Mineral Resources
Consultative Committee

Mineral Dossier No 7

Salt

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Titles in the series

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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.

Acknowledgements

This dossier has been compiled with the assistance of the Department of the Environment, the Department of Trade and Industry and the Ministry of Commerce, Northern Ireland. The help and advice generously given by members of the Institute of Geological Sciences, particularly Mr W B Evans, Mr E G Poole, Mr B J Taylor, Dr A Whittaker and Mr H E Wilson (Geological Survey of Northern Ireland) is gratefully acknowledged, as is the assistance of Mr R A Healing and Mr D Horne of the Mineral Statistics and Economics Unit of the Mineral Resources Division. For their helpful comments, thanks are due to the salt producers and the Salt Manufacturers Association.

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
grammes (g)	= troy ounces x 31.1035
kilogrammes (kg)	= pounds x 0.45359237
tonnes (1000 kg)	= long tons x 1.01605

Contents

Summary

Salt or sodium chloride (NaCl) occurs in nature either in the solid form as rock-salt or halite, or in solution as brine. It is a raw material essential to the heavy inorganic chemical industry, being used principally in the production of chlorine, caustic soda and soda ash which, in turn, are used in a wide variety of other processes. Salt is also used extensively in food processing, such as flavouring dairy products and as a preservative, for snow and ice clearance on roads and as a fertilizer. Salt production began in the United Kingdom in at least Roman times, developing into a large scale industry during the 18th century. The Cheshire saltfield has been and remains the principal source of supply, at present accounting for over 90 per cent of the total United Kingdom output. Salt is also produced from deposits in Lancashire and Durham and in County Antrim in Northern Ireland. Other deposits which have been of commercial importance in the past are situated in Worcestershire, Staffordshire, the Isle of Man and Somerset.

Rock-salt is widely distributed in England and occurs in rocks of either Zechstein (Upper Permian) or Keuper Marl (Upper Triassic) age in beds varying from a few centimetres to hundreds of metres in thickness. Reserves are extremely large, those in the Cheshire - Shropshire Basin alone amounting to perhaps 400,000 million tonnes. Large reserves also occur in a number of other saltfields and extensions to known deposits are likely to be found.

Salt is produced in the United Kingdom by the controlled pumping of artificial brines created by introducing water into beds of rock-salt, by pumping natural brines resulting from the solution of rock-salt by ground-water, by conventional underground mining methods for the production of rock-salt and, on a very small scale, by evaporating sea-water. Most of the brine pumped is used directly in the manufacture of either chlorine and caustic soda (sodium hydroxide) by electrolysis, or soda ash (sodium carbonate) by the Ammonia-Soda or Solvay process. Brine is also used in the production of white salt by evaporation. Rock-salt, accounting for about 18 per cent of the total salt extracted in the United Kingdom, is crushed before use for winter road maintenance. The production of salt by natural brine pumping has in the past caused considerable damage due to subsidence. Subsidence is still a problem but is less extensive than formerly; it is apparently not caused by rock-salt mining and controlled methods of brine pumping.

The United Kingdom is one of the world's major producers of salt, ranking fifth in 1970, when output amounted to 9,029,000 tonnes. Of this total 5,698,000 tonnes comprised salt-in-brine, 1,733,000 tonnes was brine salt and 1,598,000 tonnes was rock-salt. Exports amounted to 582,600 tonnes, valued at about £3,989,000, destined chiefly for Sweden, Nigeria, Finland and the USA. Imports were nearly 140,600 tonnes valued at about £717,000, of which

nearly 92,800 tonnes was in the form of fishery salt obtained largely from the Federal Republic of Germany. There are three major salt producing companies in the United Kingdom: Imperial Chemical Industries Limited, by far the largest producer which operates in Cheshire, Lancashire and Durham, British Salt Limited and BP Chemicals International Limited, both of which operate in Cheshire. New Cheshire Salt Works Limited and Ingram Thompson and Sons Limited are two independent producers in Cheshire. The American-owned Irish Salt Mining and Exploration Company Limited is the sole salt producer in Northern Ireland. Sea salt is produced on a small scale by the Maldon Crystal Salt Company Limited at Maldon in Essex.

Definition and mode of occurrence

Salt, or common salt, is the chemical compound sodium chloride ($NaCl$) which is composed of 39.34 per cent sodium and 60.66 per cent chlorine and is colourless to white when pure. It occurs in nature either in the solid form, as rock-salt or halite, or in solution, as brine. Rock-salt occurs in sedimentary rocks in beds varying from a few centimetres to hundreds of metres in thickness and in some regions deformation of these thick salt beds, usually at considerable depth, has resulted in the formation of large vertical structures known as salt domes or salt diapirs. Other evaporite minerals, mainly gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$) and, more rarely, potassium salts such as carnallite ($KCl.MgCl_2.6H_2O$) and sylvite (KCl), may be associated with rock-salt. Rock-salt is transparent or translucent and may be yellow, red, brown, blue or other colours because of minor impurities present: it has a vitreous lustre, a hardness of 2.5 on Mohs' scale and a specific gravity ranging from 2.1 to 2.6. Its characteristic taste, perfect cubic cleavage, relative softness and solubility are diagnostic features the small difference in solubility of rock-salt with increasing temperature being an important economic factor in the production of salt by evaporating brine. Rock-salt frequently contains more than 90 per cent sodium chloride, but minor amounts of sulphates and chlorides of magnesium and calcium, iron oxides and insoluble impurities, chiefly marl and clay, are usually present. As contamination by marl increases the rock passes into saliferous marl.

A brine may be defined as any aqueous solution containing more dissolved salts than sea-water, the average salinity of which is about 3.5 per cent. Most underground brines have been formed by the leaching action of ground-water either on rock-salt or saliferous beds and consequently contain sodium chloride as the principal salt in solution. Brine raised by pumping contains about 25 per cent of dissolved salt: most is used as 'salt-in-brine', that is, the salt is used in solution. Solid salt produced by crystallisation from brine is called 'white salt' or 'brine salt', which may also be known as either 'open-pan salt' or 'vacuum salt', according to which process is used.

Rock-salt is dissolved away by circulating ground-water and is therefore generally absent within about 60 m of the surface. Brines form locally immediately above the highest remaining rock-salt bed, and the interface at which solution is taking place or has occurred is described as a 'wet rock-head' (Fig 1); where the saliferous strata are too deep to be affected by groundwater, the normal stratigraphical contact between these and the overlying rocks is described as a 'dry rock-head'. In the absence of any outcrop the the presence of rock-salt can only be proved by boring or inferred from brine springs and surface subsidence resulting from solution.

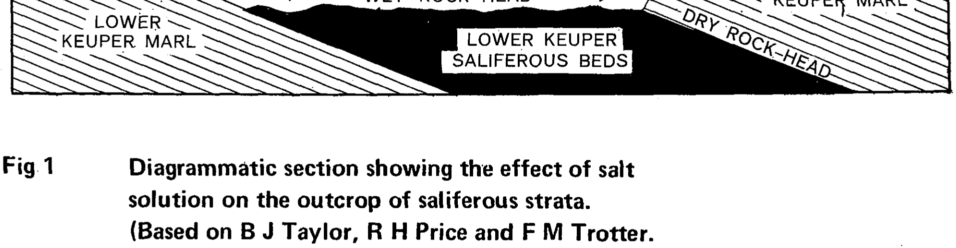

Fig 1 **Diagrammatic section showing the effect of salt solution on the outcrop of saliferous strata. (Based on B J Taylor, R H Price and F M Trotter.** ***Mem. geol. Surv. Engl. Wales,*** **1963, fig 8, p 78.)**

Salt can form in a variety of ways, but the extensive stratified deposits which are of commercial importance in various parts of the world are generally considered to have been produced by the evaporation of sea-water under arid conditions, in basins which have become separated from the open ocean but whose configuration is such that there is a continuous or periodic influx of new sea-water to replace that lost by evaporation. Under ideal conditions the principal mineral phases to appear as evaporation proceeds are, in order, calcium and magnesium carbonates (calcite and dolomite), calcium sulphate (anhydrite and gypsum), gypsum with halite, halite and finally the very soluble sulphates and chlorides of magnesium and potassium. Halite begins to precipitate only when the quantity of sea-water has been reduced to about 10 per cent of its original volume. It has been widely accepted that deposition takes place under shallow-water conditions and that downwarping of the basin can satisfactorily account for very thick salt-bearing sequences. In some evaporite successions, cyclic but not always complete sequences of carbonate, anhydrite, halite and potassium salts have been recognised. The presence of potassium salts perhaps reflects temporary isolation of the basin of deposition, possibly as a result of earth movements, and almost complete desiccation, ended by the entry of sea-water which deposited clastic sediment. The mineralogy of most evaporite beds has been complicated by extensive post-depositional changes involving various transformations and replacements.

There is not complete agreement, however, that evaporite deposits have originated in this way. Detailed stratigraphical studies of the saltfields of the Cheshire Basin and northwestern England, for example, have led to the conclusion that both clastic and evaporitic sediments were deposited in water that was in continuous contact with the open ocean across a shallow, broad shelf area. It has also been suggested that the Triassic salt in England may have been derived from the sub-aerial leaching of pre-existing salt beds, for example, from Permian salt plugs in the southern North Sea, before being re-deposited in the deeper parts of an inland basin.

Resources

Salt is widely distributed in England and occurs chiefly in the Keuper Marl of Upper Triassic age. This formation has a broad outcrop in the Midlands which extends north-eastwards to the Durham coast, while to the west of the Pennines another outcrop stretches north-westward through Lancashire and there is a large outlier in Cumberland (Fig 2). The Keuper Marl extends southwards from the Midlands through Gloucestershire into Somerset and Devon and South Wales. Saliferous strata generally occur where the Keuper Marl thickens in major depositional basins, the most important of these being the Cheshire - Shropshire Basin, which provides more than 90 per cent of the United Kingdom output of salt. Other well-known Triassic saltfields, including those which are or have been of commercial importance, are in Worcestershire, Staffordshire, Lancashire, the Isle of Man, Somerset and Northern Ireland, in south-east County Antrim. Rock-salt also occurs in Zechstein (Upper Permian) strata in Durham, Yorkshire and north Lincolnshire and is worked by brine pumping in south Durham.

