, many yielding over 3,400 g Ag per tonne, and consist of cerargyrite, native silver, some argentite and ruby silver. Primary ores average 340 g Ag per tonne with 1-4% Sn and consist of cassiterite, stannite, base metal sulphides, argentiferous tetrahedrite, ruby silver, matildite and jamesonite.

Lower temperature silver has long been mined from other silver deposits in the central tin province of Bolivia, such as Oruro, Poopo and Colquechaca. At Oruro, stocks and flows of probable late Tertiary age cut Devonian mudstones, and hydrothermal intrusion breccias cut by tin-silver veins are common. Again, the silver was originally extracted from superficial ores containing freibergite, native silver, pyrargyrite, miargyrite, argentite and proustite but today these high-grade meso-to epithermal ores are depleted and silver is a by-product of the extraction of tin, bismuth and lead ores. In the northern part of the Bolivian tin-tungsten province, silver associated with Cu-Zn-Pb-Ni-Co-Se occurs in smaller-scale deposits related to a series of small batholiths some of which are of pre-Middle Jurassic age. Large silver concentrations occur at Colquiri and at Matilde.

High-level, acid to intermediate intrusive porphyry copper deposits with molybdenum or gold, genetically associated with calc-alkaline (felsic) igneous suites.

Porphyry copper deposits are very large, relatively low-grade, occurrences of disseminated grains and veinlets in porphyry stocks and surrounding volcanics and schists, normally mined by open-pit methods on a very large scale. Silver is present in extremely small amounts, often less than 1 ppm, but because of the scale of the operations significant amounts are produced. Recovery as a by-product from Circum-Pacific Belt copper porphyries represents 10% of total Western World silver production. Examples of this type of deposit include Bingham Canyon (USA), Panguna (Bougainville, Papua New Guinea), and Highland Valley (Canada). They are closely associated with stocklike intrusions of monzonite, quartz monzonite or diorite porphyry. Primary mineralogy is simple and generally similar for most deposits, and is accompanied by hydrothermal alteration of the host rocks. Pyrite, chalcopyrite, chalcocite, covellite and bornite occur with minor sphalerite, molybdenite, and argentiferous galena.

¹Formed at high temperatures but at shallow to moderate depth.

At Bingham Canyon, some 98,500 tonnes of ore containing about 16 g Ag per tonne are mined each day. Panguna Mine produces about 30 M tonnes of ore a year containing about 2 ppm Ag. The copper concentrate produced contains 72 ppm Ag. The Highland Valley mining district of British Columbia, Canada, contains several large porphyry copper deposits associated with a large, zoned, felsic batholith cut by rhyolite porphyry dykes and irregular intrusions. The average copper content is about 0.3% with a very variable silver content, generally around 4.5 ppm at Phoenix copper mine, 7.4 ppm at Granduc copper mine and less elsewhere.

Massive, mixed base metal sulphide deposits in acid to intermediate volcanic piles, belonging to calc-alkaline igneous suites.

At the Brunswick No. 12 mine, Canada, for example, orebodies contain massive, fine grained pyrite with varying amounts of chalcopyrite, sphalerite and galena. The ore averages 8% Zn, 3.5% Pb and 0.4% Cu, and about 90 g Ag per tonne. Strata-bound deposits of this type occur within sequences dominated by felsic volcanics such as the Kuroko ores of Japan where chalcopyrite and pyrite occur throughout with superficial enrichment in galena and sphalerite. These contain significant silver values largely in galena or minor tetrahedrite-tennantite. Terrains of clearly established calc-alkaline type containing massive sulphide deposits occur around the Pacific margin (Fiji, Japan, North American Cordillera) and in eastern Australia and the Urals, USSR. Such ore deposits constitute approximately 13% of world primary silver production.

It has been suggested that, based on differing metal ratios, 'volcanic' massive sulphide deposits and their host rocks may generally be divided into three groups as follows:

- i Pyrite-sphalerite-galena-chalcopyrite, with minor tetrahedrite, possibly pyrrhotite, bornite, etc, with both silver and gold recoverable eg Roseberry, Tasmania; Kosaka and Shakanai, Japan; and Buchans, Canada; all with a grade of about 100 g Ag per tonne.
- ii Pyrite-pyrrhotite-sphalerite-chalcopyrite, and possible arsenopyrite, magnetite, etc, with both silver and gold recoverable eg Timmins and Noranda districts, Canada; from 25 to 80 g Ag per tonne.
- iii Pyrite-chalcopyrite, and possibly pyrrhotite, sphalerite, marcasite, etc, with recoverable gold, but little or no silver eg Cyprus mines; Rio Tinto, Tharsis, Spain.

However a few mines, such as Bawdwin in Burma, where silver is produced from a predominantly lead-rich ore with subordinate zinc and copper, do not fit easily into any of these categories.

'Porphyry silver deposits'.

Sometimes termed the 'Waterloo'-type, after the deposit of the same name in California. These bulk tonnage silver deposits are generally large, low grade, epithermal stockworks hosted by pyroclastic or volcanoclastic rocks, or the fluvial and lacustrine sediments frequently intercalated with volcanic piles. Where the host rocks are not volcanic, the mineralization is still thought to be directly related to associated volcanic processes. They are mainly Mesozoic volcanogenic accumulations formed in syntectonic island arc environments or Cenozoic volcanogenic deposits developed in

late tectonic extensional back arc environments. Various silver-bearing primary or secondary minerals are present, usually associated with siliceous alteration zones and often with manganese or iron. Pyrite is ubiquitous, and barytes and fluorspar are usually present. Primary mineralization is normally finely disseminated, permeability or brecciation of the host rock is often critical, and the ores are frequently refractory. Mineralization is stratiform, manto-like, tabular or lensoid and a typical deposit would be 18 M tonnes in size, grading about 93 g Ag per tonne ore, with or without by-product copper, lead, zinc or gold.

This type of silver deposit has not received much recognition until recently, when several mining projects based on very large, low grade silver ores came into operation. At the present time, porphyry silver deposits account for perhaps only 2% of total silver production, but their potential would appear to be far greater. There is still some confusion over whether the term "porphyry silver" should be restricted to those deposits intimately associated with acid volcanics, such as the De Lamar deposits in the USA, or whether other large, low grade, stratiform, disseminated ores such as those of Real de Angeles in Mexico should be included. The De Lamar mine is developed on the first porphyry type silver ore body to be brought into production in North or South America, and is designed to produce 77,000 kg (2.5 M oz) of silver annually, making it the third largest silver mine in the USA. Silver mineralization, in common with that at Round Mountain and Creede (Colorado), is located within a well-defined caldera structure. The oldest rocks, comprising a granodiorite pluton of late Cretaceous to early Tertiary age, are overlain by Miocene basalt flows, which in turn are covered by a sequence of massive quartz latite flows, rhyolite ash-flow tuffs and rhyolite flows, also of Miocene age. The most heavily mineralized rocks are found just below two major low-angle faults and ore-grade mineralization occurs over a 30.5 m thickness relatively close to the surface. Alteration of the host rock includes silicification and minor development of clays, alunite and sericite. The principal ore mineral, about four-fifths of the total at De Lamar, is naumannite, Ag_2Se , occurring together with argentite, native silver, cerargyrite and argentojarosite. These are very finely disseminated through quartz veins and silicified rhyolitic ash flow tuff. A dual syngenetic-epigenetic hot spring environment has been proposed for the De Lamar mineralization. Ore reserves are approximately 10 M tonnes with 78-156 g Ag per tonne, plus ancillary gold. The relatively iron- and manganese-free ore is amenable to cyanidation and the silver-gold concentrate is partially refined on site.

Real de Angeles, between Zacatecas and San Luis Potosi in Mexico, is the world's largest openpit silver mine, producing 218,000 kg (7 M oz) of silver a year contained in lead concentrates. It is a stratiform deposit and is classed as a 'porphyry silver' because of the large, low grade, disseminated nature of the silver mineralization, rather than a 'Waterloo' type, since there does not appear to be any close volcanic association. Some 58 M tonnes of lead-zinc-silver ore occur in bands, stringers and disseminations in a folded sequence of slightly limey Upper Cretaceous sandstones, siltstones and greywackes. Argentiferous galena, sphalerite, pyrite, arsenopyrite and tetrahedrite, are present, with the galena and tetrahedrite containing between 73 and 103 g Ag per tonne. There are no dominant alteration minerals, only minor calcite and chlorite, but slumping and brecciation are common. No intrusive rocks are known in the vicinity. A gossan about 5-7 m thick covers the deposit. Both syngenetic (Cretaceous) and epigenetic (Tertiary) origins have been

proposed for the mineralization. A 60% lead flotation concentrate is produced containing more than 4,000 g Ag per tonne; a cadmium-rich 50% zinc concentrate is also produced.

Vein deposits of silver with Pb-Zn-Cu in sedimentary piles, apparently mostly unrelated to igneous activity.

These account for perhaps 8% of primary silver production. The best known example is the major silver producing belt of the Coeur d'Alene mining district, northern Idaho, USA. In the years since mining began in the early 1880s in this district more than £1.7 billion worth of silver, lead, zinc, copper and gold has been produced. Over the 96 years to 1979, the district produced about 28,770 tonnes (925 M oz) of silver. The Coeur d'Alene district is at the intersection of a major north-south anticline and a major WNW fault line. Ore occurs in a series of steeply dipping replacement veins of relatively simple mineralogy, although six periods of mineralization have been distinguished varying in age from Precambrian to Tertiary. The most productive lead-zinc and tetrahedrite-bearing veins are thought to be Cretaceous in age. The host rocks are highly folded and sheared Precambrian quartzites and argillites. Strong structural and stratigraphic controls are evident. Vein widths at, for example, Sunshine mine vary considerably but generally average between 0.6 and 1.5 m. The principal ore mineral is argentiferous tetrahedrite (freibergite), occurring as blebs, 'spider-web' fracture fillings and narrow veinlets replacing a gangue of massive siderite and minor quartz. Chalcopyrite, galena, pyrite and arsenopyrite are also common and there is negligible variation or zoning laterally or vertically. The ore at Sunshine contains up to 1 kg Ag per tonne, although the ores of the district generally grade 65 to 300 g Ag per tonne, 3 to 12% Pb and 3 to 6% Zn. Milling produces a high-grade tetrahedrite concentrate containing about 90% of the silver and a low-grade pyrite concentrate containing 6-8% of the silver. The tetrahedrite concentrate contains over 40,000 g Ag per tonne, 25% Cu, 18% Sb and 4% Pb. Other examples of this ore type include the Bunker Hill deposit (75 ppm Ag average) from the same area of Idaho, and Keno Hill-Galena Hill (1,200 ppm Ag) in the Yukon, Canada, both of which ceased production in 1982.

Massive sulphide deposits in clastic sedimentary sequences, containing essentially Pb-Zn-Ag, but sometimes also Cu and Au.

At Mount Isa, perhaps the most perfectly stratiform lead-silver-zinc-copper deposit known, valuable sulphides occur in two types of ore bodies in Middle Proterozoic sediments. Those carrying Pb-Zn-Ag minerals are well-bedded dolomitic siltstones and shales in which there are distinct concordant layers of galena, sphalerite and pyrite. Both sediments and ores have been metamorphosed and deformed under what is generally considered to be low greenschist facies conditions. Tuff marker beds are present. Other minerals include pyrrhotite, freibergite, tetrahedrite, minor arsenopyrite, chalcopyrite, and marcasite, the mineralization being associated with fine-grained framboidal pyrite and blue-green algae microfossils. Most of the silver in the Mount Isa ores occurs as freibergite. The primary sulphide ore contains 150 g Ag per tonne with 6.4% Pb and 6.5% Zn; secondary carbonate, ore contains about 62 g Ag per tonne with 5.5% Pb.

There are a number of other extremely large stratiform Pb-Zn-Ag deposits of Middle Proterozoic age in Australia, including the unmetamorphosed zinc-rich McArthur (H.Y.C.) deposit, the low-grade metamorphosed Hilton deposit, similar to Mount Isa, and the highly metamorphosed Broken Hill deposit. Together with similar, famous orefields in other parts of the world, such as Sullivan in Canada and Rammelsberg in the Federal Republic of Germany, these very large deposits of volcano-sedimentary association are often termed 'McArthur type' ores.

The McArthur, or H.Y.C. deposit, consists of a series of mineralised tuffaceous shale orebodies with very fine-grained ore that has presented milling problems and hindered commercial exploitation. The deposit occurs near the edge of a fault-bounded trough containing a sequence over 5 km thick of Middle Proterozoic dolomites, shales, siltstones and minor tuffites. Available information points to a syngenetic-early diagenetic formation of the sulphide bands. Sea-floor precipitation (exhalative-sedimentary mineralization) is strongly implied by the perfectly conformable nature and a number of soft-sediment structures. The deposit is estimated to contain 200 M tonnes of ore grading 45 g Ag per tonne, 10% Zn, 4% Pb and 0.2% Cu. The main sulphides are pyrite, sphalerite and galena, with minor chalcopyrite, arsenopyrite, marcasite, chalcocite and covellite. Silver grades are proportional to lead grades, the highest recorded value being 120 g Ag per tonne.

At Rammelsberg, where base metals have been mined continuously since the Bronze Age, three stratiform orebodies occur in Middle Devonian sediments with tuff horizons. Finely interbanded sulphides and slates comprise the ore which exhibits some vertical metal zoning. The ore minerals include pyrite, chalcopyrite, sphalerite, and galena: average ore grades are 12-13% Zn, 6-7% Pb, 0.5-0.6% Cu and 100 g Ag per tonne. Up to 120 g Ag per tonne is present in the high-grade ore.

Pb-Zn-Ag ore at the Sullivan mine, British Columbia, Canada, occurs as a lens of banded and massive sulphide in Upper Proterozoic sediments which have been regionally metamorphosed to greenschists facies. The ore consists of argentiferous galena and sphalerite, with pyrite dominant in an upper ore shoot and pyrrotite dominant in the lower. Currently mined ore grades average 4.2% Pb and 4.5% Zn with 48 to 55 g Ag per tonne. The Sullivan deposit has a number of features not characteristic of the Australian stratiform examples cited above, in particular, a relatively high tin content.

Massive sulphide deposits (mainly Pb-Zn) in carbonate suites.

These 'Mississippi Valley'-type deposits generally have the following features: shallow-water carbonate host rocks; dolomitization; control by local structures of sedimentary, tectonic and dissolution origin; occurrence of deposits on the flanks or above major positive features (usually domal structures); solutional collapse breccias; ore occurs as open space fillings, disseminated replacements or less commonly in veins; most deposits are of relatively low grade; and the principal ore mineralogy is relatively simple. The deposits are usually fairly distinct from any obvious igneous activity.

The Pine Point ore field, North West Territories, Canada, consists of about fifty orebodies scattered over an area of 1,000 km² in a Middle Devonian carbonate barrier reef complex. Since production began in 1964, the deposits have yielded more than 50 M tonnes of ore averaging 9%

combined lead and zinc and containing significant amounts of by-product silver. The geological setting is classic and has been used to define a widely accepted model for the genesis of carbonate-hosted lead-zinc deposits of the Mississippi Valley type. Middle Devonian strata overlie a sequence of Lower Palaeozoic carbonate and clastic sediments up to 100 m thick that in turn lie on the Precambrian basement. They host all the known ore deposits which occur in two rather narrow parallel belts or 'reefs' and which in turn are parallel to facies trends. Some ore bodies are prismatic in shape with restricted horizontal extent, while others are tabular and restricted vertically.

All the processes, including sulphide mineralization, that have affected the Pine Point barrier complex appear to be diagenetic. Dolomitization and karstification are major aspects of carbonate diagenesis and with collapse brecciation were of great importance in the preparation of the sulphide-hosting structures. All the ore bodies occur in dolostones. Major solution features appear to control sulphide distribution. The metal content of the ore bodies ranges from about 3 to 20.5% combined lead and zinc, and iron is locally abundant. A district-wide pattern of major metal zoning can be demonstrated. The ore bodies are composed almost exclusively of sphalerite, galena, pyrite and marcasite with minor amounts of pyrrhotite.

The basinal model for the development of these deposits includes the concept of an original source 'bed' from which metals were extracted (compacting shales at Pine Point) prior to concentration as sulphides in a suitable sedimentary trap. Sulphur may have been derived from associated evaporites. It has also been proposed that metal concentration occurred during the weathering cycle that created the karstic porosity which hosts much of Mississippi Valley type ore. At Pine Point it appears that sulphides were deposited in karstic solution structures, following subaerial exposure, by highly saline brines at temperatures of 50°C to 100°C, the ultimate source of the metals remaining controversial.

Stratiform Mississippi Valley-type ore deposits in south-east Missouri, form one of the major metal provinces in the USA. The district ranks first in national lead production and fifth in the production of silver and is a classic example of the production of significant quantities of by-product silver where the original silver content of the ore is very low. In 1979 some 68,000 kg (2,200,000 oz) of silver were recovered. Two mineralized belts occur in the area, the 'Old Lead Belt', now largely worked out, and the 'New Lead Belt' or 'Viburnum Trend' where ores in the barrier reef-like Upper Cambrian Bonnetterre dolomite, 61-137 m thick, are now extensively exploited. The Precambrian rhyolite and granite basement was deeply eroded in the Viburnum area to form a rugged topography, and Upper Cambrian Lamotte sandstone filled in the irregularities; a number of peaks stood as islands during deposition of the overlying Bonnetterre Formation. The orebodies are irregular masses of disseminated sulphides, principally galena, with smaller amounts of sphalerite and copper sulphides, under about 300 m of overburden. Stromatolites and reef structures are much in evidence and the deposits are thought to be epigenetic in character, the mineralizing solutions being concentrated metal-bearing brines from adjacent basins.

Minor silver as a by-product from stratiform massive sulphide deposits in continental clastic host rocks.

These include a) Red-bed, sandstone-type deposits and b) shale (Kupferschiefer)-type deposits. There appear to be transitions from the sandstone or red-bed type towards Kupferschiefer on the one hand and volcano-sedimentary deposits on the other.

a. Red-bed ores are usually characterized by the low chemical and/or mechanical resistance of the economic minerals which appear to have been chemically precipitated between the clastic particles of the sandstones. There are three basic models for the genesis of these deposits; a syngenetic model where the deposits are considered as synchronous with the host sediment, the metals originating from continental weathering of the catchment area; a diagenetic model based on the concepts of early fluid migration related to sediment compaction and diagenesis, with the sedimentary pile or even the ore-bearing bed itself being the metals sources; and an epigenetic model where there is no well-defined time relationship between host rock sedimentary history and metal concentration, metalliferous solutions having been introduced via permeable horizons long after lithification.

Numerous copper deposits with associated minor silver occur in red sandstone strata of late Palaeozoic or early Mesozoic age in, for example, the southwestern USA, eastern Canada, Siberia, and Bolivia. Few of these deposits, however, are being actively mined today, for example, the deposits at Silver Reef, Utah, (where silver values exceed those of copper). In Europe, a medium-sized base metal operation produces lead, zinc and by-product silver from an arenaceous red-bed deposit in a subsiding Triassic basin on the southeastern border of a stable cratonic Hercynian block, the Massif Central, France. At Largentière, mineralization originated between periods of mechanical sedimentation and appears to have resulted from phreatic circulation involving chemical precipitation. Mineralized horizons are from 0.5 to 3 m thick and silver values vary from 44-150 g per tonne. The ore contains 2-8% Pb and up to 5% Zn.

Laisvall, a Swedish mine about 50 km south of the Arctic Circle at the eastern foothills of the Caledonian mountain chain, processes 4,200 tonnes a day of lead-zinc-silver ore to produce some 9,520 kg of silver a year from a stratabound and stratiform deposit, the ore being disseminated through a gently dipping sandstone sequence. Galena, and to a lesser extent, sphalerite, form a cement around siliceous sandstone grains in two thin Precambrian-Cambrian sandstones above a stable Proterozoic crystalline basement. The sandstones were deposited at the shallow, tidal margin of a marine environment. They are overlain by nappe slices overthrust during the Caledonian orogeny. Ore zones lie nearly flat and the deposit is 5 km long by 2 km wide, with a maximum thickness of 24 m. The three major ore zones composing the Laisvall deposit contain an estimated 32 million tonnes of ore with 4.3% Pb, 0.7% Zn and 10 g Ag per tonne.

b. The Kupferschiefer of the Central European marine Upper Permian is a horizontally persistent sedimentary layer only about half a metre in thickness extending over an area of at least 600,000 km², from England, through the Netherlands and northern Germany to Poland. Metal concentrations, mainly copper, lead and zinc, occur in this layer and in the immediately adjacent beds, but rarely in economic quantity. In some

areas, however, Kupferschiefer shales contain significant quantities of silver, for example an average of 60 ppm in Poland, where they have been mined since 1150 A.D. The Kupferschiefer is a fine-grained, organically rich, finely laminated, clayey marl or marlstone of a euxinic sapropelic facies deposited in a shallow sea. The different assemblages of sulphide minerals include a galena-sphalerite type with chalcopyrite and tennantite. Sulphides are generally aligned with the fine bedding as granules, lenticles and lenses, and are zoned horizontally. Analysis of the German Kupferschiefer has revealed silver contents varying between 9 and 191 g per tonne, highest concentrations occurring where lead-zinc values are high. Mineralization is thought to be syngenetic and diagenetic with precipitation by H₂S released during the decomposition of organic matter and the metabolism of bacteria. The metals may have been introduced into the Permian sea by Sabkha-type processes or, less likely, from submarine exhalative sources, hot springs, heated mineralized groundwater, or volcanic fluids.

The Copperbelt which straddles the Zambian-Zaire border, one of the great metallogenic provinces in the world, produces large amounts of copper, cobalt, zinc, lead and silver from syngenetic disseminated ores in clastic sediments. Zambia produces over 31,000 kg a year (1 million oz), and Zaire about 62,000 kg a year of by-product silver. The ore consists of very persistent and uniform disseminated specks, blebs and veinlets of sulphides in the sandstones, shales and dolomites of a late Precambrian folded sequence lying unconformably on older Precambrian basement rocks. Chalcocite, bornite, chalcopyrite and pyrite are predominant. Metamorphism has affected the sediments, and secondary secretion veins and coarsely crystalline sulphides occur in some areas. The deposits are generally interpreted as syngenetic and typical of continental shelf types along a rugged coastline undergoing submergence. The importance of both gypsum or anhydrite and sulphate-reducing bacteria is now widely recognized. Metals are thought to have been transported into the marine waters and concentrated via bacteriochemical processes in favourably confined basins under anaerobic conditions which prevailed intermittently during sedimentation.

Placer deposits

Placer deposits are gravels or sands derived from the weathering and erosion of solid rocks that contain such valuable minerals as gold (and associated silver), platinum and uranium. Many younger placer deposits are unconsolidated or semi-consolidated stream deposits, for example, in the Sierra Nevada of California, the Yukon River in the Yukon and Alaska, in Siberia, and in the Andes of Bolivia, Peru, Ecuador and Colombia. Ancient placers, now conglomerates and often termed 'banket', occur in the Witwatersrand District, South Africa, Tarkwa in Ghana, and in the Bahia area of Brazil. Silver from placer deposits may account for about 2% of world primary silver production. Most of the silver recovered in South Africa is contained in the gold bullion produced by gold mines in the Transvaal and Orange Free State: some 8-9% silver is present in the ore. The ratio of silver to gold content varies considerably, averaging about 1:10, but may be much higher, for example, in the oxidized Bourkes Luck reef which contains almost equal amounts of silver and gold. Apart from electrum and native silver, many other silver-bearing sulphides occur in the conglomerates, for example, galena and proustite. In the United Kingdom, gold placers that may contain some silver are known from the Mawddach Valley, Gwynedd, North Wales, and from the Helmsdale

Valley, Highland Region, Scotland. In the latter area alluvium and fluvioglacial detritus infills a glacially overdeepened section of the valley, the concentration of gold in the alluvium being about 0.1 ppm. Granite veins associated with a Caledonian injection complex are the primary source. Nuggets of gold from Kildonan, (Helmsdale), contain 80% gold and 20% silver, and from Suisgill 81.5% gold and 18.5% silver.

RESOURCES AND SUPPLY

Resources of silver include deposits in the ground and on the sea bed, stockpiles of previously untreated or untreatable ore and metal in secondary sources, eg scrap. Resources of primary silver include all those deposits which are economically workable or are likely to become so within a reasonable period of time, including those the presence of which can be postulated only on existing geological evidence. Those resources that are currently economic are termed economic resources (reserves). Resources of secondary silver include some tailings or waste from previous mining operations; various forms of wastes and residues from smelting and refining plants; and scrap in both solid and liquid form. Waste, scrap and residues are a major source of silver. More than a quarter of Western World silver refinery production in the past five years has originated in photographic materials, plating solutions, silverware, jewellery, batteries, coins and electronic scrap. Silver primary resource data are summarised in Table I.

Table 1 World primary silver resources

	<i>Reserves*</i>	<i>Other unspecified Resources</i>	<i>Total</i>
USA	46,970	130,640	177,610
Canada	49,770	52,880	102,650
Mexico	32,970	83,980	116,950
Other North America	2,800	930	3,730
Peru	18,970	37,330	56,300
Other South America	930	18,040	18,970
USSR	49,770	167,960	217,730
Other Europe	13,060	3,110	16,170
Africa	4,670	4,670	9,340
Japan	620	2,330	2,950
Other Asia	310	3,110	3,420
Australia	31,730	10,860	42,590
Other Oceania	160	1,400	1,560
World total	252,720	517,260	769,980

Source: US Bureau of Mines, Mineral Facts and Problems 1980. Washington, US Government Printing Office, 1981.

*Reserve base: the in-place demonstrated (measured and indicated) resource currently seen to be useable (see US Geol. Survey Circular 831; 1980).

Primary Resources

World

About two-thirds of the world's primary resources of silver are contained in base metal deposits from which silver is recoverable as a by- or co-product. On the basis of present knowledge, just over half are located in North America. The USSR accounts for 28%, Africa 12%, Australia 6%, South America 3%, Europe (exclusive of the USSR) 2% and Asia about 1% (Table 1). The European Economic Community has about 1% of known resources and a slightly greater proportion of economic resources (reserves). However, account must be taken of the varying effort which has been applied to base metal exploration in different parts of the world so that resource estimates are more an expression of the existing state of knowledge and foreseeable demand than an accurate indication of the ultimate availability of mineral materials in the earth's crust. The apparent low percentage share of South America, for example, reflects the low level of exploration activity and funding which has until recently, prevailed in that continent. Similarly, despite very diverse sources of supply 80% of world total primary silver resources are credited to only four countries: the USSR, USA, Mexico and Canada.

Two-thirds of total world primary silver reserves and resources are contained in base metal deposits, and their future evaluation will continue to depend largely on the accuracy of these co-product estimations. The status of silver as a by- or co- product, which has a critical importance for supply, depends on a number of factors, not least the grades and values of the other mineral products recovered. For example, in a large low-grade porphyry copper deposit grading 0.8% Cu and 1 ppm Ag, silver is very clearly a by-product. On the other hand, the silver in many volcano-sedimentary massive sulphide deposits, considered as a by-product when the price of silver was £1 an ounce, became a co-product when its price increased to £5 an ounce. During the 1979-80 silver price 'high' of \$49 an ounce, many more mines could claim that silver was their main product. More importantly, under these conditions the ratio of production cost to price shifts radically in favour of the more marginal deposits and hence may, if only theoretically bring previously sub-economic ore into the reserve base. Production of silver can be equally affected by low prices and cutbacks in the demand for its co-products. For example, in early 1982 the depressed copper market resulted in significant cutbacks at silver-producing copper mines in the USA, Canada and the Philippines, which, together with the closure of the Bunker Hill mine and plant in Idaho, significantly reduced mine production of silver.

In Western Europe *Sweden* stands out as a major mine producer of silver (Table 15), mainly from mixed base metal ore deposits, and economic resources are often maintained at twenty times or more the actual milling rate. Laisvall has recoverable base metal ore reserves of at least 32 M tonnes grading 10 g Ag per tonne, and rich deposits such as the Pb-Zn-Cu ore at Garpenberg (130-178 g Ag per tonne) contain over 6 M tonnes. New ore bodies have recently been discovered which substantially increase the reserves, (for example, the deposit at Dammsjo with 200 g Ag per tonne). In addition, Sweden has some of the most advanced flotation concentrators in the world and recoveries from the often complex ores are excellent.

In *Yugoslavia*, some 150 tonnes of silver are produced annually, again largely as a by-product of the mining of domestic copper, lead and zinc ores. Recent exploration, discoveries and development have meant that reserves appear to be considerable, for example, at Mount Kopaonik. The Treпча mine is probably the biggest producer of silver in Europe, as it has the capacity to produce 258 kg (8,320 oz) Ag a day. *Finland* produces about 44 tonnes of silver a year from the processing of domestically-mined and imported base metal concentrates. No separate figures are available, but mining may contribute about two-thirds of the total. However, reserves are apparently depleted and despite active exploration in recent years little has been added.

No silver mine production is recorded for *Norway* but silver is extracted during refining of Norwegian-mined base metal concentrates elsewhere, for example, in the Federal Republic of Germany. At least one deposit, Killingdal, near Trondheim, though small, is rich in silver.

European Economic Community

No primarily silver ore deposits are known within the Community, but substantial quantities of silver are obtained as a by-product of base metal mining and processing. Many lead and zinc deposits have been mined in various parts of the Community over several centuries, yielding perhaps 35 M tonnes of metals, and most produced by-product silver. Generally these old deposits have been exhausted but substantial quantities of unmined ore remain in some, either because mining became uneconomic at depth, or because the remaining ore was not amenable to treatment with the technology then available. Of the deposits that are still mined, some have known reserves sufficient to maintain production for many years with further investigation likely to prove additional reserves. In the last twenty years or so substantial reserves of lead and zinc have been discovered at Tynagh, Silvermines and Navan in *Ireland*, Les Farges and Saint Salvy in *France*, Salafossa and Masua in *Italy* and Black Angel in *Greenland*. (Greenland is no longer a full member of the EEC but for statistical purposes its production is still (in early 1983) considered to be part of EEC (Danish) production.

Spain produces about 170 tonnes of silver a year as a by-product of lead, zinc, and pyrite mining. Production was greatly increased from 1974 to 1980 with the opening of new mines at Aznalcollar, Aipsa and Rubiales. Major silver producers are Rio Tinto Minera SA at the Cerro Colorado Cu-Fe-Au-Ag mine, Huelva, (77 kg/2,500 oz Ag a day) and Peñarroya-Espana SA at their Pb-Zn-Ag Cartagena mines, Murcia. Recently, exploration in various districts, including the famous old silver mining area of Guadalajara, has been active and expansion or development has increased both output and reserves at mines such as Cerro Colorado, Aznalcollar, and Sotiel. About 50 tonnes of silver are produced annually in *Greece*, largely as a by-product of lead, zinc and pyrite mining. The famous argentiferous deposits at Lavrion are now mostly worked out. However, the Chalkidiki area contains argentiferous base metal deposits (for example, the Kassandra mines) and the Noechorion deposit contains more than 15 M tonnes of 1.1% Cu, 2-3 g Au per tonne and 4-5 g Ag per tonne. There are many base metal deposits around the Aegean Sea and significant reserves are known at Kirki (Pb-Zn-Ag), Milos (Ba-Ag) and at Olympias mine (Pb-Zn-As-Cu-Ag-Au) where reserves amount to 10 Mt averaging 103 g Ag per tonne. Recent exploration in Greece has been intense and reserves of base metals are being revised, although no estimate for silver is available.

