Mineral Resources
Consultative Committee

Mineral Dossier No 6

Celestite
including references to Strontianite

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Preface

The Mineral Resources Consultative Committee consists 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 has led the Committee to undertake the collation of the factual information at present available about those minerals (other than fossil fuels) which are now being worked or which might be worked in this country. The Committee has 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 are now being published for general information.

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Acknowledgements

Contributions to this dossier were made by the Department of Trade and Industry and the Department of the Environment. Within the Institute of Geological Sciences, particular thanks are due to Mr G A Kellaway. The help given by English China Clays Ltd, Albright and Wilson Ltd and Mr E F J Vincent and Mr L Vincent of Western Structures and Engineering Ltd is also gratefully acknowledged.

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 x 25.4
metres (m) = feet x 0.3048
kilometres (km) = miles x 1.609344
hectares (ha) = acres x 0.404686
kilogrammes (kg) = pounds x 0.45359237
tonnes (1000 kg) = long tons x 1.01605

Summary

Celestite (strontium sulphate, $SrSO_4$) is the main ore of strontium, the only other commercial source being strontianite (strontium carbonate, $SrCO_3$) which has been produced only infrequently. The Bristol area has supplied 50 to 70 per cent or more of world production each year since at least 1875. Celestite is mainly used to prepare strontium carbonate, the base chemical from which most other strontium compounds are prepared. Strontium chemicals have traditionally been used in pyrotechnics, although greatly increased quantities are now being required in the production of special glasses and ferrite magnets. Other uses are in ceramics, metallurgy, paints and pharmaceuticals. Strontium metal is only rarely used.

The only known commercial celestite deposits in the United Kingdom occur as nodules following the bedding of the Keuper Marl or the underlying Coal Measures, at the unconformity between these two formations and, occasionally, as continuous beds in the Keuper Marl. Current working is restricted to fairly shallow open pits near Yate, Gloucestershire. An investigation into methods of estimating resources, which is particularly difficult, is now in progress. United Kingdom annual production currently averages about 9,500 tonnes, of which about three-quarters is usually exported, chiefly to the USA: in 1971 production amounted to 9,749 tonnes.

World production and trade, which had been static for a long period, changed in 1968–1969 when there was over a five-fold increase in production in Mexico, and Spain resumed production on a significant scale. This was due to the demand in the USA and Japan for strontium carbonate for use in colour television screens; there is doubt as to the possibility of a similar demand developing in Europe. Increasing use is being made of strontium compounds in ceramic magnets.

Since the Second World War the industry in the UK has been controlled by one operator, the Bristol Mineral Company. In 1941 a major interest in the company was acquired by Albright and Wilson Limited who later sold their holding back to the original owner. In 1969 the company was purchased by English China Clays Limited.

Definition

Both 'celestite' and 'celestine' are used to describe the mineral form of strontium sulphate ($SrSO_4$). 'Celestine', derived from the original German word 'coelestin' ('coelestine' in English texts) introduced by Werner in 1798, is listed in the Chemical Index of Minerals, 2nd Edn 1955, as the preferred spelling. However, adoption of the term celestite in this dossier is not inconsistent with the Index, as it is the form currently most widely accepted in English-speaking countries. In early references 'celestite' is often referred to, erroneously, as 'strontia' (SrO) or 'strontian' and in the Bristol area was frequently called 'sugarstone' or 'spar'.

Celestite has a theoretical strontium oxide content of 56.4 per cent. It has a hardness of 3 to 3½ on Mohs' scale and a high specific gravity of approximately 3.96. It is usually white but blue and less commonly red, green and brown varieties are known. Its crystallographic form is orthorhombic often showing a tabular habit. Celestite is found as scattered crystals, friable crystal aggregates, in a fibrous form akin to satin spar, as geodes and nodules and as beds in association with evaporite minerals especially gypsum, or may occur as redistributed celestite in veins and fissures underlying nodular and bedded deposits. It may also occur as an accessory mineral in igneous rocks and as a minor constituent of certain limestones. The main substituent for strontium in celestite is barium.

Strontianite, strontium carbonate ($SrCO_3$), has a theoretical strontium oxide content of 70.1 per cent. It occurs in a number of localities including Strontian, Argyllshire, from which it takes its name, but no economically workable deposits are known. A number of strontium-barium and strontium-calcium isomorphs have been described, for example barytocelestite and calciocelestite, but none is of economic importance. 'Stromnite', found in Orkney, is not a distinct mineral but a mixture of baryte and strontianite.

Mode of occurrence and origin

Workable deposits of celestite in the United Kingdom are known only near the top of the Keuper Marl of the Triassic System and in associated rocks. These deposits are of three main types:

1. Bedded, or more often a horizontal zone bearing nodular and disseminated celestite (stratiform deposits) and thin stringers and veins of the mineral, typically 10 to 15m below the Tea Green Marl at the top of the Keuper. These are assumed to be of primary or early diagenetic origin in the main.
2. Nodular and disseminated celestite at the unconformity between the Keuper Marl and the underlying Palaeozoic rocks (mainly Coal Measures). The origin is probably secondary (redistributed) but may possibly be primary in places.
3. Veins, sheets and infillings of celestite in Palaeozoic rocks below the Keuper Marl or former Keuper cover. In some instances celestite may form the matrix in a breccia of Palaeozoic material. These are probably redistributed deposits.

The mode of origin of celestite deposits in the United Kingdom has received relatively little attention. Dr R L Sherlock postulated a river carrying traces of strontium salts flowing into a landlocked sea saturated with respect to $CaSO_4$, so that celestite rather than gypsum would be precipitated. After studying the Purbeck evaporites, Mr I M West advocated a syngenetic origin (coupled with redistribution of celestite from the Trias) for celestite at Durlston Head, Dorset, but later suggested that much of the Purbeck celestite was a residual deposit after gypsum and anhydrite.

Although no detailed petrographic studies have been published and no conclusive origin can be demonstrated, the celestite of the Bristol area has marked similarities to the supratidal evaporites of the Persian Gulf. Crystals and prismatic plates up to a few centimetres in length are found disseminated, loosely bound together, or as masses. Laths of celestite may intersect each other, geniculate forms are common and enterolithic folding is present in some celestite nodules, possibly indicating the former presence of gypsum and anhydrite. Nodules weighing up to a few tonnes (as at Abbots Leigh) may be composed of a fine mosaic of crystals sometimes showing a lineation of their long axes.

To the south of and parallel to the Mendips a number of irregular zones are discernable which, from north to south, are typified by carbonates (calcite and dolomite), celestite and gypsum: major salt beds and thick gypsiferous marls are found in the centre of the Somerset Trias basin. Localised iron oxide coatings, the association of dolomite and quartz (often amethystine and lacking prism faces) with celestite, the formation of celestite geodes and the presence of cavities in celestite beds are probably related to remobilisation and the deposition of secondary mineral, particularly in the Coal Measures. Although thick gypsum beds and extensive gypsiferous marls occur in the Upper Trias basins of the Midlands and Somerset, it is probable that the bulk of the celestite in the Bristol area is not a primary, residual, evaporite.

A possible mechanism for the concentration of strontium ions may be related to the removal of strontium from adjacent Carboniferous Limestone rocks, appreciable thicknesses of which may have been deposited as relatively high-strontium aragonite. During the conversion of aragonite to the more stable calcite, strontium is exsolved either to pore solutions or as interstitial strontianite. Circulating thermal waters may have removed strontium from the wall-rocks of fissures in the Carboniferous Limestone in a similar manner to that demonstrated by Dr P R Ineson in the Pennines. There are mineral and thermal springs in the Bristol region, those at Bath containing a relatively high strontium content, although this may be due to present day solution of strontium from the Trias.