Reserves of rock-salt are extremely large and are likely to meet demand for the foreseeable future. Prospecting specifically for new deposits of salt has rarely been carried out, most saltfields in the United Kingdom having been discovered during the search for coal, water, iron ore or hydrocarbons. Total

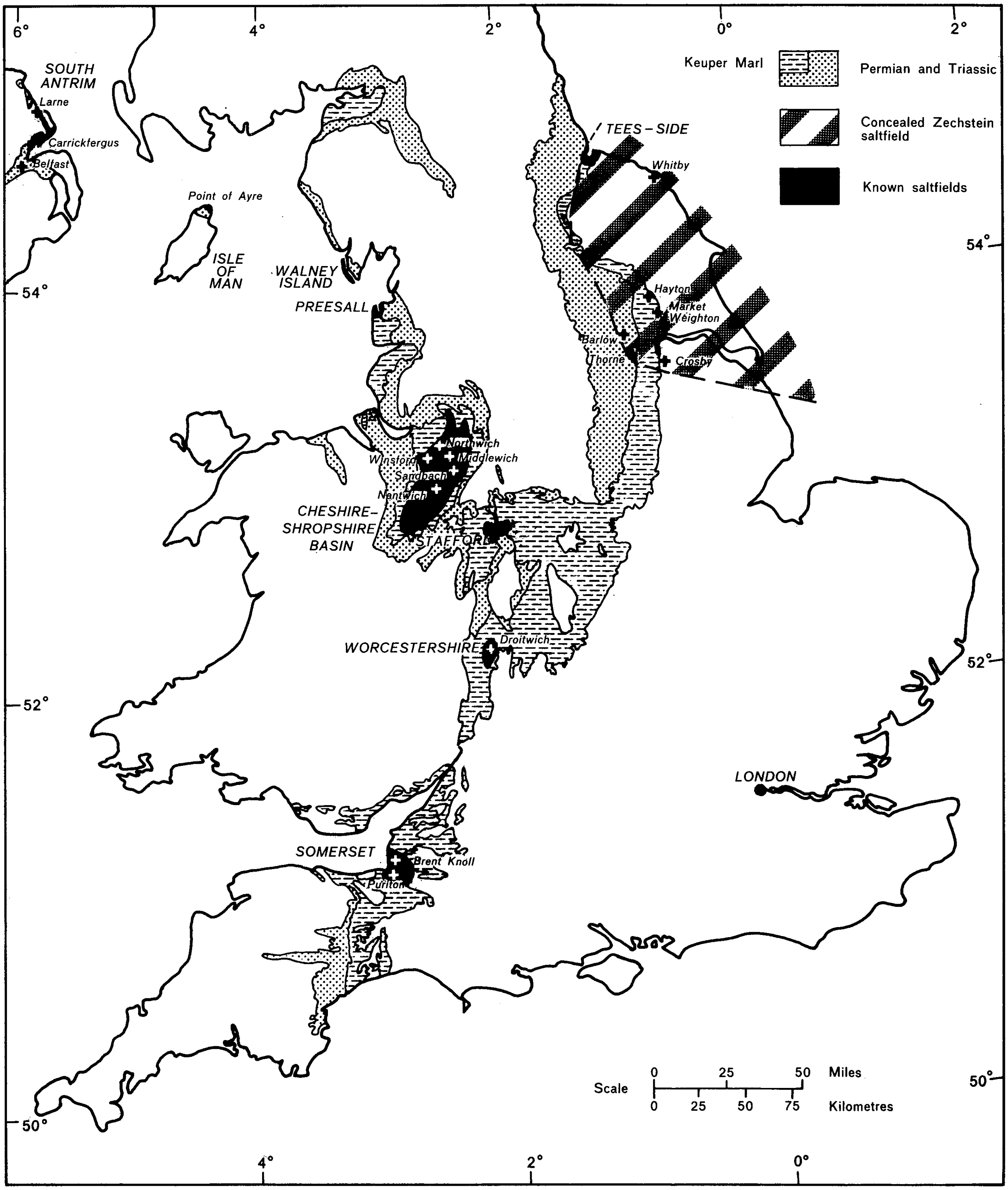

Fig 2 **Distribution of Permian and Triassic rocks and location of saltfields.**

resources have not been determined but a re-survey of the Cheshire-Shropshire saltfield by the Institute of Geological Sciences between 1951 and 1960 indicated reserves of some 400,000 million tonnes and it is conservatively estimated that at least 13,000 million tonnes of rock-salt may be present beneath an area of about 260 sq km in Somerset. The salt deposits in south Durham and north Yorkshire are known to extend to the south and east, and the Zechstein salt probably has its southern limit just south of the River Humber.

In general it has been found that where the Keuper Marl thickens within a depositional basin, the thickening tends to be associated largely with an increase in thickness of the saliferous formations. It seems possible, therefore, that a considerable thickening of the salt beds found at Droitwich and Stoke Prior might occur farther south as they pass into the Worcester Basin, where the Keuper Marl is known to be very thick.

In Northern Ireland, the saltfield in County Antrim may also prove to be considerably larger than is at present known.

Cheshire and Shropshire

The Cheshire-Shropshire saltfield occupies a basin which extends from Lymm, west of Heatley in north Cheshire, southwards into north Shropshire, a distance of about 59km, and has a maximum breadth of some 24 km. There are two major groups of rock-salt bearing strata, known as the Lower Keuper Saliferous Beds and Upper Keuper Saliferous Beds. At Wilkesley, some 16 km SSW of Crewe, an Institute of Geological Sciences' borehole showed the thickness of the Lower Keuper Saliferous Beds to be 190 m and the Upper Keuper Saliferous Beds over 396 m, the two formations being separated by gypsiferous mudstones of the Middle Keuper Marl. The generalised sequence of Keuper Marl strata in southern Cheshire, based on the Wilkesley borehole, is shown in Fig 3.

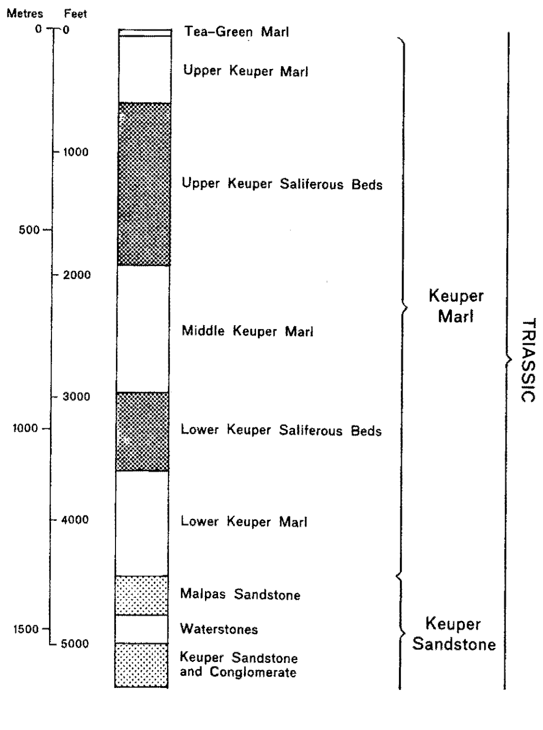

Fig 3 **Generalised section of the Keuper Marl in southern Cheshire, based on the Wilkesley borehole near Crewe. (After W B Evans. *Q. Jnl geol. Soc. Lond.*, 1970, Vol 126, fig 5, p 108.)**

The lower saliferous formation contains 143 m of rock-salt comprising six or seven beds between 15 m and 107 m thick, separated by up to 9 m of mudstone. It thickens substantially to the north and is about 285 m thick at Byley, north-east of Middlewich. The upper formation contains more than 274 m of rock-salt in the Wilkesley borehole, including beds ranging in thickness between 34.5 and 106 m. The aggregate thickness of the lower and upper saliferous beds is here some 586 m of which approximately 70 per cent is therefore composed of rock-salt. Production around Northwich and Winsford is from the Lower Keuper Saliferous Beds, and near Middlewich and Sandbach from the Upper Keuper Saliferous Beds.

Worcestershire and Staffordshire

Droitwich has been famous for its brine springs since earliest times and rock-salt was discovered and mined at Stoke Prior in 1828. In a borehole at Droitwich an aggregate thickness of 21 m of rock-salt was proved in six main beds between a depth of 91 m and the bottom of the hole at 125.5 m, with the possibility of further salt at greater depth. At Stoke Prior, until recently the local centre of the brine pumping industry, several beds varying in thickness from 2 m to 12 m and totalling some 26 m occur below 90 m, but at Redditch 11.25 km to the east and at Stratford-on-Avon, 32 km to the ESE, no rock-salt has been found in the Keuper Marl. At Saleway, about 5 km south-east of Droitwich, a borehole proved dry rock-head; the main beds were thin although the aggregate salt thickness exceeded 30 m. There is a good possibility that these rock-salt beds increase in thickness farther south towards Evesham as the Worcester basin is entered. A borehole 900 m or more deep would be needed to prove the sequence. Several rock-salt beds, in places with an aggregate thickness of 21 m, are present in the Keuper Marl at Stafford in some 46 m of strata at depths of over 60 m. The salt at Stafford, like that at Droitwich, is a marginal basin facies and is contaminated with marl. Salt has also been proved in boreholes at Chartley and Bagot's Park near Uttoxeter.

Lancashire and the Isle of Man

A small saltfield occurs in the Keuper Marl at Preesall, near Fleetwood, where rock-salt was first discovered in 1872 in boreholes put down in search of iron ore. The rock-salt formation, including marl partings, attains a maximum thickness of about 183 m at depths ranging from about 75 m to at least 365 m. The formation is preserved in a syncline and the sequence may thicken offshore under the northern Irish Sea as the Manx-Furness Basin is entered. Beneath Walney Island, near Barrow-in-Furness, two main rock-salt formations have been proved, the upper at least 61 m thick, and the lower about 18 m thick. Rock-salt was discovered in the Isle of Man in a boring put down in 1891 during a search for coal at the Point of Ayre, the northernmost tip of the island. Numerous salt beds occur in the Keuper Marl and in one borehole the aggregate thickness of salt was 23 m between depths of about 183 m and 274 m, to which could be added a further 39 m of salt-bearing strata. The salt beds have a restricted occurrence under land near the Point of Ayre, but they are known to extend beneath the sea and probably thicken in a north-easterly direction towards the centre of the Solway Firth Basin.

Somerset

Rock-salt was discovered in a borehole drilled for coal near Puriton in 1910. The saliferous deposits occur within the Central Somerset Basin, an east-west trending structure in which a thick sequence of Mesozoic rocks is flanked to the north and south by Palaeozoic rocks. The western part of the basin is submerged beneath the Bristol Channel, while much of the eastern part is obscured by a mantle of superficial deposits. The borehole proved over 610 m of Triassic strata, including about 427 m of beds assigned to the Keuper Marl. Rock-salt was encountered within the Keuper Marl at a depth of about 183 m from the surface and tests were run on brine samples during the course of drilling operations. Results were favourable and brine was extracted for about 11 years, the works closing in April 1922 after being taken over by the Salt Union in 1920. Four open pans were in operation and both table and industrial grades of salt were produced. More recently the Somerset saltfield has been explored between Puriton and Wedmore where deep boreholes have shown that salt beds occur through as much as 107 m of strata. The Institute of Geological Sciences' Burton Row borehole, drilled in 1971 near Brent Knoll about 11 km north of Puriton, has proved a northward extension of the saliferous beds at a similar stratigraphic level to those at Puriton. The main saliferous beds, containing varying amounts of siltstone, occur between depths of about 694 m and 742 m, although halite veins and stringers were first encountered at 643 m and are present to 797 m.