The production of silver-bearing base metal concentrates for most EEC countries is shown in Table 2. At some operations the silver contents of ore and concentrate are not always reported. Total western European primary silver production amounted to about 800 tonnes in 1980 of which EEC countries, as then constituted, contributed about 190 tonnes (242 with Greek production included). Spain contributed a further 177 tonnes and Portugal 9 tonnes. Industrial silver consumption in the EEC was about 3,500 tonnes in 1980 excluding Greece and Spain. An EEC report devoted to lead and zinc suggested, in 1979, that about 3,000 tonnes of silver were recoverable, but included only major operating mines in the EEC from which data were available. The EEC will almost certainly continue to rely heavily on reclamation from secondary sources and on outside sources for its supply of primary silver. EEC industrial silver consumption is about 30% of Western World consumption, but EEC mine production is only about 3.5% of Western World primary production.

United Kingdom

Deposits containing silver occur in many parts of the United Kingdom (Fig 1) in host rocks of varying geological age. In almost all cases the silver occurs as argentiferous galena in lead and zinc deposits, although a little has been mined from mineralogically more complex deposits, for example, at Alva (Ag-Ba-Co-Cu), Hilderston (Ni-Pb-Ag-Co) and Stronchullin (Pb-Ag-Au-Cu) in Scotland and in the south-west of England where silver was also produced not only from argentiferous galena but as a by-product of copper and tin mining, eg Levant (Cu-Sn-As-Ag-Au) and Wheal Dolcoath (Cu-Sn-As-Zn-Ag-Co-Ni-Bi). Silver is currently recovered from smelted copper-zinc concentrates at Wheal Jane (Sn-Fe-Cu-Zn-Pb-Ag-As). As the details of the ore genesis, mining history and resources are rarely specific to silver, the majority of these deposits have been or will be discussed in more detail in other reports in this series, for example, Mineral Dossiers No. 14: Gold, No. 9: Tin, and the dossiers on Copper and Lead and Zinc (in preparation).

Information needed to build up a picture of domestic silver resources is generally lacking. Though much geochemical exploration has been carried out in the last few years, including work sponsored by the Department of Industry for the Mineral Reconnaissance Programme, silver has not been tested for on a routine basis. It is extremely mobile in the weathering environment, is not a primary constituent of UK ores, and is thus not a good 'indicator' element. For the same reasons, silver does not appear in the series of Regional Geochemical Atlases being prepared by the Institute of Geological Sciences. Few significant levels of silver have been found during regional mineral reconnaissance programmes, except perhaps at Aberfeldy, Scotland, where up to 25 ppm Ag was detected in shallow overburden over sulphide-rich carbonate rocks, and a 4.3 m true width intersection in stratabound zinc-lead ore assayed 47 ppm Ag.

SOUTH-WEST ENGLAND

The south-west England mining field is mainly developed in Palaeozoic slaty shales and mudstones with minor silt and sandstone bands, locally known as 'killas'. These rocks are mostly of Devonian age, but the mineralized area extends into some areas of Carboniferous (Culm) strata which contain contemporaneous lava and tuff beds and pene-contemporaneous basic sills, dykes and bosses in their lower part. In the east, around Torquay and Exeter, the Devonian and Carboniferous rocks

Table 2 Selected EEC mining operations with silver-bearing base metal concentrate production

<i>Countries with 1980 Ag production (tonnes)</i>	<i>Company</i>	<i>Mine location or name</i>	<i>Silver content of concentrates, where known (g Ag per tonne)</i>	<i>Ore reserves/grades (million tonnes)</i>	<i>Daily ore capacity</i>	<i>Remarks</i>	
FRANCE 73.8	Peñarroya	Saint Salvy	Ag in mixed Pb-Ag-Zn conc: 516 g/t	4.5 at 9% Zn, 0.5% Pb, 80 g/t Ag	1,000	< 200 g/t Ag in ore (now closed)	
		Largentière	Ag in Pb conc: 1,466 g/t Ag in Zn conc: 311 g/t	0.4 of metal, at 3.7% Pb, 0.6% Zn, 44-115 g/t Ag	2,000		
		Malines	Ag in Pb conc: 1,022 g/t Ag in Zn conc: 137 g/t	0.85% Pb, 3.2% Zn	1,300		
	Soc.Min.de Corrèze Salsigne SA	Les Farges Salsigne	Ag in Pb conc: 1,200 g/t Ag in Ag-Au conc	1.9, at 5.7% Pb, 105 g/t Ag	600		
ITALY *42.5 (*N.B. smelter/ refinery production figure)	SAMIN	Masua	Ag in Pb-Zn conc: 2,000 g/t	10.0 at 1.8% Pb, 3.7% Zn, 275 g/t Ag	4,500	Several oxide and sulphide Ore bodies of varying grades	
		Funtana Raminosa	2,000 g/t	200.0 at 1% Cu, 1.4% Pb, 3.0% Zn 1,460 g/t Ag	40+ (to be raised to 120,000 tpa)		
		Montevecchio Monteponi	Ag in Pb conc: Ag in Pb & Zn concs	1.7% Pb, 3.5% Zn 2% Pb, 4.5% Zn (oxide) 7.1% Zn (sulphide); 2.2% Pb & 2.7% Zn (mixed sulphides)	1,700 6,000		Variable ore types; complex processing.
		Raibl	4.4% Zn & 0.55% Pb (sulphide) 6.0% Zn (oxide), 2% Zn sulphide & 1.2% Pb (oxide)	2,000 (sulphide mill) 400 (oxide mill)			
		Gorno	2.5% Zn (sulphide), 2.1% Zn (oxide), 0.9% Pb	700			
		Piombo Zincifera Sarda	Monteneve	4.1% Zn & 1.6% Pb	290		
			Avenas	Ag in PbS+PbCO ₃ conc	5% Pb (underground), 2% Pb (oxide), 300 g/t Ag. 300 g/t. Ag.		150,000 tpa (1974)
	San Giovanni		Ag in Pb & Zn sulphide concs: 2-6 kg/t Ag.	1.5% Pb, 2.85% Zn (sulphide), 4.0% Zn (oxide), 500 g/t Ag	225,000 tpa (1974)	Silver-rich ore has from 2 kg/t to 6 kg/t Ag in 70% Pb conc.	
	PERTUSOLA (Penarroya)	Gruppo Buggeru- Fluminese	Ag in Pb & ZnS concs	1.1% Pb, 3% Zn (sulphide), 5% Zn (oxide), 500 g/t Ag.	2,000		
		Salafossa	Ag in Pb & Zn concs	10.0 at 4.5% Zn 1% Pb	2,500		

Table 2 (Cont'd)

<i>Countries with 1980 Ag production (tonnes)</i>	<i>Company</i>	<i>Mine location or name</i>	<i>Silver content of concentrates, where known (g Ag per tonne)</i>	<i>Ore reserves/grades (million tonnes)</i>	<i>Daily ore capacity</i>	<i>Remarks</i>			
GERMANY (F.R.G.) 32.3	Preussag	Bad Grund	Ag in Pb conc: 903 g/t	4.3 at 3.5% Pb, 5.4% Zn, 50 g/t Ag	2,000	"Banded ore" contains only half the grades opposite.			
		Rammelsberg	Ag in Cu conc: 673 g/t Pb conc: 401 g/t Zn conc: 123 g/t	2.7 at 7% Pb, 18% Zn, 1% Cu and 130 g/t Ag (high grade ore).	1,230				
	Sachtleben Bergbau (Metallgesellschaft) A.G. des Altenbergs (Viellemontagne)	Meggen	Ag in Pb conc Ag in Zn conc	15.0 of 8-9% Zn & Pb	1.0 million tpa				
		Luderich	Ag in Pb conc	1.8% Pb & 6.5% Zn					
IRELAND 24.0	Irish Base Metals	Tynagh	Ag in Pb, Zn and mixed concs: 1. <i>Lead oxide ore</i> :— Sulphide lead conc: 552 g/t Oxide lead conc: 233 g/t 2. <i>Mixed oxide ore</i> :— Bulk conc: 279 g/t Oxide lead conc: 180 g/t 1. <i>Lead sulphide conc</i> : 478 g/t	<i>Secondary open-pit ore</i> :— 14% Pb, 0.96% Cu, 130 g/t Ag (oxide) 6.2-8.5% Pb, 5.1-6.8% Zn and 7.6 g/t Ag (mixed oxide) and 7.6 g/t Ag (mixed oxide) 1) Reserves very limited. 2) 4.0 million tonnes reserves <i>Primary underground ore</i> :— 4.3% Pb, 3.1% Zn, 0.35% Cu, & 43 g/t Ag	2,000	Very variable types of oxide and sulphide ores ∴ grades vary widely eg from 75 to 132 g/t Ag			
			Mogul Tara	Silvermines Navan	Ag in Pb conc Ag in Pb conc		11.0 million tonnes at 2.4% Pb, 6.2% Zn, and 25 g/t Ag	2,400 (total of 7,000 design cap) 3,000	Up to 35 g/t Ag in ore.
			Bula	Nevinstown	Ag in Pb conc		61 million tonnes at 2.4% Pb and 11% Zn. 19.0 at 5.2% combined Pb & Zn	7,500	
GREENLAND DENMARK 17.8	Greenex A/S	Black Angel	Ag in: Pb conc: 400 g/t Zn conc: 12.4 g/t	7.0 at 5.5% Pb, 15% Zn, 30 g/t Ag	2,000				
UNITED KINGDOM 1.1 in 1980 but normally 3-4.0	Carnon Consolidated Tin Mines Ltd.	Wheal Jane	130 in Cu-Zn concentrate	0.8% Sn, 4.2% Zn, 0.27% Cu	- 1,000 (290,000 tpa)				

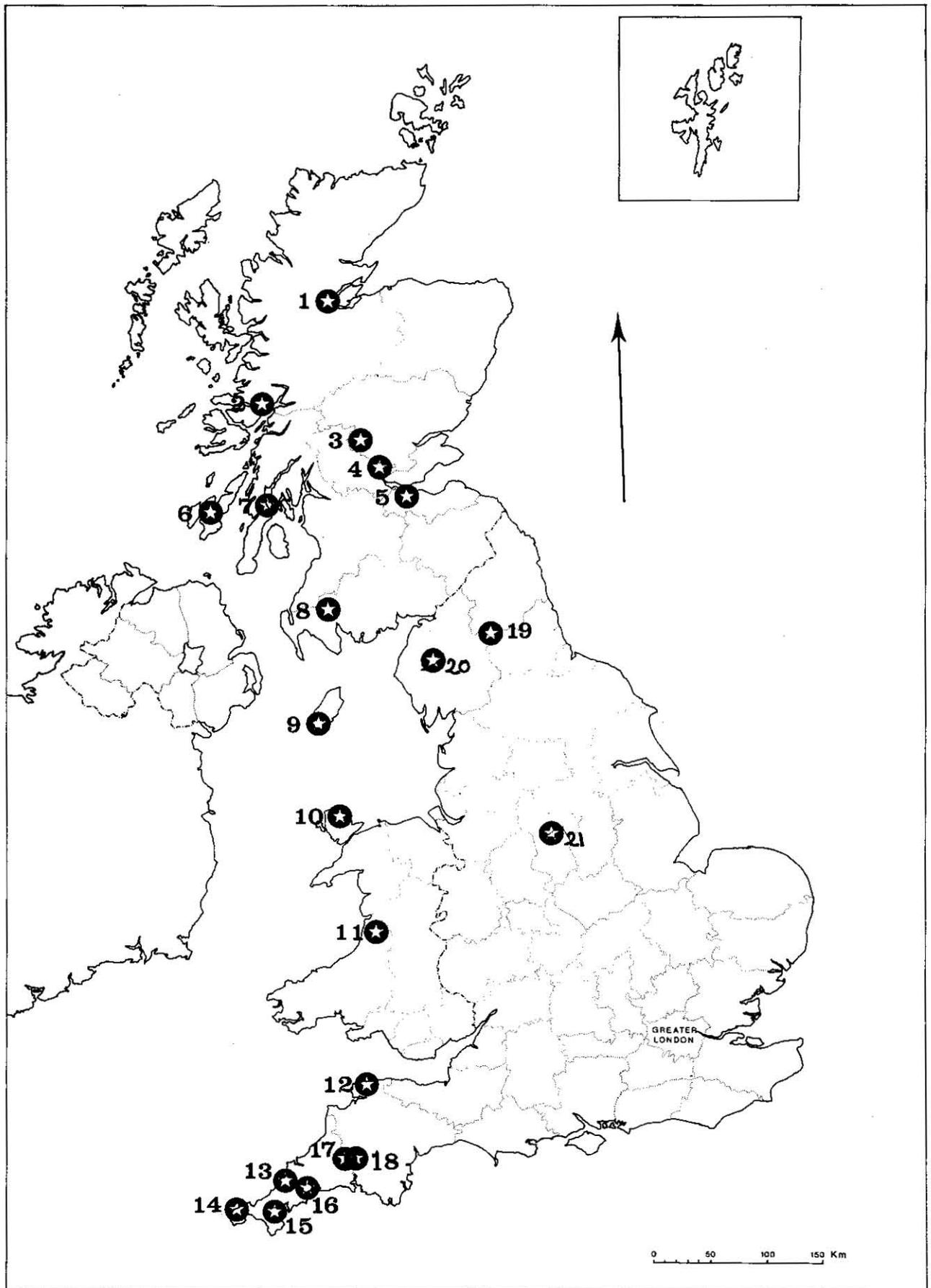


Figure 1 Former silver mining areas and silver occurrences in the United Kingdom

Figure 1 Legend and details

- | | | | | | |
|----------------------|---|--|---------------|---------------|----------------------|
| 1 | Struy mines; | first half of the 19th century; argentiferous galena; 215-675 g Ag per tonne 'concentrate'* | | | |
| 2 | Strontian mines; | 1722-1904; argentiferous galena; average of 580 g Ag per tonne 'concentrate' up to 31 kg Ag produced a year circa 1852 | | | |
| 3 | Corrie Buie mines; | circa 1860; argentiferous galena; 2,600 g-18.5 kg Ag per tonne 'concentrate' | | | |
| 4 | Alva Silver mines; | 1711-?1760; native silver, argentiferous galena, argentite; native silver ore assayed 85% Ag. | | | |
| 5 | Hilderston Mine; | 1606-1614; native silver, niccolite, argentiferous galena 13.5 to 14.7 kg Ag per tonne native silver 'concentrate' | | | |
| 6 | Islay mines; | worked by the Vikings, and 1594-1880; argentiferous galena; 87 kg Ag produced from 254 tonnes 'concentrate' in 1878 (maximum production year) (ie 350 g Ag per tonne) | | | |
| 7 | Stronchullin Mine; | dates uncertain; argentiferous galena, gold, copper; 80-140 g Ag per tonne 'concentrate' | | | |
| 8 | Silver Ridge Mine; | circa 1870; argentiferous galena; reputedly rich in silver | | | |
| 9 | Isle of Man mines: (notably Foxdale Group) | 1246-1919; argentiferous galena; up to 1.2 kg Ag per tonne 'concentrate'; 169 tonnes Ag produced 1851-1900 | | | |
| 10 | Mona and Parys: mines: (also Morpha-Du Mine) | records exist 1882-1911; argentiferous galena; 372 kg Ag produced from Mona Mine in 1897 and at least 4,355 kg Ag produced altogether. | | | |
| 11 | East (a), South (b) and Great Daren (c) mines: (Cwmsymlog, Cwmsebon and Daren); | <table border="0" style="margin-left: 20px;"> <tr> <td style="vertical-align: top;">(a) 1750-1901</td> </tr> <tr> <td style="vertical-align: top;">(b) 1840-1893</td> </tr> <tr> <td style="vertical-align: top;">(c) circa 1568-1879;</td> </tr> </table> <p style="margin-left: 20px;">(a) 520-1,225 g Ag per tonne 'concentrate' and at least 12.9 tonnes Ag produced from mine, plus 167 kg Ag from waste heaps 1876-1879
 (b) 765-920 g Ag per tonne 'concentrate' and 7.7 tonnes Ag produced over 30 years in mid 19th century
 (c) 675 g Ag per tonne 'concentrate' and 1.1 tonne Ag produced 1845-1879</p> | (a) 1750-1901 | (b) 1840-1893 | (c) circa 1568-1879; |
| (a) 1750-1901 | | | | | |
| (b) 1840-1893 | | | | | |
| (c) circa 1568-1879; | | | | | |
| 12 | Combe Martin mines: | before 1293-1875; argentiferous galena and some native silver; up to 5.1 kg Ag per tonne 'concentrate' | | | |
| 13-18 | SW England: | Many mines produced by-product silver and some deposits were particularly silver-rich. The chief argentiferous galena districts were <i>St. Agnes</i> (13), <i>St. Austell</i> (16); <i>Liskeard</i> (17) (at least 62 tonnes Ag produced from this district alone), and <i>Callington</i> (18). In the latter district, such mines as Prince of Wales and Harrowbarrow produced silver from argentiferous lead and copper ores, grades varying between 1.53 and 9.2 kg per tonne 'concentrate'; operations ceased in 1914. | | | |
| 14 | Wheal Jane: | 130 g Ag per tonne mixed Cu-Zn concentrate; 3 tonnes Ag produced a year. | | | |
| 19 | Northern Pennines: | mining from about 1100 to the present day. Sir John's Vein and its branch, Stow Crag Vein in Tynehead, were especially argentiferous (about 1,224 g Ag per tonne of lead metal). | | | |
| 20 | Lake District: | peak of mining activity in the 19th century last Pb-Zn-Ag mine closed 1961 (Greenside: 230 g Ag per tonne of lead concentrate); 200-1837 g Ag per tonne pig-lead; mines richest in silver were Driggith and Sandbeds. | | | |
| 21 | Southern Pennines: | Between 60 and 120 g Ag per tonne of galena average. Mill Close Mine, closed in 1938, was chief producer, but area not generally a major silver producer. Period of maximum production 1861-1938. | | | |

* The term '*concentrate*' is preferred to '*ore*' (ubiquitously used in mine records) since in most cases quoted silver grades refer to hand-picked, tumbled or otherwise preliminarily concentrated material; even *as-dug* material tended to reflect the pre-20th century practice of only extracting the highest grade ore.

are overlain by sandy and conglomeratic Permo-Triassic rocks. The major folding and fracturing of the Palaeozoic rocks preceded the intrusion of the granite batholith in the Carboniferous or early Permian. It is generally believed that, following the consolidation of the granite, fractures were opened up along lines of weakness and these formed favourable loci for ore deposition. Stockworks of numerous interlaced or parallel veinlets occur both in killas and in granite, and the character of the country rock does not appear to have had much influence on the deposition of tin and copper ores. The lead veins at Chiverton Mine on the other hand, were more productive in argillaceous than in arenaceous host rocks.

Cornwall has had a long history of silver production obtained largely from lead ore (commonly from more or less N-S veins) but also from copper ores and so-called 'silver-ores', as well as native silver. The main minerals in the 'silver ore' were argentite, pyrrargyrite, stephanite and cerargyrite and there is evidence to suggest that, where these minerals occurred in any quantity, the associated galena was poor in silver; conversely, where no true silver minerals were present, the galena was far more argentiferous. The silver ores were most common in the gossans of lead veins, in ENE-WSW trending copper or tin veins and in crosscourses which also carried bismuth, cobalt, nickel and antimony minerals. Variation in silver content and mineralogy is rapid and complex, even within the same vein. Hence it is impossible to estimate quantitatively silver resources in the area.

Tetrahedrite is also known from this mining field and was undoubtedly a minor, though important, source of silver at, for example, the Herodsfoot Mines in the Liskeard District. In fact, where the mines sold more than one grade of lead concentrate, lower lead contents were accompanied by relatively higher silver values, proving the presence of a second silver-bearing mineral. Other ores of antimony are also present and sometimes highly argentiferous galena is preferentially associated with pyromorphite and antimony ores. However, there is no clear mineral paragenesis.

Galena from many mines in Cornwall and Devon is preferentially enriched in silver, averaging about 1,220 g Ag per tonne (40 oz per ton) but galena from some mines was notably rich in the metal, for example, up to 4,440 g Ag per tonne from the upper parts of the Beer Alston Mines. The silver content of the galena shows no consistent pattern of relationship to depth, granite contact or other mineral distribution. Gossany and shallow material was sometimes very rich, whereas in other mines the silver content increased markedly at depth, despite the fact that the lead ore itself was sometimes found to deteriorate and die out, suggesting that tetrahedrite and other silver-bearing minerals were present.

The silver content of galena from different areas of the S-W of England have been estimated as follows (after Dewey, 1921):

	<i>g Ag per tonne</i>
North Cornwall	1,378
East Cornwall and adjacent parts of Devon	1,378
Christow valley, Devon	551-765
Chiverton Mines, N W Cornwall	1,225 to 1,531
Herodsfoot/Ludcott groups	1,225 to 1,684
East Wheal Rose and Cargoll Mines	276 to 261
Wheal Golden	49

Between 1851 and 1874 the average silver grade in Cornish mines was about 1,320 g per tonne of lead 'ore' (in most cases 'ore' refers to concentrated ore containing between 60 and 75% Pb), but this fell sharply to an average of 510 g during subsequent years, apparently arising from the closure of many of the highly argentiferous galena mines. Summarised and computed details of the most notable former silver producing mines of S-W England (Fig 2) are shown in Table 3.

Details of the silver content of the so-called true 'silver-ores' are generally lacking, but an indication of their grades is sometimes obtainable, for example, '14 tons of silver ore yielding 3,440 oz of silver' was reported to have been raised in Marazion Parish between the years 1852 and 1906, indicating a grade of 7,530 g Ag per tonne or 0.75%.

It was estimated in 1904 that copper ore from Cornwall and Devon contained 77 g Ag per tonne. Silver was extracted from copper ores at Levant in St Just District, at Credis and Tregonna in the Wadebridge District, and at Prince of Wales mine, Callington. The main areas of silver production from lead ores in Cornwall were the St. Agnes, St. Austell, Liskeard and Callington Districts.

Production of silver from lead mines was common in many areas of medieval times and it was only later that the richer, true 'silver-ores' were worked, for example at Wheal Mexico, from 1788. Possibly the best known occurrences were those at Rosewarne and Herland near Gwinear, and Wheal Newton, Callington. During the 19th century when over 2,000 tonnes of 'silver-ore' was raised, the main producing mines were the Chivertons, Cargoll and East Wheal Rose in St Agnes district, Herodsfoot, Wrey, Ludcott, Mary Ann, Trewetha in the Liskeard District and the Bere Old Mines in Callington. Small quantities of silver were present in the ores of the Great Perran Iron Lode, a major source of iron and a significant one for zinc, which extends for several kilometres southward from the north end of Perran beach. The Perran silver mine at Perranuthnoe, near Marazion, was active between 1903 and 1907. Silver was present in galena, as silver ore and as native silver.

The Menheniot area was the site of some of the most prolific silver mines of the 19th century, the combined output of for example, Herodsfoot, Mary Ann, Trelawny, Trewetha, Wrey and Ludcott, accounting for about 41% of the region's silver production. A group of N-S trending lead veins occurs 3.2 km east of Liskeard at a distance of about 5 km northwards from Menheniot; and another N-S group, the Herodsfoot veins, occur about 7.2 km WSW of Menheniot. The country rocks are Devonian slates with lavas and minor basic intrusions. The main Mary Ann/Trelawny vein was worked over a strike length of about 2 km to a depth of at least 457 m below surface. Mine plans and sections indicate that over 80% of the ground was stoped, at least to a depth of about 366 m, and that development was not very successful below this level. Both there and at Herodsfoot the 0.3 to 1.2 m wide vein is steeply dipping and transects soft grey slates. At Mary Ann it contains pyrite, barite, fluorite, siderite, chalcedony, quartz, calcite and argentiferous galena; the last mineral generally occurs at the centre of the vein, but in places it forms the cement for a breccia composed of country rock and chalcedony lying within the vein near its footwall. At Herodsfoot, the mineralogy is more complex and includes quartz, argentiferous galena, cerargyrite and pyromorphite (near

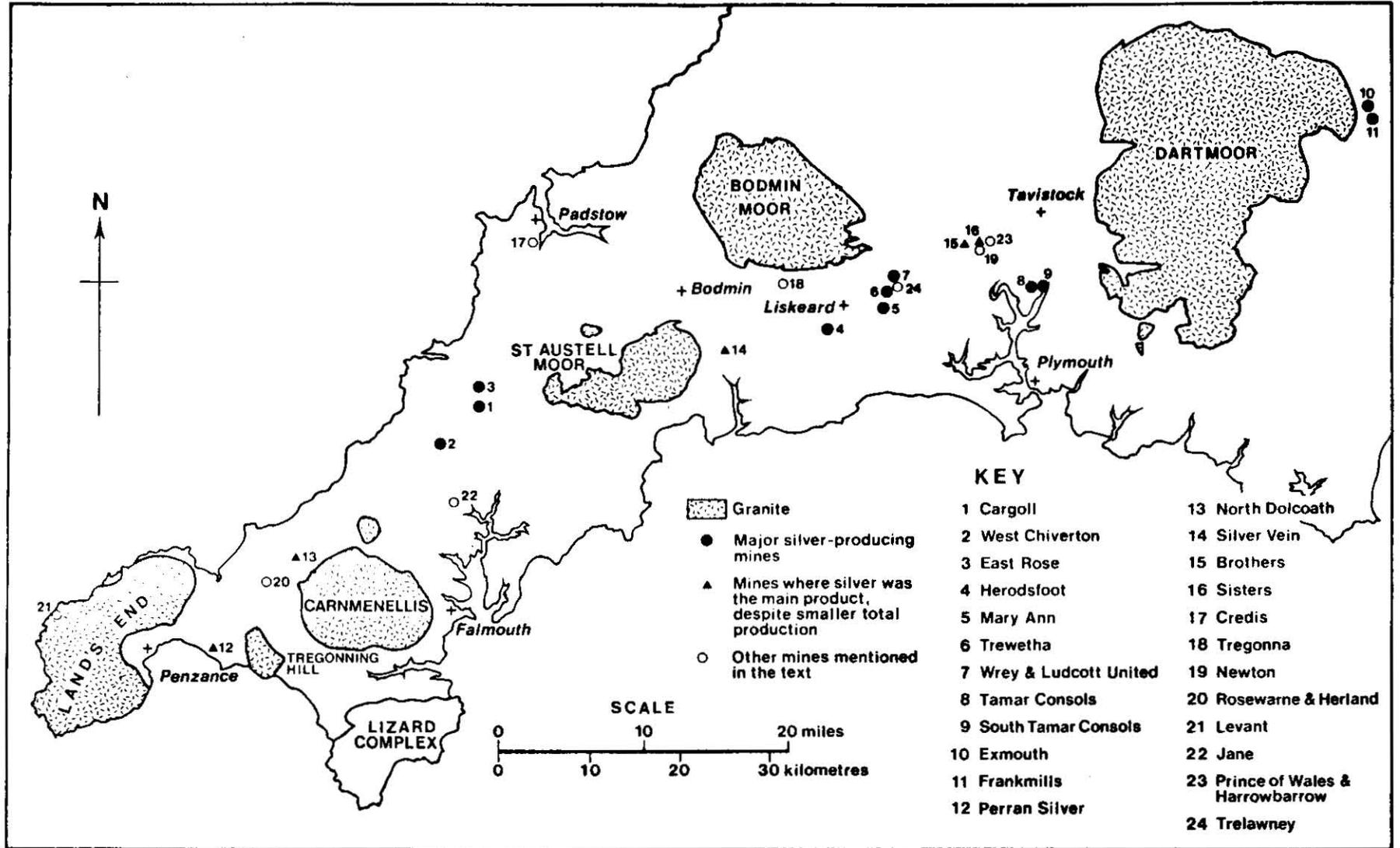


Figure 2 Location map of mines in the South-West of England.

Table 3 Historically important silver-producing mines of South-West England

Mine name	District	Number of major veins	Strike direction of veins	Recorded deepest level	Recorded longest level	Major vein details (where available)	Vein width(s)	Recorded lead ("ore") concentrate production		Recorded silver production	Quoted silver grade (per ton of ("ore") concentrate unless otherwise stated)	Computed silver grade in lead ("ore") concentrate over period recorded
				metres	metres			Grade(s) Pb	Time interval recorded tonnes			
CARGOLL (including S. Cargoll & New Cargoll)	ST. AGNES	3 1	NE-SW NNE-SSW	92.4	20.0	?	?	a) 70 b) 55	1845-84 1851-55	14,224 437	5,517.76 104.20	388.8 238.8
WEST CHIVERTON	ST. AGNES	3	NE-SW	77.7	50.3	Steeply dipping to SW Converging at depth	0.6-1.83, S. vein 0.3-0.9, N. vein 6.1 combined width at depth	1) 77 2) 71 3) 50 4) 43 a) 73	1859-86	45,822	37,983.59	753.1 593.9 489.8 382.7 829.6
EAST ROSE	ST. AGNES	2	N-S Also some E-W veins in south.	75.0	299.7	Steeply dipping Converging at depth Some branch veins	?	a) 62	1845-85	48,971	6,615.71	134.7
HERODSFOOT (North Herodsfoot)	LISKEARD	1	N-W & partly NNE-SSW.	107.4	124.9	Steeply dipping	0.3-1.2	1) 80 2) 69 a) 71 b) 52	1848-84 1853-84 1881-82	19,314 93.5	19,178.12 20.93	367.4 1,582.7 991.9 223.5
MARY ANN	LISKEARD	1	N-S	137.1 (549)	146.2	Steeply dipping to E	Up to 1.2	1) 76 2) 43 a) 69	1848-75	30,074	34,995.48	1,163.3 814.3 1,163.3
TREWETHA (Trewetha)	LISKEARD	1	NNE-SSW	45.7	?128	Steeply dipping to E	0.1 to 0.3	70	1853-72	4,303.8	4,521.39	'0.00123 Ag in 'Lead "ore"' '0.00202 Ag in lead metal' 1,034.1
WREY & LUDCOTT UNITED (amalgamated in 1863)	LISKEARD	2	N-S	35.9	20.9	Steeply dipping to E	0.6-0.9	LUDCOTT 1) 78.5 WREY 2) 77 N. TRELAWNY 3) 78 LUDCOTT a) 68 WREY b) 69 N. TRELAWNY c) 67 a + b) 67	1856-62 1853-62 1852 1863-66	3,251 5,522 332 1,900	3,291.06 3,328.10 116.76 2,537.42	1,010.3 765.4 1,530.7 1,013.3 603.1 352.1 1,334.8
TAMAR CONSOLS (south Hooe mine, Bere Alston).	CALLINGTON & TAVISTOCK	1	N-S	108(?)	164.5	Steeply dipping to E	?	a) 62	1845-76	14,874	10,149.07	4,286 per tonne lead metal in shallower parts; 1,071.5-1,224.6 per tonne lead metal in deeper parts 682.7
SOUTH TAMAR CONSOLS (Bere mine)	CALLINGTON & TAVISTOCK	1	NNE-SSW	67.6	113.3	Steeply dipping to S.E.	?	a) 64	1849-60 1852-60	7,254	8,163.74	2,449-3,674 per tonne lead metal in higher levels; 1,071.5-1,224.6 per tonne lead metal in lower levels 1,125
EXMOUTH (includes Wheal Adams & Amery, from 1853)	DARTMOOR & TEIGN VALLEY	2	N-S	57.1	205.7	Steeply dipping to W Converging at depth and then dipping to E	0.6-1.2	1) 82.5 2) 47 ADAMS a) 55 EXMOUTH b) 65	1845-52 1851-74	1,240 11,758	21.15 3,670.21	11.75 9.0 359.7 275.5 17.1 312.3
FRANKMILLS (Teign Valley Lead mine)	DARTMOOR & TEIGN VALLEY	2	N-S	80	164.5	Steeply dipping to E in upper levels, and to W. or vertical in deeper levels. Converging at depth.	?	1) 70.5 2) 60.5 a) 67	1857-80	15,037	77,298.42	25.0 25.25 765.4 773.0 514.0

the surface), sphalerite, stibnite, tetrahedrite and bournonite (at higher levels) and chalcopyrite (at lower levels). Grades of ore and concentrates produced are listed in Table 3.