The presence of mineralised waters is compatible with the hydrothermal origin of the Mendip lead-zinc ores advanced by G W Green and the exhalative origin of the lead-zinc mineralisation to the west and north of Bristol implied by G A Kellaway. Mineralised waters associated with the deposition of these ores may eventually have been discharged at the surface or mixed with local groundwater. Strontium-rich barytes is associated with old lead workings in the Bristol area and there is a tendency for the barium and calcium contents of celestite to increase towards the Carboniferous Limestone. Barium is rarely present in evaporites and may have been precipitated as barytes in veins or disseminated with galena or sphalerite on encountering sulphate-bearing groundwaters. Celestite may have been precipitated where higher sulphate concentrations prevailed farther from the point where the mineralised water issued, perhaps in lagoon waters or in the interstitial fluids of evaporite-bearing flats (sabkhas) bordering lakes or seas thought to have been present in this region in Triassic times. This theory accounts for the presence of celestite over large areas, its predominance at a limited number of horizons and the correlation of the vertical range of these horizons with that of the neighbouring lead-zinc deposits in the Bristol area noted by Kellaway.

Resources

Gloucestershire–Bristol

All the production in Gloucestershire during the past 50 years has been obtained from the vicinity of Yate. Stratiform deposits, including the only well developed bed in south Gloucestershire, lie below the Tea Green Marl and above the Butcombe Sandstone of north Somerset, at the horizon of the Woodford Hill Sandstone. The Butcombe Sandstone has been tentatively correlated with the Arden Sandstone (Late Carnian) of the Midlands, which in turn is the lateral equivalent of the Hollygate Skerry of Nottinghamshire. The main celestite deposits in the south-west of England may therefore correspond to the Newark Gypsum of the north Midlands. The thickest developments tend to be confined to areas where the Trias is thin (near basement highs), often embayed by Palaeozoic rocks. Gypsum and decalcified dolomite are frequently found as associated minerals.

Current production is from the Coal Measures. Areas formerly worked include Tortworth, Thornbury, Charfield, Latteridge, the area immediately south of Yate, and Bitton. During the last decade celestite has been worked at a number of places between Cromhall Common and Yate, for example on Cowship Farm, Barber's Court Farm, Leechpool Farm and in the Goose Green–Yate area where the zone in the Keuper Marl bearing celestite nodules ranges up to about 2 m in thickness; in the early 1960's a bed up to a metre thick was being worked. Associated float and alluvial celestite is also worked. Other areas where celestite occurs in the Keuper Marl are at Aust and Stoke Gifford, Gloucestershire and at Clifton, Cotham, Pyle Hill, Arnos Vale and Henbury in Bristol. Celestite in the Dolomite Conglomerate, the marginal facies of the Keuper in areas bordering the Severn and Bristol Channel, may be either primary or redistributed. Celestite has been recorded from the Wenlock Limestone at Brinkmarsh, near Tortworth, and has been reported from a basaltic lava of Llandovery age in the same area; in both instances the origin is probably related to the Keuper.

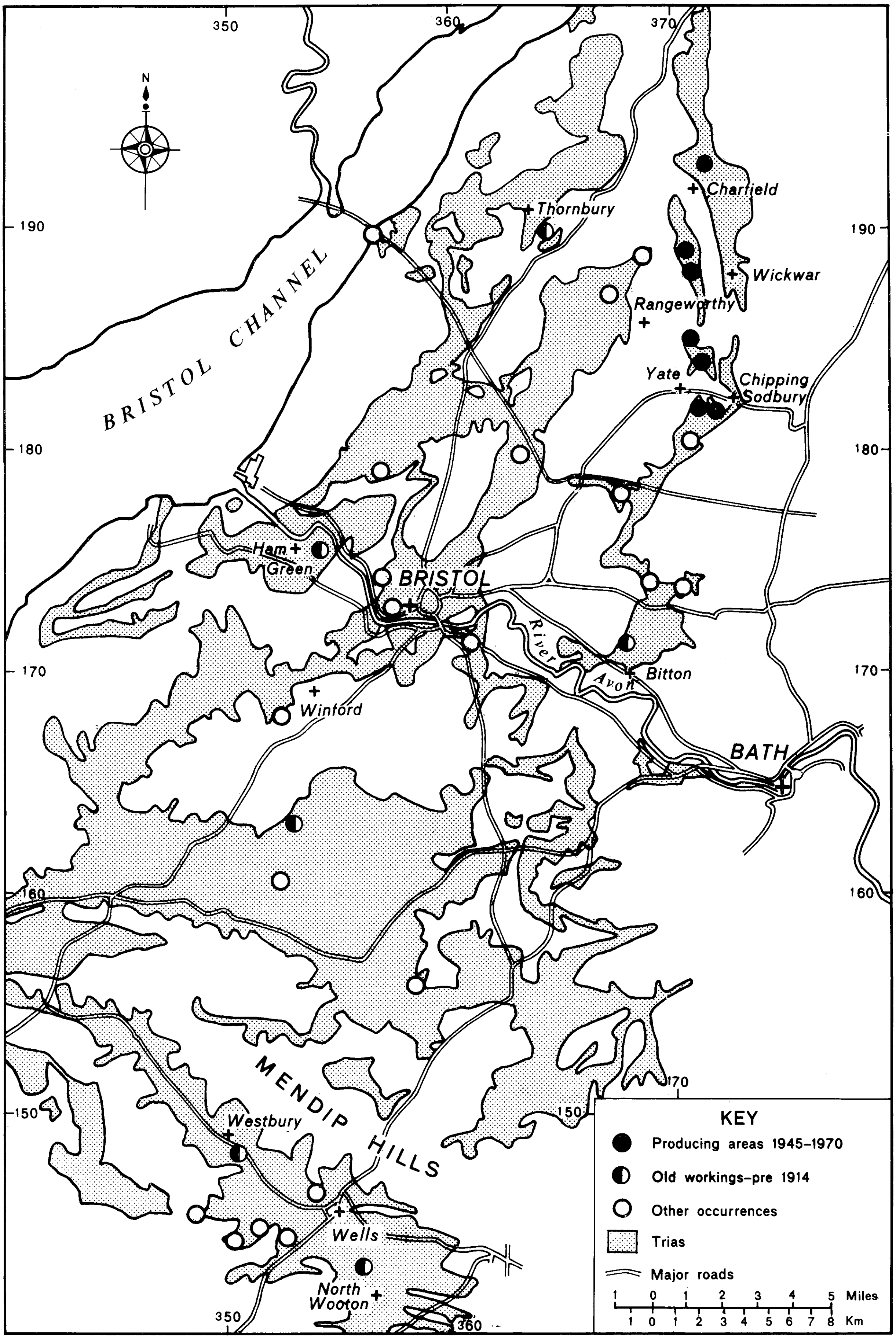

Fig.1. Celestite in the Bristol area

Somerset

In the past, celestite has been worked in the Leigh Court, Abbots Leigh; Regilbury Court near Ridgehill; Westbury-sub-Mendip and Dinder areas. The workings at Abbots Leigh produced about 15,000 tonnes of celestite a year but were closed at the beginning of the First World War, as the main markets were in Germany. All other working in Somerset ceased before 1914. Other areas in Somerset where celestite has been recorded in the Keuper are West Town, Nempnett Thrubwell; Coley near Litton; Barrow Gurney; south of Wedmore; from Westbury-sub-Mendip to Croscombe; from Wookey as far west as Bleadney and at Weston-Super-Mare and Clevedon. It has been noted as occuring in association with traces of baryte in the Lower Gypsiferous Series of the Keuper in the Puriton borehole of central Somerset. There are a number of occurrences at higher stratigraphic levels in the county, for example, in the Westbury Beds south and west of the Mendips, at Blue Anchor Point and St Audrie's Bay near Watchet, Sparkford Hill near Queen Camel, Langport and Shepton Mallet and in the Inferior Oolite of Hallatrow immediately north of the Mendips.