North-east England

The Zechstein (Upper Permian) salt extends from Tees-side at depth beneath much of east Yorkshire and north Lincolnshire. The generalised sequence of Upper Permian and Triassic strata in Durham and north Yorkshire is shown in Fig 4. Salt was originally discovered in Permian strata near Middlesborough on the Tees estuary in 1859 during a search for water and brine pumping began in 1882. The salt bed, the Middle Halite, overlies the Billingham Main Anhydrite and is up to 45 m thick. It is worked by controlled brine pumping, at depths of between 274 m and 366 m, around Greatham, north-east of Billingham. The rock-salt beds thin rapidly towards the west but extend with increasing depth to the east and south. Thick beds associated with potassium minerals and anhydrite have been found in the Permian evaporite sequences of east Yorkshire, for example, south of Whitby at depths of over 1000 m, originally while drilling for oil. A 30 m bed of rock-salt near the base of the Keuper Marl was also found in the boreholes. Further south, in both Yorkshire and north Lincolnshire, rock-salt occurs in the Middle Permian Marls in boreholes at Thorne, Barlow, Market Weighton and Hayton and in the Upper Permian Marls at Hayton, Market Weighton and Crosby. In the Market Weighton and Barlow boreholes rock-salt beds 7 m and 6 m thick occur in the Middle Permian Marls at depths of 756.5 m and 294.9 m respectively and at Crosby, near Scunthorpe in Lincolnshire, an 8 m bed of marl and salt occurs at a depth of 658 m in the Upper Permian Marls.

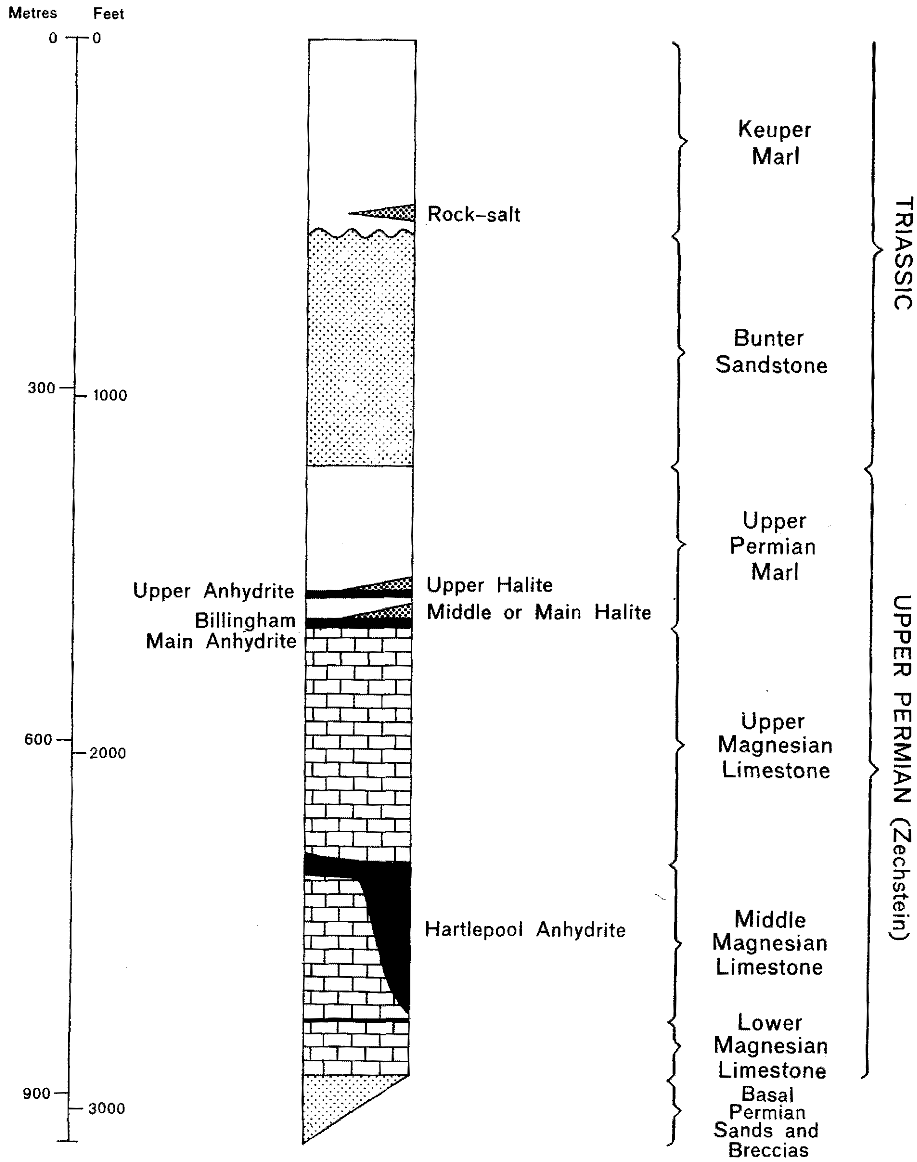

Fig 4 **Generalised section of the Permian and Triassic rocks in Durham and North Yorkshire. (After B J Taylor, I C Burgess, D H Land, D A C Mills, D B Smith and P T Warren. *Br. reg. Geol.*, 1971, fig 25, p 73.)**

Northern Ireland

Rock-salt was discovered at Carrickfergus, north-east of Belfast, in 1850 at a depth of about 170 m, again while searching for coal. The deposits occur within the Keuper Marl beneath the north shore of Belfast Lough from Carrickfergus to Larne, where an extension of the saltfield was proved by geophysical surveys and drilling carried out by the Geological Survey of Northern Ireland for the Ministry of Commerce in the years 1959-63. The thickness of the saliferous beds increases from about 40 m in the Carrickfergus area towards Larne, where a borehole proved a total thickness of some 457 m of rock-salt at depths of between 363 m and 1029 m (Fig 5). The thickest deposits occur at depths of less than 777 m. Commercial exploration was undertaken in 1963 near Ballycarry, on the west side of Larne Lough, and near Castle Dobbs, north-east of Carrickfergus.

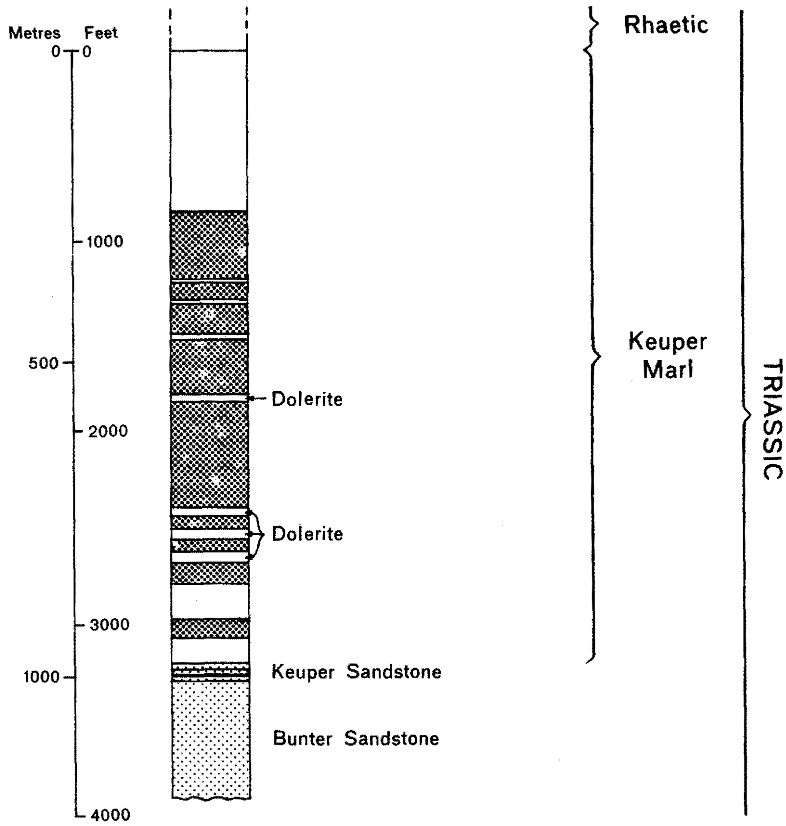

Fig 5 **Generalised section of the Keuper saliferous strata (shown in heavy stipple) in the Larne borehole, County Antrim. (After W B Evans. *Q. Jnl geol. Soc. Lond.*, 1970, Vol 126, fig 11, p 119.)**

Continental shelf

Triassic rock-salt almost certainly occurs beneath parts of the northern Irish Sea, beneath the Bristol Channel (in the western part of the Central Somerset Basin) and possible under the southern part of Cardigan Bay. Permian salt is widely distributed under the southern North Sea, where it occurs in various structures including large diapiric salt plugs.

Sea Water

Salt is produced from sea-water by solar evaporation in many countries including France, the Bahamas, the USA, Japan and Australia. Formerly a large proportion of the salt made in Britain was obtained by heating sea-water and this method continues to be used on a limited scale at Maldon in Essex. Desalination by freezing produces fresh water ice crystals and leaves a brine solution from which salt could conceivably be recovered, although the concentration is increased only to a limited extent. Such a process was developed by the Water Research Association in collaboration with the United Kingdom Atomic Energy Authority during the 1960's and a desalination plant, expected to be the largest in operation in the world with a daily output of 4.5 million litres of fresh water, was to be built on the Deben estuary east of Ipswich in Essex. However it was announced early in 1972 that the project was to be abandoned. Salt is unlikely to be extracted from sea-water on a substantial scale in the United Kingdom nor are deposits beneath the sea-bed likely to be exploited while there are very large reserves of salt on land.

Other resources

Brine occurring as surface spring water has been recorded from pre-Permian rocks in various parts of Britain and at some localities was formerly worked. Some of the spring waters continue to be used for therapeutic purposes. The brines, which occur chiefly in rocks of Coal Measures (Upper Carboniferous) age, have a variable composition but generally contain relatively high concentrations of chlorides, notably of sodium, calcium and magnesium.

Salt brine is the major constituent of waste produced in the processing of the potash ore sylvinite (a mixture of sylvite and halite), but recovery is not generally commercially feasible, although a very small quantity of salt is recovered from potash operations in the USA, in New Mexico, and is used for animal feed purposes. When potash mining begins in north-east Yorkshire this waste will probably be conveyed out to sea by pipeline, although there is a possibility that salt may be recovered and used for snow clearance.

Land use

Planning permissions for the various methods of salt extraction cover considerable areas of land but only a small percentage of the permitted area is taken up by plant, buildings, pipelines and borehole sites. Salt extraction by mining and controlled brine pumping takes place within the boundaries of the permitted area and therefore the area affected by extraction can be closely controlled. Natural or 'wild' brine pumping may give rise to subsidence which causes damage to property and flooding, often at distances of several kilometres from the pumping site, indicating that salt solution is taking place well outside the permission areas. In parts of Cheshire and at Droitwich and Stafford considerable tracts of ground have been affected by salt subsidence. In Cheshire planning permissions cover approximately 7,680 acres (31 sq km) whereas in Worcestershire, at Stoke Prior, only a little over 6,000 acres (243 hectares) were involved. On Tees-side most of the planning permissions cover both salt and anhydrite; existing consents cover a few hundred hectares.

There is very little dereliction associated with current salt and brine extraction although the disposal of waste from the saltworks is a problem. Flooding caused by subsidence may be considered to be permanent dereliction of agricultural land, although the lakes and ponds so formed often have an amenity value. Pipelines are usually dismantled after pumping has ceased but in the abandoned areas of controlled brine fields, well-heads and access roads are maintained.