In the Teign Valley, on the eastern edge of Dartmoor, Carboniferous shales, mudstones, cherts and tuffs, with intrusions of igneous rock, are traversed by an 8 km belt of north-south fractures. Galena from the main lode, about 1 m wide and about 4 km long, yielded from 300 to 600 g Ag per tonne of ore.

At Combe Martin, North Devon, dark grey slates of Middle Devonian age belonging to the Ilfracombe Beds, contain disseminations of extremely fine-grained silver-lead ore with some chalcopyrite. Small filaments of native silver have been noted in the galena. The Combe Martin mines are reported to have yielded ore containing up to 5,143 g Ag per tonne of lead. Devonian and Carboniferous sediments in the valley of the river Tamar, West Devon, are cut by two parallel crosscourses about 1 km apart which extend for about 7 km south of Calstock. Silver was being produced from mines around Bere Alston at the end of the 13th and beginning of the 14th centuries and these were reopened in the 18th and 19th centuries when they were known as Bere Old Mines or Tamar Valley mines. The veins carried sphalerite, fluorite, siderite and galena; the latter was rich in silver near the surface, sometimes containing as much as 5 kg Ag per tonne of lead, but in depth the content fell to about 1 kg per tonne. The area as a whole has contributed about 9% of the region's silver production. The largest producer in more recent times was probably Tamar Consols (or Tamar) silver-lead mine. The South Tamar mine was particularly rich, averaging 1,133 g Ag per tonne of lead concentrates; one estimate puts the silver content at 2,450-3,674 g per tonne of lead in the upper levels and 1,072 to 1,225 g per tonne in the lower levels. The mine was abandoned in 1856 when it was flooded by river water breaking into the workings. Economically viable ore may still exist at depth.

The only production of silver from south-west England at present is as a by-product of tin-copper-zinc mining at Wheal Jane, near Baldhu, Cornwall. The silver, some 3,000 kg per annum, is recovered during smelting and refining of copper-zinc concentrate, which contains between 140 and 165 g Ag per tonne. UK commercial exploration for new base metal deposits or development of existing ones is perhaps most active in Cornwall and Devon where several companies are working at present. Reported silver grades are however very low; for example, some 44 million tonnes of material grading 0.25% Cu, 0.1% Zn, 0.1% Sn and 3 g Ag per tonne have been outlined in a sheet-like orebody in the Redmoor Mine area, Cornwall.

WALES

In Wales, deposits containing silver minerals or, more commonly, argentiferous galena, occur in the pre-Carboniferous rocks of the Caledonian structural belt and in Carboniferous rocks of the post-Caledonian, pre-Variscan cover. The former, mainly late and post-orogenic mineralization, include Parys Mountain, Anglesey; the Dolgellau Gold Belt; the Llanrwst lead-zinc field; Llanengan, on the Lleyn Peninsula; the Llangynog area; and the metallogenic province of Central Wales. Deposits in the Carboniferous cover include epigenetic veins in the

Halkyn-Minera lead-zinc district of North Wales, and the very small lead deposits on the southeastern rim of the South Wales coalfield near, for example, Machen (north of Cardiff).

NORTH WALES

In the highly mineralized area of North Wales, two major and quite distinct groups of rocks host the main argentiferous base metal ores. This orefield was second only to the Northern Pennines in importance for lead and zinc in the United Kingdom.

The most important of the former lead-silver-zinc mining areas of Wales occurs in Clwyd, northeast Wales (formerly east Denbighshire and Flintshire), where ores occur in the Carboniferous Limestone and succeeding Cefn-y-Fedw Sandstone. Two main groups of mines, covering an area of about 10,360 hectares and separated by a major fault, were active in the Halkyn-Llanarmon and Minera districts in Clwyd. The ore-bearing rocks are part of the belt of Lower Carboniferous strata which flanks the Lower Palaeozoic complex of North Wales, and are either unconformable on, or faulted against the Silurian of the Clwyd Hills. As in the Northern Pennines of England, the ore deposits are located on the eastern side of a graben in eastward dipping strata. No mineralization has been found in the Silurian or above the Cefn-y-Fedw Sandstone. The most productive horizons are found in the White and Upper Grey Limestones directly below the Main Shale. However, in the Minera district stratigraphic control by the shales is less evident. Production was mainly from veins with ribbon-shaped steeply-dipping ore shoots, though stratiform replacement 'flats' and 'pipes' also occur. The veins trend E-W in the northern part of the area, near Halkyn, but NNE-SSE further south, at Llanarmon and Minera. Galena is ubiquitous, increasingly accompanied by sphalerite in the Minera district. The lowest level reached at Minera was 397 m and, as in many other British orefields, galena tends to become impoverished with depth. Argentiferous lead and zinc ores of the area are reputed to have contained up to 551 g Ag per tonne of galena. The ores generally appear to have contained less silver in the north than in the south and there is some evidence that the silver content in any vein increased with depth; as there was also said to be less galena at depth, this may indicate either that the records are inaccurate or that the proportion of tetrahedrite increased with depth.

Lead-zinc mineralization occurs in Lower Palaeozoic sediments and volcanics in three main, and several smaller, areas of N-W Wales around the Harlech Dome. The Llanrwst district, formerly in east Caernarvonshire, now Gwynedd, was the main Lower Palaeozoic lead-zinc-silver bearing region of North Wales. The majority of the workable veins occur in steep normal faults in the gently folded Crafnant Volcanic Group of the Upper Ordovician. The series consists of interbedded shales, tuffs and rhyolite lavas. The main lode is developed in the volcanic rocks, the sedimentary rocks being generally poorly mineralized. Two other areas, the Llanengan (on the Lley Peninsula) and Llangynog (on the southern flank of the Berwyn Dome) districts, were also formerly important. The Lower Ordovician flagstones and mudstones that rest unconformably on the Cambrian in the Llanengan area contain argentiferous lead-zinc-copper mineralized fault zones. Lead from the lode worked at Llanengan mine averaged about 158 g Ag per tonne when it was in operation between 1870 and 1892. Middle and Upper Ordovician interbedded shales, mudstones,

slates and lavas in the Llangynog district (formerly in Montgomeryshire) host argentiferous galena, sphalerite and chalcopyrite in, for example, east-west fractures at Llangynog mine itself. This mine yielded over 4,000 tonnes of 'ore' annually prior to 1850 and records suggest a silver content of between 57 and 109 g Ag per tonne of 'ore' circa 1865/1866.

In all these areas the ore-bearing veins occur in steeply-dipping normal faults. Fissure-fills of suitable structural openings in favourable lithologies accounted for most of past production. As in Central Wales, the ore shoots generally bottomed in soft shales where the dip of the faults decreased. The greatest working depth was about 153 m at Parc Mine, Llanrwst. Production was relatively small scale, but temporary re-working of the Parc Mine between 1952 and 1958 showed there to be still a considerable amount of ore remaining. The period of maximum production in the three areas was 1870-1893.

Near Dolgellau, in the Mawddach valley, there were many small mines which produced gold and some copper ores with associated silver. The mineralization occurs mainly in slightly metamorphosed Middle and Upper Cambrian sediments intruded by dolerite sills and sheets. The Clogau and the Glasdir Mines were the most important, the latter producing rich copper 'ore' containing between 54 and 153 g Ag per tonne.

ANGLESEY

At Parys Mountain, on the island of Anglesey, polymetallic sulphide mineralization is associated with the calc-alkaline Parys Mountain Volcanics. These are a thin sequence of ash-flow tuffs and dacitic lavas, volcanoclastics, siliceous sinter, quartz-pyrite rock (possibly cherty iron formation) and shales associated with one of several small rhyolitic vents that lie adjacent to the margin of an Upper Ordovician sedimentary basin. The host rocks are overlain by Silurian shales and underlain by Lower Ordovician shales; all have been synclinally folded during the Caledonian Orogeny, the deformation being accompanied by the remobilization of the sulphides.

The Mona and the Morfa-dhu-mines, on Parys Mountain, were worked from at least Roman times and produced large quantities of lead, zinc, copper and silver during the 19th century before ceasing production in the early 20th century. In 1887, for example, some 328,080 g of silver were recovered from the Mona mine alone. Analyses of selected high grade samples in 1919 indicated between 205 and 428 g Ag per tonne of 'bluestone' ore. Recent analyses have revealed much lower average silver values.

Several types of ore are present, reflecting slightly different conditions of mineralization. Primary sulphides occur at the base of a series of volcanic rocks as disseminations, layers and massive lenses associated with siliceous sinter (Carreg-y-doll and Morfa-Du 'Lodes') and at the top of the Parys Mountain Volcanics as a series of lenses in shales and cherts (Great 'Lode'). There are two main types of ore, 'pyrite-chalcopyrite' ore in a fine quartz matrix (1-2% Cu, and several per cent combined Pb and Zn), and the 'bluestone', a very fine-grained intimate intergrowth of sphalerite, pyrite, chalcopyrite, galena and chalcocite, occurring mainly to the south of the chalcopyrite area. Minor amounts of tetrahedrite and lead-bismuth sulphosalts also occur. The ore contains up to 1.5% Cu, 30% Zn and 14%

Pb. There are also low grade stockworks on the northern limb of the syncline, and crosscutting veins of coarsely crystalline dolomite, barytes and galena representing later mineralization.

In general, the lead and copper contents vary antipathetically across the deposit, but despite a decrease in lead content with depth and to the north-east, the silver content does not decline. Much of the galena is not particularly argentiferous and most of the silver appears to be associated with the tetrahedrite, although there was a zone in the Great Lode that was reputedly rich in 'argentian' galena. Tetrahedrite-group minerals tend to have a restricted occurrence within the chalcopyrite and, to a lesser extent, the sphalerite-galena rich parts of the ore. Both tetrahedrite and tennantite are reported as small inclusions or veinlets, as rims between other sulphide species, or as isolated grains.

Various origins have been inferred for the mineralization at Parys Mountain, ranging from truly epigenetic, through combined syngenetic and epigenetic, to syngenetic associated with rhyolitic volcanism. The deposit has been compared with the Kuroko deposits of Japan and it now appears that all the host rocks, volcanic and sedimentary, were deposited in a shallow, subaqueous environment. The primary mineralization is thought to be of the same age as the host rocks, and related to exhalative activity, while remobilization took place during later metamorphism, producing a second phase of coarse-grained mineralization. The cherty iron formation, mainly pyrite, occurring within the Parys Mountain Volcanics is typically found in association with volcano-sedimentary sulphide deposits.

CENTRAL WALES

The second most important lead-zinc mining district in Wales comprises approximately 103,600 ha of mid-Wales, where ENE-trending lodes traverse a belt of Upper Ordovician and Lower Silurian sediments. The bulk of the ore field lies mainly in what were north Cardiganshire and west Montgomeryshire, where many mines raised argentiferous galena, sphalerite and some copper ore.

The sequence consists of an alternating series of sandstones, mudstones and shales with two main, dark, pyritic shale horizons up to 183 m thick. Ore-producing veins follow steeply dipping faults and tension fractures, the most productive being in the Frongoch Formation (Lower Silurian). At Van Mine, associated flats were also developed. Some 1,830 m of strata were worked, though the greatest working depth was about 305 m at Cwmsebon Mine. Despite contributing only 10-12% of British lead and zinc output between 1845 and 1920, at least 108,862 kg of silver were produced, mostly from lead concentrates at the leading 50 mines. Recent assay figures put the silver content at 1.36 kg Ag per tonne of lead, though older returns indicate a much lower average. At Llanfair Clydogau Mine, however, up to 2.2 kg Ag per tonne of lead was returned. There was evidence that at some mines silver increased with depth, so that the average content of silver per tonne of ore increased, for example, at Esgairwyn from about 92 g in 1852 to 505 g in 1918. Although a small producer compared with other areas in Great Britain, the Central Wales orefield contained some of the most highly argentiferous galena in the country, for example at the Daren Mines, Cwmsymlog, Cwmsebon and Daren; the former reputedly produced dressed ore containing 2,265 g Ag per tonne, and the last 1,531-1,837 g Ag per tonne.

Little information exists as to the characteristics and composition of the ores in north Cardiganshire and west Montgomeryshire although it appears that veins on the western limbs of anticlines (or domes) were more productive than those on the eastern limbs.

When the great silver vein at Cwmsymlog in Central Wales was discovered towards the end of the 16th century, the annual output of Welsh silver increased greatly. Argentiferous lead mining thrived in Cardiganshire during the 17th century, but by comparison the silver content of deposits in Flintshire and Denbighshire did not at that time warrant the cost of refining. After a general period of depression throughout Welsh mines in the early 18th century, several important argentiferous lead veins were 'discovered' or rather re-discovered, for example, Old Daren Mine near Aberystwyth. By the second half of the 19th century, a considerable decline in the silver content of ores raised in Wales, notably in Cardiganshire, is recorded. In 1868 the eight argentiferous lead mines operating in Denbighshire produced a total of 1,038 kg silver, averaging about 125 g Ag per tonne of dressed lead 'ore' (concentrates). Some 24 similar mines operating in Flintshire the same year produced 897 kg silver from ore grading 204 g Ag per tonne. Of all these mines, only Minera and Talargoch were big silver-lead producers. The first accounted for over 70% of Denbighshire production, the latter for about 60% of Flintshire production.

OTHER PARTS OF WALES

Elsewhere in Wales many derelict mines attest to the former small-scale extraction of lead-zinc sulphide ores predominantly from Lower Palaeozoic rocks. The veins were usually found in sequences of interbedded sediments and lavas or tuffs, and because most of the mines were originally opened to produce silver, the content of this metal seldom fell below 70 g Ag per tonne or so of dressed ore.

The Carboniferous limestone of South Wales is poorly mineralized compared with its outcrop in northeast Wales, but minor amounts of argentiferous galena have been produced on the southeastern rim of the coalfield and also around the Vale of Glamorgan. Here, also, small amounts of lead were obtained from Triassic limestone conglomerates and marginal Lower Liassic limestones. Silver values for these deposits are not readily available.

ISLE OF MAN

The Isle of Man was famous for its lead-zinc production and its galena was especially noted for its high silver content. The area produced at least 268,000 tonnes of argentiferous lead concentrate, 93% of which came from two mines – Foxdale and Great Laxey – as well as substantial quantities of zinc. The mineralization occurs in Cambrian Manx Slates and, at Foxdale, traversed the Manx Granite basement, the whole being overlain by Carboniferous sediments. The most productive veins cut the basal blue-grey flaggy slates of the Manx Slates, and no ore has been found in the quartz-veined grits. All the more productive lodes occur on or near the structural axis of the Manx Slates. The sulphides occur either as disseminations or as thin lenses in steeply dipping veins. Where these were worked in an underlying granite the galena is less argentiferous: the greatest working depth was 640 m. A late Mesozoic, probably Upper Triassic, age is envisaged for the mineralization.

Galena from Laxey was reputedly very 'pure', generally containing 612 g Ag per tonne but occasionally much more. During the period 1864-1879 returns indicate that the dressed ore was grading up to 1,286 g Ag per tonne. In some veins, for example at Foxdale Mine, highly argentiferous galena was developed on the north wall and 'ordinary' galena on the south wall, separated by 1-3 m of mixed vein material. Tetrahedrite also occurred in Manx veins, for example, in the northern part of the Foxdale lode where it was associated with galena assaying 3,061-6,123 g Ag per tonne of lead. The tetrahedrite appears to have occurred in specks and lumps in the veins and was richest near the granite-slate contact. Small quantities of richly argentiferous tetrahedrite ore were raised, for example about half a tonne of 'rough, highly argentiferous fahlerz' was raised in 1868. Sometimes a part of a vein 'adjoining a granite dyke' would be especially enriched in silver, up to 9,184 g Ag per tonne of lead is recorded and veins yielding an average of 2,143 g Ag per tonne were by no means rare. About 1823 the Foxdale group of mines alone employed 350 men and boys and for at least a decade yielded dressed ore containing 70% Pb and 276 g Ag per tonne.

CENTRAL AND NORTHERN ENGLAND

NORTHERN PENNINES

The geology and mineral deposits of the Northern Pennines have been extensively described in the literature, and the area has probably been the subject of more study than any other mineralized area in the United Kingdom.

The Northern Pennine Orefield covers an area of about 3,885,000 ha in Northumberland, Durham, Cumbria and Yorkshire. It is defined by the distinct structural units of the Alston and Askrigg Blocks, being bounded by faults on three sides: – the Stublick Faults to the north, the Pennine and Dent faults to the west, and the Craven faults to the south. On its eastern margin the orefield disappears below Carboniferous (Coal Measures) and Permian strata. The Alston Block is separated from the Askrigg Block to the south by the Lunedale/Stainmore trough but the sedimentary sequence in each area is comparable.

There are mineral occurrences in the Alston Block in rocks ranging in age from Ordovician to the Permian (Magnesian Limestone). Economically viable veins are confined, however, to the Lower and Middle Limestone groups of the Visean and the Namurian Upper Limestone Group, with a concentration at the level of the (Namurian) Great Limestone. The rhythmic (limestone, calcareous shale, non-marine shale, sandy shale, sandstone, gneiss and coal) sedimentation gave rise to host rocks of varying competence which have influenced the shape and content of the ore shoots. The Carboniferous rests unconformably on highly folded Lower Palaeozoic strata in which there are concealed Caledonian granite batholiths. In the Alston Block there is also some post-Carboniferous intrusive activity, quartz-dolerite sills and dykes of the Whin Sill, which caused induration of the adjacent shales. The orebodies are mainly fissure veins following the pattern of faults which may date from a period of doming possibly influenced by the intrusion of the Whin Sill. At some horizons workable replacement flats and mantos occur. Ore deposits are present in the Askrigg Block as ribbon veins and stratiform bodies in the rhythmic succession of the Main Limestone, the Great Scar Limestone and in basal Millstone Grit beds. A complex genesis is currently postulated for

the deposits of the Northern Pennine orefield, involving interplay between juvenile and connate water, basin migration over structural 'highs' and karstification of the limestones. The main metallic ore minerals are galena and sphalerite with sporadic chalcopyrite, pyrite, marcasite, pyrrhotite and siderite. The gangue of many veins, especially in the Alston Block, is fluorite, but barite, quartz, calcite and witherite also occur. Alteration has produced a wide variety of secondary minerals and horizontal and vertical zonation is apparent in the primary gangue minerals.

The lead ores in the Carboniferous Limestone are generally more argentiferous than those of the Southern Pennines, normally containing about 120 g Ag per tonne of lead metal. Exceptionally high silver values occur along Sir John's vein and its branch, Stow Crag vein, in the neighbourhood of Tynehead, worked at Leehouse Well, Stow Crag, Sir John's and Clargillhead mines, in which the average silver recovery was about 1.2 kg per tonne of lead. More highly argentiferous galena appears to have been found commonly in the early days of mining when workings were near the surface, although the London Lead Company's operations in the Hudeshope-Eggleshope area of Teesdale at the beginning of the 19th century apparently encountered higher silver values with increasing depths.

During the 19th century lead ores were generally converted to metal by open-hearth smelting. Records show that the unrefined lead issuing from the hearths in Swaledale, for example, contained about 0.02% or 215 g Ag per tonne combined with acceptably small quantities of antimony. Ore from the famous Allendale mines produced smelted metal containing about 153 g Ag per tonne lead, while the Derwent mines (also prolific silver producers) contained ore that yielded 275 g Ag per tonne of lead.

Not all the silver in the orefield is present in galena, however. In the Alston Block some sphalerite contains small inclusions of tetrahedrite-group minerals, generally as a result of exsolution. Tetrahedrite also occurs intergrown with chalcopyrite and galena, and electron-probe microanalysis shows it to be rich in silver. Tetrahedrite sometimes appears to have been a major silver-carrying phase in the ores, and a generally positive correlation between silver and zinc has been demonstrated. Ore remains in 'flats' and 'strings' between the Firestone and Four Fathom limestones at Allenheads and in the higher sills and beds below the Great Limestone. The more easily accessible parts of veins have, in general, been worked out in the orefield, but replacements and flats probably have not.

Recent exploration in the Northern Pennine orefield has been almost exclusively for fluorspar, barytes and witherite, and recent estimates of lead ore reserves (and, by inference, silver) are almost entirely informed speculations or computer predictions. The Weardale Lead Company reported in 1975 that fluorspar, lead and zinc ore reserves can be inferred from diamond drilling in County Durham, while a deep borehole, drilled to prove the granite underlying the Carboniferous, showed that mineralization continued to greater depths than had previously been thought. Mineral values associated with the Craven reef limestones on the Yorkshire-Lancashire border are encouraging. An important aspect of base metal and silver resource evaluation in the Northern Pennines is that exploration has been largely concentrated in the parts of the orefield where the fluorspar to metal ratio is high. The eastern flank of the Alston Block may extend some 20 km offshore, and mineralized Carboniferous Limestone may therefore also extend eastwards below the Durham

Coalfield, along the Stockdale monocline, or along the continuation of the Craven faults.

Statistical appraisal of the orefield as a whole using computer modelling has suggested that some 5.6 Mt of lead concentrate equivalent may still be discovered and that in every 20 km² area at least one ore deposit can be expected. At a nominal grade of 150 g Ag per tonne of lead this would indicate a hypothetical resource of some 590 tonnes silver metal. If base and precious metal prices rose significantly and mineral rights legislation were simplified, mobile processing plant could be used to process old mine waste in the Northern Pennines.

SOUTHERN PENNINES

The Carboniferous Limestone of Derbyshire is traversed by hundreds of mineral veins containing galena, fluorite, barite, sphalerite and calcite. A thickness of approximately 458 m of limestone is exposed in the anticlinal structure and the base is below the deepest mine workings. Mineralization extends through a thickness of about 244 m in the Lower Carboniferous, the reef limestones being very favourable for the formation of replacement ores, whereas the darker limestones in the sequence are less so. Volcanic horizons occur in the limestone and at Mill Close, one of the most prolific and famous of Derbyshire mines, at least five lava horizons are known. Derbyshire lead mines have been unproductive in the 'Millstone Grit' which generally rests unconformably upon the mineralized Lower Carboniferous. This contrasts with parts of the Northern Pennine orefield where considerable production came from these rocks. This may be because, by the end of the Lower Carboniferous, the area was capped by impermeable Edale Shales (Namurian). Some evidence of karst formation occurs on the erosion surface, and cave development during mid-Carboniferous times may have provided channels for water or fluid migration.

The deposits take the form of veins, 'pipes' or stratiform 'flats'. The vein mineralization, which appears to be polyphase, is developed along steeply dipping wrench faults in the near-horizontal sequence of inter-bedded limestones and shales. Most of the veins trend between ENE and ESE, though the main vein at Mill Close has a N-S trend. The type of sedimentary environment is similar to that of the Northern Pennine orefield and similar fissure filling has given rise to ore shoots limited by lithological changes (shale, tuff or lava) or by variations in dip and strike of the vein. Small anticlinal structures are also important to ore localisation. Stratiform 'flats' and 'pipes' have been produced by replacement of the limestone and are considered to be epigenetic telethermal mineralization related to palaeogeomorphological features. The deposits are interconnected and have remarkable continuity. Zonation of the gangue minerals has long been known. Although nearly all the veins carry galena, there is relatively little silver, generally between 60 and 120 g Ag per tonne of galena (although exceptionally more, ie at Balls-eye Mine, Bonsall, where a pocket of ore yielded some 550 g Ag per tonne). The deepest working was to a depth of 225 m, the ores tend to become impoverished with depth and there is no record of galena being replaced in depth by sphalerite, as occurs in other areas. Although Derbyshire did produce silver, for example some 1,000 ounces (31 kg) in 1869 from Mill Close Mine, records of silver production are poor. Despite producing a total of some 678,000 tonnes of lead concentrates, the county ranked only

fifteenth in order of silver-producing counties and areas in the UK. The last lead mine, Mill Close Mine, ceased operations in 1938, but small quantities of lead concentrate are produced as a by-product of fluorspar and barytes mining. These concentrates do not generally command much bonus for their silver content, but between 50 and 120 g per tonne silver are obtainable from some operations, especially those where barite-rich ores and dump material are processed.

LAKE DISTRICT

Argentiferous lead ores occur in veins in the Lower Palaeozoic rocks of the Lake District, the silver content appearing to be related to the barite content of the lodes. At Force Crag Mine and Driggith-Sandbeds where the veins are rich in barite, up to 1 kg silver per tonne of lead was sometimes obtained, whereas at Greenside, where barite is rare except in the upper levels, the silver content of the ore was lower, not more than about 300 g Ag per tonne of lead. However, investigation of Force Crag Mine in 1976 indicated silver contents between 30 and 570 g per tonne of lead, figures far lower than records had previously suggested.

The geology of the Lake District is complex but broadly consists of a dome of severely folded and faulted Ordovician sediments and volcanics and Silurian sediments intruded by many acid and basic masses. Viséan, Namurian, Permian and Triassic rocks surround those of the Lower Palaeozoic, often unconformably. Almost all metal production has been from deposits in the Lower Ordovician, particularly the Borrowdale Volcanic Series and the underlying Skiddaw Slates.

The district may be divided into the Caldbeck Fells, the Keswick area and the Coniston area, the last of which mainly produced copper ore. The Caldbeck Fells exhibit the greatest diversity of rocks and minerals ranging from Carboniferous to Ordovician with the Carrock gabbro-granophyre complex and the Skiddaw Granite. Ores of tungsten, copper, lead, zinc and barytes have been worked. The northwest of the Keswick field has yielded lead, zinc, copper and barytes from folded shales, mudstons and flagstones in the Skiddaw Slates; to the south the Borrowdale Volcanics contain lead and some graphite.

There is an upward zoning in the orefield, galena-sphalerite giving way to barytes-dolomite and then pyrite-manganese. There are no strong lithological controls in the Lower Ordovician rocks, though harder bands tend to be better ore-bearers and, although the Keswick and Caldbeck areas flank the main anticline, little structural control is evident. Isotopic determinations suggest Upper Triassic mineralization, but more than one phase probably occurred and Lower to Middle Carboniferous ages have also been obtained.

Several Lake District mines produced more than 31 kg (1,000 oz) of silver (see Table 11) but average silver contents were not good, normally about 215 g Ag per tonne of lead metal. Some mines however, produced richer argentiferous galena ores, as shown as follows:

Mine	Area		g Ag per tonne pig-lead
Thornthwaite	Keswick	:	306
Threlkeld	„	:	240
Force Crag	„	:	918-1,000
Goldscope	„	:	214
Brandlehow	„	:	275
Roughtongill	Caldbeck	:	306
Redgill	„	:	918
Driggith	„ (1810-1822)	:	1,377-1,837
„	„ (around 1860)	:	765-918
Greenside	Penrith	:	321

The most productive and recently operating mine was Greenside, where the main vein runs approximately N-S and is spatially associated with a quartz-porphry dyke. Most of the veins are steeply dipping normal faults filled by country rock breccia. Mineralization was generally localised in steeper dipping parts of the vein and at vein intersections in the Borrowdale Volcanics and, in the northern part of the mine, at depth in Skiddaw Slates.

The peak of mining activity in the Lake District was in the 19th century, and Greenside Mine alone produced some 46.7 tonnes of silver at an average grade of 230 g per tonne of lead concentrate, before it closed in 1961.

SOMERSET: THE CENTRAL MENDIP MINES

Silver is present in lead and zinc veins in Carboniferous limestones of the Mendip Hills, some 24 km south of Bristol. Maximum production was in the 17th century, with decreasing amounts in the 18th. Mining virtually died out in the first half of the 19th century, apart from later attempts at working surface dump material.

A cover of gently folded Lower Mesozoic rocks rests unconformably on a complex basement of Upper Palaeozoic rocks. Host rocks for the veins are the Carboniferous Limestone and the Triassic Dolomitic Conglomerate. The NW and WNW trending veins occupy steeply dipping normal faults and are associated with three east-west *en echelon* periclinal; major N-S faulting also took place. As well as fissure filling mineralization, some limestone replacement deposits also occur. Oxidised lead and zinc ores are characteristic of the area but galena and barite also occur. The silver content averaged only 107 g per tonne of lead (although hand picked samples are said to have contained several percent silver). Workings extend to only about 90 m depth and little information exists as to probable remaining ore or whether the lodes were 'bottomed out'. Even the grade of ore worked and ultimate tonnages of metal obtained are in dispute. Several dressing and smelting plants were established in the 1830s to process the surface dumps and a small Pattinson desilvering plant was erected at Charterhouse.

CHESHIRE AND STAFFORDSHIRE

Barium, copper, manganese and, in places, silver mineralization associated with post-Triassic faulting occurs in the Permo-Triassic sandstones in Cheshire. The richest deposits are situated where the sandstones have been

faulted against impervious marls, for example, at Alderley Edge. Here and at Mottram St Andrew small amounts of silver have been detected in copper ore occurring in the Upper Mottled Sandstone and in the basal beds of the Sherwood Sandstone. The minerals are disseminated throughout the rocks, coating the pebbles and sand grains or acting as cement, but are more concentrated in veins that occur along faults and in lenses or patches parallel to the bedding. The chief ore minerals are those of copper and lead, but cobalt, silver and iron were also obtained, and arsenic, nickel, manganese, molybdenum, vanadium, antimony and gold have been recorded. As the ore-bearing sandstones lie above the water table in the zone of oxidation, most of the minerals are secondary, with the exception of galena which occurs in both disseminated and massive form.