Other occurrences of celestite

Outside Gloucestershire and Somerset, celestite occurs in the Keuper of Llantrisant (Dolomitic Conglomerate) and Barry (Keuper Marl) in Glamorgan, at Windygate and Salcombe Mouth near Sidmouth, Devon, and in the Upton borehole near Burford, Oxfordshire, where it was recorded in the Keuper Marl 18 m below the base of the Rhaetic and also immediately above the Keuper Sandstone. At Marchington Cliff near Uttoxeter, Staffordshire, celestite occurs in beds probably belonging to the Tea Green Marl.

Traces of celestite have been recorded from the Rhaetic of the Newark-Leicester area, for example, at Glen Parva and in the White Lias limestones of Lyme Regis, Dorset. Celestite has been noted in Yorkshire in the Permian evaporites from the Eskdale No 2 borehole, and in association with gypsum in the Lower Magnesian Limestone from the bank of the River Nidd at Bilton, near Knaresborough and in the Bunter Sandstone at Green Hamerton.

In the Gypsiferous Beds of the Upper Jurassic (Purbeck Beds), celestite is found with remnants of former evaporite deposits between Lulworth, Worbarrow and Durlston Head, Dorset and immediately above the gypsum at Mountfield Mine, Sussex.

Thin beds of celestite may be present in Co Fermanagh, Northern Ireland, similar to those recorded in the Lower Carboniferous (Viséan) evaporites of Co Leitrim, Eire.

Celestite, probably of late magmatic origin, is present as small irregular plates in microadamellite dykes cutting the main plutonic complex of Glenelg–Ratagan on the Inverness–Wester Ross border, but is of no economic importance. It occurs at a number of places in Sutherland: for example it is associated with baryte in a fault in carbonate rock at the north-east shore of Loch Loyal.

Strontianite and a number of minor strontium minerals have been noted in several areas in England and Scotland but have never been worked commercially. For example, on the western side of the Ben Loyal syenite, strontianite occurs in fibrous form and as small sheets. The syenite itself has a relatively high strontium content. Strontianite also occurs nearby at Ben Bhreac, Tongue. Other known localities include Green Laws Lead Mine, east of St John's Chapel, Weardale, Co Durham; west of Old Gang Smelt Mills, Swaledale and Merryfield near Pateley Bridge, Yorkshire; Ecton Copper Mine, Staffordshire (although possibly celestite); Warebeth Lead Mine, west of Stromness, and elsewhere in vein material on the Orkney Islands. Strontianite occurs with celestite at Free Donald and Whitesmith mines near Strontian, Argyllshire, and at Clachnaharry near Inverness. Although strontianite is found on dumps at a number of these mines, it is unlikely to be present in sufficient quantity and of suitable quality to enable it to be recovered economically.

Brines from the Coal Measures sampled recently by the Hydrogeological Department of the Institute of Geological Sciences at collieries in Northumberland and Durham have strontium values ranging from 18 to 870 mg per litre (mg/l): they also contain significant amounts of barium chloride which has been recovered commercially. Other work by the Department has shown 23 mg/l Sr at the Frampton Cotterell pumping station, Gloucestershire (rate of extraction 1,800 cu m per day) and a median Sr content of 1.0 mg/l for Derbyshire thermal springs. Normal sea water contains 8 mg/l Sr. These values can be compared to the strontium content of Great Salt Lake, Utah, recorded as 2.1 mg/l and 962 mg/l noted from water at Bristol Dry Lake, California, which have been considered for commercial exploitation. Patents have been taken out by a US firm covering the extraction of strontium salts from such brines.

Reserves

The distribution of celestite deposits associated with the Keuper beds of south Gloucestershire and north Somerset is not known in detail. The grade, persistence over small distances and quantities present are very uncertain outside the immediate working area. Very little is known about its distribution in the Coal Measures. Furthermore it is understood that until recently virtually no prospecting has been carried out by industry outside the main working area, at Yate. No realistic estimate of reserves of the Severnside area has, therefore, ever been made. However, within the last two years more extensive exploration work has been undertaken by the producing company and other interested concerns. Reports of the presence of celestite nodules of high grade in stream sections, pipeline trenches and road cuttings indicate that workable deposits may well be present in areas not designated on the basis of the 1951 Ministry of Housing and Local Government report (see 'Land use and restoration'). West Somerset, which has never been investigated in detail, may contain celestite deposits and the occurrences in the north Midlands may prove to be more extensive than is indicated by the few available reports.

Concern about the need to avoid sterilisation of celestite deposits has led to work on this mineral being undertaken by the Institute of Geological Sciences (see pages 9 and 16).

Land use and restoration

A conference on celestite, particularly concerned with the Gloucestershire deposits, was convened by the Ministry of Housing and Local Government (now the Department of the Environment) in 1951. Interested Government departments, local authorities, mineral operators and land owners took part, and geological information was supplied by the Geological Survey (now part of the Institute of Geological Sciences). On the basis of this and the operators' information, a map was prepared which defined:

i working areas

ii areas where celestite can probably be worked

iii areas where celestite may possibly be found in workable quantities.

The areas thus defined include the Yate belt, running from Wapley north through Yate village (as it was then) to Cromhall, and curving westwards towards Tytherington, a narrow zone at Latteridge to the west, and a parallel north-south zone between Wickwar and Tortworth. Gloucestershire County Council recognised the national and international significance of the deposits, and subsequently areas covering some 433 hectares (1,070 acres) within the Yate zone were 'reserved' for celestite working on the Gloucestershire County Development Plans approved in 1955 and 1968.

Current planning permissions for celestite working north of the Bristol-Chipping Sodbury road (A 432), between north Yate and Cromhall, total about 405 hectares (1,000 acres). Apart from the northern fringe of Yate, the area involved is agricultural land. According to Gloucestershire County Council some 162 hectares (400 acres) of this total had been worked by mid-1970, although it is possible that some areas may be reworkable, owing to the rather inefficient methods and selectivity of earlier working. A permission area of about 121.5 hectares (300 acres) to the south of Yate town centre was regarded as worked-out by the operators and most of it has been developed for housing. This area might also have been reworkable using current extraction methods. Further south, a small area of agricultural land south of the London-South Wales direct line was permitted for working in 1970, representing an extension to the previously exploited celestite field.

Gloucestershire County Council have also recognised the importance of celestite by normally requiring prior extraction before building operations take place. Until recently this has only affected the expansion of Yate, a new town development. It is noted in the Yate and Chipping Sodbury Town Map Written Statement that some 22.3 hectares (55 acres) allocated for residential purposes in north Yate and believed to contain celestite would not be developed until the mineral has been extracted or is proved to be uneconomic to extract.

Hitherto the area of land consumed annually by celestite working to satisfy the requirements of the single firm engaged in the industry has been small. The situation is changing, however, because in addition to the marked increase in world demand for celestite, there are rapidly growing pressures for the expansion of Bristol and other urban growth in south Gloucestershire which would affect the areas where celestite is known to occur.