Modern methods of rock-salt mining and controlled brine pumping do not, apparently, cause surface subsidence. Most of the linear hollows and circular depressions or 'craters' produced at the surface by subsidence have a natural origin, although they may have been accentuated by natural brine pumping, often to a significant extent. Where the depressions are deeper than the water table, narrow linear 'flashes' are formed. As a very rough guide, the average rate of natural subsidence over the 'wet rock-head' is probably about 1 m in 300,000 years. Even along the linear subsidence channels, which have developed above natural brine-runs active since the last glaciation some 12,000 years ago, natural subsidence is not a major hazard, the average rate being about 1 m in

1,500 years over this period. However, artificial pumping of brine passing along these channels greatly increases this rate, and the subsidence may be unpredictable in its occurrence and magnitude and its control almost impossible. When natural brine is pumped to the surface, fresh, unsaturated water is able to reach the rock-salt beds causing further solution to take place. However, if pumping is at a moderate rate, brine levels may not be reduced to any significant extent. The distribution of linear subsidence channels has been fairly accurately defined, largely by work carried out by the Institute of Geological Sciences, which enables the effective risk area to be much more clearly delineated, but the stability of the ground immediately adjacent to these channels is still imperfectly understood. A formula exists for calculating the potential subsidence, but the time taken for actual subsidence to match potential subsidence is unknown.

Rock-salt mining as practised on an extensive scale in Cheshire during the 18th and 19th centuries was based on inadequate techniques which resulted in the frequent flooding and collapse of mines, while from the middle of the 19th century to the early 20th century the pumping of 'bastard brine' from abandoned flooded mines and the consequent solution of the walls and pillars led to catastrophic subsidence, particularly in the Northwich area. Flooding can be a very serious hazard in rock-salt mining and at the Meadowbank Mine exploratory drilling with special equipment precedes the headings to ensure that no 'wet' faults are encountered. Despite the care taken, an inrush of brine occurred in 1968 when a test borehole which had not been completely plugged was intersected. The inrush was sealed in three weeks but it has been estimated that during this time over 100 million litres of brine were pumped from the mine, a large proportion of which was returned to brine streams down brine wells.

The main economic and social costs of salt extraction are thus attributable to subsidence damage sustained by houses, factories, public buildings, roads, railways, bridges and canals. Although subsidence is still a problem, it is not as extensive as it was during the 19th and early part of the 20th century. The extent of damage to property in Northwich was so severe by 1860 that owners combined in an attempt to obtain compensation, but their efforts were unsuccessful. Following a request by Northwich Salt Chamber of Commerce in 1871 to the Board of Trade a report was prepared by a Mr J Dickinson which was presented in Parliament in 1873 and clearly placed the responsibility for subsidence on the brine pumpers. In 1891 the Brine Pumping (Compensation for Subsidence) Act was passed, providing for the setting up of compensation Boards to collect an annual levy on brine pumped and to assess claims for damage. The Boards were also empowered to advise on special precautions to be taken in constructing new buildings. Brine pumpers, land owners who received rents or salt royalties, local authorities, gas, water, railway and canal companies, all of whom were regarded as profiting directly or indirectly from the salt trade, were excluded from the right to claim compensation. In 1896 Northwich was made a compensation district under the Act but the Northwich Salt Compensation Board was the only compensation Board set up. Later proposals, recommendations and consultations and in particular a report prepared in 1934 by Messrs M G and R W Weeks, Consulting Engineers, resulted in the Cheshire Brine Pumping (Compensation for Subsidence) Act, 1952, under which a single compensation district was set up covering nearly all areas of Cheshire where subsidence was regarded as a possibility. The Cheshire Brine Compensation Board was made responsible for raising a levy for the payment of compensation for subsidence damage and for contributing towards the additional expense to developers of providing special structural precautions in new buildings, as recommended by the Board. Under this Act, brine pumpers who employ controlled methods of extraction are allowed a 66 2/3 per cent rebate of the levy charged, provided that there is no subsidence attributable to their activities. A consultation procedure between the Compensation Board and the Local Planning Authority was also laid down. The Compensation Board prepared a series of maps defining 'Yellow Areas' which were considered to be subsiding or liable to subside. The Local Planning Authority consults the Board when considering any application relating to the erection of buildings within these areas. The Cheshire Brine Compensation Board provides, on average, approximately £50,000 a year compensation for subsidence damage and in costs towards additional precautions against damage to new buildings.

Expansion of surface developments to the east of Droitwich has been limited because of the risk of subsidence, but this problem will be greatly alleviated by the closure of Imperial Chemical Industries Limited's natural brine pumping operations at Stoke Prior in February 1972. In Stafford, considerable damage has been caused to buildings, roads and other surface installations. In 1970 the High Court held that damage to the property of the Lotus Shoe Company had been caused by subsidence resulting from brine pumping and an injunction was issued preventing further pumping of natural brine at Stafford by the salt producers. The Lotus Shoe Company was awarded damages and costs, and a compensation trust fund was set up by the salt producers.

Uses and specifications

Salt, principally as brine, is an essential raw material in many manufacturing processes. As shown in Fig 6 approximately 63 per cent of the total salt produced in the United Kingdom is consumed directly by the heavy inorganic chemical industry for use, in about equal proportions, in the electrolytic process for the production of chlorine and caustic soda (sodium hydroxide) and the Solvay process for the production of soda ash (sodium carbonate). These chemicals are in turn used in a wide variety of other processes. Salt is also used in the manufacture of hydrochloric acid, sodium sulphate (salt cake), sodium sulphide, metallic sodium, sodium cyanide and sodium peroxide.

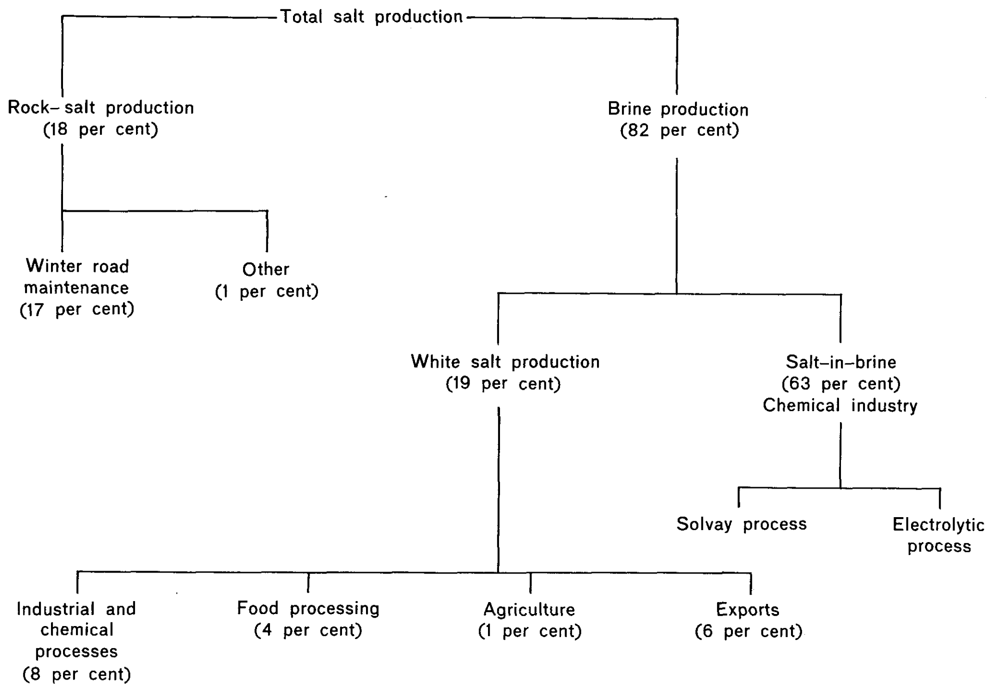

Fig 6 Use of salt produced in Great Britain in 1970.

Chlorine is one of the most versatile of chemicals and has a very large number of uses. Production capacity is estimated to be about 1 million tonnes a year. Its most important use is in the production of chlorinated solvents, the plastic polyvinyl chloride (PVC) and bromine and ethyl chloride, which is used in the preparation of tetraethyl lead, the 'anti-knock' agent employed to raise the octane rating of motor fuel. Chlorinated hydrocarbons are the principal link between the heavy inorganic and petrochemical industries. Chlorine is also used as a bleach, disinfectant and oxidant. In the United Kingdom bleaching powder was the main outlet for chlorine until the 1920's.

Caustic soda is used in the manufacture of soaps, drugs, viscose rayon and bleaching solutions, in the refining of petroleum and the production of alumina. Soda ash is a basic heavy chemical used chiefly in the glass industry, but also in the manufacture of paper and textiles, the refining of certain non-ferrous ores and in the preparation of various cleaners, water softeners and soap. Evaporated white salt is used principally by the heavy inorganic chemical industry, in the manufacture of salt cake, used chiefly in the glass industry and in the preparation of sodium metal, and as a source of brine for the production of chlorine. Sodium metal is used chiefly in the preparation of some lead compounds, notably tetraethyl lead and a very pure form of sodium is used in the production of titanium metal. White salt is used also in such processes as the manufacture of dyestuffs, synthetic rubber, explosives and soap, in the tanning of leather and for the regeneration of water softening systems.

Salt is an essential item of diet and an average adult consumes between 5 and 10 g per day. In food processing, white salt is used for flavouring dairy products, in vegetable preservation, curing bacon, canning and preserving meat, baking bread and for other purposes in addition to its culinary and domestic uses. It is also used in the fishing industry as a preservative, although this latter use is declining as a result of the increasing use of refrigeration.

The use of rock-salt on roads to melt the ice and snow has grown considerably in recent years, particularly since the late 1950's when a non-caking variety of rock-salt, which could be stored in the open without cover, was developed. About 95 per cent of the total rock-salt production in the United Kingdom is used for the winter maintenance of roads; smaller amounts are used as an ingredient in animal and poultry foodstuffs, as a flux in the recovery of aluminium and light alloy scrap and for glazing pipeware. In agriculture, rock-salt is used in significant amounts as a fertilizer for sugar beet and mangolds. It is also used as a cattle lick, for which United Kingdom requirements are imported, and to produce saturated salt drilling muds. These are employed to prevent enlargement by solution of boreholes which are expected to penetrate rock-salt. Two grades of rock-salt with maximum particle sizes of 9.5 and 2.5 mm, are produced in Cheshire. Both grades have a bulk density of 1200 kg/m^3.

There are British Standards specifications for the following:

Vacuum salt for butter and cheese making and other food uses – B.S. 998: 1969

Salt for spreading on highways for winter maintenance – B.S. 3247: 1970

Part 1 Rock-salt

Part 2 Salt other than rock-salt

Price and cost

The bulk of the salt produced in the United Kingdom is used captively by the producers in chemical manufacture or food processing: only rock-salt and relatively small amounts of white salt are sold on the open market. The following prices were quoted by Imperial Chemical Industries Limited in November 1972:

Rock-salt, crushed, minimum 8 tonne lots, bulk £3.36 per tonne, ex-mine.

Rock-salt, crushed, minimum 6 tonne lots, 50 kg bags, £4.94 per tonne, ex-mine.