Mining in the area dates from pre-Roman times and continued sporadically until 1919 when all activity finally ceased. Silver was extracted at various times and records exist of, for example, 150 oz (4.7 kg) produced in 1859, 45 ozs (1.4 kg) in 1860, and 95 ozs (3 kg) in 1861. However, production of silver was small compared with other UK mining areas.

At West Mine, the orebody was a complex mixture of sandstone impregnated with various secondary copper and lead minerals, barite and galena. Various samples from the orebody contained:

'In copper ore:'	480 g Ag per tonne 'ore'
'In galena:'	235 g Ag per tonne 'ore'
'In cerussite:'	77 g Ag per tonne 'ore'

Some silver is said to have been produced from lead ore mined at the Ecton Hill copper mines in Staffordshire. Ecton Hill is a complex N-S anticline of Carboniferous Limestone limestones and shales with mineralized veins occupying WSE – ENE and N – S fractures, although pipe-like bodies also occur. The dominant mineral is chalcopyrite but the galena, which is said to have been more common in higher levels, was very poor in silver, although Dale Mine produced 14.8 kg during 1860-61.

SHROPSHIRE; THE MALVERNS; THE FOREST OF DEAN

The west Shropshire lead-zinc mining field was centred on a small anticlinal area lying within a 5 km radius of Shelve. The mineralized area is bounded to the north, west and south by unconformably overlying Silurian strata, and to the east by a major fault.

The veins occur in vertical normal faults and are largely confined to the Lower Ordovician Mytton Beds. These beds crop out as an inlier on the Shelve anticline and are composed of about 460 m of flagstone and gritstone. Lithological control is evident since the mineralized Mytton Beds are capped by the Hope Shales and floored by the Stiperstones Quartzite, neither formation affording any workable ore. The Ordovician strata include contemporaneous andesites and andesitic tuffs, and the veins cut dolerite dykes and sills of early Silurian age. Production came largely from ENE trending veins but NW trending veins were also productive. The deepest workings attained, 505 m, were Snailbeach mine.

Silver was produced from the area but no values were returned in the official statistics from 1883 onwards and the silver content of the galena was generally low. Between 15 and 77 g Ag per tonne of dressed lead 'ore' were recovered in the early 1880s, although in 1839 184-214 g Ag per tonne of ordinary ore were recovered from the Rider and Squilver Veins at the Grit Mines.

The mines of central England, extending up to Shropshire, contained little silver, so that, in common with those in Derbyshire and Yorkshire, they generally received no credit from the smelters for the silver contained in the dressed ore. The silver was not therefore returned in the official statistics.

One or two abortive attempts at mining took place at Gold Mine, in the Malvernian, north of Wyche where up to 65 ppm silver was reported in granites. Silver has also been recorded in the Upper Old Red Sandstone Quartz Conglomerate of the Forest of Dean.

SCOTLAND

In Scotland silver occurs in lead ores in greatly varying proportions at several localities, many of which have been worked, though mostly on a small scale. Silver also occurs as native silver with cobalt and nickel at Hilderston, Lothian, and with erythrite, cobalt, arsenic and copper at Alva, Central Region. The main areas of activity in the 19th century were the Leadhills – Wanlockhead area (Lowland Region), Tyndrum (Central Region), Strontian and Islay (Highlands and Islands Region) and Newton-Stewart (Lowlands Region).

LEADHILLS – WANLOCKHEAD

Leadhills and Wanlockhead, in the Southern Uplands, formed an important lead-zinc mining district accounting for a significant proportion of the silver produced in Scotland. Over seventy veins were worked of which about twelve were extensively mined to a maximum depth of 440 m.

The area occurs within Ordovician rocks which were intensely folded along NE – SW axes during the Caledonian orogeny. This synclinal belt is bounded to the north and south by anticlinoria of older rocks. In general, Arenig volcanics are successively overlain by radiolarian cherts, Caradocian black shales and greywackes of the Lowther Group (Ashgill). A prominent structural feature of the greywacke belt is a marked NNW – SSE jointing. The mineralization generally occurs in steeply dipping fractures.

Most of the Wanlockhead veins terminate against a low angle thrust which forms the southern margin of the cherts and black shales. It has been suggested that the thrust shear zone or the thrust mass of the black shales themselves acted as an impermeable barrier and governed the localization of ore deposits.

The country rock is intruded by numerous Caledonian dykes which are usually parallel to the mineralized fractures. As these dykes are brecciated and altered by the mineralizing fluids, the vein-filling post dates the Caledonian dyke emplacement; a Lower to Middle Carboniferous isotopic age has been recorded.

The veins are filled with brecciated greywacke cemented by gangue minerals, and the sulphide minerals are usually concentrated on the vein walls. Galena and sphalerite, the two widespread primary ores worked in the district, occur with smaller amounts of chalcopyrite, pyrite, hematite, limonite, ankerite, marcasite, witherite and numerous secondary minerals. The galena occurs both as coarsely crystallized and as fine grained 'steel ore' varieties, the latter being more argentiferous. Between 1881 and 1890 when the lead production of the area was at its peak, the silver content of the ore mined at Wanlockhead and Leadhills averaged 180 g Ag per tonne of dressed lead 'ore'.

ALVA

Silver-bearing ore was mined at a number of localities in the Ochil Hills, east of Stirling, central Scotland. A mass of native silver weighing 430 g, which yielded 370 g of pure silver, was discovered here in 1711 and miners were sent from Leadhills to work the deposit. Some nine mines were operational in the area, although silver was produced from only four of them, notably Alva, Airthrey, Carnaughton and Tillicoultry. Alva Mine is situated about 160 m up the steep Silver Glen, 300 m east of Alva. At least 45 tonnes of 'ore' assaying 85% Ag were produced as well as a substantial amount of cobalt ore. The mineralization occurs in faults in the gently dipping Lower Devonian Ochil Volcanic Formation (330 m thick), the andesitic rocks of which might have been the source for the metals. These volcanic rocks forming the Ochil Hills are separated from Carboniferous sediments to the south by a major fault, the Ochil Fault (minimum displacement 2,000 m), and are cut by numerous intrusions, the most important being diorite stocks with a metamorphic aureole near Tillicoultry. Apart from the Ochil Fault, there are two other main trends of fracturing (NW and NE) closely associated with Lower Devonian dykes. All these trends are mineralized to a greater or lesser degree.

The mineralization in the Burnside – Alva area occurs in fault breccia (0.6 m wide in Silver Glen) and comprises argentite, galena, erythrite, pyrite, chalcopyrite, malachite and arsenopyrite as the main metallic minerals. The famous 4×6 m 'Silver Chamber' was the site of the rich silver lode east of Silver Glen. Sometimes ore-bearing breccia was developed in pipe-like structures of varying diameter, and particularly rich deposits were developed as 'nodes' on the pipe. The Alva silver mine was opened in 1714 by the sinking of a shaft directly on the vein. At a depth of only 6 m the miners hit the largest mass of silver ore ever found in the British Isles. Samples were sent to the Royal Mint in London and the assay was carried out by Sir Isaac Newton, the then Master of the Mint. When the rich silver ore ran out, the mine was worked for cobalt (circa 1729), but eventually the cobalt ore was also exhausted and since then there has been only sporadic reworking of the dumps.

HILDERSTON

Hilderston, near Bathgate, Lothian Region, became famous as a silver producer for a short time at the beginning of the 17th century following the discovery of native silver in a local stream in 1606. The 1.8 m wide vein was subsequently located associated with an altered E – W quartz-dolerite dyke; maximum vein width is recorded at a point below the silver deposits and the Ag-Ni-Co mineralization occurred in the sandstone-shale sequence above the Lower Carboniferous Petershill Limestone. A thick sequence of basaltic lavas caps the succession. Two mineral suites appear

to have existed. The Ag-Ni-Co suite was extracted during the early shallow workings, and contained filiform native silver with niccolite, annabergite and erythrite as the principal minerals. Current theories propose that the native silver was not derived from argentiferous galena, but was a primary phase associated with niccolite or was derived from an arsenide compound. The silver ore was found entirely within 18 m of the surface assaying up to 1.34% Ag over a width of 5 cm.

The vein was laterally restricted within the fault plane and vertically between the top of a major tuff unit and the base of the overlying basalts, only the top one-third carrying economic concentrations of silver and nickel. The maximum possible yield of silver from this orebody would have been only about 4 tonnes. The ore at Hilderston yielded about 14 kg Ag per tonne. The second type of mineral suite (Pb-Zn-Ba) was intersected by later, deeper workings and was composed entirely of primary minerals, in particular lead and zinc sulphides, with no appreciable Ni, Co, Ag or As. The surrounding limestone country rocks contain only a few ppm of silver. Mining ceased in 1614 and attempts to work the vein during the 18th century and the second half of the 19th century proved unprofitable.

TYNDRUM

This former lead-zinc mining district in Central Region is cut by a large NE – SW fault, to the north-west of which the rocks are Moinian quartzites and quartzose flags with rare mica-schist bands and several, almost parallel, mineralized veins. On the eastern downthrow side there are soft grey micaschists in which no workable ore has been found. At many localities the main fault is itself ore-bearing. Stringers to veins 6 m in width are associated with NE – SW fractures of probable Old Red Sandstone age, and are generally filled by massive quartz with patchy calcite and barytes. The primary minerals were galena, sphalerite, chalcopyrite and pyrite, but the latter two were not worked. Uraninite, kasolite, tetrahedrite and pyrargyrite are also recorded. The galena and sphalerite are usually disseminated throughout the quartz but may occur as distinct ribs. Secondary minerals include pyromorphite, malachite, calamine and native sulphur occurring in veins, irregular masses and metasomatic replacements. Tetrahedrite inclusions are present in many galena samples from the area, but are most abundant in fine-grained massive galena from the 'Hard Vein' of the main mine, where they may be up to 100 microns in size. Inclusions from cadmium-rich samples contain over 20 wt % silver.

Mining was carried out intermittently from 1741 to 1925, in which year 90 tonnes of lead concentrates were produced. Cobalt bloom (erythrite) found in very small quantities in Tyndrum Mine yielded 1837 g silver per tonne. The only economically viable silver was found as argentiferous galena which appears generally to have assayed 300 g silver per tonne and, more rarely, 1.2 kg silver per tonne in so-called 'steel ore'. The maximum recorded annual silver production was 7.1 kg in 1860.

STRONTIAN

Lead-zinc mineralization occurs in the Movern and Sunart districts of Highland Region, collectively known as the Strontian area, and mining took place during parts of the 18th and 19th centuries. The country rocks consist of Moine mica schists, banded quartzites and augen gneisses cut off to the south and east by the Strontian granite. A dolerite and

camptonite dyke system has intruded pre-existing fractures in both schists and the Caledonian granite. Nearly all the lead-bearing veins follow E – W or WNW – ESE trending faults and the mineralization appears to be associated with the emplacement of E-W trending vertical camptonite dykes.

The E-W trending Strontian Main Vein, up to 8 m wide, is proved over 1.7 km, and follows camptonite dolerite dykes lying close to the edge of the Strontian granite. By analogy with the occurrence of camptonite dykes in other parts of Scotland, the mineralization probably post-dates the early Permian. The primary minerals are galena and sphalerite with some pyrite. Strontianite and zeolites also occur.

The period of maximum exploitation was the 18th century, when annual production was about 400 tonne of lead. The Bellsgrove Mine, at the eastern end of the Main Vein, reported 115 g silver per tonne of 'ore' in 1852, but only 47 g per tonne in 1865. At Corrantree Mine some galena samples assayed 570 g silver per tonne. Much interest has been shown in the economic potential of the Strontian deposits during the last 25 years and the area has been subjected to detailed investigation and commercial feasibility studies, but mainly for barytes. A flotation mill is due to be commissioned in mid 1983 to produce barytes concentrates with by-product lead, zinc and silver, the latter minerals accounting for a substantial percentage of total sales value.

NEWTON STEWART

Numerous small lead-zinc veins occur in the south-west Southern Uplands in west Kirkcudbrightshire near the edge of the Cairnsmore of Fleet granite, and some have yielded some quantities of silver in the past. The area is composed of Silurian flags, shales and greywackes, with underlying Birkhill Shales. Intense folding, hornfelsing by granite, and intrusion of numerous felsite dykes have occurred. The majority of the veins, which are preferentially associated with greywackes, trend WNW – ESE. The Wood of Cree mine yielded up to 70 g silver per tonne of 'ore'; the Silver Ridge Mine, about 1 km from the River Cree, was reported at one time to yield lead ore rich in silver. The East and West Blackcraig mines, about 4 km south-east of Newton Stewart, were worked for lead at the end of the 18th, and during the 19th centuries. They yielded some silver, as did the nearby Cairnsmore Mine the lead from which contained about 110 g silver per tonne. Galena at the Woodhead mines, 5 km west of Carsphairn, assayed about 100 g silver per tonne.

ORKNEY, CAITHNESS AND SUTHERLAND

At least one argentiferous lead mine was in operation on the island of Hoy, Orkney, before 1529, although most of the workings date from the 18th century. Lead was worked most extensively in west Mainland from the Stromness Flags, the basal formation of the Middle Old Red Sandstone succession, which is here banked unconformably against Moine basement. Other lead and copper workings were located in the Rousay Flags and Eday Flags. Throughout the sequence there is a clear relationship between lithology and abundance of lead-zinc and copper and, hence, silver. The channel sands always contain the least, while the dark bituminous shales contain the most concentrated mineralization. However, these metals do occur locally in basal conglomerates at Yesnaby.

The argentiferous galena is disseminated throughout the siltstones, occurs as veins in association with minor faults or replaces stromatolitic layers. The Orkney ores are believed to be of remobilized syngenetic origin, the metals introduced on the clay detritus, having been deposited in the presence of sulphate-reducing bacteria. Galena at Selwick on Hoy was said to contain 1.4 kg silver per tonne and argentiferous lead 'ore' at Scabra Head on Rousay contained about 2.1 kg silver per tonne.

The silver content of argentiferous galena mined on a small scale at Achanarras in Caithness and reported elsewhere in Caithness and eastern Sutherland has not been recorded.

Alluvial deposits in Suisgill Burn, Helmsdale Valley, Sutherland District, Highland Region, have yielded electrum containing 70% silver. Production took place on a very small scale for a few years during the 19th century.

STRUY

Argentiferous lead mineralization occurs in the southern part of Highland Region west of Strath Glass near the village of Struy. Small scale mining took place at three localities early in the 19th century from veins which also contained barytes and a little sphalerite. The country rocks are flaggy micaceous Moine schists and quartz granulites, with concordant lenses of hornblende schist and pegmatite. The veins are associated with E – W crush zones and are up to 1.8 m wide. Assays in 1867 from four mines near the west end of Loch na Meine showed 62% lead concentrate grading 688 g Ag per tonne, and 75% lead concentrate grading 130 g Ag per tonne.

STRONCHULLIN

Veins in Dalradian rocks north-west of Stronchullin, Loch Fyne District, Strathclyde Region, were formerly worked for lead but in about 1909 were found to contain significant gold and, to a lesser extent, silver values. The complex ore consisting of galena, sphalerite and chalcopyrite assayed 12% Pb and up to 145 g Ag per tonne. Trial concentrates containing up to 21% Pb, 2.2% Cu and 100-180 g Ag per tonne were produced from the Clachan Beag Mine.

CORRIE BUI: TOMNADASHAN

Argentiferous galena occurs in north-south trending siliceous veins cutting Upper Dalradian schists south of Loch Tay which, when worked in the 19th century at Corrie Bui, about 20 km SW of Aberfeldy, Tayside Region, yielded from about 2-18 kg Ag per tonne of galena. Silver occurs at Tomnadashan, about 4 km NNW of Corrie Bui, associated with tetrahedrite, chalcopyrite and molybdenite.

NORTHERN IRELAND

There are numerous records of small lead-zinc deposits in crush zones in the Lower Palaeozoic of Co Down and South Armagh, and areas in the Sperrin Mountains of northeast Antrim, are underlain by Dalradian schists which contain small local galena deposits. However, very little is recorded of their silver content and the only mines known to have worked argentiferous galena operated during the 19th century in both Co Down and Co Antrim. The main producer was the Conlig – Newtownards lode

which extends nearly N – S for several kilometres south of Bangor, Co Down. It contained less than 70 g Ag per tonne of lead. Three small lead mines, Castleward Mine near the south end of Strangford Loch, Co Down, and College and Dundall mines in the SW of Co Armagh, also produced a little silver, at an average grade of about 100 g Ag per tonne of galena. The Northern Ireland area produced up to about one-third of the lead output of mines working in the whole of Ireland in the 19th century and in its peak production year of 1852 contributed only 2% of the United Kingdom total.

CHANNEL ISLANDS

Silver was produced on a very small scale from several localities in the Channel Islands – at Le Pulec in N-W Jersey during the 1870's and at Sark's Hope Mine, Little Sark, in the 1840s. At Le Pulec, three predominantly zinc veins cut the Precambrian Brioverian Shales close to their contact with the Northwest Granite. Small amounts of argentian tetrahedrite occur, as well as galena, the latter grading from 9.1 to 20.1% Ag. The more extensive deposit at Hope mine comprises an argentiferous galena vein that cuts the foliated Precambrian granites of Little Sark. Secondary minerals are common in the upper zone, and in the northeast the lode contains cerargyrite and argentite. Argentiferous enargite (Cu_3AsS_4) is also present (3.9% Ag) and increased amounts of silver have been reported with alteration of the primary minerals.

A report in 1843 on the Blancheland mines in the Parish of St Martin, Guernsey, describes silver-lead lodes at Petit Bot and Moulin Huet Bay with gossans similar to those found on Sark. Mining ceased due to local opposition and legal problems. Lead veins with 'good quality silver-lead ore' have been found in L'Etacq in the north-west of Jersey, but were not mined.

Secondary Sources

For many years world consumption of silver has been well above mined output and recently secondary, or above-ground, supplies have accounted for anything up to 40% of world demand. Such sources of silver include the following:

- Scrap (new and old);
- Demonetized coin;
- Government stockpiles, commodity exchange stocks;
- Refiners, fabricators and dealers stocks;
- Hoarding

Scrap

New scrap is generated during the manufacture of silver-bearing products and components. It consists of such materials as clippings, tank scrapings, sludges, and rejected new film. The most important source of old silver scrap is the photographic industry, (well over half of the total supply) with subordinate amounts from batteries, electrical components and domestic ware. Normally new or 'run-around' scrap cannot be considered as a resource, but new and old scrap are not readily separable in the production statistics of the big secondary refiners such as Johnson Matthey and Engelhard.

Increases in the price of silver generally promote great efforts to improve silver recovery from scrap; for example, after the increase of the early 1970's and, more spectacularly, in late 1979 and early 1980, recovery from photographic wastes was greatly improved. Manufacturers collect feed-pipe sludges and rejected film, processors recover silver from their exhausted fixing solutions, and hospitals, among others, collect old photographs and negatives (primarily radiographs) as well as recovering silver from spent fixer solutions. When colour films and papers are processed, almost all the silver is removed by the fixing or bleaching baths. When black-and-white films are processed, between 60-80% of the silver in the emulsion is removed and can be recovered from the fixer. Most photographic processors and almost all hospital X-ray departments recover silver from spent fluids, and DIY chemical recovery cartridges are available from such producers as Kodak Ltd., and such refiners as John Betts Refiners Ltd.

Depending on the type of black-and-white film and the percentage of exposure, up to 22 g of silver can be available for recovery from each kilogram of processed film scrap.

Other sources of industrial scrap are usually widely scattered and more difficult to collect economically. Silver solders or alloy parts of large components are sometimes separated by scrap merchants, but normally find their way to the silver recovery unit of a base metal smelter. It is only in the battery sector that re-cycling is acknowledged as profitable, although the use of silver in batteries has been halved in the last decade.

Less important sources of scrap include the melting down of old jewellery, old mirrors and vacuum flasks. The early 1980 silver price 'high' brought out supplies of antique silver jewellery for a short period, but generally these scrap sources are fairly insignificant.

Silver scrap recovery figures exist only for the USA (25% recovery rate) and Japan (around 10% recovery rate). Much of Japan's photographic film is exported, so that large amounts of silver recovered from Japanese-made film appears in the secondary silver statistics of other countries. Recovery in most industrialised countries is about as efficient as it can be using current technology, so that the recovery level of 25% will probably not be greatly improved upon in the medium term, unless the price rises again significantly.

Demonetized coin

A major, if irregular, source of secondary silver is demonetized coin. This can be the result of official demonetization by governments or unofficial demonetized coin contributed by collectors and other individuals. Large scale demonetization took place after the First World War and again reached a peak in 1968, mostly resulting from large demonetization programmes in the USA. Sometimes demonetization results in a net surplus of silver supply from coin, for example in the last decade, while at other times there is a supply deficit. The USA is the largest source of demonetized coin, although countries such as Germany F.R., Austria and several of those in the Middle East have small amounts of coin (both private collectors items and government supplies) available for melting. The US Treasury releases small amounts of silver for coinage requirements

on a regular basis. In 1982 there were over 20,000 tonnes of silver in US silver coin alone, with a further 800 tonnes in silver coin from other countries (Table 4).

Government stockpiles and commodity exchange stocks

Stocks of silver exist in most countries in the form of bullion, coin and even jewellery. Statistics covering these sources of supply are most reliable for the USA where refiners, fabricators and dealers report to the US Bureau of Mines. The US General Services Administration stockpile has been a potential silver supply source for many years and from 1977 the stockpile objective was declared to be zero (based on the theoretical security of supplies from Canada and Mexico). Silver from this stockpile has appeared on the market periodically since 1981, although the effect is generally thought to be disruptive. Sales are restricted to US buyers and releases were originally planned at 31.1 tonnes a month. However, interest has waned, and the government stockpile of 5,200 tonnes in March 1982 remained largely intact in November of that year, representing a significant potential resource. The budget for fiscal year 1984 projects a sale of 10 million ounces. The US Defense Department also holds a small stockpile of about 150 tonnes to cover its requirements. The reported size of government stocks held in the USA and elsewhere are shown in Table 4. Stockpiles in countries other than the USA are not known and sales are usually irregular; for example, the USSR often pays for urgently required imports by selling off stocked silver. The Mexican government occasionally puts large amounts of silver on the market to reduce stocks provided the price does not fall too far.

Commodity exchange stocks include those of the London Metal Exchange and COMEX (New York). Four groups of stockholders may be termed 'private': the Chicago Board of Trade (CBT); the London Metal Exchange; COMEX; and the US refiners, fabricators and dealers inventories. The London Metal Exchange usually carries around 1,000 tonnes of silver while US and other refiners' stocks vary considerably and may amount to only about seven days supply (Table 4).

Hoarded silver

Large 'above-ground' resources of silver occur as privately hoarded silver, the most significant of these being distributed among the citizens of India and the Indian sub-continent. The silver, occurring as jewellery and ornaments etc., has been accumulated over centuries and has made India a major supplier to the world silver market, despite very small domestic primary production. Dishoarding occurs when the free market price rises rapidly and private individuals cash in their family heirlooms. However, the Indian Government curtailed the private exportation of silver in early 1979 in an attempt to stem the flow of silver out of the country, and exports dropped from about 930 tonnes per annum to virtually zero, but by the end of the year illicit trade via Middle East countries, notably Dubai, had been re-established and some 260 tonnes were exported. Estimates suggest that between 600 and 1,000 tonnes of silver were shipped out of India in 1980 and 1981. At present India's total stocks (not shown in Table 4) are estimated to be as much as 155,518 tonnes. The ultimate destination of about two-thirds of legal exports of Indian silver is the United Kingdom, frequently via Federal Germany, France and Switzerland (for refining).

There are also large 'above-ground' hoards of silver in the People's Republic of China, with official stocks estimated as between 6,200 and 7,800 tonnes, and there are very large unrecorded private stocks, largely accumulated as a result of China being the last country in the world to abandon the silver standard. It has been suggested that up to \$120 million worth of coins were smuggled out of China in 1980.

Table 4 *Summary of World Silver Stocks: 1982
(excluding those in Communist countries)

	Tonnes
Reported private stocks:	
New York Commodity Exchange	2,820
Chicago Board of Trade	490
London Metal Exchange	1,090
Industry stocks in the USA	650
Total	5,050
US Government stocks:	
Strategic stockpile	4,280
Defense Department	150
Treasury (Mint)	1,140
Total	5,540
Stocks of foreign governments:	4,670
Conjectural stocks:	
Unreported bullion stocks in USA and elsewhere	23,950
US silver coin	26,500
Foreign coin	780
Total	51,230
Grand total	66,520

*after Handy and Harman, 1983.

Individuals in other parts of the world hold very substantial silver stocks. The most celebrated are the Hunt brothers in the USA who, with others, were reported to have been involved in some degree of market manipulation which led, according to the final report to Congress of the Commodity Futures Trading Commission in May 1981, to the creation of an artificially high price for silver in 1980.

TECHNOLOGY

Silver mines may, for convenience, be divided into three major categories. Firstly, there are high-grade silver mines of the type found in northern Idaho, USA, where ore typically grades between 300 and 680 g Ag per tonne. Secondly, there are base metal mines in, for example, Mexico, Peru and western Canada, where silver is a co-product, some deposits grading 5 to 15% combined Pb and Zn with from 68 to 275 g Ag per tonne of ore, or mines with only nominal base metal values but up to 400 g Ag per tonne of ore. The third category comprises by-product silver mines such as the large porphyry copper deposits of the USA, the ore from which contains about 2 g Ag per tonne.

Mining

Silver ores are mined in many parts of the world by both open-pit and underground methods. For both silver ores and argentiferous base metal ores, underground mining of veins by drifting, cross-cutting, raising and stoping is the commonest extraction method. For example, in the silver mines of the Coeur d'Alene district of Idaho, USA, access is by vertical shaft with several winzes and development drifts along the veins. The nature of the steeply dipping mineralization, which increases with depth, lends itself to cut and fill or modern blasthole stoping methods. Because of the great depths involved (these are the deepest mines in North America) there is extensive roof bolting, and rock bursts are minimized by the use of sand fill and supports.

Large open-pit operations, either mixed base metal or low grade porphyry coppers, normally involve large face shovels and trackless rubber-tyred haulage. A typical example of such an operation which produces a significant amount of by-product silver is the Kidd Creek Cu-Zn-Pb-Ag mine, at Timmins, Ontario, Canada. However, the type of extractive method employed depends on such factors as orebody geometry, depth, character of host rock, terrain topography, transportation availability, reserves, grade, amortization of capital expenditure and other economic factors.

The Romans obtained silver in Great Britain from lead deposits at or near surface using very elementary mining methods. Even steep, narrow veins were generally exploited by trenching, but there were also some shallow underground operations. Fire-setting was used to break the ore, ie firing, followed by the application of water, causing the rock to crack and crumble. By the 19th century, the mining of silver from argentiferous lead ores in Great Britain had become much more sophisticated, with accurate mine plans, the use of explosives, mechanical pumping and sometimes forced ventilation, although the mines were still relatively shallow by modern standards. At the West Chiverton Mine in Cornwall, well known for the enhanced silver content of its ore, development was by means of at least five shafts giving access to a series of levels spaced at about 18 m intervals to a maximum depth of just over 133 m. Probably the most recently active argentiferous lead mine in the UK, the Greenside Mine in Cumbria, was worked until 1963 by adits and internal shafts to a depth of over 610 m.

There are at present no operating silver-lead mines in the United Kingdom, but lead is produced as a by-product of underground and open-pit fluorspar and barytes mining in the Northern Pennines and Derbyshire.

The resulting lead concentrates may contain a small but valuable proportion of silver which is recovered during smelting and refining.

Mineral Processing

Most primary silver is obtained by froth flotation of sulphides, followed by smelting and refining of the separate silver-bearing lead, copper and zinc concentrates.

Historically, silver was recovered from high grade, oxidized ores by relatively simple techniques based essentially on differences in density between the ore minerals and the gangue. Prior to 1900, rich oxide ores in the western USA were treated by smelting followed by *cupellation*, roasting followed by *amalgamation*, or sodium thiosulphate leaching subsequent to a chloridizing roast. Many different chloridizing, pan amalgamation (Washoe process), brine and hypo-sulphite leach processes were applied to the decreasing supply of simple silver ores. However, the *cyanidation* process patented in 1887 displaced these methods of silver recovery and by 1900 an increasing proportion of argentiferous base metal ores was being concentrated by gravity methods. The concentrates were smelted to recover precious and base metals. Froth flotation, first applied in the USA in 1911, was a revolutionary and greatly superior method of beneficiation which is effective in recovering finely divided sulphide particles and makes possible higher recoveries, particularly from copper ores.

Amalgamation and cyanidation

Only a very small proportion of newly mined silver is recovered from simple silver or gold-silver ores amenable to amalgamation and/or cyanidation. The Patio process, first employed in 1557 in Mexico, comprised the amalgamation of silver formed by the reaction of silver minerals with sodium chloride and copper sulphate. Amalgamation is applied to a limited extent to placer and vein gold ores in which silver occurs alloyed with the gold. Modern amalgamation practice involves washing coarsely ground ore with water on a mercury coated table or in a barrel amalgamator. The amalgam is ground with water to remove impurities, pressed to remove excess mercury and heated to vaporise remaining mercury which is then recovered by condensation. The sponge residue containing the precious metal is melted with fluxes and the resultant gold-silver bullion poured into bars.

Vein gold-silver ores are usually processed by a combination of amalgamation and cyanidation, whereas amalgamation of a gravity concentrate is the main recovery method for gold and by-product silver from placer ores. Hence, silver from placers is usually marketed as gold-silver bullion, while the silver in 'doré' bullion (silver bullion containing some gold) produced by combined cyanidation and amalgamation is often separated from the gold by chlorination or acid leaching.