The preparation of the Severnside Study undertaken by the Central Unit for Environmental Planning (Department of the Environment and the Welsh Office) involved the primary selection of 'areas of search' to guide the Unit to the most suitable locations for future large scale urban and industrial development. The more detailed studies which followed resulted in fourteen sites being selected, three or four of which were suited to especially large urban development. The last category included 'Frampton Cotterell' with the smaller adjacent areas of 'Wapley' and 'Thornbury'. The main area chosen is bounded by the M5 to the north-west and, on the east, by the Liassic scarp from a point near Cromhall to Chipping Sodbury and the Bristol-Birmingham railway. The southern margin is formed by the northern outskirts of Bristol. The 'Wapley' area is that lying between the M4 and the South Wales-London direct line. These areas, and additionally that around Thornbury, constitute nearly all the known celestite-bearing land of south Gloucestershire. However, it is stated that the extent of the areas involved affords a choice of areas for building and for mineral working as well as opportunities for phasing extraction and development. The Study recommends that any decisions in favour of large scale growth should await the outcome of a survey to be carried out by the Institute of Geological Sciences (now at the feasibility stage) in co-operation with the industry, and an assessment of the potential value of the mineral. The reported yield of about £15,000 worth of celestite per acre cited in the Study is only an approximate figure of the gross yield per acre at the then current market price of the mineral.

In this context, indications of the occurrence of economically workable mineral outside the Yate zone might have serious implications on the broader, regional scale.

At the present scale of working there is little or no dereliction, due to the fact that workings are shallow and restoration to agriculture or other uses is carried out in accordance with the conditions attached to the planning permissions and the terms of mineral leases. No waste tips remain, although occasionally workings have given rise to small ponds and patches of scrub where restoration was incomplete eg north-east of Goose Green Farm, Yate. Minor settlement occurring after reinstatement is unlikely to be detrimental to agricultural land, but could prove to be an adverse factor when subsequent building is contemplated as at Yate (a Gloucestershire County Council new town development) if backfilling and working are not closely controlled. The current method of working opencast small scattered pits, 5 to 10 m deep, when back-filled may give rise to ground of variable loading capacity. The cost of back-filling pits, especially if layered compaction of fill is required, adds to the relatively low price of the mineral. The cost of building on worked-out land may also be increased due to the necessity of testing the ground and the use of special foundations.

There may be some disturbance caused by the use of heavy lorries on narrow, mainly unclassified roads between the pits and processing plants and later, during delivery to customers.

Although Keuper Marl is worked for brick clay in the Bristol area only one instance of the production of clay and celestite together is recorded, celestite having been the by-product at Charfield brickworks some years ago. The works closed in 1970.

Uses

The main use of strontium compounds is in pyrotechnics which, together with the electronics, glass, ceramics and paint industries, consumes some 80 to 90 per cent of the strontium chemicals that are produced from British celestite. Of the remainder, metallurgical uses are the most important. Nearly all the celestite used in the United Kingdom is first processed to the carbonate, the chemical from which most other strontium compounds are derived. There are two major UK producers of strontium carbonate one of which, Albright and Wilson Limited, produces most of the other strontium salts for the open market, including strontium chromate, strontium chloride, strontium hydroxide, strontium nitrate, strontium oxalate and peroxide.

Pyrotechnics

A number of strontium salts, including the carbonate, nitrate, peroxide, oxalate and formate, burn to produce a brilliant crimson flame. They are used for example, in marine distress flares, fireworks, in tracer ammunition and signal flares. A new application in this country is in flares for use by the police to give warning of accidents in fog on motorways, while other warnings are being installed. Strontium compounds usually comprise less than 10 per cent by weight of fireworks, but in other pyrotechnics the proportion may be much higher.

Electrical applications

Strontium chloride is used to produce the phosphors in the activated coatings for fluorescent lighting and colour television screens. Strontium carbonate and iron oxide are processed to produce strontium ferrites (strontium hexaferrite $SrO.6Fe_2O_3$) which are used to make ceramic magnets. The use of this type of ceramic magnet, particularly in DC motors, telecommunications and computers is increasing; other applications are in radio and television sets, oscillators, lifting equipment, magnetic separators and elsewhere to replace conventional metallic magnets, where saving in size and weight and higher efficiency are required. Strontium titanate, stannate and zirconate are used as ceramic dielectric material for electrical capacitors. Strontium nitrate is used in the heating elements of thermionic valves.

Glass and ceramics

In the United States and Japan strontium carbonate is now used on a substantial scale in the manufacture of face plates for colour television tubes. Strontium compounds in glass reduce the risk to the viewer from secondary X-ray emission more than barium compounds. This glass contains about 7 per cent by weight of strontium, calculated as the oxide. Strontium compounds are used in the production of several other types of glass, for example, iridescent, special optical and leadless crystal glasses.

Small amounts of strontium salts, especially strontium oxide (strontia), are used in a wide variety of glazes, particularly in leadless, low temperature and matt glazes and in extending the firing range of lime glazes. Strontium compounds are occasionally used in ceramic bodies.

Paints

Celestite has been used as a filler and as a brightening and whitening agent in paints. Strontium-bearing formulations analogous to the paint pigment lithopone (a mixture of barium sulphide and zinc sulphate) were produced during the First World War. Strontium sulphide has been used for many years as the phosphorescent pigment in luminous paints. Recently strontium chromate has been used on an increasing scale in anti-corrosive primers, particularly applied to zinc, magnesium and aluminium, and in alloys used for aircraft where high heat, water and alkali resistance are needed. Solvent-based water-soluble resins bearing strontium chromate are used in stoving primers and surfacers for road vehicles and aircraft and there are similar marine applications. Particular advantages of using the strontium salt are non-toxicity, non-flammability, non-gelation of acid media and the fact that tapwater may be used as a diluent. Small amounts of strontium chromate are used in artists' colours and as a substitute for barium chromate in jointing compounds.

Metallurgy

Strontium metal is not produced in the United Kingdom but is produced in Canada by Dominion Magnesium Limited at Haley, Ontario, as a by-product of magnesium manufactured from ferro-silicon and dolomite. The metal is used in 'getter' alloys to remove gas from vacuum tubes, as a scavenger in metallurgy to purify other metals and in very small amounts to improve the hardness and durability of lead and copper. A strontium-silicon inoculant used in the production of high quality iron castings has been developed by the British Cast Iron Research Association and is being marketed by Union Carbide under licence.

Increasing quantities of strontium carbonate are being used in the production of high purity (low lead) electrolytic zinc by a process patented by the American Smelting and Refining Company, and used in Australia, South Africa (both using strontium carbonate imported from the United Kingdom), the United States and probably Japan. The patent notes that strontium chloride and strontium sulphate may also be used for this process. Licencees operating under this patent are understood to be using 5.5 to 6.5 lbs of strontium carbonate per short ton (2.8 to 3.3 kg per tonne) of zinc produced. Strontium chromate is used in self-regulating chrome plating in the United States and the United Kingdom. Strontianite has been used, particularly in Germany, for dephosphorising and desulphurising very high grade open-hearth steel, as it produces a fluid, highly basic flux. The use of strontium chloride in case-hardening salts has been discontinued in the UK as supplies of barium chloride or other substitutes are more readily available.

Pharmaceutical uses

Strontium hydroxide and sulphide are used as depilatories and the chloride is used in toothpaste; other salts used in medicine include the salicylate, bromide and iodide.

Fillers

Celestite has been used as a filler in rubber, plastics and paints. A possible use in this field is in rubbers used in X-ray work. Low-grade celestite was used as a component of drilling mud in the United States instead of barytes until the barytes patent lapsed in about 1943.