Vacuum salt, minimum 6 tonne lots, dried 50 kg bags, £7.99 per tonne, ex-works.

Vacuum salt, minimum 6 tonne lots, undried, bulk £6.17 per tonne, ex-works.

The cost of salt is small in relation to the various end products manufactured from the mineral. Plants which use brine on a large scale for the production of chlorine, soda ash and white salt are usually situated fairly close to the wells and the brine is pumped by pipeline at a relatively low cost. However, when white salt is used in large quantities for chemical manufacture away from the saltfields, transport costs are a significant item. Transport costs for rock-salt for winter road maintenance may be a substantial proportion of its final price particularly in areas remote from the two mines, in Cheshire and Northern Ireland.

Technology

Salt is produced in the United Kingdom by mining bedded rock-salt deposits, by pumping natural ('wild') brines, by solution mining methods in which water is injected into the deposit forming an artificial brine which is pumped to the surface and, on a very small scale, by evaporating sea-water.

Mining

The only rock-salt mine in Great Britain is the Meadowbank Mine at Winsford in Cheshire operated by Imperial Chemical Industries Limited. The mine was first sunk in 1844, abandoned in working order in 1892 and re-opened in 1928. Until the late 1950's production remained at a fairly modest level, amounting to some 40,000 tonnes a year, but in the 1960's major modernisation schemes greatly increased the capacity of the mine and annual production is now over 1,800,000 tonnes, the bulk of which is used for winter road maintenance. It is planned to increase annual output to 2,250,000 tonnes by 1974. At Meadowbank two main beds of salt each 24 m thick occur at depths of 79 m and 122 m, mining operations being confined to the bottom 7.6 m of the lowest bed, where better quality salt occurs. The present workings extend over an area of more than 52 hectares.

Mining at Meadowbank is by conventional room and pillar methods. The rock-salt is first undercut by means of a short-wall cutter to a depth of 3 to 5 m at floor level along the working face. Shotholes are then drilled to a fixed pattern by a mobile hydraulic drill and charged with explosive which is electrically detonated. Normally one firing provides some 1,000 to 1,200 tonnes of rock-salt. The parallel headings which are blasted through the salt bed are connected by crosscuts of similar size, square pillars of salt being left to support the roof, so that extraction rates of 65 to 75 per cent are achieved. Diesel dumpers transport the rock-salt to an underground, primary, impact, crusher, from which the salt is transported by conveyor belt to a surge bunker capable of holding about 18 tonnes. The rock-salt is then weighed, fed into aluminium skips which are brought to the surface through a shaft and carried by conveyor belt to the main crushing plant. Here the rock-salt is crushed and screened to provide the required grades and specially treated to prevent caking, before being fed into silos, from which it can be bagged or loaded direct into road vehicles, or carried to an outside stockpile by overhead belt conveyor. Anti-caking treatment enables the rock-salt to remain in a friable condition suitable for use even after prolonged outdoor storage. The rock-salt produced contains about 94 per cent sodium chloride, with marl as the chief insoluble impurity. A typical analysis is as follows:

	per cent
$NaCl$	94.0
$CaSO_4$	0.9
$CaCl_2$ } $MgCl_2$	0.1
Insoluble matter (chiefly marl) and minor impurities	5.0

Similar mining methods are employed in Northern Ireland in the Kilroot adit mine operated by the Irish Salt Mining and Exploration Company which came into production in December 1966. A beneficiation plant is planned to remove the marl contaminant. Almost the entire output is exported. The salt-field is situated on tidal water and the mine has a private jetty which can accommodate bulk carriers and load three ships simultaneously by a conveyor belt system. Easy access to sea transport enables Northern Ireland to compete favourably with Cheshire for rock-salt markets in Great Britain and apparently it can also compete on the eastern seaboard of North America with producers in the USA and Canada.

Natural brine pumping

Natural brine springs have been known since ancient times in Cheshire and Worcestershire and were the basis of the medieval salt industry. However, from the end of the 17th century, the gradual lowering of the fresh water/brine interface led to the sinking of shafts to pump the brine. Today, natural or 'wild' brine is pumped from boreholes sunk to the wet rock-head, which is usually at depths of about 100 m. As the brine is pumped to the surface, fresh ground-water flows in to dissolve more salt, eventually leading to the removal of substantial quantities of rock-salt from the saliferous beds. Natural brine is pumped near Sandbach, Middlewich and Northwich in Cheshire, and was discontinued recently at Stoke Prior in Worcestershire and at Stafford. Production of salt by natural brine pumping is, however, expected to continue to decline in the United Kingdom because of the subsidence problem, and any change to the controlled and deeper method of brine pumping would entail high initial capital expense in acquiring expertise, land, mineral rights and water supply. In areas away from existing refining or chemical works, there would be the cost of additional pipelines.

Controlled pumping

Probably more than 90 per cent of all the brine pumped in the United Kingdom is produced by the controlled pumping method which, although more costly than pumping natural brine, enables salt to be removed by solution from cavities carefully located in the saliferous strata (Fig 7) well below the level at which natural brine will be found, that is, below the level of ground-water circulation. In Cheshire about 88 per cent of the brine produced is obtained by this method. The individual cavities are worked in series and may produce brine for some 20 to 30 years.

The method was first used in an elementary form about 1892 in the Preesall saltfield near Fleetwood by the United Alkali Company Limited. Water was forced down a steel tube cemented into the salt and the brine formed by solution was forced up a smaller concentric moveable tube. The arrangement was described as a 'forced well'.

Since the formation of Imperial Chemical Industries Limited in 1926, when the techniques of the United Alkali Company became available to the new company, the method has been refined by the addition of roof control effected by a cushion of air or oil and by the use of echo-sounding (sonar) techniques for measuring the size of the cavities. When the isolated cavities reach the maximum size and shape consistent with the stability of the ground above, pumping is stopped and the cavities are left standing full of saturated brine. This method is used by Imperial Chemical Industries at its brinefields at Holford in mid-Cheshire, at Preesall in Lancashire and on Tees-side in south Durham.

In the Holford area the Lower Keuper Saliferous Beds are 244 m thick and some 122 m below the surface at their shallowest point. The maximum depth to the top of the salt in the present workings is about 300 m. The cavities are arranged in a grid pattern, on average 180 m apart; an extraction rate of about 20 per cent is achieved over the area as a whole. At Preesall the saliferous beds are from 100 to 183 m thick, while on Tees-side they are only up to 45 m thick, but consist mainly of rock-salt.

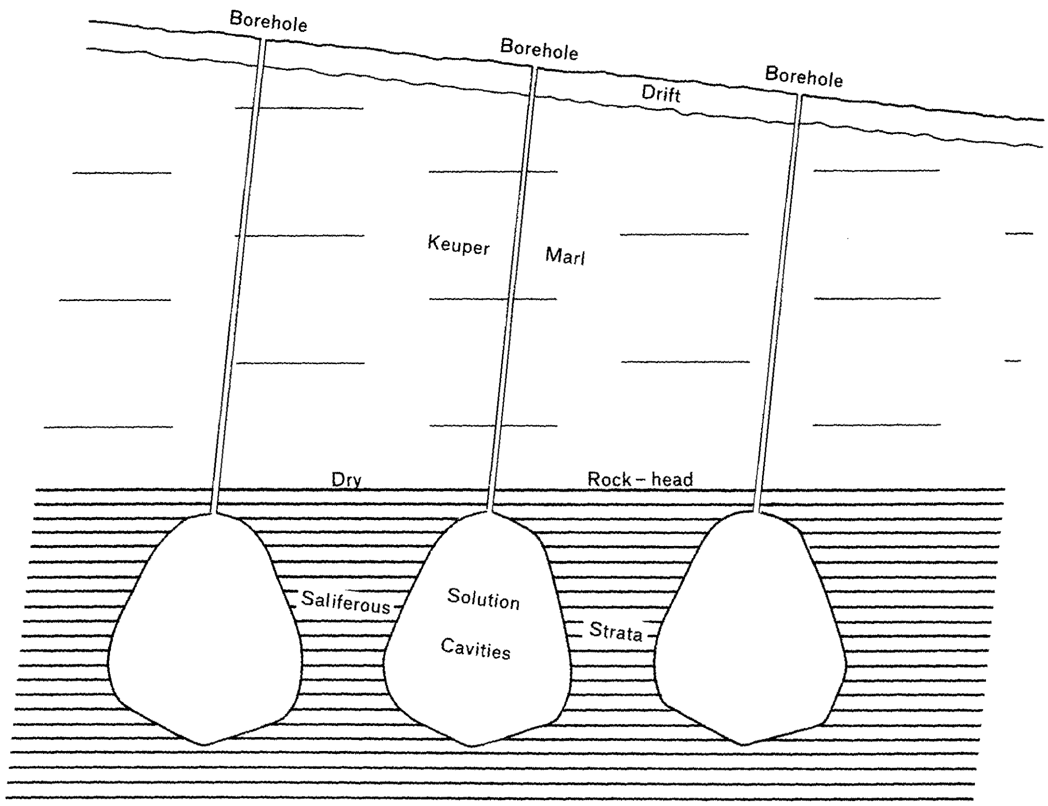

Fig 7 **Generalised section of solution cavities produced by controlled brine pumping.**

In contrast to the controlled method of developing isolated cavities in salt, a system of extraction from multiple-connected wells has been developed in North America and Europe, initially by oil producers, to increase output. In the most common application of this system, the 'Hydrafrac' method, a connection between the bottoms of two boreholes is made by hydraulic fracturing of the intervening rock-salt. The salt is extracted by pumping water down one borehole and recovering brine from the other. The multiple-well system is commonly used where the salt is relatively thin; because of the difficulties of controlling the shape of the cavities in these conditions, subsidence may occur, but careful control will confine this to the vicinity of the wells.

Selected cavities developed in salt deposits by both dry mining and solution mining methods have been found in the USA to be suitable for storing petroleum products and radioactive waste. In mid-Cheshire, Imperial Chemical Industries Limited have disposed of inorganic waste from the Solvay process in solution cavities since 1955 and on Tees-side a solution-mined cavity has been used by the Northern Gas Board for storing town gas since 1959. Other cavities in that area have been used since 1960 for storing various fluids and gases associated with oil refining and chemical manufacture. The use of solution cavities in Permian salt for the storage of gas is being considered by the British Gas Corporation and a plan was announced in May 1972 to drill an exploratory borehole at Atwick near Hornsea in the East Riding of Yorkshire, to a depth of about 2000 m. Storage of gas involves special provisions with regard to the depth, shape and size of the cavities; the optimum depth for gas storage is probably in the region of 900 m to 1500 m, compared with maximum depths of 300 m to 460 m for existing salt solution-mined cavities.

White salt

White salt is produced by evaporating brine using either the vacuum plant or open-pan systems. Formerly open pans were used almost exclusively; there are said to have been over 1,000 open pans in 1881 in the Winsford-Northwich area of Cheshire alone. By the end of 1962, however, the number of pans had been reduced to about 70 producing about 150,000 tonnes a year, compared with about 1 million tonnes produced by the cheaper vacuum process.