Cyanidation for the recovery of gold-silver from simple vein-type deposits and from tailings involves leaching finely ground ore in tanks by percolation or by air agitation of a slurry and counter current decantation, followed by clarification of the gold-silver-bearing solutions. A final addition of zinc dust or shavings precipitates the precious metal. It is a technique that is still employed in Mexico and Peru, for example, and at De Lamar, Idaho, the largest silver cyanide plant in the world. Refractory

ores or complex telluride and sulphide ores normally require prior froth flotation, acid leaching and roasting to make the precious metals amenable to cyanide dissolution. A simple gold-silver ore, containing 2.7 g Ag and 11.3 g Au per tonne, is mined underground and processed at the Homestake mine in South Dakota, USA. Some 5,000 tonnes a day of ore are treated by gravity concentration, leaching and cyanidation, and chlorination to separate silver from gold. A major trend in recent years has been toward the processing of lower grade ores by heap leaching, a method which is considerably more economical than leaching after crushing and grinding. Cyanide heap leaching is also employed to recover silver from high-grade veins at the long famous Candelaria openpit mine in Nevada, USA. The crushed and agglomerated ore is placed on 91×366 m leach pads, the bases of which are composed of compacted clay. The caustic leach solution is distributed over the heaps by sprinklers and the resultant pregnant solution draining from the pads is collected, clarified and de-aerated. Zinc dust precipitation is used to recover the silver and gold, followed by melting of the precipitate in a reverberatory furnace. The doré metal resulting from the furnace melt is then weighed and assayed before shipment to refiners. Heap leaching operations are relatively easy to control environmentally. All solutions are recycled and the coarse ore does not tend to dust. Research is under way in the UK into the bacterial recovery of silver from leaching systems applied to low grade sulphide ores. Certain species of bacteria, naturally occurring in these deposits, are able to accumulate large quantities of silver, the recovery of which is under investigation.

Selective Froth Flotation

Current treatment of silver-containing ores is almost entirely by froth flotation. The process is applied to high-grade silver and argentiferous lead ores, low-grade porphyry copper ores, and complex copper-lead-zinc-silver ores. It is thus capable of treating ores which vary considerably in mineralogy, composition and grade. Processing may be complex, although remarkably standardized, with design of a particular circuit depending on the mineralogy of the ore, the grain size of the valuable minerals, the degree of intergrowth, and the flotation characteristic of the minerals, as well as the need to balance efficient separation with economic cost.

Fine grinding in water liberates the sulphide minerals and produces a slurry, which is then subjected to conditioning by surface active reagents which adhere selectively to the ore minerals. The pulp passes through banks of flotation cells where valuable mineral particles made hydrophilic by conditioning adhere to air bubbles and rise to the surface where they can be removed as a frothy concentrate. Selective recovery of different sulphide minerals into high quality concentrates can often be achieved. Very rich silver concentrate composed of silver minerals only is very rarely produced, and usually the silver occurs in an argentiferous lead concentrate or in lesser quantity in simple lead, copper and zinc concentrates. Even trace amounts of argentiferous tetrahedrite in, for example, low grade copper ore, can be successfully upgraded by bulk flotation to about 120 g silver per tonne of typical copper sulphide concentrate.

Flotation of silver ores, including, for example, some mined in northern Idaho, USA, results in separate argentiferous tetrahedrite and argentiferous lead-iron concentrates; the former may contain 38,228 g Ag per tonne, while the latter assays about 5,143 g Ag per tonne. The final

copper concentrate from low grade, open-pit copper ores mined in, for example, the western USA, contains about 110 g Ag per tonne and represents an estimated recovery of over 90% of the silver in the ore.

Complex sulphide ores that contain by-product silver may be composed of a variety of mineral associations and several high grade products may be recovered, hence milling practice is necessarily complicated. Because of relatively low base metal values, economical operation frequently depends upon a high recovery of all marketable by-products, including silver. Furthermore, it is desirable that the silver be recovered with the lead or copper, rather than with the zinc, because of the comparatively low credit given for silver at zinc plants. The silver content of typical lead and zinc concentrates originating from a complex sulphide ore (for example, the former Bunker Hill Mine, Idaho, USA) might be about 1,426 g Ag per tonne and 200 g Ag per tonne respectively.

Relatively high-grade lead-silver ores tend to be mineralogically fairly simple, and are worked on a relatively small scale with simple flotation plants of moderate capacity. Flotation of a typical ore containing 12% Pb, 1% Zn and 720 g Ag per tonne (for example, Lucky Friday Mine, Idaho, USA) produces a lead concentrate containing essentially 70% Pb and 4,114 g Ag per tonne, and a zinc concentrate assaying 55% Zn and 137 g Ag per tonne.

Argentiferous zinc ores were thought to be uncommon until it was shown that significant amounts of silver can be present in zinc sulphides, notably sphalerite. However, even when predominantly zinc rich deposits are mined, most of the silver is recovered with the lead concentrate. For example, in Montana, USA, the Anaconda Co. processes ore containing 5% Zn, 1% Pb and 34 g Ag per tonne to produce a 1,714 g Ag per tonne lead concentrate; the zinc concentrate contains about 105 g Ag per tonne.

Occasionally, metallurgical problems arise in the flotation of silver minerals when manganese is present. At a medium-sized operation, at Uchucchauca, Peru, conventional flotation did not separate alabandite, a manganese sulphide, from the silver and a lixiviation process had to be included following flotation. The silver-manganese concentrate is treated with sulphuric acid to dissolve the manganese and leave the silver as a solid residue.

Research into silver extraction technology of many types is active, including investigation of collecting systems for the extraction of silver from seawater. A variety of chemical collectors has been suggested and currently a resin collector is favoured as part of a low capital, low operating cost plant, relying upon the dynamics of sea water motion for its energy requirements.

Tests have shown that it is feasible to mine silver and base metal-rich muds which occur on the bed of the Red Sea using a suction head at the end of 2,000 m of steel pipes suspended below the mining ship. A vibrating screen and jets of sea water break up the mud, which is then sucked up the pipe. In the ship the metals are separated by froth flotation and the resultant concentrate further upgraded to at least 32% zinc, 5% copper and 0.074% silver before transfer to the shore, where a metal-chloride leach will probably be applied.

Primary smelting and refining

The production of refined metals, including silver, from base metal concentrates normally involves a number of pyrometallurgical and/or hydrometallurgical operations. As the precious metals content of the concentrates varies widely, most modern base metal smelters are designed to achieve an economic balance between high recovery of the principal metals and moderate recovery of by-products from variable feedstocks.

The smelting of lead concentrates involves sintering and agglomeration, followed by blast furnace reduction with coke and fluxes to make lead bullion; silver is carried down with the lead, while zinc and gangue minerals remain in the slag. After drossing to remove any copper, silver is separated from the lead bullion by the Parkes Process which was patented in the UK in 1850 and involves the addition of zinc to the molten silver-lead. Silver has a higher solubility in zinc than in lead, and the higher melting point zinc-silver alloy solidifies first to form a crust which can be skimmed off. The resultant silver-zinc (Ag_2Zn_3) alloy is pressed to remove any entrained liquid lead and sent to retorts where the zinc is removed by distillation. The residue is cupelled to recover gold and silver as 'doré' metal (crude silver containing a small amount of gold). Desilvering is normally carried out in two stages to ensure a high recovery, after which the lead contains very little silver, 0.0007% Ag, for example, at the Buick Lead Smelter, Missouri, USA. Cupellation is applicable to both the residue from the Parkes Process and to lead bullion resulting from secondary smelting operations (Fig. 3).

The Parkes Process is employed at the Northfleet, Kent, refinery of Britannia Refined Metals Ltd., for extracting silver from lead bullion imported from Mount Isa Mines Ltd., Australia. The bullion normally contains about 3,086 g Ag per tonne. The typical 'BL Co' Fine Silver thus produced contains no less than 99.92% Ag and not more than 0.035% Cu, 0.015% Pb, 0.0001% Bi, 0.0009% Au and 0.0003% Fe. Plant capacity is currently over 450 tonnes silver a year. Lead bullion, assaying 600 g Ag per tonne, is produced by the Imperial Smelting Process by Australian Mining and Smelting Europe Ltd., at its Avonmouth smelter, but further treatment of the bullion for the separation and recovery of precious metals is undertaken elsewhere.

During the smelting of copper concentrates silver remains with the copper and is eventually recovered from the argentiferous anode slimes (Fig 4). Silver is not produced as a direct by-product of the smelting and refining of zinc concentrates. In the retort process, silver remains in the retort along with lead, copper, and other non-volatile impurities. If the silver content of these residues is sufficiently high, they can be shipped to a specialist smelter for recovery. In electrolytic zinc plants most of the silver, with the lead and some gangue, remains in the primary leach residue which can be processed in a lead smelter. Silver-bearing leach residues are usually rich in silver and lead, and more easily reprocessed by lead smelters than the complex zinc retort residues. Research is actively being carried out in several parts of the world to try and improve zinc refining technology and in particular the treatment of residues for the recovery of silver and lead.

The range of primary materials that are processed for the recovery of silver is illustrated by Canada, one of the world's six largest producers. The most important producer of refined silver is a copper company, recovering the metal mainly from the treatment of anode and blister

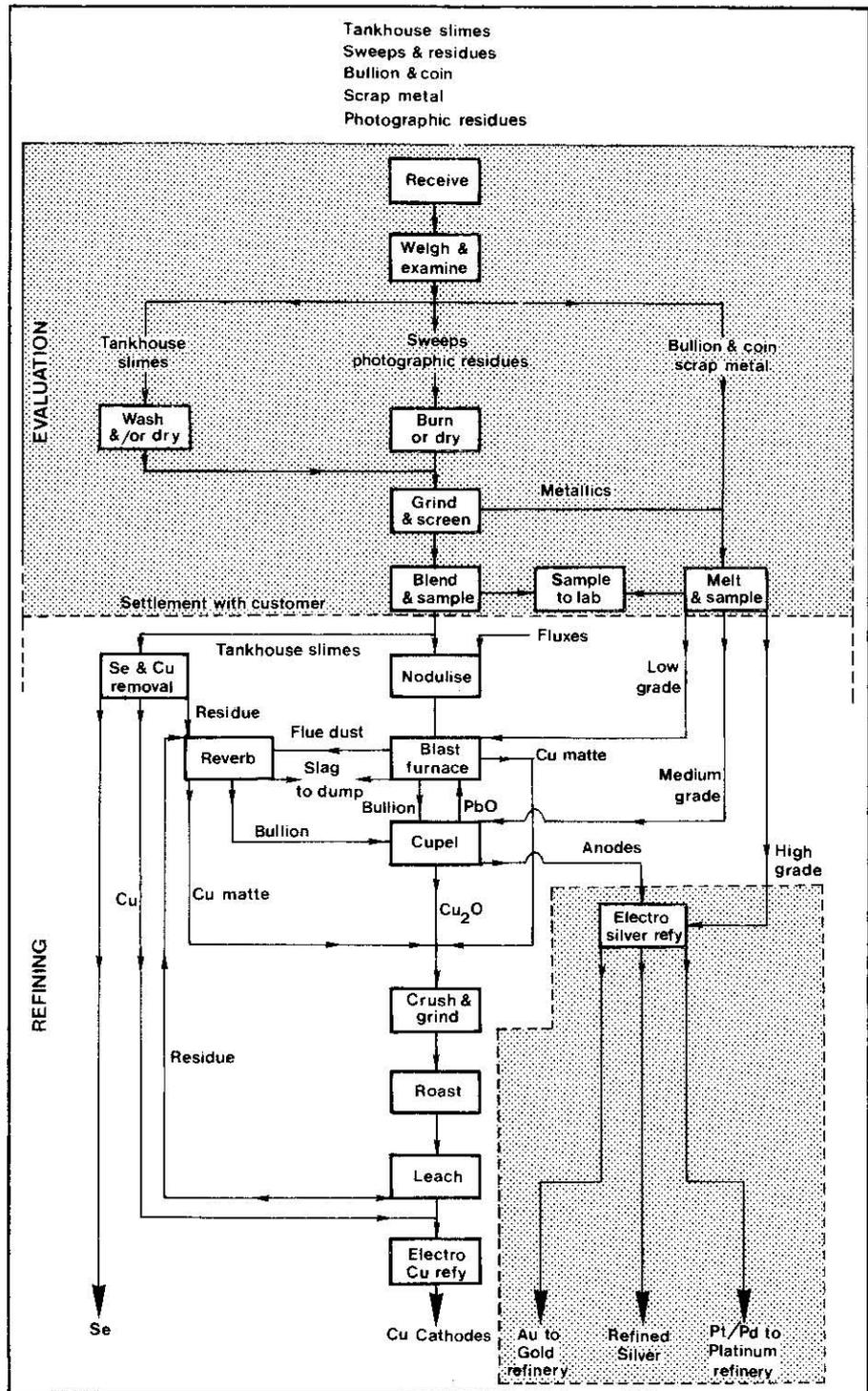
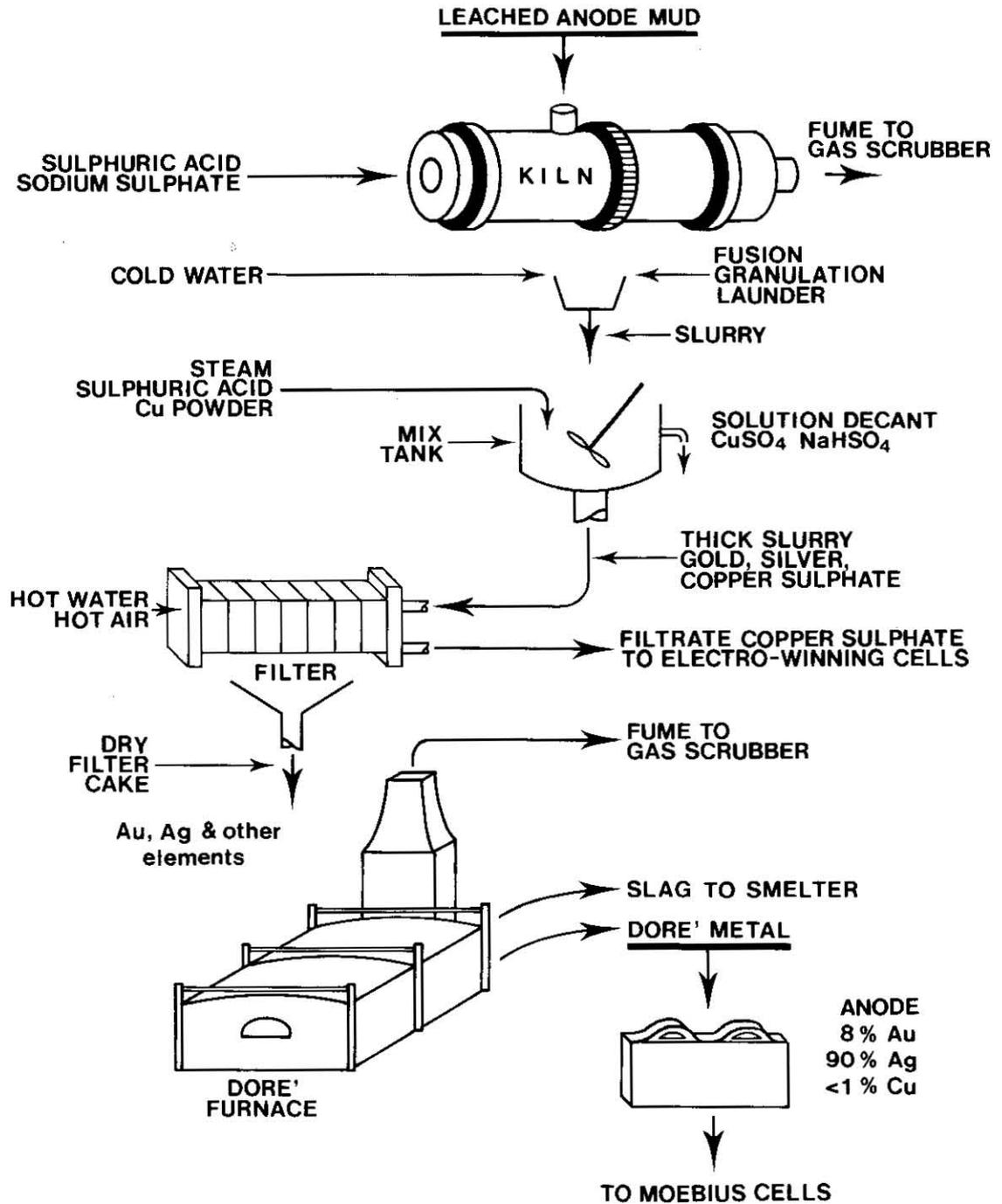


Figure 3 Process flow sheet at a large precious metals refinery (Johnson Matthey Chemicals Limited, Brimsdown, Enfield).

Source: after Embleton, in Robbins (ed.) 1979.

Figure 4 Processing of copper anode mud (slimes) for the recovery of precious metals

<i>Anode mud composition</i>		<i>Doré metal analysis</i>	
Copper	30%	Copper	less than 1%
Selenium	12	Selenium	" " 0.001%
Tellurium	3	Tellurium	" " "
Lead	2	Lead	0.02%
Arsenic	2		
Antimony	0.5		
Silver	99,427 g/tonne	Silver	86 – 92%
Gold	9,94 g/tonne	Gold	8%
Palladium	72 g/tonne	Palladium	0.16 to 0.18%
Platinum	6.9 g/tonne	Platinum	0.005 to 0.009%



After: LEIGH A.H., 1981 (Utah refinery example)

copper and the further refining of lower-grade silver bullion. Another major producer recovers by-product silver during the processing of its own, as well as custom, lead and zinc concentrates. Other sources of refined silver include nickel-copper concentrates, the Royal Canadian Mint (from gold bullion) and silver-cobalt concentrates.

Secondary recovery

Scrap silver has been recovered for centuries, but because of increases in industrial use and major price rises, there has been a considerable growth in secondary recovery in recent years.

At one time scrap silver was obtained mainly from jewellery manufacturers, but photographic materials and electrical and electronic scrap are now the most important sources. In the United Kingdom, this wide variety of silver-bearing materials is received by the major refineries of Johnson Matthey Chemicals Ltd., Sheffield Smelting Ltd., (Engelhard Industries UK) and John Betts Refiners Ltd., (W. Canning Group), for the separation and refining of precious metals.

Scrap and waste materials that contain recoverable silver occur in many physical and chemical forms and much of that generated and collected by industry is too impure for direct use or simple refining. The processing, smelting and refining of secondary precious metal scrap thus necessitates the use of complex but highly flexible flowsheets. Two main routes for silver recovery are in use: --

- i. a pyrometallurgical process, primarily for low-grade refractory-containing solids;
- ii. chemical techniques for liquids and solid wastes taken into solution.

The pyrometallurgical route may involve incineration to remove organics, drying, grinding, screening to remove metallic particles and homogenising for sampling and evaluation. The powder may then be mixed with suitable fluxes and nodulised (briquetting having been largely replaced some twenty years ago) prior to smelting in a blast or reverberatory furnace. Nodulising is often omitted in reverberatory smelting, but its use may improve the smelting reaction and reduce dusting losses. Three main material refining routes are operated by Johnson Matthey at Brimsdown incorporating secondary and primary materials: tankhouse slimes, sweeps and bullion (Fig 3).

Silver-containing liquid (and some solid) wastes are chemically processed to recover the metal. Chemical routes may also involve an initial incineration followed by acid attack; silver can then be recovered by precipitation as chloride, oxide or metal.

The sharp, albeit somewhat temporary, rise in the price of silver in 1979/80 prompted many metal finishing, electrochemical machining and photographic companies to attempt to recover the valuable metal discharged with their effluents. In addition, there has been more pressure to render wastes less toxic before disposal in landfill sites and as agricultural sewage sludge. Recovery of precious metals such as silver along with less desirable and toxic metals such as cadmium, mercury and lead, helps to create a more favourable balance in the costs of metals recovery. Methods for recovering metals include electrolysis, chemical

displacement and ion exchange. Process solutions containing salts of valuable metals can also be recovered by evaporation or occasionally by reverse osmosis. These techniques can be used for recovering almost any metal, but are obviously more cost effective when applied to silver than, say, lead.

The black and white, colour and X-ray film manufacturers, processors and users generate large quantities of both solid and liquid silver-bearing wastes including trimmings, spoiled and out-dated film, print paper, contaminated emulsion, spent fixing and bleach solutions and waste water. Waste film contains about 1-10 g Ag/m², emulsion wash solution contains about 0.1 g Ag/l and spent fixing bath contains about 4-10 g Ag/l. Precipitation and electrolytic methods are applied to the more silver-rich liquid wastes, while ion exchange techniques are sometimes used for dilute solutions.

There are two basic methods commonly used for recovering silver from photographic solutions – metallic replacement and electrolytic plating. Several companies market metallic replacement silver recovery cartridges and/or electrolytic silver recovery cells in the UK, for example Kodak Ltd., John Betts Refiners Ltd., Metelec, Photographic Silver Recovery (PSR) and others. The units can be bought by the processing laboratory or leased from one of these companies, who will then install it, monitor it, and remove the silver-bearing waste for refining.

Commercially available metallic replacement cartridges usually consist of a plastic bucket or metal barrel containing steel wool. The iron in the wool reacts with the silver in the fixer and replaces it in solution. The silver settles to the bottom of the cartridge in the form of a sludge.

Electrolytic cells are more complex than metallic replacement cartridges, both in design and operation; they are also much more expensive, but the silver recovered by them is purer and more easily refined. A large variety of electrolytic cells of differing capacity are available. In general though, they all work on the electrolytic plating principle. The silver is removed by passing a controlled electrical current between two electrodes suspended in the silver-rich fixer solution. Nearly pure silver plates out on the negatively charged electrode and these cathodes are removed and stripped of their silver from time to time. Electrolytic recovery cells have the advantage that they can be incorporated into a continuous circulating system which will recover 90-95% of the silver in a fixer and if, in addition, chemical recovery cartridges are used on the desilvered fixer, reductions of up to 99% are possible.

Liquid wastes from the silver-plating industry are processed to precipitate the silver and oxidize the cyanide; typical silver cyanide plating waste solution contains about 250 ppm silver. Solid wastes from the sterling silver industry are, depending upon their composition, generally directly reused or shipped to a refinery. Silver-bearing scrap from the production and use of solders, brazing and other silver alloys, bearings, electrical and electronic components and batteries is generally very heterogeneous and is carefully sorted before processing by specialized precious metal smelters and refiners. Demonetized coin and coin manufacturing scrap, known as 'sisal', as well as stamping waste from coin and metal manufacture are usually cast into skillets. 'Lemel', the filings and turnings produced during jewellery manufacture, is passed through a fine sieve, heated to destroy all organic matter and mixed with flux before melting and casting.

For either pyrometallurgical or chemical routes, every individual consignment is carefully evaluated to determine the exact content of precious metals, on which payment to the customer is then based. The crude silver obtained from all sorts of secondary (and primary) materials is then electro-refined.

Electro-refining

Silver anodes cast from fire-refined metal are further refined by electrolysis in anode compartmented cells, where an insoluble anode sludge, which contains gold, is recovered. There are two distinct electro-refining methods now used in the UK. The Moebius process, (Fig. 5), introduced in 1884, is best used when considerable quantities of gold and platinum are present; the Balbach-Thum process is more economical when a smaller proportion of gold is present. Both processes use anodes with a purity greater than 95% Ag and the cathodes are either thin sheets of silver or stainless steel. A few Balbach-Thum installations, however, still use graphite cathodes. The electrolyte is always an aqueous solution of silver nitrate. In the Moebius cell, crystalline silver is deposited on the cathodes and removed by mechanical wooden scrapers. In the Thum cell the anodes and cathodes are horizontal and there are no moving parts, but otherwise their operation is similar to those used in the Moebius cell. The Thum equipment can accept any refinable metal whose silver content exceeds 75%, but the gold content must be limited to less than 20%. The silver deposit can be removed without interruption to the process in the Thum cell, but power consumption and labour costs are greater than for the Moebius cell. The Balbach-Thum installation requires more floor area per unit of output than does a Moebius plant. The refined metal is cast into 'Good Delivery Market Bars', 1,000 oz ingots, which bear the stamp of an accepted Melter and Assayer, rendering the silver suitable for sale on world bullion markets.

PROPERTIES AND USES

Silver is the whitest of metals and, as one of the 'noble' metals, possesses great chemical stability. The aesthetic appeal of its colour and its resistance to corrosion and atmospheric oxidation were factors determining the uses to which silver was put by early man, but the metal exhibits a number of other important physical and chemical attributes upon which its major modern industrial applications are based. The metal surpasses all other substances in both thermal and electrical conductivity, these being respectively about 33% and 8% greater than those of copper, for example. The electrical resistivity of annealed silver is the lowest for any metal, and it is slightly diamagnetic with a relatively high cross section for neutron absorption in the low-energy region. In general, silver is second only to gold for ductility and malleability and possesses good deep-drawing characteristics; one grain (five-hundredths of a Troy ounce) of silver can be drawn out into 122 m of wire.

The alloying properties of silver include low melting temperature, 960.8°C (one of the fixed points on the International Temperature Scale), fluidity, low strength and high ductility, excellent eutectic properties, small dimensional changes, good thermal conductivity, low solubility in iron and resistance to corrosion. The standard potential of silver is exceeded only by those of platinum and gold and it thus acts as a good cathodic depolarizer in aqueous solutions. The ease of electrodeposition of silver from, for example, the double alkali-metal cyanide, accounts also for its

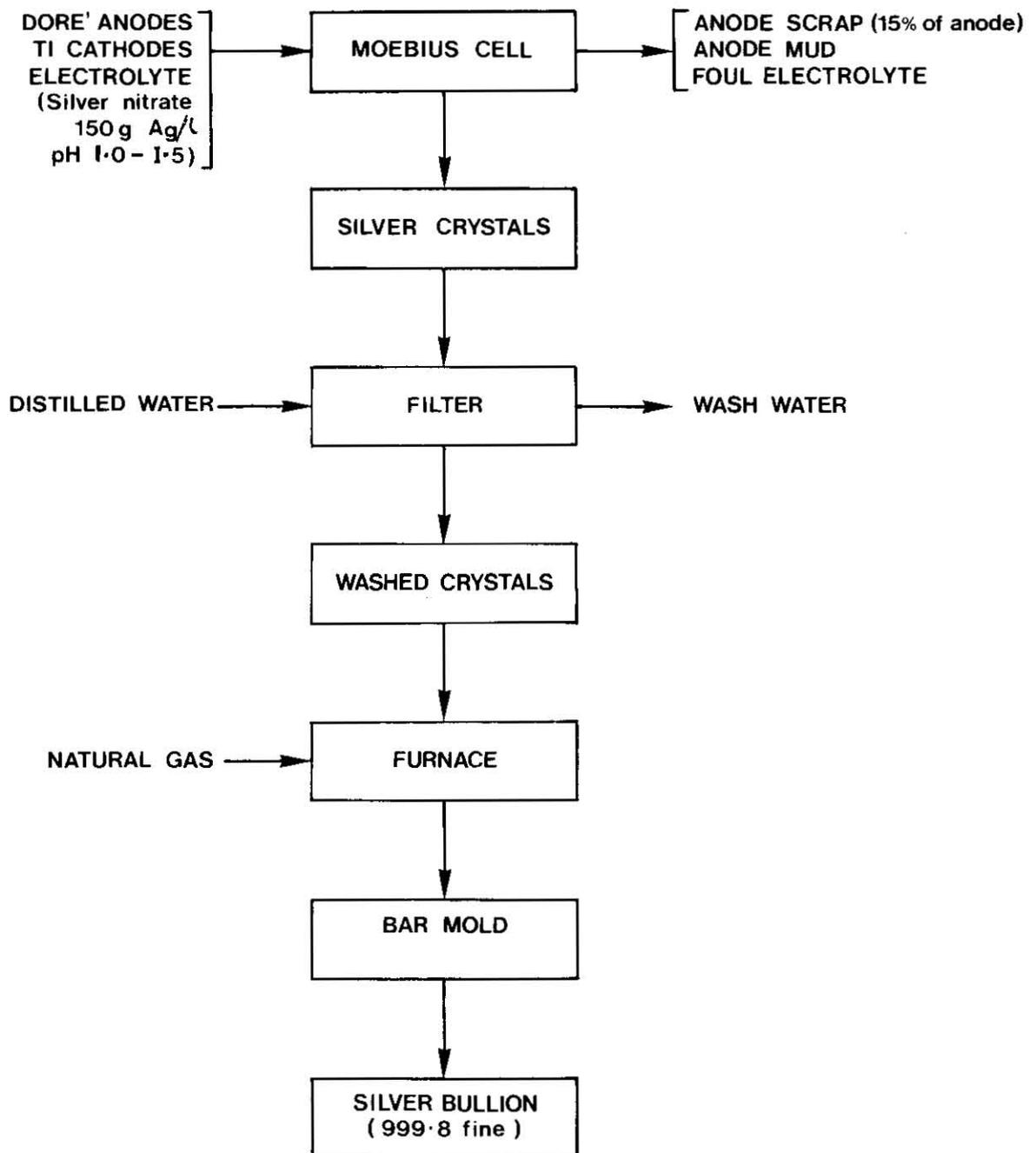


Figure 5 Electro-refining of silver: flow sheet
 After: LEIGH A.H., 1981 (Utah refinery example)

use in various coating applications. Silver has an exceptionally high reflectivity and can be readily reduced chemically from certain unstable compounds, hence its use in mirror and reflector surfacing. The photosensitivity of silver halide crystals and the ease with which silver can be reduced are the basis of its largest use, photography.

About 95% of total silver consumption is for 'industrial', that is, non-monetary, purposes (Table 5). Silver and silver compounds are used mainly in the following fields (in order of importance): photographic

Table 5 World silver consumption, proportion by country*: 1978-1982

<i>Industrial uses</i>	1978 %	1979 %	1980 %	1981 %	1982 %
USA	36.0	37.5	35.6	33.9	34.2
Canada	2.0	1.9	2.5	2.5	2.5
Mexico	1.3	1.3	1.0	1.0	1.1
UK	6.6	6.3	5.9	5.4	5.6
France	5.0	5.1	5.8	6.0	5.2
Germany F.R.	10.7	8.8	8.3	8.0	9.4
Italy	9.4	7.9	6.4	7.2	6.5
Japan	14.6	16.4	17.6	17.4	16.8
India	4.5	4.5	5.4	5.5	6.3
Belgium	3.8	4.0	4.5	4.7	4.2
Other	6.0	6.3	7.0	8.4	8.2
	100.0	100.0	100.0	100.0	100.0
Total tonnage	13,766	13,057	10,883	10,703	11,110
<i>Coinage</i>	%	%	%	%	%
USA	0.3	0.4	0.7	—	12.7
Canada	0.8	0.8	1.5	2.2	2.5
Austria	12.4	18.0	31.4	33.3	33.9
France	30.6	27.7	—	—	—
Germany F.R.	10.0	13.3	—	—	—
Mexico	17.4	18.0	44.5	—	—
Other	28.7	21.6	21.9	64.5	50.9
	100.2	99.8	100.0	100.0	100.0
Total tonnage	1,129	865	426	280	367
Total consumption	14,895	13,922	11,309	10,983	11,477

Source: After Handy & Harman, 1983.
* excludes Communist-dominated areas.

products; electrical and electronic products, including batteries; silver plating and silver ware; brazing alloys and solders; jewellery; catalysts; coins, medallions and commemorative objects; dental and medical supplies; mirrors; and other miscellaneous uses. The amount of silver consumed in different countries for each of these end uses varies quite widely. For example, silver used in the photographic industry accounted for some 57% of Japan's total industrial silver consumption in 1981, whereas in the U.S.A. it accounted for only about 37%. The European Economic Community and, more specifically, the United Kingdom's silver consumption for this end use fall about mid-way between the two (Table 6). Consumption of silver for coinage varies considerably, both geographically and in time. Certain European countries and Mexico, for example, have traditionally been important minters of silver coin. Mexico consumed about twice as much silver in coinage as for industrial purposes in 1980. However, she did not mint any silver coins in 1981, a fact which caused her total silver consumption to drop by some 63% over the previous year. Generally, though, total consumption of silver in coinage is so small compared with its industrial consumption that even the 1978-1981 marked decline in the minting of silver coin worldwide failed to affect world total silver consumption by more than about 4%.