Miscellaneous uses

Prior to the First World War the major use of strontium compounds was in German sugar refineries which employed strontium hydroxide to recover sugar from sugar beet molasses by the Scheibler process. Most of the strontium hydroxide was recycled. Generally, the loss was said to be so high that the process became uneconomic and strontium hydroxide was replaced by cheaper materials. As far as is known this is the only application of strontium compounds where recirculation was economically possible. It is believed that by the end of the Second World War the Scheibler process was only in use at Dessau, East Germany.

Strontium carbonate has been used in special alloy welding rod coatings in the United States, where strontium soap-greases with special heat, water and chemical resistance are also manufactured. Strontium sulphate is used in the United Kingdom for removing such elements as manganese and iron that are likely to lead to discoloration in the production of high-purity caustic soda for rayon and paper-making. Strontium stearate and naphthenate are used as non-toxic stabilizers in PVC plastics. The optical properties and hardness of synthetic crystals of strontium titanate enable them to be used as artificial gemstones.

The isotope strontium 90 (employed in radio-therapy, as a self-luminous light source, in industry to gauge the thickness of sheet coating materials continuously, in various fields of research and as an 'exciter' in luminous paints) does not occur naturally and strontium minerals are not used in its production.

Specifications

Celestite sold in the United Kingdom normally contains a minimum of 95 per cent $SrSO_4$, not more than about 2.0 per cent each of barium sulphate ($BaSO_4$) and silica (SiO_2) and approximately 0.5 per cent each of calcium carbonate ($CaCO_3$) and iron oxide (Fe_2O_3). The US National Stockpile Purchase specification P-10-R3 dated 25 April 1968 which applies to sales of celestite to the US General Services Administration, demands a minimum of 96 per cent $SrSO_4$, a maximum of 2 per cent $CaSO_4$ and free moisture not more than 2 per cent by weight. Many manufacturers in the United States demand celestite comparable to this specification, although lower grade material is also used. Although details are not known, it is understood that a slightly lower grade of celestite may be used in high-purity zinc production and in fillers. However, for some applications, for example, in brighteners and whiteners, low iron content is essential whereas low calcium and barium are less important, good colour being of paramount importance. Celestite containing 97 per cent $SrSO_4$ was specified by one firm for use as a white extender in paint.

Canadian strontium metal contains 98.5 per cent strontium, 0.1 per cent barium, 0.8 per cent calcium and 0.5 per cent magnesium. Details of a number of formulations used in paint manufacture involving strontium chromate are given by R F Bennett in 'Paint Manufacture' (1962). The range of strontium chromate contents of various anti-corrosive and water-soluble primers is given as 1.29 per cent to over 15 per cent by weight although most contain 3 to 5 per cent $SrCrO_4$. British Standard 4313: 1968, 'Strontium chromate for paints', is the only British Standard Specification known to refer to strontium compounds. The Directorate of Technical Development Specification DTD 911 'Protection of magnesium-rich alloys against corrosion' also refers to the use of strontium chromate in a special paint.

For use in the faceplate of colour television tubes, the iron content of the strontium compound must be low; one company specifies not more than 0.01 per cent of oxides, as Fe_2O_3, (and barium oxide less than 1.4 per cent). It is understood that at present strontium carbonate produced in the United Kingdom does not reach this grade. Strontium nitrate required for pyrotechnics should be at least 99.5 per cent pure and have as low a sodium content as possible. Strontium ferrite producers can tolerate up to 0.1 to 0.2 per cent Fe_2O_3 in strontium carbonate. Further information is included in US National Bureau of Standards specifications.

Price and cost

Prices are usually negotiated and only nominal prices are published. For many years these were in the range of £8 to £11 a long ton, but they were increased to £13 to £17 for 95 per cent $SrSO_4$ celestite early in 1969. Approximate prices during 1970 were as follows:

Celestite, crushed, washed, graded, 95 per cent $SrSO_4$, ex works	£15.60 per tonne
Celestite, minus 240 mesh	£20.85 per long ton

Since 1971 only one grade has been offered for sale:

Celestite washed and graded, 95 per cent $SrSO_4$, bulk, ex works, minus 240 mesh	£22 per tonne

Prices of the more important strontium chemicals in 1971 were as follows:

Strontium carbonate (commercial), 1,000 kg lots in 50 kg sacks	12p per kg
Strontium carbonate (technical white), 1,000 kg lots in 50 kg sacks	14p per kg
Strontium chloride dihydrate, 1,000 kg lots in 50 kg sacks	28p per kg
Strontium chromate, 1,000 kg lots in 25 kg sacks	53p per kg
Strontium hydroxide, 50 kg lots in 50 kg bags	53p per kg
Strontium nitrate (commercial), 1,000 kg lots in 110 kg drums	27p per kg
Strontium oxalate, 250 kg lots in 12½ kg packs	87p per kg
Strontium titanate	90p per kg
Strontium stannate	£2.50 per kg
Strontium zirconate	£2.40 per kg

The cost of the mineral is only a small proportion of the cost of most of the finished products in which it is used. For example, the cost of celestite is just under 20 per cent of the price of strontium carbonate, the lowest priced chemical, and in many other strontium chemicals the mineral price accounts for only 3 to 5 per cent of the cost. The cost of strontium chemicals compared with the finished product is usually an even smaller percentage; for example only about 0.4 per cent of the cost of high purity zinc (99.99 per cent Zn) is attributable to strontium carbonate.

In the case of pyrotechnics, both compositions and prices are so variable that it is difficult to give an estimated figure; in a normal 'red-fire' firework strontium carbonate would probably account for about 2 to 5 per cent of the cost. It is equally difficult to estimate the proportion contributed to the cost in paint manufacture.

The costs of inland delivery of celestite are not known, although one merchant quotes a delivered UK price of about £10 per tonne more than the ex works price. A typical transatlantic shipping rate is £6.10 per tonne for a 4,000 tonne load with additional dock and rail charges to ports in South Wales of £1.13 per tonne. Although reported to be rather more expensive than Mexican ore, delivered prices to the north-eastern seaboard of the United States are comparable. Thus the proximity of the workings in Gloucestershire to major ports, in addition to the high grade and relative ease of working, has contributed to its importance in world markets.

The prices of many substitutes are lower than those for celestite and strontium compounds. Prices for various substitutes given below were current in January 1972:

Barytes:	
Unground, 90-98 per cent $BaSO_4$, bulk, cif	£8-£11 per tonne
Ground white, paint grade 96-98 per cent $BaSO_4$, 99 per cent 240 mesh, 10 tonne lots delivered UK	£40 per tonne
Barium carbonate:	
Standard paint grade delivered, according to load	6-6.35p per kg
Chrome yellow:	
Powder pigment (average of a number of grades)	Approximately 30p per kg
Lime:	
Chemical hydrated, fob works	Approximately £6 per tonne

Technology

Mining and processing

Celestite is extracted by front-end loaders from small excavations up to 10 m, but often less than 5 m deep in the Keuper Marl and underlying Coal Measures. The celestite-bearing marl is tipped on either side of the track leading to each pit and is hand-picked by teams of about three men. The average output per man is about 10 tonnes per week rising to 30 tonnes in some of the richer areas. When about 20 tonnes of celestite has been accumulated it is taken by lorry to the processing plant at Hall End near Wickwar. The minimum payable celestite to waste ratio has been regarded as being of the order of 1:10 in marl, although there is now a tendency for lower grades to be worked. Before 1959 celestite was sold only in lump form after hand scraping to remove clay. The average yield per acre at present is understood to be between about 500 and 1,000 tonnes.