In the vacuum plant system crude brine is first passed through a purification plant, in which the unwanted salts of magnesium and calcium are removed by precipitation and filtration. Purified brine is then pumped to a series of evaporation vessels, which are operated under partial vacuum to lower the boiling point of the brine. The so-called 'effects' are arranged so that the vapour produced by boiling the brine in one 'effect' is used to heat the brine in the second 'effect', which being operated at reduced pressure allows the brine to boil at a lower temperature. Subsequent 'effects' are operated at progressively reduced pressures thus allowing a continual reduction in the boiling point of the brine. Fuel is saved by arranging up to five 'effects' in series. The salt crystals sink to the bottom of the vessel and are drawn off as a slurry, which is dewatered to provide undried salt. Three different types of crystal are produced by the vacuum process, and additional grades are produced by drying and screening.

The open-pan system consists essentially of heating brine in shallow open pans, which are directly heated at the base by burning coal or oil, in contrast with steam heating, which has been used in the USA in 'Grainer' pans. The capacity of the pans has ranged from 20,000 to 110,000 litres. The salt crystallises and is removed from the surface of the gently boiling brine by mechanical rakes. One advantage of the system is that a relatively wide variety of shapes and sizes of crystals can be produced by varying the size of the pan, the depth of the brine and the rate of heating. Thus, for finer grades the salt is removed continuously, while coarser grades are produced if an open pan is allowed to run for seven, fourteen, or even twenty-eight days in the case of very coarse 'Bay' salt.

Salt is produced by the evaporation of sea-water at Maldon in Essex on the south bank of the River Blackwater. Two steel-lined brick pans are employed, each about 4.2 m square, from which about 200 to 250 kg a day of salt crystals are produced. Maldon sea-salt is sold as high quality table salt.

Chemicals

The routes by which salt enters into various chemical processes is shown in Fig 8. In the electrolysis of brine for the production of chlorine, the diaphragm and mercury cells are commonly employed. In both cases chlorine and sodium are liberated but in the diaphragm cell the sodium reacts instantly with water to produce caustic soda (sodium hydroxide, NaOH) and hydrogen, and approximately half the salt content of the brine is recovered as solid salt. This salt may be dissolved to produce brine for recycling or used as feed for the mercury amalgam cell. In the mercury cell process, on which the United Kingdom chlorine industry has been largely based since the 1920's, sodium is deposited on the mercury cathode to form a sodium mercury amalgam, which is then withdrawn from the cell and treated with water to produce caustic soda and hydrogen. Producers of chlorine in the United Kingdom, other than Imperial Chemical Industries Limited who discharge their waste brine into the sea, re-circulate the brine. However, chlorine plants can be situated away from the sea without developing an effluent disposal problem provided there is recirculation of the brine in the mercury cells. With re-circulation 1.1 tonnes of caustic soda is produced per tonne of chlorine, normally using 1.7 to 2 tonnes of salt in brine. Without re-circulation some 5 tonnes of salt in brine are required to produce one tonne of chlorine.

The Solvay or Ammonia-Soda process for the production of soda ash (sodium carbonate, Na_2CO_3) is based on the reaction between carbon dioxide and brine saturated with ammonia. Sodium bicarbonate ($NaHCO_3$) is formed initially and converted to the carbonate by heating in a furnace. Ammonium chloride and calcium chloride are by-products of the process. Caustic soda may also be produced by the Lime-Soda process by the reaction of sodium carbonate with slaked lime (calcium hydroxide, $Ca(OH)_2$). However, in recent years the rising demand for chlorine produced by the electrolytic process has greatly increased the output of co-produced caustic soda, so that use of the Lime-Soda process is declining.

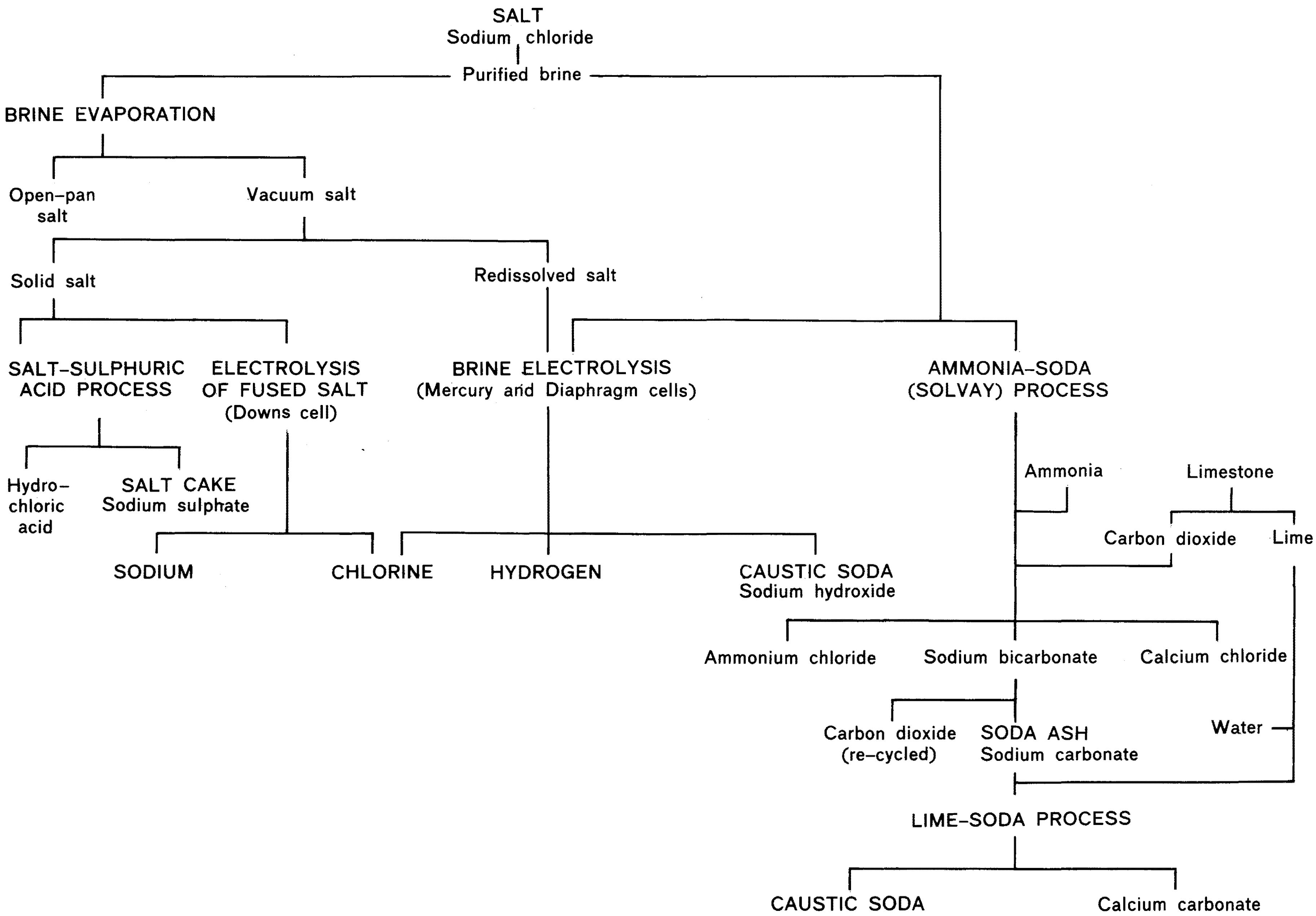

Fig 8 **Outline flowsheet of chemical processes based on salt.**

Before the Solvay process began to be developed around 1869, the Leblanc process for the manufacture of soda ash was widely used, the United Alkali Company being the most important producer. Originally hydrochloric acid obtained as a by-product was discharged as waste, its emission into the air as gas leading to the passing of the Alkali Act in 1863, which compelled manufacturers to take steps to absorb these acid fumes. Towards the end of the 19th century, however, most of the hydrochloric acid was used in the production of chlorine. The Leblanc process, as a whole, became obsolete in 1923 although the first stage, involving the manufacture of sodium sulphate or salt cake from salt and sulphuric acid, is still in use. Hydrochloric acid is a by-product, but most hydrochloric acid is now produced from hydrogen and chlorine. The electrolysis of dry or fused salt in Downs cells yielding sodium and chlorine is a process used mainly for the production of sodium metal.

Production

The United Kingdom is self-sufficient in salt and in 1970 ranked fifth among the major producing countries, as shown below:

Table 1. World production of salt, 1965-1970, by major producing countries

	Thousand tonnes					
Producing country	*1965*	*1966*	*1967*	*1968*	*1969*	*1970*
U.S.A.	31,466	33,078	35,329	37,442	40,137	41,555
China (estimated)	13,200	13,200	13,200	15,200	15,200	16,300
U.S.S.R. (estimated)	9,500	9,300	10,600	11,000	11,500	13,000
Federal Germany	6,701	6,903	6,907	8,054	8,859	10,456
United Kingdom	7,000	7,333	7,113	7,755	8,726	9,029
India	4,702	4,508	4,469	5,039	5,591	5,592
France	4,449	4,463	5,009	4,120	4,790	5,502
Canada	3,619	4,159	4,800	4,413	4,225	4,583
World total (estimated)	110,000	113,000	117,000	126,000	133,000	143,000

Source: Statistical Summary of the Mineral Industry, Institute of Geological Sciences.

Official United Kingdom statistics relating to the production of salt were first published in 1874 (Table 2) but some production figures are available back to 1860. In Northern Ireland statistics have been available since 1853 when salt production commenced. Since 1874 some 305 million tonnes have been produced in the United Kingdom, of which rock-salt accounts for about 20 million tonnes, brine salt (ie white salt) between 128 million and 133 million tonnes and salt-in-brine between 152 million and 157 million tonnes. Production during the period 1923-1970 is shown in Fig 9; details for the period 1951-1970 are shown in Table 3.