Table 6 EEC and UK silver consumption by major end-use, as reported in 1978*

	<i>EEC</i>		<i>UK</i>	
	<i>tonnes Ag</i>	<i>%</i>	<i>tonnes Ag</i>	<i>%</i>
Photographic products	1,588	41	407	45
Electrical and electronic products:	587	15	207	23
Contacts and components,	n.a.	n.a.	167	18
Batteries	n.a.	n.a.	40	4.5
Brazing alloys and solders	496	13	135	15
Jewellery and silverware	800	20	27	3
Other industrial uses	429	11	126	14
Total industrial uses	3,900		902	
Coinage	457		—	
Total consumption	4,357		902	

* Source: adapted from ERA Report No. 80-136, 1978.

Photographic materials

The largest single use for silver is in the manufacture of photographic materials which account for some 40% of the metal used industrially in the Western World. Nearly all black-and-white and colour films contain silver salts and despite the small quantities of silver required for each film, the growth of colour photography has been a major factor in the

increasing consumption of silver. The photographic process is based on the presence of light-sensitive silver halide crystals in the unexposed film. The effect of light on silver halide is to produce minute grains or clusters of metallic silver which may be as small as five atoms in size and which are the latent images which can initiate development. The silver salts, when immersed in mild reducing agents (photographic developers), are changed to metallic silver, the rate of reduction being significantly increased if silver halide crystals carry very small amounts of metallic silver at the developer-crystal interface. The silver clusters serve as very efficient catalysts for this reduction, providing an amplification factor of $\times 10^6$ - 10^7 of the effect produced by the original light exposure.

Developments in silver photographic technology include the first black-and-white consumer film, produced in 1980, in which the final image consists exclusively of dyes from which the silver has been completely removed and can therefore be recovered and recycled. It is unlikely, however, that the availability of monochrome films of this type will have any impact on the amount of silver used or recovered by the photographic industry.

Electrical and electronic components

Electrical contacts, conductors and batteries account for about 25 per cent of the silver used industrially in the United Kingdom. Silver has been used extensively for many years, both in solid form and as an electroplate, on electrical contact material for electrical switches operating over a wide range of current and voltage. It offers advantage over copper for electrical purposes, principally because of its resistance to oxidation, and is used in both AC and DC applications. The ductility of pure silver enables it to be formed easily into components used in contact devices such as solid, tubular and composite rivets, solid buttons and composite silver-faced screws.

Silver-based alloys containing copper are used in both AC and DC applications where there is a need for greater hardness. However, the presence of copper lowers the melting point considerably as well as the electrical and thermal conductiveness, and increases the tendency to oxidation as well as the surface film resistance. A greater force is therefore required during closure of the contacts to assist in breaking down surface films. These silver-copper alloys are cheaper and can be fabricated by methods similar to those used for pure silver. The addition of cadmium provides alloys with good arc-quenching properties and high resistance to material transfer, mechanical wear, welding and arc erosion. Whereas pure silver contacts weld at a current load of 800 A, comparable silver-cadmium oxide contacts can resist welding at a load of 2,000 A. The resistivity and hardness of these alloys increase with cadmium content. Such alloys are used in AC and DC circuits, switching both light and medium currents. Silver alloys used in television tuners contain about 5.5% cadmium and 7.5% copper; those employed in motor car and aircraft starter switches and other devices subjected to high surge currents contain about 15% cadmium. Where high electrical currents are carried for long periods, it is now usual to employ contacts prepared by powder metallurgy methods, using silver powder and various oxides, the most common of which are silver-cadmium oxide mixtures.

Electrical switchgear employed in the generation and distribution of electricity incorporates silver in conjunction with tungsten, tungsten

carbide or molybdenum to avoid overheating and as a means of coping with short-circuit currents of several thousand amperes. These materials, which are fabricated by powder metallurgy techniques, have good electrical and thermal conductivities, resistance to arc erosion, high strength, and resistance to welding or sticking. The higher the electrical conductivity desired, the higher the required silver content of the material.

High voltage switches of both air and oil type can be manufactured from alloy with 27.5% silver and 72.5% tungsten. Circuit breakers for household and aircraft use may contain about 35% silver and 65% tungsten. As molybdenum is arc-resistant, like tungsten, but has a lower density, silver-molybdenum materials have applications where mass is a critical factor. Thus a 50:50 silver-molybdenum mixture is used in high voltage oil circuit breakers, while arcing contacts in power circuit breakers may contain up to 60% molybdenum and 40% silver.

A group of alloys containing small amounts of magnesium and nickel in silver behave like fine silver in being resistant to corrosion and staining, and are used where a combination of high electrical and thermal conductivities is required, together with a hardness uninfluenced by the temperatures of soldering and brazing or by high working temperatures. Characteristic applications include brazed electrical contacts; high-heat-conductive spring clips for miniature vacuum-tubes; instrument and relay springs; and electrical parts that have to be severely formed and hardened. About 15 tonnes of silver are consumed annually in the United Kingdom in the manufacture of 200 million fuses.

Batteries

The use of silver in electrical batteries arose from military requirements during the Second World War, the main advantage being high energy output per unit weight and volume. Disadvantages are relatively short life when in use and higher cost, factors which have deterred extensive commercial use. About 85% of the silver battery market is concerned with military and space technology and, to a lesser degree, life saving equipment. A battery unit for military purposes normally contains from 5 to 10 kg of silver.

Silver oxide-zinc primary batteries are widely used in torpedoes, missiles and rockets. They have excellent 'shelf life' prior to activation and, stored below 40°C, show very little change in performance over a five year period. More importantly, they are able to deliver full wattage and capacity instantaneously. Very small silver oxide primary cells are used to power hearing aids, quartz watches and pocket calculators. Silver oxide secondary batteries are also used in torpedoes, missiles, aircraft, submarines, satellites and space vehicles, where energy delivered per unit of weight and space is of prime importance.

Silver chloride-magnesium batteries have been produced almost entirely for military purposes, including torpedoes and sonobuoys, and can be activated at the time of use by immersion in either sea or fresh water. The energy output is 15 to 20% less than that of compatible silver oxide-zinc batteries, but the activating system is simpler and more reliable. Use for emergency lights on ships is still a minor application. Silver oxide-cadmium secondary batteries have been developed for use in torpedoes and aircraft, but short life and maintenance problems have so far curtailed use. Silver tungstate is used in the positive electrodes of alkaline

batteries containing metallic lithium or metallic sodium negative electrodes. Sealed button cells which can be recharged up to 500 times have been developed for use in electronic watches. They contain silver peroxide and oxide anodes with an alkaline electrolyte and have high electrical capacity.

Silver oxide electrodes with improved polarising properties have been developed for use in the oxygen side of fuel cells. An alternative is made by preparing an alloy containing 79% aluminium, 20% silver and 1% gold, and dissolving the aluminium to leave the silver and gold in a structure with a very high surface area. High energy silver-hydrogen fuel cells with long life and reliable performance have been developed for space applications; their ability to both overcharge and overdischarge permits the use of a simplified battery circuit. Power for heart pacemakers is obtained from miniaturised fuel cells with very thin silver cathodes.

Brazing alloys and solders

Silver brazing alloys, sometimes known as 'silver solders', are based on silver-copper alloys, with additions such as zinc, cadmium, phosphorus, silicon, tin, nickel, manganese and indium. The alloy and its composition is varied to suit the metals to be joined and the method to be employed. They account for about 80 tonnes of silver used annually in the United Kingdom. Brazing alloys and the silver solders are together sometimes termed 'hard solders' to distinguish them from the lower melting point and weaker 'soft solders', predominantly composed of lead and tin. They contain from 10 to 80% silver and are designed for the joining of ferrous and non-ferrous metal parts. To a lesser extent they are also used to join certain refractory and rare metals, and dissimilar combinations such as stainless steels to non-ferrous metals and powder metal parts to graphite. These alloys liquefy at much higher temperatures than soft solders, are ductile, and produce a union giving considerably better mechanical properties (eg resistance to shock and vibration) and higher corrosion resistance. The silver lowers the melting range of the alloys so that they have great fluidity at temperatures between 680 and 870°C.

A silver-lead-tin soldering alloy is used in special applications where the tin content renders the solder resistant to a damp atmosphere. Gold-silver-copper alloys are used as solders for jewellery manufacture and in dentistry. Small quantities of other metals may be added to adjust melting points (step soldering) and aid colour matching.

Catalysts

Silver is used as the catalyst in a number of processes, for example, in the dehydrogenation of methanol to formaldehyde, where the silver must be of minimum 99.95% purity and where specifications may call for levels of certain base metal impurities to be less than 1 ppm. The oxidation of ethylene to ethylene oxide (an intermediate stage in the production of solvents, artificial fibres and detergents) is performed on an industrial scale using a silver catalyst supported on a carrier such as pumice. A silver-beryllium catalyst has also been developed for a similar purpose. Silver and silver-iron-palladium catalysts are used in motor car exhausts to reduce nitric oxide emission. Silver-palladium is a catalyst for

the reduction of nitro-benzene to azobenzene, an insecticide. In the synthesis of nitrites from aldehydes and ammonia, a combination of silver and zinc is used as the catalyst.

In the industrially important process of reforming or converting paraffin petroleum distillates into the more valuable high octane petrol, catalysts made of platinum and rhenium have been widely used. It has recently been discovered that the inclusion of silver greatly improves their chemical activity and enables the process to take place at lower temperatures.

Mirrors and reflectors

The silvering of glass to make mirrors and reflectors dates from only 1835, before which date either speculum (a copper tin alloy) or a mercury coating was used. The modern silvering process involves two separate solutions, one containing silver and the other a reducing agent. The two solutions are mixed together just prior to use and the prepared glass surface is covered with the reacting mixture, from which the silver precipitates. An important advance in the mirror industry was made when a protective coating was developed that could be baked on at temperatures of up to 115°C, thus sealing the vulnerable silver. The spent silvering solutions carry significant recoverable silver values. The reflectivity of clean silver is extremely high in visible and infra-red light but shows a sharp drop in the near ultraviolet end of the spectrum, where the metal is therefore unsuitable for use in reflectors. The motor car industry is an important user of silver-coated mirrors and reflectors and silver has also proved to be very efficacious in the enhancement of the sun's rays on solar collectors. In 1980, one of the largest single orders ever placed required 9.32 ha of mirrors coated with pure metallic silver for use in a major solar energy installation in California.

Bearings

Silver became important as a bearing material primarily in the aircraft industry during the Second World War. Steel bearings electroplated with silver have greater fatigue strength and higher load-carrying capacity than any other type used in aircraft engines. Optimum fatigue strength and highest anti-seizure properties are obtained by using very high purity silver only. For heavy-duty bearing applications, silver plated with an overlay is almost invariably used, because silver itself possesses poor surface characteristics. Silver on steel with an overlay is regarded as the most fatigue-resistant bearing material. However, the high cost of silver can be justified for only a few specialized applications, chiefly in the aerospace industry. In the main engines of NASA's space shuttle, for example, silver seals reduce friction and prevent sparks that could ignite the shuttle's explosive liquid-oxygen propellant.

Dental and medical

The good mechanical properties and small dimensional changes that occur during the setting of certain silver-tin-mercury alloys are the basis for the extensive use of silver in dental amalgams. The silver content may be from 65 to 70% and there are sometimes additions of small quantities of copper and zinc. The silver-tin fillings supplied are ground with mercury, generally five parts of alloy to eight parts of mercury. Such dental amalgams are more durable and much less prone to breakage and

replacement than are silverless fillings. Figures for the UK are lacking, but in the USA some 60 tonnes of silver are used each year in dental work. Silver compounds such as silver thiocyanate or ammoniacal silver nitrate are effective in killing dental bacteria and arresting dental caries.

The bacteriocidal properties of silver and certain silver compounds, notably nitrates and citrates, are also employed in antiseptics, particularly for the treatment of eye, nose and ear diseases. Silver iontophoresis, or 'super antibiotic' treatment of sepsis, depends upon electrically generated silver ions which act as extremely potent anti-microbial agents with an exceptionally broad spectrum of activity and which penetrate deeply into body tissue. The technique is useful in the treatment of wound infection, bed sores, chronic ulcers, massive third degree burns and other difficult infections.

Metallic silver is used in the production of alloys for surgical instruments and parts. Its ability to activate oxygen to kill bacteria is employed in some swimming pools. Charcoal filters impregnated with silver eliminate germs and the need for irritating chlorine in the water. The metal is also used by European airlines to purify drinking water.

Jewellery and domestic uses

Silver has working qualities comparable with gold, possesses greater reflectivity, and can take the most brilliant polish of any metal. Pure silver does not tarnish, but in order to make it durable enough for jewellery it is normally alloyed with small quantities of copper, when it becomes liable to tarnish unless gilded. The introduction of rhodium plating has made it possible to produce silver with a tarnish-resistant surface, but the appearance of the surface is then slightly altered.

The quantity of silver used in jewellery has fluctuated markedly with changes in fashion since the Bronze Age. For example, it replaced gold in popularity in the 1880s but during the 1890s was generally considered to be vulgar. It is illegal in the United Kingdom to offer for sale as 'silver' any goods or objects containing less than 92.5% silver.

Britannia silver, which contains 95.83% silver, is occasionally used because it is softer and more easily fashioned into difficult shapes. Filigree, a decoration with fine gold or silver wire twisted into patterns, has been used in jewellery since about 2500 BC and there was a revival of filigree jewellery during the 19th century.

Sterling silver, an alloy of 92.5% by weight of silver and 7.5% copper, is harder than pure silver and, by varying the heat treatment, a wide range of properties can be obtained. It has been the principal standard of silver used in England since 1300. Sterling silverware is divisible into 'flatware', ie forks and spoons, and 'holloware', which includes teapots, coffee pots, jugs, bowls and chalices. Flatware is now produced from sheet or strip metal, mainly by machine. Holloware is produced both by modern industrial mass production methods and by craftsmen using hand techniques that have altered very little over the centuries.

Copper articles coated with silver by a fusion process invented in 1742 by Thomas Boulsover are known as '*Sheffield Plate*'. From 1840 to 1860 nickel-silver gradually superseded copper in Sheffield Plate and the

process lapsed soon after the introduction of electroplating. 'Close plate' was produced in Birmingham by soldering silver foil to iron or steel articles.

By about 1870 *electroplate* had largely replaced Sheffield Plate and is frequently used in the United Kingdom in the manufacture of spoons, forks, teapots and coffee pots. The marking EPNS refers to the electroplating of silver on to Nickel Silvers or 'German Silvers', a group of alloys containing copper, zinc and nickel; EPBM signifies the electroplating of silver on to Britannia metal, a type of lead-tin alloy, or pewter, containing tin, antimony and copper. It is an offence under the Trade Descriptions Act, 1968, to offer for sale as silver plate any objects which are produced by electroplating silver on base metals. Instead, they must be described as 'silver plated'.

The aesthetic beauty of silver and the ease with which it could be worked led to its widespread use for ornamental purposes in the Ancient World, but unfortunately, because of its relatively perishable nature, few objects have survived compared with those of gold. In the United Kingdom, the use of domestic silver dates from at least the first half of the 7th century and by the middle of the 11th century many silver objects had accumulated in English abbeys and monasteries. During the Middle Ages silver objects 'made in the English manner' were highly prized throughout Europe. Most medieval English silver was wholly or partially gilded, using the amalgam process, many objects being decorated with brightly coloured enamels and inset with precious or semi-precious stones. English commemorative medals were first issued in the reign of Henry VIII and coronation medals date from Edward VI. Silver medals were produced to commemorate, for example, the defeat of the Spanish Armada, the Battle of Blenheim and the Battle of Waterloo; they reached a peak of mass production in the reign of William IV. Silver medals, medallions and insignias are now produced in large numbers for a wide variety of occasions, for example, a large tonnage is usually required for the Olympic Games medals.

Coinage

From the early days of its availability until comparatively recently, the largest use of silver was for monetary purposes, as a safe store of value and as a means of exchange, by virtue of its scarcity (high value per unit), corrosion resistance and ductility. Silver coinage is not now a regular requirement and accounts for only about 4% of total world silver consumption.

The original form in which silver entered trade was as 'pieces of silver', which comprised roughly melted ingots, or lumps of cut or sawn metal. The 'talent', the Phoenician unit, based on Babylonian usage, weighed about 46.5 kg. The first coins, 'staters', were made from electrum, a natural alloy of gold and silver, in the state of Lydia, Asia Minor. Coined money spread to Greece in the latter half of the 7th century BC; the first silver coins, known as 'drachmae', were struck on the island of Aegina and were the world's first international currency, circulating widely in the eastern Mediterranean. In 269 BC, a Mint was established in Rome producing silver coins known as 'denarii', which became full legal tender in 207 BC and became the basis of the monetary system devised for the Roman Empire by Augustus in 14 BC. Partly as a

consequence of Arab disruption of Mediterranean trade, Charlemagne, King of the Franks, abandoned the gold standard in 793 AD and established a monetary system based on the silver 'denier', 240 of which were cut from a pound of silver.

Gold and silver coins based on Greek models circulated in Britain prior to the first Roman invasion in 55 BC. After the final departure of the Romans, these continued to circulate for some time, but local rulers soon began to strike their own coins. A multitude of small and rather crude silver coins, collectively known as 'sceats', appeared in the early Anglo-Saxon period (575–775). Some have a small bird on the obverse side, which has been identified as a starling, perhaps the origin of the word 'sterling'. The first English silver 'penny' was probably struck in about 765 AD, and remained the standard of value in England until 1816 when a complete recoinage was begun with the transfer of the Mint from the Tower of London to Tower Hill. The Act of Union of 1707 provided for a coinage of the same standard and value in both England and Scotland.

Silver coins issued between 1920 and 1946 were produced from an alloy containing only 50% silver; these were replaced by coins of the same type and weight made of cupro-nickel in 1947. Currently circulating United Kingdom coinage contains no silver, unlike commemorative proof and uncirculated coins or sets. The 25 pence crown is composed of 925 (92.5%) silver, and Maundy money (penny, twopence, threepence, and fourpence) has the metallic composition 925 silver, 75 copper. The latter is minted for special distribution of the Royal Maundy on Maundy Thursday.

About 84 countries now produce silver coins of over 240 different types. One of the largest current issues is the Mexican 925 fine sterling silver bullion 'coin' called the Onza Troy, weighing exactly 1 Troy ounce. The most popular silver coins celebrate the Olympic Games, conservation themes and international causes as well as the usual births and marriages of the famous. In the UK silver proof coins were produced by the Royal Mint to celebrate the marriage of Prince Charles and Lady Diana Spencer in July 1981.

SUBSTITUTES

Silver is generally unsurpassed in the majority of its applications and the most important factor influencing substitution, in the absence of supply interruptions, is price. The price of silver is high in relation to other metals, and it will inevitably be substituted wherever possible by cheaper materials. In some uses, however, performance must be sought without regard to cost. For example, a considerable amount of silver is used as the optimum material for bearings and engine sealing rings in the NASA space shuttle, although silver-on-steel and other composites are acceptable and economically preferable in most other applications.

In its main industrial use, photography, some substitution of silver will take place as progress continues with silverless image reproduction. Improved technology has led to reduced silver requirements in some photographic products, particularly X-ray films, and all manufacturers will no doubt continue to strive for future improvements. There is at least one technique in which silverless X-ray pictures are made on low cost plastic sheets. Also, substitution for traditional X-ray methods is taking place with the introduction of computer-backed electronic scanners

which detect X-rays and synthesize digital information to produce a VDU picture. Silverless thermographic films also exist for high resolution aerial photography where the image is composed of an organic dye. Other silverless photographic techniques have been studied, including photopolymer contact lithofilm electrophotography. In addition, research has been conducted on black and white film which does not fix silver in the negative. Agfa-Gevaert, for example, developed a film in 1981 in which the silver is totally replaced by bismuth, which is much cheaper. Although not as effective as bismuth, several other metals are theoretically suitable substitutes. However, none of the new techniques are as yet adaptable to colour film. Silver is not recovered from instant photographic film, the use of which has been increasing, although about half of the silver in 'peel-apart' instant materials could be recovered from the discard sheet.

As well as research into silverless photography, methods have been devised to minimize the silver content of existing products. One of the aims is to improve the design of more sensitive photographic emulsions and the methods of coating. Similarly, in electrical and electronic applications, solid-state switching devices will reduce the demand for the silver coating of switch contacts, as will micro-miniaturization. The study and development of sintered powder metallurgy, silver deposition processes on common metal substrates, and improvement of the physical characteristics of existing contacts will all provide substantial economies in the electrical contacts field. However, it is difficult to substitute totally for silver in this sector because of its excellent electrical and thermal conductivity, but research is progressing on the study of the role of filler elements, such as cadmium oxide, tungsten or tungsten carbide.

The biggest reduction in the industrial usage of silver may occur in brazing. Smaller volumes of brazing alloy will be employed through improved joint design and partial replacement by different bonding agents. In some cases good results have been achieved with phosphorus. Lower percentage silver alloys are already being used. New modes of assembly using new technology without brazing (bonding, friction assembly, etc) are being used in many industries. On the other hand, extensive substitution for silver in button cell batteries is unlikely. Some reduction in silver content and increase in the manganese oxide content is possible, but the current intensity thus obtained is only sufficient for certain new instruments which contain low current-consuming displays.

In the manufacture of mirrors and reflectors, aluminium and rhodium have been used as substitutes, but with less efficiency. Similarly, the high fatigue strength layer provided by silver in bearings can be substituted by one containing aluminium, copper-lead or bronze, but these materials are not as efficient in combatting welding and seizure. In catalytic applications there has been little research into alternatives and advances in this sector are likely to be slow. New varieties of dental amalgams also incorporate a lower percentage of silver and composites are available which contain no silver. Although not as good as silver amalgams, they may find greater application as the price difference becomes more pronounced. Tantalum is a generally accepted alternative metal to silver in, for example, surgical plates and pins. Sulphonamides and antibiotics have largely replaced silver in the treatment of serious infection. Cupro-nickel, cupro-zinc, nickel and aluminium are now extensively used substitutes for silver in circulating coinage, although silver is still

preferred for collectors coins and medallions. Much domestic silverware has for many years been substituted to various extents by stainless steel and, more recently, bronze.

SPECIFICATIONS

The following British Standard Specifications relate to silver:

BS 1561:1966. 'Silver anodes and silver salts for electroplating' defines the minimum silver content and the maximum amount of insoluble matter permitted.

BS 1845:1966. 'Filler metals for brazing': Silver brazing alloys are included.

BS 1871:1952. 'Minimum requirements for silvering for glass reflectors for lighting purposes'.

BS 2816:1957. 'Electroplated coatings of silver for engineering purposes' covers the ranges of thicknesses for various base metals and deals with the purity of the silver used.

BS 2938:1961. 'Dental amalgam alloy (silver-tin)' specifies requirements for an alloy composed essentially of silver and tin used in preparing amalgam fillings for teeth.

BS 3382 (6):1967. 'Electroplated coatings on threaded components. Silver on copper or copper alloy (including brass) components' includes sampling procedures and methods of thickness determinations for bolts, screws and nuts.

BS 4290:1968. 'Electroplated coatings of silver for decorative purposes on nickel, silver and copper'. Appendices give methods of test for average thickness, local thickness and adhesion.

In addition the British Standard Code of Practice CP 3003 Part 8 1970, 'Lining of vessels and equipment for chemical purposes: Precious metals' gives guidance to manufacturers and users of vessels and equipment lined with silver and other precious metals on selection, design application, maintenance, inspection and testing. The standard specification for refined silver accepted in the trade is the American Society for Testing Materials Designation B 423-69. It covers refined silver in cast bar form in the following three grades:

Grade 99.90 which has a minimum purity of 99.9% and is commonly referred to as commercial bar or bullion.

Grade 99.95 which has a minimum purity of 99.95%.

Grade 99.99 which is a premium grade with a minimum purity of 99.99%.

Maximum permitted contents of bismuth, copper, iron, and lead are specified for each grade, and for *Grade 99.99* a maximum permitted content of palladium, selenium and tellurium is specified; special attention is paid to sampling procedures. In case of disagreement, the chemical composition of the material must be determined in accordance

with ASTM E378. The bar has to be marked to identify the manufacturer, the minimum fineness, the melt number, the bar number, and the weight to the nearest 0.1 troy ounce.

Other ASTM specifications relating to the determination of silver are as follows:

E37. 'Chemical analysis of (silver in) pig lead'.

E46. 'Chemical analysis of (silver in) lead- and tin-base solder metal'.

E56. 'Chemical analysis of silver brazing alloys'.

E86. 'Chemical analysis of (silver in) cadmium metal'.

E227. 'Spectrochemical analysis of (silver in) aluminium and its alloys by the point to plane technique using an optical emission spectrometer'.

E378. 'Spectrochemical analysis of silver by the powder D-C Arc technique'.

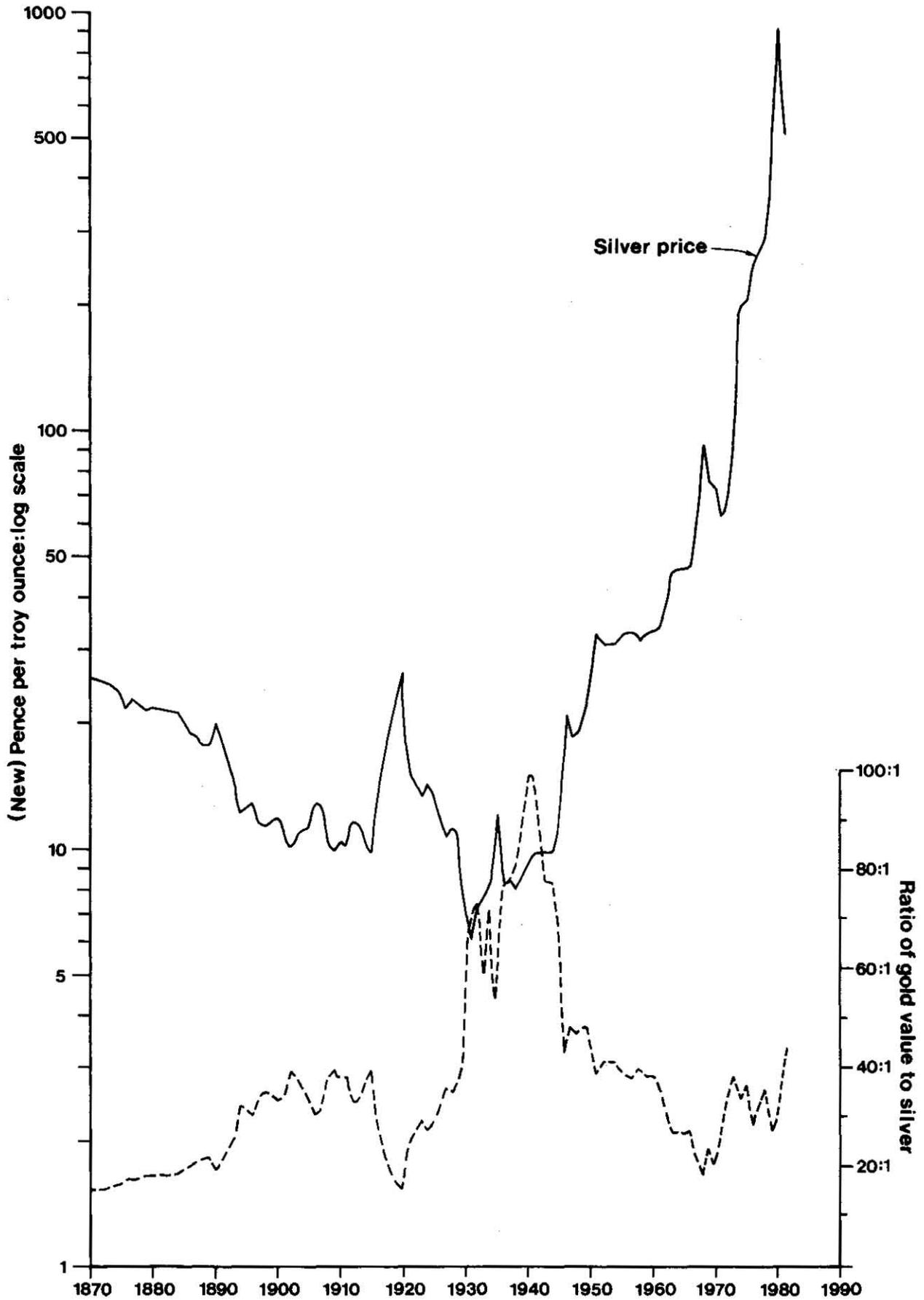
Silver delivered under contracts with the London Silver Market, the London Metal Exchange (LME), the New York Commodity Exchange (COMEX) and the Chicago Board of Trade must be in bar form and should have a minimum purity of 99.9%. Bars with a minimum purity of only 99.5% are traded in Chicago on the Mid-America Commodity Exchange. Silver with less than 99.9% can be sold in the London Silver Market but is subject to charges incurred in refining it to the required level to make it of good delivery (and is not available until it has been refined). Commercial silver bars vary in weight: approved bars up to about 1,250 troy ounces are acceptable in the London Silver Market; the London Metal Exchange accepts bars weighing between 450 and 1,250 troy ounces; 1,000 troy ounce bars are traded on the New York Commodity Exchange, the Mid-America Commodity Exchange and the Chicago Board of Trade.

PRICE

Figure 6 illustrates the course of the silver price between 1870 and 1981. From 1870 to 1944 it is the London spot price for a standard bar .925 fine and from 1945 onwards for a standard bar .999 fine. At the end of 1982 the price stood at around 680 pence per troy ounce. Because of silver's dual character, as both store of value and industrial commodity, its price is the product of an unusually complex process.

As a store of value and sometime means of exchange, silver shares with gold some of the same price determinants. As a monetary standard silver has frequently been subject to government controls, notably in the USA which operated a bi-metallic (gold-silver) standard until 1873 and where silver prices continued to be regulated through Treasury purchases and sales until 1967. Silver, like gold, is also widely sought after as a store of value outside the strictly monetary context, particularly in those countries where there are legal restrictions on the private holding of gold. Some indication of the relative values accorded to silver and gold during the past century is given by the price ratios in Figure 6.

Figure 6 Price of silver and ratio of the value of gold to silver, 1870–1981.