The celestite is first reduced to -1½ in (38 mm) by means of a jaw crusher, then washed and sized by counter-flow trommel screens producing roughly ¾ in to 3/16 in (-19 mm + 4.75 mm) gravel. The finer material is dewatered and the oversize is recirculated to the crusher. In 1970 the plant had a capacity of about 5 tonnes per hour of gravel, although between 500 and 1,000 tonnes of -240 mesh material was produced annually by air separation. From 1971 the bulk of the output has been ground finer than -240 mesh. The calcium, barium and iron contents vary in different working areas, and the celestite is blended to meet specifications. In the manufacture of strontium carbonate, -240 mesh celestite is mixed with hydrochloric acid to convert the calcium carbonate and iron oxides into water-soluble chlorides. After washing, strontium sulphate is converted to the carbonate by mixing the resultant slurry with boiling sodium carbonate solution.

Transport of the dried and bagged product to the customer is by road although formerly much of the output was sent by rail via Chipping Sodbury station. Celestite for export is shipped via Newport and other South Wales ports, where sailings and terms are more convenient than Bristol or Avonmouth. Some of the crushed and powdered celestite is forwarded by road to Par, Cornwall, for conversion to the carbonate.

Another method of producing strontium carbonate and other salts, not employed in the United Kingdom but currently being introduced at some works in the United States, involves reducing celestite to the sulphide using, for example, powdered coke. This is leached with water, filtered and treated with carbon dioxide (or the acid of the desired salt) to produce the salt directly. It is understood that the process requires a throughput of about 8,000 tonnes a year to be economically viable.

Research

In the late 1950's the industry experimented with different prospecting and extraction techniques, in an effort to improve methods of working. This was followed by the construction of crushing, washing and grading plant in 1959. The old method of prospecting by probing with a bar has been replaced by pitting on a grid pattern, or by mechanical trenching immediately ahead of working often down to about 6 or 7 m. Geophysical exploration methods have not been applied successfully, although a shallow seismic technique might detect celestite when it occurs as layers of nodules or beds isolated from other rocks by a metre or so of Keuper Marl.

In 1971 the Mineral Assessment Unit of the Institute of Geological Sciences initiated a feasibility study to assess celestite resources on behalf of the Department of the Environment. Preliminary results suggest that it may be possible to use geochemical prospecting methods in spite of high background strontium values and the presence in some areas of old, unrecorded workings. The Hydrogeological Department of the Institute has investigated the strontium hydrogeochemistry of an area to the north of Bristol. Such work could prove to be a useful geochemical exploration technique when applied on a regional scale in areas where the hydrogeology is known in outline.

There may be scope for further research into a more efficient means of separating celestite from marl, as recovery rates are believed to be generally low. One difficulty is that the mineral, although it has a high specific gravity, is very friable. Acid washing, similar to that employed in upgrading barytes, froth flotation, tabling and heavy-media separation techniques were tested during the Second World War in the United States on Texan celestite and found to provide a high-grade product although recovery was poor. After the war these proved to be uneconomic in the face of competition from imported ores. Furthermore the mineralogy of these ores differs from UK material. A number of separation processes and methods for the conversion of celestite to carbonate have been developed recently but none are in commercial use in the United Kingdom.

In April, 1971 the Nova Scotia Technical College (NSTC) was awarded a grant of $285,000 by the National Research Council of Canada to conduct research into new uses for strontium compounds. This work is being undertaken by the Atlantic Industrial Research Institute, which is affiliated to the NSTC and has been involved with the Nova Scotia Department of Mines in the exploration and processing of the Loch Lomond celestite deposit, Cape Breton County, Nova Scotia. At this mine, operated by Kaiser Celestite Mining Ltd (a subsidiary of Kaiser Aluminum and Chemical Corporation), ore containing 50 to 60 per cent $SrSO_4$ is upgraded to 85 per cent by flotation with specially developed reagents. Strontium chemicals are prepared by the company at Point Edward, near Sydney, Nova Scotia.

Production and overseas trade

Since commercial production of celestite in England began, probably in about 1875, most of the world production outside the Communist countries has been provided by the United Kingdom. However, in 1969 the proportion contributed by the United Kingdom fell to about 30 per cent and in 1970 there was a further decline as a result of large increases in production in Mexico and Canada: smaller amounts are produced in Spain, Argentina, Pakistan and Italy. Free world production in 1970 was about three times the annual average over the period 1959-1968. United Kingdom production has ranged from about 400 to 33,000 tonnes a year: in 1971 production amounted to 9,749 tonnes.

Production statistics have not been published by the Department of Trade and Industry, the statutory authority, since 1938 because of the application of confidentiality rules. Overseas trade figures are also not published by the Department because of the small size of the trade. However, production figures from 1939 and export statistics from 1958 have been made available by industry to the Mineral Resources Division of the Institute of Geological Sciences and are published annually in the 'Statistical Summary of the Mineral Industry'. Annual production figures for celestite from 1884, when production was first officially recorded, are shown in Table 1 and Fig 2, although the statistics for the period of the Second World War are incomplete. No production of strontianite has ever been recorded in the UK. In most years since production began, between 50 and 90 per cent of the celestite output has been exported. Trade sources estimate that current domestic consumption is in the region of 1,000 tonnes a year, but the difference between total production and recorded exports suggests that consumption may be higher, even allowing for stock movements in the trade.

Exports have accounted for about three-quarters of average annual production during the past ten years, in most years the United Kingdom being both the world's major producer and exporter of celestite (Table 2). The principal importing countries are the United States, Germany, France, Italy and Japan. A number of strontium chemicals are known to be exported, for example strontium carbonate is sent to Australia and South Africa for use in the electrolytic refining of zinc. Many countries consuming small quantities of strontium chemicals ultimately derive their supplies from the United Kingdom. The lack of domestic facilities for producing strontium carbonate of the quality required to meet colour television screen specifications leads to the export of celestite rather than strontium carbonate, thus reducing the potential benefits to the balance of payments. It is very unlikely that strontium minerals are regularly imported.

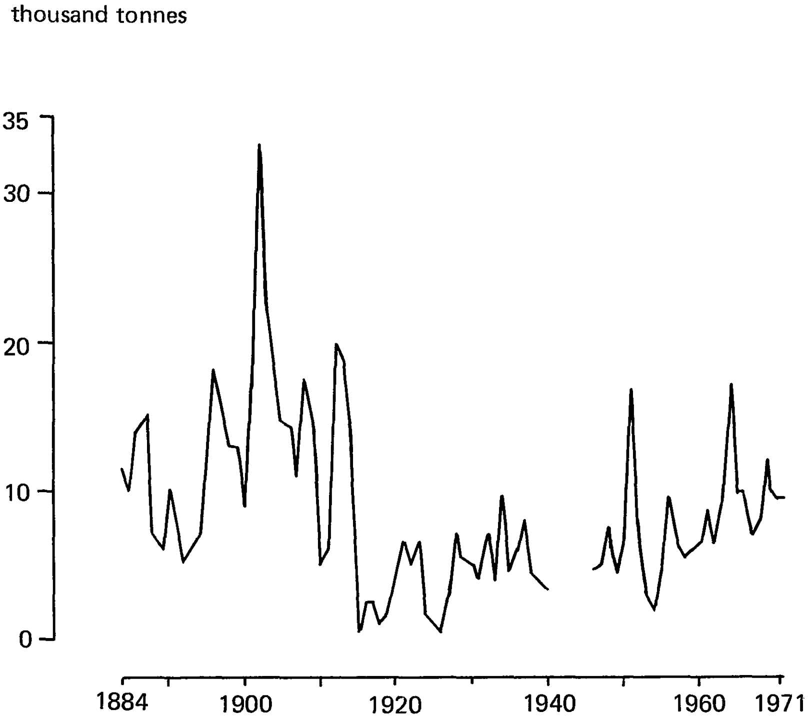

Fig.2. UK Production of Celestite
1884-1971

The total effect of overseas trade in celestite on the balance of payments is small. The value of celestite exports is not published in official trade returns, but the fob value of United Kingdom celestite imported by the United States (the main export market) in 1970 was given as £70,417 (converting to sterling at $2.40 = £1) in United States trade returns (see Table 3).