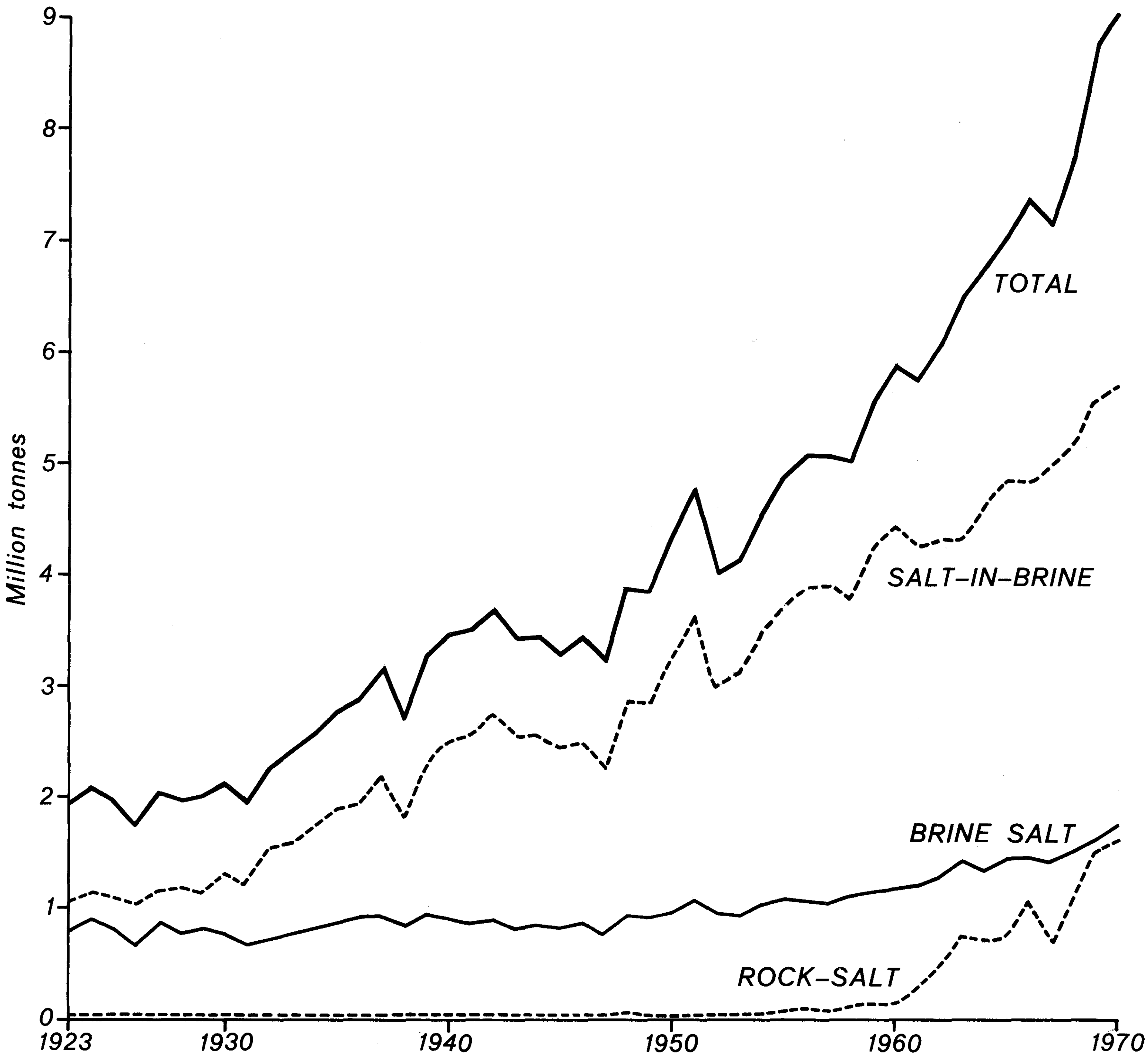

Fig 9 **United Kingdom: Production of salt-in-brine, brine salt and rock-salt, 1923-1970.**

Table 2. United Kingdom: Production of salt by decades, 1874-1970

Thousand tonnes

Year	Rock-salt	*Great Britain* Brine salt	*Great Britain* Salt-in-brine	Northern Ireland	Total
1874 - 1880	1,295	16,503		209.5	18,008
1881 - 1890	1,977	20,410		286.4	22,673
1891 - 1900	1,969	18,265		431.2	20,665
1901 - 1910	2,047	17,270		456.4	19,773
1911 - 1920	1,543	19,330		345.2	21,218
1921 - 1930	311	18,694		157.4	19,162
1931 - 1940	197	8,312	18,668	72.9	27,250
1941 - 1950	293	8,833	26,666	101.2	35,893
1951 - 1960	865	10,685	37,252	70.0	48,872
1961 - 1970	8,970*(a)*	14,466	48,596	*(b)*	72,032

(a) United Kingdom production.

(b) Northern Ireland production of rock-salt not disclosed from 1968.

Source: Great Britain
1874 - 1938: Mines Department, Annual Reports.
1939 - 1970: Department of Trade and Industry, Digest of Energy Statistics.

Northern Ireland
1874 - 1933: Geological Survey of Northern Ireland.
1934 - 1966: Ministry of Commerce, Northern Ireland.

Table 3. United Kingdom: Production of salt, 1951-1971

Thousand tonnes

Year	*Rock-salt*	*Brine salt*	*Salt-in-brine*	*Total*
1951	55	1,071	3,635	4,761
1952	46	970	2,999	4,015
1953	44	955*(a)*	3,123	4,122*(a)*
1954	44	1,035	3,470	4,549
1955	71	1,090	3,714	4,875
1956	101	1,067	3,896	5,064
1957	89	1,061	3,915	5,065
1958	118	1,103	3,793	5,014
1959	145	1,150	4,252	5,547
1960	152	1,253	4,455	5,860
1961	290	1,208	4,262	5,760
1962	485	1,280	4,312	6,077
1963	764	1,410	4,320	6,494
1964	704	1,369	4,672	6,745
1965	735	1,451	4,814	7,000
1966	1,047	1,478	4,808	7,333
1967	703	1,413	4,997	7,113
1968	1,105	1,519	5,131	7,755
1969	1,539	1,605	5,582	8,726
1970	1,598	1,733	5,698	9,029
1971	1,857	n.a.	n.a.	n.a.

(a) No production in Northern Ireland.

n.a. = not available.

Source: Department of Trade and Industry, Digest of Energy Statistics.
Ministry of Commerce, Northern Ireland.

The production of salt is one of Britain's oldest industries, the recovery of salt by open-pan evaporation of brine from springs having been introduced by the Romans. The Domesday Survey records the existence of 1,195 salinae or 'salterns' along the coast between Lincolnshire and Cornwall, the main concentrations being in Sussex and Norfolk. This industry extended as far north as Scotland, notably at Prestonpans, 14 km east of Edinburgh, where salt was produced by the monks of Newbattle Abbey during the 13th century. Salt is also one of the first minerals in which there was overseas trade on a significant scale. The development in the 14th century of the salt industry in Brittany, which became the main producing area for northern Europe, made most of the English coastal salt operations uneconomic. Rock-salt was first discovered in England at Marbury, just north of Northwich in Cheshire, in 1670, but probably only one or two mines were worked before the end of the 17th century. Some coastal salt refineries increased production by adding rock-salt to the sea-water. For example, salt was produced at Frodsham on the Mersey Estuary from sea-water and Cheshire rock-salt and in the Firth of Forth area from sea-water and rock-salt obtained from Ireland or England. At the beginning of the 18th century some 200 pans were in operation on the River Tyne for the production of salt from sea-water and from spring brines associated with Carboniferous sediments. Salt was also made from sea-water in the Ballycastle coalfield, County Antrim, from the 17th until the 19th century.

The Northwich, Middlewich, Nantwich, Winsford, Holford and Sandbach fields in Cheshire have been and, with the exception of Nantwich, remain the core of the British salt industry. Droitwich, in Worcestershire, has also been a centre of production of salt from brine since earliest times; rock-salt was first mined at Stoke Prior in 1828. Salt was made from brine springs in Staffordshire at least as early as the 17th century and in 1893 a regular industry was established at Stafford Common. Brine was first pumped in Lancashire in 1889, at Preesall, where rock-salt mining began in 1893. Salt production on a commercial scale began in the Isle of Man in 1903 and in Somerset soon after its discovery at Puriton in 1910. In Durham brine pumping commenced near Middlesborough in 1882. Salt was discovered in Northern Ireland at Carrickfergus in 1850 and rock-salt mining commenced in 1853, but was suspended from 1939 until 1967, when the Kilroot adit mine, some 4 km ENE of Carrickfergus, was brought into production. Brine pumping ceased in 1958, the last production being from two brine wells sunk in 1953 at Maidenmount, NNW of Carrickfergus.

Overseas trade

Traditionally the United Kingdom has been a substantial exporter of salt (Table 4). Trade has a favourable affect on the balance of payments, the fob value of exports exceeding the cif value of imports by nearly £3.4 million in 1971. In that year exports of salt totalled nearly 472,000 tonnes (Table 5), of which 384,700 tonnes was in the form of vacuum salt, exported chiefly to Sweden and Nigeria (Table 6).

Table 4. United Kingdom: Exports of salt, by decades, 1874-1970

Period	*Thousand tonnes*	*Period*	*Thousand tonnes*
1874 - 1880	6,380	1931 - 1938	2,177
1881 - 1890	9,136	1939 - 1945	n.a.
1891 - 1900	6,772	1946 - 1950	1,020
1901 - 1910	5,913	1951 - 1960	2,809
1911 - 1920	4,419	1961 - 1970	4,251
1921 - 1930	2,911 (a)		

n.a. = not available

(a) 1924 figure not available.

Source: 1874 - 1938: Mines Department, Annual Reports.
1946 - 1971: HM Customs and Excise.

Table 5. United Kingdom: Exports of salt, 1951-1971

Year	*Thousand tonnes*	*Year*	*Thousand tonnes*
1951	285	1962	325
1952	281	1963	369
1953	252	1964	363
1954	258	1965	405
1955	281	1966	454
1956	269	1967	421
1957	276	1968	483
1958	292	1969	519
1959	300	1970	583
1960	315	1971	472
1961	329		

Source: HM Customs and Excise.

Table 6. United Kingdom: Details of exports for selected years, 1964-1971

Thousand tonnes

	1964	*1966*	*1968*	*1969*	*1970*(a)	*1971*(a)
Vacuum salt						
to Australia	5.9	5.3	7.2	6.9	7.8	7.2
New Zealand	24.6	26.9	28.7	26.1	24.1	26.0
Nigeria	35.8	45.4	57.1	59.3	31.5	82.0
Denmark	21.9	31.9	10.6	–	2.8	3.7
Finland	24.9	33.5	37.5	26.4	56.3	43.6
Norway	22.7	26.6	30.2	31.0	28.9	30.3
Sweden	95.8	113.2	129.8	154.7	167.7	122.8
Irish Republic	20.6	21.9	23.5	25.8	29.9	25.5
Other countries	34.2	34.8	42.2	49.4	67.7	43.6
Total	286.4	339.5	366.8	379.6	416.7	384.7
fob value	£1,712,567	£1,913,494	£2,219,995	£2,361,276	£2,215,028	£3,017,352
Other salt						
to Nigeria	30.1	44.8	38.0	52.9	73.9	30.1
Denmark	5.3	18.2	12.9	11.1	7.6	4.4
Irish Republic	9.8	10.0	12.9	11.9	14.9	13.8
Norway	5.4	9.9	5.5	–	3.9	3.0
Sweden	5.4	14.5	14.0	14.5	12.6	12.7
USA	–	–	19.0	30.0	44.7	15.1
Other countries	20.4	17.3	13.9	18.7	8.3	8.4
Total	76.4	114.7	116.2	139.1	165.9	87.5
fob value	£777,653	£1,004,139	£1,063,761	£1,285,061	£1,774,145	£1,032,229
All exports						
Total fob value	£2,490,220	£2,917,633	£3,283,756	£3,646,337	£3,989,173	£4,049,581

(a) For comparative purposes subdivisions (A) and (C) of the 1970 United Kingdom Trade Classification (see page) have been totalled to provide a figure for 'Other salt'.

Source: HM Customs and Excise.

Fig 10 **United Kingdom: Exports of salt, 1874-1971.**

Exports

The United Kingdom has been a large traditional exporter of salt since 1732 when the River Weaver in Cheshire was made navigable. Shipments of white salt rose from about 5,000 tonnes in 1732 to about 1 million tonnes in 1880. Exports during the period 1874-1971 are shown in Fig 10. These have been increasing, following a decline in exports from the 1880's until the period between the two World Wars.