Sources: Metallgesellschaft A.G., *Metal Statistics*, Frankfurt am Main; *Metal Bulletin*, London; Samuel Montague and Co., *Annual Bullion Review*, London; U.S. Treasury, *Annual Report of the Director of the Mint*, Washington.

The 'quasi-monetary' property of silver is reflected in the considerable quantities traded by private investors and speculators and especially in the fact that the metal frequently finds favour as an alternative to 'paper' currency holdings during periods of international crisis and rapid inflation. Since the market for silver is, in value terms, considerably smaller than that for gold, movements in private stockholdings have a correspondingly greater effect on the silver price and contribute significantly to its instability. The seven-fold increase in the silver price, from under £3 to over £21 per troy ounce, between the end of 1978 and the beginning of 1980 has been attributed, at least partly, to the speculative activities of the Texan millionaire, Nelson Bunker Hunt, and associates, who at one time are thought to have held around 29% of the world's commercially available silver bullion. Another important, if rather less dramatic, stock factor since the early 1960s has been the substantial release onto the world market of silver from private hoards in India.

Although silver pricing would still appear to be predominantly conditioned by the metal's quasi-monetary characteristics, since World War II the demand for silver as an industrial commodity has become an increasingly important influence on its market behaviour. The use of silver in photographic materials, electrical contacts and solders advanced so rapidly that throughout most of the 1960s and 1970s, a period during which the price of silver advanced strongly in real as well as money terms, industrial consumption of the metal constantly outstripped mine production, sometimes very substantially. Though accumulated stocks of silver and the increased amounts of salvage scrap which the industrial use of silver has generated proved adequate to meet this supply deficit, the deficit was nonetheless thought to be one of the factors contributing to the final demonetization of silver in the USA in the 1960s and to the market tightness of 1978-1980. Future silver prices will clearly continue to be influenced by the existence of this deficit, which will in turn depend, among other things, on developments in the metal's industrial uses and on the extent to which new metal production is constrained by its dominantly by-product status. Silver in private stockholdings, demonetized coin and scrap will remain important potential supply sources, and the price level will have to be such as to draw supplies from these sources onto the market as the deficit between industrial demand and mine production requires. Perhaps less sensitive to prices than to domestic policy considerations, supplies regulated by governments, notably those of India, Mexico, the USSR and the USA, will continue as an important market variable. Of particular significance may be the policy adopted by the US Government towards the GSA stockpile (which, at 31 March 1982 contained 137.5 million ounces of silver). Partly because the annual production of new silver is small in relation to above-ground stocks of metal, producers tend to have little influence over the market and only poorly developed relations with industrial consumers. Consequently, there is little likelihood that a producer pricing system could be developed. With the ending, in 1967, of the US Government's attempts to regulate prices, the world price of silver has been largely determined by free market forces in London, New York and Chicago. Each of these centres offers silver for immediate delivery at a cash or 'spot' price, and also provides quotations for future deliveries, such quotations being extensively influenced by interest rates. The most important markets, in terms of volume of business and influence on world price levels, are the futures markets operated by the New York Commodity Exchange (COMEX) and the Chicago Board of Trade.

However, relations between the various markets are close and all are subject to similar influences. A great deal of 'arbitrage' takes place (that is, trading the same commodity in two markets when their prices diverge) and price quotations on the different markets generally move in line with one another.

In London there are two important markets. The first of these, which owes much to silver's more traditional monetary role, is the London Silver Market (LSM), in which prices are 'fixed' by three major bullion brokers, Mocatta and Goldsmid, Samuel Montagu and Sharps, Pixley, in much the same way as London gold prices. These three brokers meet in private every day at noon to negotiate the prices, both spot and future, at which they are prepared to do business in prevailing market conditions. Less significant in terms of silver traded, but important nonetheless, is the London Metal Exchange (LME) which has dealt in silver intermittently throughout the present century, resuming in 1968 after a break of almost thirty years. The determination of silver prices takes place in a manner similar to that employed for other metals traded on the exchange, with dealings done orally by ring-dealing firms seated in a circle in four five-minute sessions a day. Lots are of 10,000 troy ounces of metal .999 fine and delivery may be made at London, Amsterdam, Rotterdam or Hamburg. Though LME prices tend to follow those of the LSM and the US markets, the LME serves as an important 'hedging' medium for bullion brokers and silver refiners, while its warehouses provide convenient additional storage for surplus silver stocks.

LAW

Legislation on silver is extensive, covering all aspects from ownership through production to trade and use, and is closely associated with that relating to gold. References to legislation concerning silver have been found in records from Ancient Egypt and Classical Greece, and much of modern precious metal legislation can be traced to Roman origins.

In the United Kingdom the rights to silver and gold, known as 'royal mines', whether occurring in land or the sea bed below territorial waters, are the property of the Crown. These rights are held in England and Wales by royal prerogative under common law. The Crown also has rights in respect of other ores which contain silver and gold in minor quantities. However, these rights were qualified by the Royal Mines Acts, 1688 and 1693. Silver and gold in Scotland became the property of the Scottish king by the Act of Annexation of 1424. These rights were passed on to the British sovereign by the Acts of Union, 1706-1707. Crown rights to royal mines in Northern Ireland are set out in the Royal Mines Act (Ireland), 1705. Silver and gold on or beneath the UK continental shelf beyond territorial waters belong to the Crown as a consequence of the Continental Shelf Act, 1964.

Following the precedent set by George III in 1760, each British sovereign surrenders to the nation the hereditary revenues due to the Crown in return for a fixed income known as the Civil List. The Crown Estate, including royal mines, is managed by the Crown Estate Commissioners established by the Crown Estates Act, 1961, who are empowered to issue prospecting licences and mining leases for the royal metals. Prospecting licences can be issued to *bona fide* mineral operators, for periods of two to five years on payment of a sum dependent, for example, upon the area licenced and its potential value. This gives the licensee the right to

take out a mining lease, the heads of terms being specified on the licence. Mining leases can be issued for specified periods, for instance 21 years, with options to terminate the lease at regular intervals. The lessee pays a specified annual rent merging into royalty.

Before a licence is granted, the applicant must satisfy the Commissioners that he has the consent of the surface owner to enter the land. If the Crown does not own the minerals which occur associated with the royal metals and they have been severed from the surface rights, the consent of the mineral owners is also required. A royalty rate of one-twentieth of the net value of the silver and gold recovered is charged where the production of these royal metals is the main purpose of the mining operation; where the mine is primarily a base metal producer and royal metals are only a by-product, the royalty rate charged is one-twentyfifth of the net value of the silver and gold recovered.

Rights to all minerals, excluding sand and clay, in the Isle of Man were vested in the UK Crown by the Isle of Man Purchase Act, 1765. However, under an agreement with the UK Government, Manx minerals are now under the jurisdiction of the Manx government or Tynwald. Exploration and mining permits, licences and leases are issued by the Forestry, Mines and Lands Board.

Hallmarking

The practice of marking precious metal objects to denote their quality dates from Ancient Egyptian times and is intended as a guarantee of the fineness, and therefore the value, of the metal.

Organised hallmarking of silver in Britain began in the 13th century, (the first legislation to regulate hallmarking being issued in 1238) and was controlled by guilds set up by medieval goldsmiths to protect their trade. Since then numerous pieces of legislation controlling hallmarking and the standard of coinage have been issued. Current hallmarking practice is set out in the Hallmarking Act, 1973, and is carried out at the official Assay Offices in London, Birmingham, Sheffield and Edinburgh. There are four marks indicating the standard of fineness, the Office where the article was assayed, the year of assay, and the marker's initials. The standard hallmark is a lion passant on articles 925 standard (ie 925 parts silver in 1000) and the figure of Britannia for articles of 958.4 standard. Foreign-made silver objects are hallmarked in the UK with the standard of fineness in figures only.

The Royal Mint has the right to visit any assay office to inspect, ascertain and assess the accuracy and efficiency of the methods and procedures used in the assay. Various silver articles are exempted from hallmarking under the 1973 Act, including silver plate, coinage, and articles used or intended for use in medical, dental, veterinary, scientific or industrial applications.

INDUSTRY

The largest world mine producers of silver include Centromin Peru, MIM Holdings (Australia), Industrias Penoles S.A. de C.V. (Mexico), Industrial Minera Mexico S.A., Asarco Inc. and Amax Inc. (USA),

Cominco Ltd. and Texasgulf Inc. (Canada). The Mount Isa Mine is currently the largest single producer of silver. Together with one or two other producers, such as Compania Fresnillo and Peñarroya, these companies or groups control about 70% of silver mine production. Silver is not, however, thought to be particularly vulnerable, since there is a fair amount of diversity in the major producers' political backgrounds and origins. Western Europe mined silver production is dominated by the Boliden Aktiebolaget group in Sweden, several companies in Spain (for example, Rio Tinto Minera S.A., Sociedad Andaluza de Piratas SA (APIRSA) and Soci ete M.M. Pe narroya—Espan a), and Rudarsko-Metalurski Kombinats Treпка (RMKH) in Yugoslavia.

Vertical integration is normally advanced, although within the EEC it is less so, since adequate domestic primary silver sources to supply its metallurgical plants are lacking. The metallurgical to manufacturing stages are, however, fully integrated. Table 7, although incomplete, summarises the main components of the industry structure in the EEC from the metallurgical stage. A clear distinction should be noted between metallurgical producers of silver (precious metals refining units integrated into base metal refineries) and silver refiners and fabricators who do not handle the metallurgical treatment of silver-containing minerals.

Pe narroya, Preussag, Norddeutsche Affinerie and Metallurgie Hoboken-Overpelt produce silver largely as a result of their own metallurgical production of base metals based essentially on imported concentrates or blister copper. Some base metal refiners do not process their silver-bearing residues (Pb-Ag residues, Cu anode slimes etc) themselves and have them treated by other metallurgical producers or silver refiners.

Table 7 Main components of EEC (excluding Greece and Spain) silver metallurgical to manufacturing industry

Company	Connection	Type of activity	Remarks
BELGIUM			
Metallurgie Hoboken-Overpelt	Société Générale de Belgique	metallurgical producer	1,800 t Ag/y, at Hoboken. feed:—silver-bearing materials resulting from Pb, Cu and Zn metallurgy —various kinds of scrap
Etma	—	smelter and refiner	a few tonnes Ag per year, at Wilsele. feed: all kinds of industrial scrap
Johnson Matthey & Pauwels	Johnson Matthey & Co (U.K.)	refiner and fabricator	a few tonnes Ag per year. feed: industrial scrap. manufacture of industrial jewelry and dental products, mainly.
FRANCE			
Peñarroya	Imétal (Rothchild group)	metallurgical producer	1978 production: 203,529 kg Ag, at Noyelles-Godault. Feed: silver-bearing materials resulting from the metallurgy of Pb and Zn.
Comptoir Lyon Alemand Louyot		refiner and fabricator	200 t Ag/y recovered from old scrap at Vienne ± 4500 t Ag scrap/y of refining capacity at Vienne and Noisy-le-Sec fabrication of semis at Noisy-le-Sec, Villeurbanne (wire drawing), Fontenay-Frésigny (electromechanics)
Compagnie des Métaux Précieux (and affiliates)		refiner and fabricator	fabrication of semis at Ivry and at subsidiaries' plants: Couragent (wire drawing) and Samex (electrotechnics) scrap treatment by Meprex
GERMANY F.R.			
Preussag A.G. Metall	Preussag A.G.	metallurgical producer	100 t Ag/y (91.6 t Ag in 1977) feed: residues from Pb-Zn metallurgy
Berzelius Metallhütten	Metallgesellschaft	metallurgical producer	124 t Ag in 1977 at Binsfeldhammer from Pb-Ag residues (doré silver)
Norddeutsche Affinerie	Metallgesellschaft—The British Metal Corp.— Degussa		600 t fine silver per year at Hamburg feed: Cu electrolysis slimes, Pb-Ag residues, scrap
Degussa	—	refiner and fabricator	1,500 t Ag per year, all semis
W.C. Heraeus	—	refiner and fabricator	all semis
ITALY			
Pertusola	Peñarroya	metallurgical producer	1978 production: 3.8 t fine silver 22.6 t Ag contained in Pb sulphate and Cu matte
Metalli Preciozi	Johnson Matthey & Co Ltd.	refiner and fabricator	contacts, brazing alloys, dental alloys, catalysts, gauges, industrial jewellery semis, salts
Ditta Gori e Zucchi		fabricator	silversmith and jewelry products
NETHERLANDS			
Drijfhout & Zoon's	Comptoir Lyon Alemand	fabricator	Ag compounds; melting, rolling and drawing of Ag feed: Ag bars
UNITED KINGDOM			
Britannia Lead	MIM Holdings	refiner	1978 production: 321,359 kg of 99% Ag at the Northfleet refinery. feed: lead bullion from Mount Isa
Johnson Matthey & Co Ltd.		refiner and fabricator	1,800 t Ag/y can treat low Ag-containing scrap
Engelhard Industries Ltd	Engelhard Minerals & Chemicals Corp.	refiner and fabricator	
John Betts Refiners Ltd	W. Canning plc	refiner	100 t Ag/y, as good delivery bullion bar; can treat low-Ag containing scrap

In the EEC, industrial scrap is usually treated in the country where it is generated, since treatment facilities of adequate capacity usually exist and the tariff structure discourages trade movements between member countries. Reliable estimates of the tonnages supplied to the EEC are impossible to obtain since supply sources are so diverse, eg imported and domestically produced lead, zinc and copper concentrates, blister, lead-silver residues and copper anode slimes, industrial scrap etc. However, as far as fine silver is concerned, all countries of the Community depend on non-EEC sources for more than 50% of their requirements, with about 87% of the UK imports coming from non-EEC countries.

United Kingdom production and processing

In the United Kingdom small amounts of base metal concentrates are produced containing a variable quantity of silver which is recovered during smelting and refining.

Silver mine production in the UK amounted to 3.3 tonnes in 1982 and comes from the copper-zinc concentrate produced by *Carnon Consolidated Tin Mines Ltd* at *Wheal Jane*, near Truro, Cornwall. The company is owned by Rio Tinto-Zinc Corporation Ltd. From 1969 to 1978, when the mine was operated by Consolidated Gold Fields Ltd., the concentrate was exported to Sweden for treatment at the Ronnskar plant of Boliden AB where silver was produced as a by-product at the electrolytic refinery. Since 1978 the copper-zinc concentrate has been sent to France, Belgium or Commonwealth Smelting Limited at Avonmouth.

Major UK producers of fluorspar and barytes, which also produce lead concentrates containing very variable minor quantities of silver, include Swiss Aluminium Mining (UK) Ltd., British Steel Corporation Ltd., Laporte Industries Ltd., and Dresser Minerals Ltd. Strontian Minerals Ltd., a joint venture including the Derbyshire-based Minworth Ltd., plans to mine barytes near Loch Sunart in Scotland, and bulk lead-zinc concentrate with 'small quantities of silver' will also be produced. Full-time lead mining operations in Clwyd by Halkyn District United Mines Ltd., a subsidiary of Courtaulds Ltd., ceased in 1958 because of falling lead prices. The lead ore produced was exported to Belgium where the silver was recovered by Metallurgie Hoboken-Overpelt S.A.

Britannia Refined Metals Ltd., an English company registered in 1930 and now wholly-owned by MIM Holdings Ltd., (Australia), operates a silver-lead refinery at Northfleet, Kent, on the river Thames. The company treats crude lead bullion received from Mount Isa Mines Ltd., a Queensland company wholly owned by MIM Holdings Ltd. The refinery at Northfleet was expanded in 1968 to increase recovery of silver. Excluding a number of companies that only up-grade silver-bearing materials and tend to sell to major refineries, there are at present four true silver refiners in the UK: *Britannia Refined Metals Ltd.*, *Engelhard Industries Ltd.* (Sheffield Smelting Company Ltd.), *Johnson Matthey Chemicals Ltd.*, and *John Betts Refiners Ltd.*, (W. Canning Refiners Ltd.). Each of these companies produces good delivery fine silver bullion bars for the London Silver Market.

Johnson Matthey and Co Ltd., the holding company and parent company of the Johnson Matthey group, was founded by Percival Norton Johnson who, in 1822, set up as a gold assayer in Hatton Garden, London. By 1851, when the George Matthey company came into being, the company's

activities had expanded to include the refining of platinum and palladium. As London was then the silver market of the world, silver refining became a major interest and in the early 1850s the company's first large refineries were built. From them came the raw materials for the wide range of fabricated forms of silver and gold alloys produced towards the end of the century by the then Johnson Matthey and Co. The company has grown and diversified to become an international group with more than thirty subsidiary and affiliated companies trading in over one hundred countries throughout the world. Their activities include all aspects of precious metal refining and fabrication, merchant banking and bullion dealing, and the manufacture of electronic products, engineering materials, catalysts, chemicals, pigments, ceramic colours and transfers, and speciality organics.

Johnson Matthey Chemicals Ltd., operate a refinery at Royston, Hertfordshire, for silver refining and chemical manufacture, and a recently extended and modernized refinery at Brimsdown, near Enfield in north London. The two plants together provide the world's largest and most technically up-to-date precious metals refining facility, able to treat a wide spectrum of primary and secondary precious metal-bearing materials including gold and silver bullion, doré, demonetized coin, jewellers sweepings, lemls, silver scrap, electronic scrap, photographic emulsions, film and paper, plating solutions, spent industrial catalyst, and copper tankhouse slimes. These materials are initially refined at Brimsdown and then transported to Royston for final purification. The refined precious metals, including silver, become available to the market in purities of up to 99.99%. Special high-purity silver is available with a total metallic impurity content of less than 10 ppm, whilst silver and other precious metal salts are available in very high purities.

The European operations of *Engelhard Corp.*, New Jersey, USA, started in 1930 with the sale of dental products and precious metals for the jewellery trade. Today the company's precious metal involvement, *Engelhard Industries Division*, includes chemical and petroleum catalysts, purification catalysts and systems, chemicals and electro-chemicals, metallurgical manufacturing and refining. With five refineries in Europe – three complementary facilities in the U.K., one in Paris and one in Rome – Englehard specializes in the recovery of precious metals from most forms of waste materials. The corporation has its European headquarters at Chessington in Surrey and serves a wide range of industries from aerospace and electronics to pharmaceuticals and fibres. At Cinderford, in Gloucestershire, the Engelhard Chemical Group Refinery specializes in the recovery of platinum group metals, as well as precious metal chemicals and catalyst manufacture. The Englehard Metallurgical Group Refinery in Surrey concentrates on gold scrap refining and precious metal metallurgical fabrication. The *Sheffield Smelting Co. Ltd.*, established in 1760 was taken over by Engelhard in 1972 and produces silver rolled coil, silver rolled sheet, strip, foil, tubes, rod, wire, powder and silver brazing alloys from a wide variety of predominantly secondary materials including dental amalgams. It has recently been re-equipped to provide advanced refining technology and is an important coin and medallion producer. It is one of the few plants which can produce blanks to the standard that national and private Mints demand. Apart from North America and Europe, Engelhard is also represented in the Far East, Japan and Australia, where refining and the production of dental and silver brazing alloys is carried out at Thomastown, Victoria.

John Betts Refiners Ltd., of Birmingham specialize in reclaiming and refining precious metals from all kinds of waste, collected nationwide, as well as from many international sources. The waste is either bulk purchased or originates from the various silver recovery units marketed by the company. In 1978 the Canning Group acquired the assets of the John Betts and Sons Company which was more than 200 years old. The re-launched company, John Betts Refiners Ltd., and its subsidiary, W. Canning Refiners, benefitted from extensive investment and gained acceptance of its silver bars by the London Silver Market in 1981. All processes are carried out in-house at the company's factory and the development of the refinery was greatly facilitated by the considerable electro-plating expertise within the W. Canning Group. Apart from electro-plating activities, the latter incorporates companies specialising in, for example, the manufacture of effluent treatment plant, water reclamation equipment and chemicals, supply of electronic components, fuel measurement devices and aluminium casting.

United Kingdom and EEC consumers

In the UK and the EEC the largest consuming sector, the photographic industry, is organized around a few multinational producers and their subsidiaries (Table 8).

Table 8 EEC photographic products producers.

<i>Parent company</i>	<i>Company</i>	<i>Country</i>	<i>Distribution of EEC silver consumption for photographic purposes: per cent</i>
<i>Eastman Kodak, USA</i>	<i>Kodak Ltd.,</i>	<i>United Kingdom</i>	<i>20</i>
	<i>Kodak Pathé</i>	<i>France</i>	
<i>CIBA-GEIGY AG, Switzerland</i>	<i>ILFORD Limited</i>	<i>United Kingdom</i>	<i>12</i>
	<i>ILFORD SA</i>	<i>France</i>	<i>2</i>
<i>Photo Produits, Gevaert, Belgium</i>	<i>Agfa Gevaert</i>	<i>Belgium</i>	<i>38</i>
	<i>Agfa Gevaert</i>	<i>Germany F.R.</i>	<i>12</i>
	<i>Agfa Gevaert</i>	<i>France</i>	<i>4</i>
<i>3M, USA</i>	<i>3M Ferrania</i>	<i>Italy</i>	<i>12</i>

Source: Adapted from 'Raw materials research and development': materials substitution dossiers. I. Silver and chromium. Brussels: Commission of the European Communities, 1980.

Most of the producers of photographic materials buy fine silver and have it converted to silver nitrate by silver refiners, but Gevaert process the metal themselves. The geographical organization of production and supply within each group is often complex. For example, Kodak Pathé concentrate on the production of high silver content emulsions (radiography films etc) while Kodak Ltd., concentrate on colour and graphic arts products. Also, Kodak Ltd., send new scrap generated during the manufacturing process, partly to Kodak Pathé, partly to Eastman Kodak (at Rochester, USA) for treatment and recycling, and partly to major outside refineries such as John Betts Refiners Ltd. Kodak Pathé send films to Kodak AG for sale in Federal Germany and directly supply other EEC countries and the French overseas territories, whereas Kodak Ltd., supply the free trade area and former Commonwealth countries.

Changes in the production organization of these multi-nationals, therefore, has an impact on the silver consumption breakdown among EEC countries.

In the electric-electronic industry, the second largest silver consuming sector, silver-based electrical contact materials used by fabricators of relays, switches, circuit breakers and conductors are generally manufactured by the major silver refiners, ie Johnson Matthey, Comptoir Lyon Alemand, Degussa, and their affiliates, which offer both the basic materials and a range of semis. In the UK the most important end-users in this sector are Sheffield Smelting, GEC (Elmet Alloys), Plessey, STC (ITT). ERA Technology Ltd., (Electrical Research Association) in the UK, is a research laboratory funded by electrical-electronic end-users and refiners. The structure of the silver battery industry in the UK is shown in Table 9. The bulk of production is for military batteries and button cells.

Table 9 United Kingdom producers of silver-containing batteries

<i>Batteries for military uses</i>	<i>SOGEA Batteries (CGE, France)</i> <i>Chloride Industrial Batteries</i> <i>Mallory</i>
<i>Button cells</i>	<i>Timex</i> <i>Berec Micro Batteries</i> <i>Mallory</i> <i>Varta</i>

Silver brazing alloys are usually supplied by the manufacturers of semis, the silver refiners, ie Johnson Matthey in the UK. They are offered in various forms such as wires, rods or preformed shapes.

STATISTICS

Production

United Kingdom

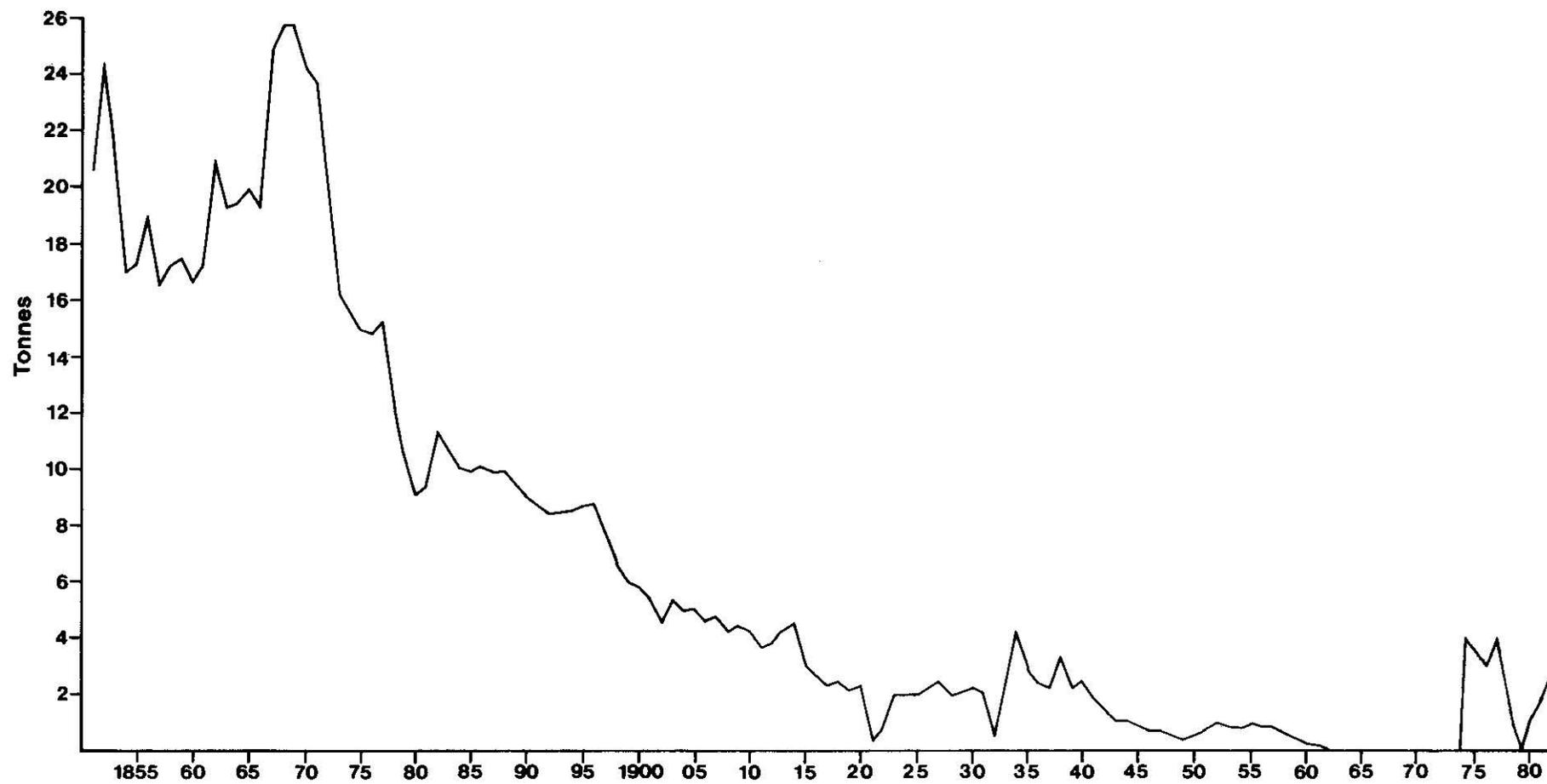
There are no active silver or argentiferous lead mines in the United Kingdom at present. The last argentiferous lead mine, Greenside in Cumbria, was finally abandoned in 1963. In its last years of working the silver content was generally 305 g per tonne of pig (crude) lead. However, the Jane tin mine at Baldhu, near Truro, Cornwall, has been producing a copper-zinc concentrate for about ten years, with the exception of 1979 when the operation was temporarily in abeyance. This concentrate contains silver and was exported to Sweden for treatment at the Ronnskar plant of Boliden Aktiebolaget. After being refurbished in 1979-80 by Carnon Consolidated Tin Mines Ltd., the mine recommenced production in mid-1980 and achieved rated capacity of 290,000 tonnes ore milled per annum by the end of the year. About 630 tonnes of copper and 10,000 tonnes of zinc per annum are contained in the concentrate which grades 130 ppm silver (130 g Ag per tonne of copper-zinc concentrate). Most of the concentrate is exported to Belgium for smelting and refining, and the silver extracted commands a bonus payment. A small tonnage was sent to Commonwealth Smelting Ltd., at Avonmouth in 1982.

The fact that statistical data on UK silver mine production from various sources do not always concur reflects the metals' minor by-product status. It appears that the bulk, if not all, of the mine production figures for the last decade quoted in Table 10 is accounted for by Wheal Jane and that any by-product silver production from fluorspar and barytes mines (primarily the Northern Pennines) is extremely small and not taken into account. Mine production of silver from Wheal Jane, during the last six years or so, reached a maximum of 4.17 tonnes in 1977, was nil in 1979 and amounted to 3.28 tonnes in 1982.

United Kingdom mine production of silver, by decades 1851-1982, and annually since 1975 is shown in Table 10 and in graphical form in Figure 7. Over 880 tonnes of silver are known to have been produced from ores mined since 1851, when reliable statistics were first collected and published by Robert Hunt, Keeper of Mining Records at the Geological Survey of Great Britain. One of the main problems in analysing UK silver and lead mine production statistics is their non-uniformity. The parameters chosen varied over the years so that for some detailed information exists, while for other years, notably since about 1920, only a UK total figure is available. Additionally, where some attempt has been made to record the grade of the material raised, this is usually given in the form of ounces of silver per long ton of lead 'ore' or per ton of lead metal. In the former case, the 'ore' mentioned was in fact not 'ore' as understood in current terminology, containing as it did about 60 to 70% lead, but was the handpicked, tabled or otherwise 'cleaned' product ready for smelting, usually equivalent to a modern day 'concentrate'. In only a very few cases is the lead content of the deposit recorded, far less its silver content. Most analyses of the historical mine production of silver in the UK are therefore based on the amount of silver 'recoverable' during the metallurgical processing of argentiferous galena concentrates. Sometimes relatively primitive technology was involved in the smelting of the lead and in the separation of silver from lead, so that significant amounts of silver were 'lost' (not recovered or not recoverable). The probable inaccuracy and low value of many historical silver mine production statistics is underlined by a footnote in many editions of the Mineral Statistics which states that when 3 ounces (94 g) or less of silver were present in the 'ore' it was not recorded.

The peak production years were 1868 and 1869 and since that time there has been a steady decline. In the second half of the 19th century ore containing silver, mostly in association with lead, was extracted at a large number of mines extending across the UK. The generally rich argentiferous galena and other ores that were almost 'handpicked' during this period contained an amount of silver well worth recovering. A minor upturn occurred in 1913 when, coincidentally, detailed mine by mine statistics were no longer published, but production slumped drastically in the post-war depression years. There was a significant upturn prior to and during the early years of World War II largely as a result of raw material demands for rearmament, but by 1941-1942 the lack of manpower at domestic mines and the availability of raw materials consequent upon the US entry into the war initiated the final decline of UK lead and silver mine production.

Statistics of silver mine production on a county basis continued to be collected and published up to 1920 and can be consulted in the archives of the Minerals Strategy and Economics Research Unit, IGS, London. A brief summary of the more important mine producers of silver for the



Source: Institute of Geological Sciences.