Demand trends and forecasts

Production of celestite in the United Kingdom has been closely related to military and overseas demand. During the three decades preceding the First World War most of the production was exported to Germany, primarily for sugar refining, the balance being used in the manufacture of strontium chemicals. Although domestic demand increased between 1914 and 1918, largely because of the substitution of formerly imported barium compounds by strontium equivalents (eg for use in paints), production declined because of the loss of European markets. Exports to the USA also increased and were maintained at about 1,000 tonnes per annum between the wars. During this period the German market diminished considerably with the reduction in the number of sugar refineries employing the Scheibler process.

Table 1 United Kingdom: Celestite production, 1884–1971 and exports, 1946–1971

Year	*Production* *tonnes*	*Year*	*Production* *tonnes*	*Year*	*Exports* *tonnes*
1884	11,605	1928	7,240		
1885	9,957	1929	5,415		
1886	13,820	1930	5,223		
1887	15,412	1931	4,117		
1888	7,177	1932	6,962		
1889	6,072	1933	3,924		
1890	10,441	1934	9,591		
1891	8,190	1935	4,582		
1892	5,147	1936	5,864		
1893	5,905	1937	7,719		
1894	6,932	1938	4,670		
1895	12,470	1939	3,821		
1896	18,332	1940	3,756		
1897	15,228	1941	*na*		
1898	13,149	1942	2,283		
1899	12,832	1943	*na*		
1900	9,267	1944	*na*		
1901	16,918	1945	*na*		
1902	32,799	1946	*na*	1946	2,295 (a)
1903	23,209	1947	5,092	1947	3,941 (a)
1904	18,461	1948	7,526	1948	5,482 (a)
1905	14,523	1949	4,871	1949	4,448 (a)
1906	14,338	1950	6,760	1950	6,037 (a)
1907	10,917	1951	16,612	1951	10,861 (a)
1908	16,733	1952	8,200	1952	7,403 (a)
1909	14,267	1953	3,013	1953	4,003 (a)
1910	4,837	1954	2,100	1954	1,256 (a)
1911	5,963	1955	4,830	1955	3,677 (a)
1912	19,681	1956	9,300	1956	6,459 (a)
1913	18,721	1957	7,000	1957	4,194 (a)
1914	13,368	1958	5,700	1958	4,414
1915	650	1959	6,100	1959	4,901
1916	2,553	1960	6,710	1960	5,002
1917	2,618	1961	8,818	1961	6,038
1918	1,030	1962	6,637	1962	3,580
1919	1,902	1963	9,164	1963	9,588
1920	4,250	1964	17,306	1964	15,479
1921	6,728	1965	9,702	1965	5,528
1922	4,787	1966	9,556	1966	7,501
1923	6,448	1967	6,787	1967	3,925
1924	1,473	1968	7,888	1968	5,917
1925	1,089	1969	11,721	1969	7.667
1926	386	1970	9,501	1970	5,850
1927	3,140	1971	9,749	1971	5,635

na Information not available

Sources:

Production:

1884-1919	Mines and Quarries General Report with Statistics. Home Office.
1920-1938	Annual Reports of the Secretary of Mines and HM Chief Inspector of Mines (with statistical appendices), Mines Dept, Board of Trade.
1939-1971	Statistical Summary of the Mineral Industry, Mineral Resources Division, Institute of Geological Sciences.

Exports (not available prior to 1946):

(a)	USA imports of celestite from UK published by US Bureau of Mines.
1958-1971	Figures made available by the producing company for publication in the Statistical Summary of the Mineral Industry.

Table 2 Strontium minerals: World production and exports, 1961–1970(a)

Country & description	*1961*	*1962*	*1963*	*1964*	*1965*	*1966*	*1967*	*1968*	*1969*	*1970*
Production					*Tonnes*					
United Kingdom	8,818	6,637	9,164	17,306	9,702	9,556	6,787	7,888	11,721	9,501
Canada (b)	–	–	–	–	–	–	–	–	6,000	8,000
Pakistan	421	293	385	269	451	535	379	650	772	299
Italy	980	598	654	457	640	597	660	778	926	844
Spain (c)	*na*	*na*	*na*	*na*	*na*	*na*	1,000(d)	4,000(d)	3,600	*na*
Mexico	*na*	*na*	*na*	5,461	2,620	5,685	2,543	3,453	18,076	26,500
Argentina	*na*	*na*	540	30	598	370	30	70	13	14
Exports										
United Kingdom – Celestite	6,038	3,580	9,588	15,479	5,528	7,501	3,925	5,917	7,667	5,850
Italy – Celestite & strontianite	290	91	90	134	99	119	120	81	*na*	*na*
Mexico – Celestite (e)	2,528	4,269	6,190	4,892	3,125	6,301	2,833	2,540	18,066	27,537
Spain – Strontium minerals (e)	–	–	–	–	1,477	–	–	4,031	2,043	3,048

na Information not available.

(a) Mostly celestite but may include some strontianite: in terms of output of natural ore.

(b) Estimated strontium sulphate content of crude material reported stockpiled.

(c) Quarry worked on a care and maintenance basis (1961–1966) with only sporadic output which may account for US imports shown for 1965.

(d) United States Bureau of Mines' estimate.

(e) Imports into USA.

Table 3 USA: Imports of strontium minerals, 1961–70, by country of origin

Year	*UK*	*Mexico*	*Elsewhere*	*Total*
		Tonnes		
1961	6,602	2,397	10	9,009
1962	2,638	4,131	25	6,794
1963	8,841	5,875	10	14,726
1964	14,808	4,789	14	19,611
1965	4,429	2,925	1,482(a)	8,836
1966	4,602	5,837	9	10,448
1967	2,217	2,856	18	5,091
1968	4,134	3,519	4,046(a)	11,699
1969	3,763	19,416	2,043(a)	25,222
1970	4,233	26,515	3,048(a)	33,796
Fob value 1970	*£70,417*	*£245,417*	*£28,750*	*£344,584*
Average value per tonne in 1970	*£16.6*	*£9.3*	*£9.4*	*£10.2*

The US dollar values in 1970 have been converted to sterling at $2.40 = £1

(a) Chiefly or all from Spain

Source: Minerals Yearbook, US Bureau of Mines.

Immediately after the Second World War, production ceased in the USA and exports to that country were resumed but the small pre-war exports to the German sugar refineries ceased. Demand for military pyrotechnics for use in the Korean War gave rise to greatly increased production, 16,612 tonnes, and exports, 10,861 tonnes, in 1951: the Vietnam War produced a similar effect in 1964 when UK production reached 17,306 tonnes and exports 15,479 tonnes.

Fluctuations in recent production have tended to follow US Stockpile requirements and large contracts from US chemical firms producing strontium carbonate (see Table 3).

Clearly, consideration of the future demand must take into account international markets. In 1951, the conference on celestite (see p 8) estimated that theoretical peace-time demand throughout the world was about 8,000 tonnes per annum. Average annual world production for the ten-year period to 1961 was in fact about 9,550 tonnes. The demand for strontium minerals is particularly sensitive to military needs and changing technology. The multiplicity of minor uses and the absence of any statistical breakdown of end uses, the uncertain demand for exports, particularly in US markets, and, recently, competition with other exporting countries, notably Canada and Mexico, are other factors that complicate forecasts of demand for British celestite. A change in demand of a few thousand tonnes a year has a significant effect on the present world market, which is small.