Vacuum salt accounted for 80 per cent of the total exports in 1971. There is a traditional and steady export trade with Australia and New Zealand, while shipments to Nigeria are mainly of dendritic salt, a vacuum salt with a high volume/weight ratio developed by Imperial Chemical Industries Limited for this market where salt is sold by volume. There are also exports of large-crystal 'Lagos' salt produced by open-pan methods by Ingram Thompson and Sons Limited. Exports to Norway and Sweden are mainly for use in chemical manufacture; there has been a marked increase in demand from Sweden.

Until 1969 United Kingdom exports of salt have been recorded by HM Customs under the heading: 'Common salt (including rock salt, sea salt and table salt); pure sodium chloride; salt liquors; sea water: Vacuum salt (code no 27631) and Other (code no 27633)'. Since 1970, however, exports and imports have been recorded under the same major heading but with the following sub-divisions: '(A) Fishery salt, being salt in coarse crystals of a kind used for curing fish (2501 002), (B) Vacuum salt (2501 0130) and (C) Other (2501 0276)'.

Imports

Imports for the years 1952-1971 are shown in Table 7 and details for 1970 and 1971 are shown in Table 8. United Kingdom imports of salt are very variable but generally small. The increase in some years is due in part to temporary shortages of rock-salt for winter road maintenance. Most of the salt imported into the United Kingdom in 1971 was obtained from Italy and the Federal Republic of Germany.

Table 7. United Kingdom: Imports of salt, 1952-1971

Year	*Thousand tonnes*	*Year*	*Thousand tonnes*
1952	37	1962	43
1953	30	1963	180
1954	33	1964	39
1955	49	1965	60
1956	52	1966	62
1957	27	1967	38
1958	52	1968	34
1959	55	1969	55
1960	53	1970	140
1961	36	1971	126

Source: HM Customs and Excise.

Table 8. United Kingdom: Details of imports, 1970 and 1971

	1970		*1971*	
	Tonnes	*c.i.f. value £*	*Tonnes*	*c.i.f. value £*
Fishery salt				
from Federal Germany	67,416	351,484	23,641	127,698
Poland	12,021	54,123	11,737	53,437
France	7,425	37,831	407	3,234
Spain	2,120	11,175	2,255	11,445
East Germany	1,884	4,816	1,229	5,303
Norway	1,027	8,567	664	10,347
Netherlands	724	3,813	1,227	15,395
Irish Republic	168	1,730	174	1,998
Total	92,785	473,539	53,269(a)	284,143(a)
Vacuum salt				
from Denmark	–	76	8	630
USA	2	715	2	1,161
Total	2	791	10	1,791
Other				
from Italy	38,578	161,315	64,297	267,155
Federal Germany	4,324	31,323	4,265	31,963
Portugal	3,851	15,653	–	–
Spain	635	5,014	2,068	15,447
Belgium	120	1,663	30	3,387
Norway	99	1,781	96	1,679
France	91	9,274	322	13,661
USA	71	13,702	18	12,813
Netherlands	12	556	1,068	14,221
Others	3	2,315	396	9,061
Total	47,784	242,596	72,560	369,387
All imports				
Total c.i.f. value		£716,926		£655,321

(a) Totals include 9,402 tonnes valued at £41,529 from Italy, 2,330 tonnes (£11,357) from Tunisia and 203 tonnes (£2,400) from Sweden.

Source: HM Customs and Excise.

Demand trends

Demand for Cheshire salt, principally as white salt, grew rapidly after 1732 when the River Weaver Navigation was opened and an export trade developed. Britain dominated the world's white salt trade until the late 19th and early 20th centuries, when the exploitation of deposits overseas and the rapid expansion in production of cheaper solar salt brought a sharp decline in exports (Fig 10). Other factors which contributed to the decline of the white salt industry were the introduction of the Solvay process, which started to replace the Leblanc process for the production of soda ash during the late 19th century, and the development of the electrolytic method in the 1890's for the production of chlorine and caustic soda. Both processes utilise salt-in-brine, the demand for which increased correspondingly: the total demand for salt during this period remained relatively constant (Table 2). The demand for white salt remained relatively stable until the mid-1950's. A recent example of the continuing increase in demand for white salt is BP Chemicals' chlorine plant at Baglan Bay, near Port Talbot, which came into operation in September 1972 and which initially will require about 260,000 tonnes of white salt to produce 152,000 tonnes of chlorine a year. Since the mid-1950's exports have also shown a steady increase (Fig 10) and in 1970 about 30 per cent of the total white salt production was exported. In 1971 exports declined sharply probably reflecting the effect of the closure of the Stafford works, which produced about 100,000 tonnes of white salt a year, rather than a falling off in overseas demand.

All salt-in-brine is used in the chemical industry for the production of chlorine, caustic soda and soda ash and about 90 per cent of this industry's demand for salt is met by salt-in-brine (Fig 6). The demand for salt-in-brine is, therefore, directly related to the demand for these chemicals. Chlorine consumption is increasing steadily at a rate of about 7 per cent a year, strongly influenced by the demand for plastics, notably PVC, which is growing by 11 to 12 per cent annually and further heavy investment in chlorine production is now being made or is anticipated. As a substantial proportion of the increasing demand for chlorine will be met by chemical plant using white salt, it seems likely that the demand for salt-in-brine will grow perhaps at about 3 or 4 per cent a year. The demand for caustic soda and soda ash is probably growing at no more than 2½ per cent a year.

During the 19th century Britain exported rock-salt for use in the saturation of weak natural brines before these were evaporated for the production of white salt. The decline of this trade by the early part of the 20th century restricted the demand for rock-salt to agricultural and limited industrial purposes. Production remained at a low level from 1920 to the late 1950's (Table 2), when its large scale distribution for winter road maintenance was made possibly by the introduction of an anti-caking agent that enables rock-salt to be stored in the open. As a result there was a dramatic increase in demand (Table 3): according to Imperial Chemical Industries Limited, the quantity of rock-salt used on Britain's roads rose from 170,000 tonnes in 1961 to 800,000 tonnes by 1966 and 1,600,000 tonnes in 1969-70, annual demand depending on the severity of the winter. Although continued growth is expected in the short term, demand will probably level off unless new markets can be found.

Substitutes

The chemical uses for salt are directly related to its composition. It is so abundant and cheap that it is very unlikely that any other source of sodium or chlorine could be economically substituted. Calcium chloride (white waste from the Ammonia-Soda process) has been used as an anti-freeze, but it is not likely to be used on roads because of its higher cost. Similarly urea, which is better known as a nitrogenous fertilizer, has been used on the Severn Bridge because of its non-corrosive properties; in view of its cost it is likely to be limited to such specialised applications.

Industry

At one time there were a large number of salt producers in the United Kingdom. Difficulties caused by excess production capacity were considerably increased towards the end of the 19th century, when the overseas demand for British salt began to decline markedly: during the 1882-1913 period the output of white salt in central Cheshire fell by 62 per cent. In order to rationalise and stabilise the salt trade, the Salt Union Limited was formed in 1888 by the merger of 64 manufacturers from Cheshire, Worcestershire, Northern Ireland and the Middlebrough area, accounting for well over 90 per cent of the production of rock-salt and white salt. However, the merger proved unsatisfactory and the Salt Union was subsequently acquired by Imperial Chemical Industries Limited in 1937. The formation of the Salt Union did, nevertheless, lead to a considerable amount of exploration which proved extensions to the Cheshire saltfield. Salt was produced until the late 1950's in the Isle of Man by the Manx Salt and Alkali Company Limited.

At present the British salt industry is dominated by three internationally known companies; Imperial Chemical Industries (Mond Division), British Salt Limited, a subsidiary of Staveley Industries Limited (75 per cent) and Ranks Hovis McDougall Limited (25 per cent), and BP Chemicals International Limited. There are also two small independent firms, New Cheshire Salt Works Limited and Ingram Thompson and Sons Limited, operating at Wincham and Marston near Northwich in Cheshire. The Irish Salt Mining and Exploration Company Limited, which is American owned, is the sole producer in Northern Ireland. The distribution of the operations of these producers is as follows:

Cheshire

BP Chemicals International Limited

British Salt Limited

Imperial Chemical Industries Limited

Ingram Thompson and Sons Limited

New Cheshire Salt Works Limited

Durham

Imperial Chemical Industries Limited

Lancashire

Imperial Chemical Industries Limited

Northern Ireland

Irish Salt Mining and Exploration Company Limited

All the manufacturers of salt in Great Britain are represented by the Salt Manufacturers Association, formed in 1969, which is concerned primarily with the promotion of exports and serves as a focal point for collating information and statistics as well as a contact point with other trade associations, Government Departments and other organisations.

Imperial Chemical Industries Limited accounts for about 90 per cent of the salt produced in the United Kingdom, the Holford brinefield in Cheshire being the principal source of supply. The brine produced from the Preesall saltfield in Lancashire was used for the local production of soda ash until 1964; the brine is now used in the manufacture of chlorine and caustic soda by electrolysis in the neighbouring Hillhouse works. The company's Cassel works at Billingham uses brine for the same purpose but small amounts of solid salt are also used in the manufacture of sodium metal. British Salt Limited, the second largest producer, commissioned a new vacuum plant near Middlewich in Cheshire in 1969, with a capacity of 600,000 tonnes a year and in the same year Cerebos Foods Limited (subsequently acquired by Ranks Hovis McDougall Limited) ceased brine pumping at Greatham on Tees-side. In 1967 BP Chemicals International Limited acquired the interests of Murgatroyd's Salt and Chemical Company Limited which, through its predecessors, had been associated with the salt industry since 1890. British Salt Limited and the British Soda Company Limited (owned by Staveley Industries Limited) ceased brine pumping at Stafford in 1970 and Imperial Chemical Industries closed their Stoke Prior works in Worcestershire in February 1972. Small quantities of sea salt are produced by the Maldon Crystal Salt Company Limited at Maldon.

The four major chlorine manufacturers in the United Kingdom are Imperial Chemical Industries Limited (Runcorn, Fleetwood and Billingham), BP Chemicals International Limited (Sandbach and Baglan Bay near Port Talbot), Staveley Industries Limited (Staveley, near Chesterfield) and The Associated Octel Company Limited (Ellesmere Port), a subsidiary of the British Petroleum Company Limited, the Shell Transport and Trading Company Limited and the Standard Oil Company of California. Imperial Chemical Industries Limited is the sole manufacturer of soda ash in the United Kingdom.

British Gypsum Limited is conducting exploratory work on Walney Island and in Shropshire, while in Northern Ireland a Prospecting Licence granted by the Ministry of Commerce, under the Mineral Development Act (Northern Ireland) 1969, is held by Anglo United Development Corporation. This company, which holds a substantial share interest in Northgate Exploration Limited, has carried out drilling in the saltfield around Larne Lough. Consolidated Goldfields Limited had licences covering two separate areas of the south-east Antrim saltfield, near Ballycarry on the south-west side of Larne Lough and the north-east of Carrickfergus, but the company withdrew in 1971 after some exploratory work had been undertaken.

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