Fig 7 UK production of silver: 1851-1982 (mine production)

**Table 10 United Kingdom: mine
production of silver
1851-1982**

<i>'Decade'</i>	<i>Production kg</i>	
1851-1860	187,081	
1861-1870	216,839	
1871-1880	151,594	
1881-1890	100,039	
1891-1900	77,947	
1901-1910	47,754	
1911-1920	32,360	
1921-1930	10,595	
1931-1940	22,645	
1941-1950	9,260	
1951-1960	7,438	
1961-1970	2,000	
1971-1980	18,000	
1981-1982	6,558	
<i>Total</i>	1851-1982	890,110

<i>Year</i>	<i>Production kg</i>	
1975	4,400	
1976	3,345	
1977	4,166	
1978	1,272	
1979	—	
1980	1,373	
1981	3,278	
1982	3,280	
<i>Total</i>	1975-1982	21,114

Source: Institute of Geological Sciences

peak production year of 1868 is shown in Table 11, and Figure 8 shows the county share of silver production for the decade 1861-1870.

Cornwall contributed the largest share of mine silver production during the 'boom' decade of 1861-1870. Table 12 lists those mines in the South west of England (Cornwall and Devon) whose total recorded silver production was in excess of 100,000 ounces (3,110.4 kg). Most of the silver was obtained as a byproduct of lead mining. Significant amounts also came from tin and copper-rich veins.

Table 11 UK mines that produced more than 31 kg or about 1,000 ounces of silver in the peak production year for silver of 1868

<i>County/area</i>	<i>Mine</i>	<i>kg</i>	<i>grams Ag per tonne lead metal</i>	
Cornwall	Cargoll	413.7	857	
	Chiverton	99.9	1,102	
	Chiverton Moor	99.8	459	
	Chiverton, South	36.7	1,776	
	Chiverton, West	4,494.8	1,316	
	Herodsfoot	1,204.6	2,970	
	Mary Ann	1,899.2	2,204	
	Trelawney	952.3	1,653	
	Trewetha	179.0	1,286	
Devonshire	Frank Mills	1,239.9	1,072	
Derbyshire	(mines not separately itemized)		9	
Lancashire	Whitewell	47.6	144	
Yorkshire	(mines not separately itemized) but: Arkendale } probably produced Old Gang } most of the silver		15	
Cumberland	Browngill	41.2	214	
	Carrs and Hanging Shaw	114.5	214	
	Long Cleugh	220.3	214	
	Rampgill	41.7	214	
	Brownley Hills	44.8	184	
	Rodderup Fell	46.7	153	
	Driggith	53.2	612	
	Roughtongill (or Caldbeck Fells)	230.8	612	
	Yewthwaite	61.8	245	
	Westmoreland	Greenside	622.1	520
Durham and Northumberland	Allendale, East and West and Weardale	1,395.8	153	
Northumberland	Coldberry	112.9	92	
	Flakebrigg	55.9	92	
	Little Egglesthope	48.6	92	
	Wire Gill	142.1	92	
	Cornish Hush	55.2	214	
	Stonecroft and Greyside	160.3	92	
	Derwent Mines	293.1	276	
	Fallowfield	35.6	123	
	Healeyfield	166.8	429	
	Cardiganshire	Bwlch Consols	142.8	459
		Cwm-Erfin	446.4	949
		Cwm Sebon (South Daren)	313.2	1,163
		Cwm Symlog (East Daren)	491.2	735
		Glogfach	289.5	796
		Glogfawr	73.9	398
East Logylas		69.9	153	
Goginan		244.5	918	

Table 11—continued

<i>County/area</i>	<i>Mine</i>	<i>kg</i>	<i>grams Ag per tonne lead metal</i>
Caermarthenshire	Nant-y-Mwyn	67.0	184
Pembrokeshire	Llanfyrnach	89.0	398
Montgomeryshire	Dyliffe	165.9	153
	Llanerchyllau	100.7	245
	Van	287.9	306
Denbighshire	Maes-y-safn	170.6	123
	Minera	737.3	153
	Minera Boundary	64.6	245
	Pool Park	41.8	184
Flintshire	Bryngwiog	75.5	276
	Holywell Level	44.9	123
	Rhosesmor	104.9	337
Talargoch	Maes-yr-Erwddu	159.5	306
	Coetia Llwyn	400.2	367
	Trelogan	49.7	306
Isle of Man	Foxdale	2,252.7	1,776
	Laxey	3,266.5	1,929
Scotland	Wanlockhead	177.7	214
	Isle of Islay	75.1	459

Source: Institute of Geological Sciences.

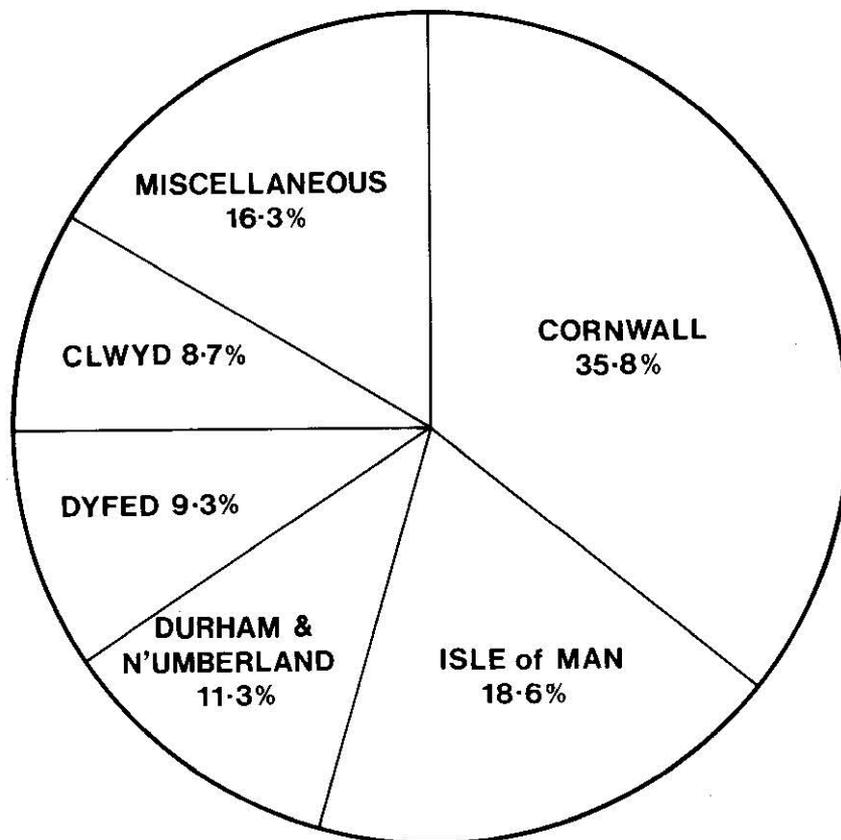


Figure 8 UK production of silver, by county: 1861-1870

Table 12 Mines in South West England whose total silver production was greater than about 3 tonnes (100,000 oz)

<i>Mine</i>	<i>District</i>	<i>Mineral Association</i>
Cargoll	St. Agnes	Pb-Ag-Zn-Cu
West Chiverton	St. Agnes	Pb-Ag-Zn-Cu
East Rose	St. Agnes	Pb-Ag-Zn-Cu
Herodsfoot	Liskeard	Pb-Ag-Cu-Wo
Ludcott	Liskeard	Pb-Ag
Mary Ann	Liskeard	Pb-Ag
Trewetha	Liskeard	Pb-Ag
Wrey Consols	Liskeard	Pb-Ag
Wrey and Ludcott United	Liskeard	Pb-Ag
Tamar Consols	Callington and Tavistock	Pb-Ag-F
South Tamar Consols	Callington and Tavistock	Pb-Ag-F
Exmouth	Dartmoor and Teign Valley	Pb-Ag-Zn
Frankmills	Dartmoor and Teign Valley	Pb-Ag-Fe-F

Mines whose total production was smaller than the above, but where silver was the main product

<i>Mine</i>	<i>District</i>	<i>Mineral Association</i>
Perran Silver	Mount's Bay	Ag
North Dolcoath	Camborne, Redruth and St. Day	Ag-Cu
Silver Vein (Lostwithiel)	Liskeard	Ag-Pb
Brothers	Callington and Tavistock	Ag-As-Pb-Sn-Cu
Sisters	Callington and Tavistock	Ag

Source: Institute of Geological Sciences.

However, official records did not show silver production from copper ores until 1912. Prior to this date the bulk of UK silver production is recorded as coming from argentiferous lead ores, although it is known that mines such as Levant in Cornwall were producing significant amounts of by-product silver from copper ores well before this time. An estimate made in 1904 suggests that nearly 29 million ounces of silver (902 tonnes) were contained in copper ores sold between 1501 and 1900. This is more than the recorded total of mixed silver production for the UK as a whole up to the same year, yet another example of how published, and, indeed, other available historical statistics appear to be greatly underestimating the total quantity of the metal raised.

World production and the United Kingdom in the world context

World mine production of silver in 1981 was 11,195 tonnes. Mine production by decades, 1821-1970, and annually since 1970 is shown in Table 13. Most of the increase in world production since about 1880 has been the result of the mining of base metal ores, particularly in the USA and Canada during both World Wars, when silver production from precious metal ores declined sympathetically. The fall in silver price between 1930 and 1940 discouraged silver recovery from lower grade base

Table 13 World mine production of silver: 1821-1981*

<i>Period</i>	<i>Tonnes</i>	
1821-1830	4,605	
1831-1840	5,964	
1841-1850	7,804	
1851-1860	8,955	
1861-1870	12,201	
1871-1880	22,098	
1881-1890	31,246	
1891-1900	50,275	
1901-1910	56,802	
1911-1920	59,656	
1921-1930	74,536	
1931-1940	70,698	
1941-1950	58,910	
1951-1960	68,988	
1961-1970	80,719	
1971	9,183	
1972	9,176	
1973	9,285	
1974	8,963	
1975	9,242	
1976	9,735	
1977	10,668	
1978	10,824	
1979	10,690	
1980	10,622	
1981	11,195	
<i>Total:</i>	1821-1981	723,040

Sources: 1821-1920 – Annual Report of the
Director of the Mint
Washington DC 1922
1921-1981 – Institute of Geological
Sciences

*1982 figures n.a.

metal ores, except in the USA where special support was given and large government stocks built up. In recent years, production has continued to increase in Mexico, Chile, Ecuador, USSR, Poland and China, but has been either roughly static or declining in most other countries. World mine production of silver by major producing countries is indicated in Table 14. Mine production of silver in the EEC is about 2.1% of the world total today and fell from 197 tonnes in 1976 to 179 tonnes in 1980. France is currently the principal producer but, upon its entry into the Community (scheduled for 1983-4), Spain will replace France as the leader with nearly 45% of total EEC mined silver production, including production from Greece which joined the Community in 1981.

UK silver production has been extremely small by international standards. For example, even the largest annual mine production of 4,500 kg at West

Table 14 World mine production of silver, by major producing countries: 1976-1981*

<i>Country</i>	<i>tonnes</i>					
	<i>1976</i>	<i>1977</i>	<i>1978</i>	<i>1979</i>	<i>1980</i>	<i>1981</i>
Australia	779	856	813	832	767	745
Canada	1,281	1,314	1,267	1,147	1,070	1,071
Mexico	1,326	1,463	1,579	1,537	1,473	1,655
Peru	1,117	1,236	1,152	1,221	1,337	1,460
Poland (e)	550	644	680	702	766	640
USA	1,068	1,187	1,225	1,179	1,006	1,265
USSR (e)	1,370	1,550	1,570	1,550	1,550	1,580
Other countries	2,244	2,418	2,538	2,522	2,653	2,779
of which EEC Countries	197	197	171	178	179	239(a)
<i>Total</i>	9,735	10,668	10,824	10,690	10,622	11,195

(a) includes 60.5 tonnes of Greek production.

(e) estimate

Source: Institute of Geological Sciences

*1982 figures n.a.

Chiverton mine, Cornwall in 1868, corresponds to only one-quarter of the annual silver production from current medium sized Canadian mines eg Flin Flon and Snow Lake mines. It also represents only one-hundredth of the amount at present produced annually, over 500,000 kg, by the premier silver producing mine in the world, Mount Isa in Australia. Additionally, total UK mined silver production in 1868 (26,168 kg) represented only 1.76% of the world total. Other European countries were producing more silver than the UK at the time; some details of the percentage of world production contributed by various countries, 1866-1870 and 1980, appear in Table 15. From this it can be seen that the percentage share of most European countries has fallen markedly over the last 120 years or so. The exceptions are Sweden and the USSR. The most significant increases are shown by Canada, Australia, the USSR, the Asian countries including Japan, Sweden, Peru and central America. Table 16 gives an indication of the changes in World and UK historical primary silver production from earliest records. World average annual production over the years has consistently increased, while the UK's percentage change shows the well known trend of increase, culminating in the second half of the 19th century, followed by a fairly consistent negative trend up to about 1973. Similarly, the UK's percentage share of world total silver production has fallen consistently from the high of 0.57% in the second half of the 19th century to the current average of 0.01%.

Overseas trade

London is a major centre for world-wide trade in silver through the activities of the London Silver Market and the London Metal Exchange. These are responsible for considerable imports and exports of silver bullion largely for speculative and investment purposes. Indeed, in 1980, imports of unwrought silver (predominantly bullion) were equivalent to

**Table 15 Percentage share of world silver mine production:
1866-1870 and 1980**

<i>Country/Area</i>	<i>1866-1870 period %</i>	<i>1980 %</i>
Mexico	37.8	13.9
USA	22.1	9.5
Canada	0.1	10.1
North America (total)	60.0	33.5
Central America (total)	—	1.1
Peru	5.1	12.6
Chile	8.1	2.8
Bolivia	6.5	1.8
South America (total)	19.9	18.1
Austria	2.9	—
France	2.9	0.7
Germany (FRG) }	6.5	0.4
Germany (GDR) }		0.4
Greece	1.5	0.5
Italy	0.8	0.4
Poland	small	7.2
Spain (& Portugal)	1.9	1.3
Sweden	0.1	1.6
United Kingdom }	1.8	0.0
Irish Republic }		0.2
USSR	1.2	14.6
Yugoslavia	small	1.4
Europe (total, excluding USSR)	18.6	15.6
Japan	0.1	2.6
Asia (total)	0.3	5.6
Australasia (total)	0.0	7.6
Africa (total)	0.0	4.0

Source: US Department of Commerce, Bureau of Mines Economic Paper 8, 1930 and Institute of Geological Sciences.

more than one-third of world mine production in that year. However, physical trading represents only a portion of the total trading, much of which takes the form of paper transactions. The United Kingdom is also a leading consumer of silver (approximately 700 tonnes in 1980), although industrial consumption is small in comparison with its role as a major trader. The major forms in which silver is imported into the United

Table 16 World and UK mine production of silver, by periods: 1493-1980

<i>Number of years</i>	<i>Period</i>	<i>World production tonnes</i>	<i>Average annual production tonnes</i>	<i>Percentage increase in annual average over previous period</i>	<i>UK production tonnes</i>	<i>Average annual UK production tonnes</i>	<i>Percentage change in annual average over previous period</i>	<i>UK percentage share of world production</i>
100	1490's-1600	23,234	218	?	?	?	?	?
100	1601-1700	39,564	404	84	?	?	?	?
100	1701-1800	57,012	560	39	31	3.2	?	0.05
100	1801-1900	158,628	1,586	183	865	8.7	+ 172	0.55
50	1801-1850	33,094	653	17	152	3.0	- 65	0.46
50	1851-1900	125,472	2,519	286	712	14.2	+ 63	0.57
25	1901-1925	152,451	6,096	142	82	3.3	- 77	0.05
30	1901-1930	190,994	6,367	152	190	3.0	- 10	0.05
30	1931-1960	198,596	6,620	4	39	1.3	- 57	0.02
20	1961-1980	178,415	8,921	35	20	1.0	- 23	0.01

Source: Merrill C.W., 1930 and Institute of Geological Sciences.

Kingdom are unwrought metal and waste and scrap (Table 17). Substantial quantities are also contained in lead bullion imported from Australia as follows:

	<i>Tonnes</i>					
	1977	1978	1979	1980	1981	1982(p)
Total imports of lead bullion	121,378	122,847	152,496	136,056	109,679	123,870
of which, from Australia	120,340	122,640	151,237	133,019	109,541	111,808
Estimated silver content ⁽¹⁾	260	240	320	310	260	265

(1) Based on Australian trade data, which states the silver content of exported lead bullion.

(p) Provisional.

Table 17 United Kingdom imports of silver: 1977-1982

	1977	1978	1979	1980	1981	1982(p)
Unwrought silver (a)						
Kg	917,903	1,306,199	1,102,420	3,715,230	1,884,761	1,387,162
£ thousand cif	76,870	118,052	170,216	1,131,084	315,682	212,444
Semi-manufactured silver (a)						
Kg	201,008	144,309	117,589	76,254	56,290	46,809
£ thousand cif	13,019	6,603	11,297	15,492	7,868	6,549
Rolled silver, unworked or Semi-manufactured						
Kg	5,040	3,798	6,419	7,783(b)	25,610	25,895
£ thousand cif	287	169	261	571	608	450
Waste and Scrap						
Kg	386,674	364,756	701,254	584,952	982,040	1,360,722
£ thousand cif	26,385	23,481	84,651	129,387	121,427	61,262
Colloidal silver						
Kg	471	831	414	9	165	27
£ thousand cif	18	37	105	1	1	3
Compounds of silver						
Kg	52,083	93,311	27,232	7,046	8,949	4,213
£ thousand cif	2,217	3,836	1,372	1,137	1,133	382

(a) Including silver gilt and platinum-plated silver

(b) Amended figure, differing from that published in the official 'Overseas Trade Statistics of the United Kingdom' as a result of verbal communication with Customs and Excise.

(p) Provisional.

Source: HM Customs and Excise

In addition silver coins, jewellery and silversmiths' wares, and photographic materials containing silver are imported in significant quantities. Silver is also imported in unknown, but probably small, quantities in base metal ores and concentrates. The major forms in which silver is exported from the United Kingdom are unwrought and semi-manufactured metal, and waste and scrap (Table 18). In addition silver coins, jewellery and silversmiths' wares, photographic materials and electronic components containing silver are exported in substantial quantities.

Trends in the United Kingdom trade in silver are hard to discern, although it does appear that there has been a decline in imports together with an increase in exports of semi-manufactured metal, with a converse trend for waste and scrap. Tables 19 and Table 20 show trade in the major forms of silver, by country of consignment and destination. The features of most note are the enormous increase in trade in unwrought silver and the preponderance of imports over exports in 1980 compared with both

Table 18 United Kingdom exports of silver: 1977-1982

	1977	1978	1979	1980	1981	1982(p)
Unwrought silver (a)						
Kg	1,270,309	1,231,704	1,101,394	1,951,384	1,103,794	1,692,688
£ thousand fob	107,350	103,047	182,304	562,885	198,792	269,834
Semi-manufactured silver (a)						
Kg	379,044	473,376	566,992	542,372	538,293	878,709
£ thousand fob	12,448	23,524	66,297	94,198	98,363	127,118
Rolled silver, unworked or semi-manufactured						
Kg	20,785	21,480	90,665	64,582	264,755	86,316
£ thousand fob	459	467	206	459	1,602	925
Waste and Scrap						
Kg	516,939	310,182	552,346	296,810	137,812	97,883
£ thousand fob	16,409	12,378	10,711	59,030	13,591	5,816
Colloidal silver						
Kg	1,859	759	2	101	—	88
£ thousand fob	111	39	1	0	—	4
Compounds of silver						
Kg	42,618	136,804	249,786	75,883	118,966	138,519
£ thousand fob	2,370	7,497	15,549	13,646	11,236	11,763

(a) Including silver gilt and platinum-plated silver

(p) Provisional

Source: HM Customs and Excise

Table 19 United Kingdom imports of silver, by major countries of consignment: 1977-1982

<i>Country of consignment</i>	<i>Kilogrammes</i>					
	<i>1977</i>	<i>1978</i>	<i>1979</i>	<i>1980</i>	<i>1981</i>	<i>1982(p)</i>
1 Unwrought silver						
Belgium-Luxembourg	1,463	23	8,658	355,168	323,611	53,446
France	33,013	127,122	31,774	389,911	261,976	124,576
Germany, Fed. Rep.	5,348	5	9,420	568,937	50,673	1,948
Netherlands	3	8,486	51,572	152,868	79,834	657
Other EEC countries	25	—	—	55,588	5,272	11,998
Total EEC	39,852	135,636	101,424	1,522,472	721,366	192,625
Value £ thousand cif	3,363	12,148	22,077	485,692	124,234	30,113
Australia	74,109	105,696	99,534	55,914	35,396	172,295
Dubai	—	6,279	65,463	311,718	39,029	37,829
Germany, Dem. Rep.	270,108	218,163	203,550	28,967	153,883	325,159
India	147,270	348,680	113,699	171	—	—
Mexico	208,618	171,281	102,007	226,899	173,765	175,662
South Africa	61,851	67,864	66,197	67,631	61,961	76,833
USA	80,107	83,614	72,684	927,446	128,708	1,388
Other countries	35,988	168,986	277,862	574,012	570,653	405,371
TOTAL	917,903	1,306,199	1,102,420	3,715,230	1,884,761	1,387,162
Value £ thousand cif	76,870	118,052	170,216	1,131,084	315,682	212,444
2 Semi-manufactured silver						
France	36,087	35,725	47,000	19,233	23,517	11,103
Germany, Fed. Rep.	49,295	14,429	17,202	8,239	6,154	5,654
Italy	19,982	1,527	1,411	6,272	856	939
Other EEC countries	4,309	1,576	4,526	5,273	3,464	5,976
Total EEC	109,673	53,257	70,139	39,017	33,991	23,672
Value £ thousand cif	6,713	3,791	7,382	6,555	3,641	3,100
Canada	26,099	3,607	1,101	422	215	568
India	11,548	1,718	11,053	—	—	—
Sweden	2,037	43,895	528	2,858	417	1,972
Switzerland	3,811	2,611	4,693	5,011	7,604	2,072
USA	36,486	30,375	20,203	14,812	9,529	10,465
Other countries	11,354	8,846	9,872	14,156	4,534	8,060
TOTAL	201,008	144,309	117,589	76,276	56,290	46,809
Value £ thousand cif	13,019	6,603	11,297	15,488	7,868	6,549
3 Waste and scrap of silver						
Belgium-Luxembourg	3,593	4,018	7,577	16,242	32,125	8,447
Denmark	14,094	18,979	18,432	25,292	22,372	29,638
Other EEC countries	18,343	11,503	9,125	11,202	27,870	60,289
Total EEC	36,030	34,500	35,134	52,736	82,367	98,374
Value £ thousand cif	1,963	1,689	2,319	6,077	4,982	3,403
Canada	35,790	29,139	55,477	37,883	19,537	31,322
Dubai	2,422	—	20,587	38,234	450,577	28,077
Hong Kong	372	30	9,977	113,231	26,357	26,405
Sweden	8,028	10,214	9,787	40,880	12,996	45,445
Switzerland	7,589	16,962	25,284	13,049	18,963	34,984
Turkey	—	92	85,928	—	98	—
USA	216,930	210,478	388,141	226,138	328,021	1,043,629
Other countries	79,513	63,341	70,939	69,370	43,124	52,486
Total	386,674	364,756	701,254	591,521	982,040	1,360,722
Value £ thousand cif	26,385	23,481	84,651	130,667	121,427	61,262

(p) provisional Source: HM Customs & Excise

Table 20 United Kingdom exports of silver, by major countries of destination: 1977-1982

<i>Country of destination</i>	<i>Kilogrammes</i>					
	<i>1977</i>	<i>1978</i>	<i>1979</i>	<i>1980</i>	<i>1981</i>	<i>1982(p)</i>
1 Unwrought silver						
France	505,291	413,473	330,782	38,437	44,987	59,709
Germany, Fed. Rep.	226,356	105,651	5,072	9,208	2,360	347,899
Italy	115,063	19,133	64,178	31,346	37,270	17,770
Netherlands	36,241	57,909	6,748	15,391	26,016	15,447
Other EEC Countries	13,512	481	2,963	6,015	6,472	15,408
Total EEC	896,463	596,647	409,743	100,397	117,150	456,233
Value £ thousand fob	75,215	53,589	58,342	29,577	20,732	56,969
Germany, Dem. Rep.	186,678	80,332	55,191	89,509	9,460	51
Switzerland	80,702	454,788	248,287	1,596,999	937,870	338,524
USA	3,978	—	295,371	110,250	3,389	776,270
Other countries	102,488	99,937	92,802	54,199	35,970	121,610
TOTAL	1,270,309	1,231,704	1,101,394	1,951,354	1,103,794	1,692,688
Value £ thousand fob	107,350	103,047	182,304	562,885	198,792	269,834
2 Semi-manufactured silver						
Denmark	22,289	17,871	16,481	26,298	16,865	12,443
France	19,301	114,391	20,493	14,806	7,565	7,193
Irish Republic	15,834	19,359	16,317	6,362	5,413	2,774
Italy	58,870	53,454	94,656	19,277	31,698	61,291
Netherlands	13,554	21,049	6,267	20,937	2,683	5,310
Other EEC Countries	18,304	26,248	9,427	24,641	7,747	10,884
Total EEC	148,152	252,372	163,641	112,321	71,971	99,895
Value £ thousand fob	6,499	14,412	14,008	23,848	9,300	10,973
Finland	27,200	14,053	15,084	59,901	8,962	9,316
Norway	6,697	14,836	21,138	36,661	15,979	13,793
Sweden	97,637	62,978	84,462	131,835	18,898	10,776
Switzerland	41,779	37,050	188,492	149,989	386,981	465,282
USA	796	10,568	30,761	18,460	8,075	30,547
Other Countries	56,783	81,519	63,414	33,205	27,427	249,100
TOTAL	379,044	473,376	566,992	542,372	538,293	878,709
Value £ thousand fob	12,448	23,524	66,297	94,198	98,363	127,118
3 Waste and scrap of silver						
Belgium-Luxembourg	81,592	100,974	127,032	83,095	48,640	9,839
France	312	18,229	8,269	35,239	17,644	23,308
Germany, Fed. Rep.	309,326	61,858	100,741	43,800	14,744	1,749
Other EEC Countries	10,817	8,310	13,994	38,741	2,479	597
Total EEC	402,047	189,371	250,036	200,875	83,507	35,493
Value £ thousand fob	6,934	5,940	6,726	33,443	5,702	5,129
Germany, Dem. Rep.	—	—	—	50,128	—	—
Spain	105,400	75,792	49,569	50	39,246	2,040
Sweden	9,482	42,233	248,983	7,659	3,438	57,485
Other countries	10	2,786	3,758	38,098	11,621	2,865
Total	516,939	310,182	552,346	296,810	137,812	97,883
Value £ thousand fob	16,409	12,378	10,711	59,030	13,591	5,816

(p) provisional Source: HM Customs & Excise

previous and subsequent years. This reflects the substantial increase in that year in the physical movement of bullion through London and, particularly, the very large increase in investment in stocks of silver held in the United Kingdom.

APPENDIX

Terminology

Terms relating to silver used in the text and in the literature in general are defined as follows:

Argentiferous: Containing silver.

Britannia standard is an alloy containing 95.8% silver, in compulsory use from 1697 to 1719, but optional thereafter, distinguished by a hallmark with the figure of Britannia.

Brittle silver ore is a synonym for stephanite, a sulphide of silver and antimony, Ag_5SbS_4 .

Close plate: Iron or steel articles coated with molten tin, covered by silver foil and burnished. The technique, which dates back to the Roman era, was much used in Birmingham in the late 18th and early 19th centuries to produce small articles requiring good cutting edges.

Coin silver is 900 parts fine (or 90%) silver and the balance copper.

Commercial bar silver or silver bullion contains at least 99.9% silver and is sold and shipped by refiners in bars usually weighing about 1,000 troy ounces (31.1 kg).

Damascene refers to the inlaying of metal, usually steel, with gold and/or silver beaten into undercut grooves. The term is derived from Damascus where the technique was much used.

Doré silver is silver bullion containing a small amount of gold. In the USA, doré bullion is synonymous with *base bullion* which is crude lead containing recoverable silver, with or without gold.

Dry gold-silver ores are ores in which gold and silver values are equal to, or exceed, one fourth of the combined gold and silver values.

Dry ores contain precious metals but insufficient lead or copper to be smelted without the addition of richer lead or copper ores.

Dry silver ores are dry ores in which the silver value equals or exceeds three-fourths of the combined gold and silver values.

Electroplate: Copper or copper alloy objects coated with silver by electrolysis, a process patented in England in 1840 by Elkington.

Electrum is the name given to a naturally occurring gold-silver alloy containing up to 26% silver.

Fine silver: pure silver, 1,000 parts fine, or at least 99.9% silver.

French plate is brass coated with silver foil, heated and burnished, a technique mainly used in the late 17th and early 18th centuries.

Frosted silver is a film of pure silver left on the surface after a copper-silver alloy has been heated and dipped into hot dilute sulphuric acid.

Hallmarks are authenticating marks struck on English, Scottish and Irish silver, after testing that the quality of the metal conforms with the official standard. They enable the place and year of assay to be traced; the term also embraces the maker's mark.

High fine silver contains at least 99.95% silver.

Nickel silver, otherwise known as *German silver*, contains no silver, but is an alloy of copper, nickel and zinc.

Niello is a fusible black alloy of sulphur, lead, silver and copper used to fill engraved ornament to heighten the contrast with silver.

Parcel plate: silver articles which have been partly gilded.

Plate: derived from the Spanish word *plata* meaning silver; articles made of solid silver.

Refining silver is between 99.6 and 99.9% pure and is practically free from gold.

Sheffield plate articles made from sheets of a copper alloy coated with silver by a fusion process discovered in 1742 by Thomas Boulsover, a Sheffield cutler.

Silver amalgam is a solid solution of mercury and silver crystallizing in the cubic system. The silver content is usually about 26%, but in the variety *arquerite* it reaches 86%. It is of rare natural occurrence in both mercury and silver deposits.

Silver bloc: a group of American senators from the silver-producing states of Idaho, Utah, Montana, Nevada, Colorado and Arizona.

Silver glance is an alternative name for the naturally occurring silver sulphide, argentite.

Silver lead ore is the name given to galena containing silver. When 1% or more of silver is present, it becomes a true ore of silver. Also called argentiferous galena or argentiferous lead ore.

Silver plate is silver electroplated onto copper or nickel-silver tableware.

Spectroscopically pure silver contains a total of not more than 0.001% of identifiable impurities.

Standard silver used in the United Kingdom for silver coins up to 1920 was 92.5% pure. It is by definition '925 fine' but a tolerance allowed it to be between 925 and 921 fine.

Sterling silver is an alloy containing 92.5% silver and 7.5% copper, the principal standard for silver in England since 1300.

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