Clearly, although strontium compounds may have the optimum properties required, they are used in, for example, electronics and metallurgy only when these outweigh price and availability disadvantages. An example is the increasing demand for strontium ferrites, which are smaller (or lighter) and more efficient than other magnets, for use in computers, transistorised systems, miniaturised recording and metering equipment, electric motors and communications relays. Other cheaper ferrites, for example containing barium, are available, but are less efficient for some applications.

At present the main difficulties in forecasting demand concern the uncertainty of the potential consumption by the colour television industry and the impact of production from new facilities in Nova Scotia, Canada. In the USA, legislation has been introduced to reduce the permissible X-ray emission from colour television sets. The Corning Glass Works in the United States hold patents relating to the use of strontium salts in television glassware, although licences have been issued to some European companies. However, following a conference of European electronic component manufacturers in Toulouse in 1970, European manufacturers decided to adopt other methods which are claimed to be as effective, such as the modification of electronic circuits to cope with runaway voltages (the main cause of X-ray emission) and increasing the lead oxide content of the glass at the neck of the tube. It is claimed that emission can also be reduced by other less expensive methods, for example by the use of barium salts or zirconia rather than strontium carbonate in the glass face plates.

Earlier demand forecasts suggested that the colour TV glass market in Europe would require over 10,000 tonnes of strontium carbonate a year by 1972. As the result of current uncertainties, two 1970 estimates of UK consumption of strontium carbonate for colour TV in 1971 varied substantially and both had wide ranges, from 70 to 100 tonnes and from 800 to 2,000 tonnes: as far as is known, none was used.

In 1970, the United States Bureau of Mines published high and low forecasts of world demand of 37,200 tonnes and 23,900 tonnes of strontium equivalent in 2000 AD. The corresponding forecasts of US consumption were 19,500 and 11,500 tonnes. These were derived from the projection of demand for various end uses (estimated in 1968), taking into account forecasts of general economic indicators and contingency considerations leading to the high and low figures. However in 1968 there was no significant manufacture of either strontium ferrite or strontium-bearing television glassware, although a sizeable provision for the latter was made in the estimates. The prediction in the 'Oil, Paint and Drug Reporter' (June 1969) of an increase in US strontium carbonate production from about 9,000 tonnes in 1969 to 14,500 tonnes in 1970, was subsequently borne out by increases in production capacity or changes in plant to produce strontium in place of barium carbonate.

The potential market in glassware in the USA for compounds made from celestite mined in the UK is uncertain, as initially a large part of this increased requirement is being supplied by Mexico and Spain (see Table 3). Both Mexican and Spanish production is being expanded. The latter, in particular, may have an impact on UK exports as material containing 96 per cent of strontium is marketed at a relatively low price.

It is understood that the bulk of the planned 30,000 short tons (27,200 tonnes) a year output of the Kaiser strontium chemicals plant at Sydney, Nova Scotia will be carbonate for television tubes together with smaller amounts for strontium hexaferrite and strontium metal. An investment of about $18m is involved in the mine, concentrator and chemical plant. Output of ore, containing 50 to 60 per cent celestite, is planned to increase to 90,700 tonnes a year within the next five years. Current reserves are given at 2.45 million tonnes, ranging from 30 to 60 per cent celestite.

Although providing a major part of the world supply of celestite, production in the United Kingdom has been on a modest scale. Until now the value of the world market has been almost insignificant compared with most minerals, dealings being in relatively small quantities and at prices in a range more usually associated with bulk minerals than with a specialised product. This situation has reflected the very limited uses for which strontium compounds have been specifically required and the difficulty of expanding into wider markets in competition with more readily available, cheaper materials.

Any potential economies to be derived from the larger-scale production and processing of celestite have therefore not been realised so far. However, recent substantial increases in demand resulting from a preference for strontium compounds in two major new fields of application has encouraged the development of larger-scale, lower-cost production, especially in Canada, and this in turn could lead to a more widespread use of strontium products generally. A larger, diversified world market might provide a suitable base for expansion of the United Kingdom celestite industry, particularly if savings in costs can be achieved with a higher level of output.

Substitutes

No satisfactory substitutes have been found for strontium compounds in pyrotechnics, traditionally their principal use, for although lithium nitrate and some calcium compounds produce red flames they are impracticable because the former is hygroscopic and more expensive while the latter are deliquescent and have poor burning characteristics.

However, for several other uses the higher cost of strontium chemicals and their limited availability (see 'Industry') in the past have resulted in large-scale substitution, particularly by barium and calcium salts. Many substitutes, however, have disadvantages. For example, lead oxides and certain barium compounds used in glass, paints and rubber radiation shielding may be toxic; barium and lead compounds are often heavier than comparable strontium salts.

In the preparation of high grade caustic soda two alternative processes have been developed, using either dolomitic limestone or ammonia in place of celestite or strontianite, while in the extraction of sugar from beet-molasses, either lime (the Steffen process) or barium hydroxide or barium silicote (the BARSI process) are now used almost exclusively in place of strontium hydroxide.

Similarly, lime or fluorspar is now used to desulphurise and dephosphatise stainless steel, while barium chloride is used in case-hardening. Although strontium chromate has a number of valuable qualities such as light-fastness, low toxicity and resistance to heat, which make it suitable for use in special paints, chrome yellow (lead chromate) is usually preferred, particularly because of its lower cost and higher tint strength. Cadmium sulphide may also be substituted for strontium sulphide in some paints. Nevertheless, strontium compounds are still used in paints for uses allied to its special properties. Strontium metal may be replaced by barium in several applications, for example in 'getters' (see page 11). Alternatives to the use of strontium salts in colour television face plates are discussed under 'Demand trends'. In ceramic bodies and glazes, lead, zinc, magnesium, barium and calcium oxides may all be used instead of strontium compounds.

Industry

The Bristol Mineral Company (formerly the Bristol Mineral and Land Company) accounted for much of the celestite produced in the United Kingdom before 1912 and almost all since 1945, although until the early years of the Second World War there were three or four producing companies, including Strontium Products Ltd and British Quarrying Company Ltd. In 1941, 67 per cent of the equity of the Bristol Mineral Company was sold to Albright and Wilson Limited but this was sold back to the original owner in 1963. The company was acquired by English China Clays Limited in October, 1969.

Within the last four years another company, Western Structures and Engineering Limited prospected successfully over a number of areas in Somerset and south Gloucestershire. A market survey was undertaken and a plant was established in Bristol to convert celestite to high-grade strontium carbonate, but the firm went into liquidation in 1970.

Strontium carbonate is produced by English China Clays Limited and Albright and Wilson Limited. In June, 1971 Tenneco International Incorporated, a subsidiary of Tenneco Incorporated, a major American oil company, acquired a majority holding in Albright and Wilson Limited who are the largest producers of strontium chemicals in the United Kingdom.

About 12 members of the Chemical Industries Association manufacture 25 strontium chemicals, although most produce small quantities of laboratory reagent and pharmaceutical chemicals. A number of non-member firms buy carbonate from the two main producers and manufacture chemicals for special outlets, for example, strontium chromate for paints is produced by Cowan Bros (Stratford) Limited and SCC Colours Limited, Stratford, London, and other companies produce compounds for the electronic and ceramic industries.

Mexican and Spanish producers have close trade links with American interests.

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