

The economic and social factors which tend towards the location of the industries using the key metals near the centres of older metal-working industries are further strengthened by the recent tendency—very prominent in steel-making—to an increasing use of ‘scrap metal’ as a raw material, which has long been practised with the more expensive metals. A note in the *Monthly Labour Review* of May, 1935 (p. 1155) states that in the U.S.A. ‘scrap iron and steel’ formed 9.9 per cent of all the materials used in steel-making, and approximately half of that of the finished steel. These proportions may have increased under war conditions. They are likely to remain high, and to be applied to all metals, if we can attain a sanely conservative use of our metal resources. In that case we would regard the world’s stock of a metal as a ‘revolving stock’—to be used over and over and only replenished by ‘new’ metal to the extent needed to make good losses due to fair wear and tear and to provide for new uses.

‘Scrap’ is already a substantial part of the immediate raw material of these industries. But scrap is produced where metal goods are made and used; so that this part of the raw material comes back from the markets. Thus it tends to increase the pull of the market on the location of the industry, and so to strengthen the factors which keep it in the regions of developed industry.

The increase in the number of different materials needed by an industry necessarily lessens the relative importance of each one of them. So the complex industry, by spreading its dependence over a wider range of natural resources, becomes less dependent on the location of any one of them; and as the factors which influence its location thus become more numerous, the possibilities of effective intervention to control that location become greater.

## MINERALS, OLD AND NEW, FROM THE SEA\*

By DR. E. F. ARMSTRONG, F.R.S.

**H**AD I been writing a book on the subject I should have first described the crust of the earth, some 20 miles in thickness, and then gone on to point out how, by the processes of destruction and denudation, this is continually being washed first into the rivers and finally into the sea, much of it going into solution. As the poet tells us, “even the weariest river winds somewhere safe to sea”. The quantity of any one constituent of the crust in a thousand parts of sea-water is infinitely small and indeed many are only detectable by the most refined methods of the chemist, but there is so much ocean in the world that in the aggregate it contains many tens of thousands of tons of even the very rarest constituent.

In the past, but for one constituent—common salt—sea-water has never been regarded as a source of raw materials for industry. To-day three other essential substances—potash, bromine and magnesium salts—are being extracted in considerable quantity from the sea by methods which are both novel and

interesting. Such methods open up an avenue to the winning of other even scarcer but coveted minerals.

Common salt is an essential for both man and beast, and those countries which lack it go to any end to obtain it. In New Guinea, for example, it was used by traders not so long ago as the best currency for the purchase of native goods. In Britain and in Europe there are large deposits of pure salt resulting from the drying up of inland seas in past geological ages. The Dead Sea in Palestine is an example of such a sea in process of evaporation. At Stassfurt in Germany the sea dried up entirely, so that both the salt and the mixture of potassium and magnesium chlorides, sulphates and bromides remain in the earth, though, strange to say, there is no iodine.

The composition of the ocean varies considerably in different places and at different depths. The salinity expressed as total salts per 1,000 parts of sea-water varies from a minimum in the southern part of the Indian Ocean, 33.01 parts, to a maximum from the middle of the North Atlantic, 37.37 parts.

In hot countries the sea is led into basins and allowed to evaporate in the heat of the sun until first the calcium sulphate and then the salt crystallizes: the salt is impure but suffices. The bitter or residue is of no commercial value though it has been further treated to obtain potash in an Italian colony.

The export of salt from England has for long been a significant part of our overseas trade. Together with the chemical products made from it, for salt is one of the foundations of chemical industry, it has helped to make Liverpool one of the world’s greatest ports.

The exploitation of any particular source of a mineral is determined by economic considerations. Bromine affords a good example: so long as the demand for it was relatively small, the Stassfurt monopoly maintained it at a high price. When it was required in very large amounts to make ‘ethyl’, other cheaper sources had to be found. One of these is the Dead Sea, which is a half-evaporated inland sea situated in a climate where there is more evaporation than precipitation. As the concentration of salts at the bottom of the lake is greater than that at the surface, the solution is pumped from depth, concentrated and processed to obtain potash salts and bromine, thus affording a British Empire source of these minerals. There are similar inland lakes in the United States. The Americans went to the sea itself for their bromine, having devised a simple method of extracting the traces of bromine from very large quantities of water. At first they fitted up a ship as a floating chemical factory so as to ensure new water all the time. Later the factory was put on land, the effluent water being run to the other side of an isthmus so that it never mixes with the untreated incoming water. It requires 4,000 gallons of sea-water to yield a pound of bromine, so that a factory making only 50 million pounds, say 25 thousand tons, a year has to pump a great deal of the sea through its apparatus. The sea-water is made of a particular acidity, the right amount of chlorine gas added, and the free bromine so liberated is blown out by a stream of air counter current to the water which is falling down high towers with wooden packing. It is absorbed in soda solution, forming bromides and bromates. The process is continuous and automatic and under instrumental control: it is one of the triumphs of

\* Paper read at the Conference on Mineral Resources and the Atlantic Charter, arranged by the Division for the Social and International Relations of Science of the British Association, on July 25.

modern chemical engineering design and construction.

Though in practice the recovery of magnesium metal from sea-water involves comparatively simple operations, it is far from being an easy task economically to utilize a raw material which contains about 1 part of magnesium in 800 of water. Quite unusual chemical engineering methods, equipment and control had to be invented. At the most successful and largest plant use is made of milk of lime, made from large deposits of fossil oyster shells found in the vicinity, to precipitate magnesium hydroxide from sea-water which has been freed from extraneous matter. The hydroxide is collected in special filters and converted into magnesium chloride, using for this operation a 10 per cent aqueous solution of hydrochloric acid which is largely derived from a latter stage of the operation. The magnesium chloride is evaporated and dried until anhydrous, when it is electrolysed in suitable cells to produce metallic magnesium; hydrogen chloride is evolved from the cells. Natural gas is used as a source of power; the effluent water is discharged seven miles from the intake into a current of sea-water which is always in the same direction.

Such, in a paragraph, is a description of a factory which is full of new methods and devices. Magnesium, the lightest of metals, cost a sovereign a pound in 1915 and barely a shilling last year. It is expected that the capacity of a single sea-water plant will be increased to 100,000 tons of metal by the end of this year, which represents an incredible number of gallons of sea-water.

At the same factory, though in a separate plant, bromine is being extracted, and the acid effluent from this mingles with the alkaline effluent from the magnesium to make a largely neutral return flow to the sea.

Magnesium metal was first made around 1869 mainly as a source of high-intensity light for photographic purposes. Later on, sundry uses in fireworks came along. It awaited war to start its use in aeroplanes and in incendiary bombs.

Magnesium in combination is one of the most abundant elements on the earth's crust. The most favoured source is magnesite, which in particular is used for refractories. Other sources are dolomite, where it is associated with carbonate of lime and carnallite. If the metal is to be made by electrolysis, hitherto the favoured process, the magnesite has to be converted into chloride by briqueting the calcined material with carbon and binding substance and exposing to the action of chlorine in an electric furnace. Since in the course of electrolysis chlorine is involved, the process becomes in theory cyclic, although in practice there is waste through formation of hydrogen chloride.

There are also competitive thermal methods for the reduction of magnesite to the metals. The two principal reducing agents are calcium carbide and ferro-silicon. The retorts are either heated externally by gas or internally by radiators. A good vacuum is maintained, and the metal distils in a pure form, only requiring melting. These processes can use dolomite in place of magnesite, merely at the expense of a smaller yield. There are many varieties of these processes, especially in the United States.

Direct reduction by carbon requires a very high temperature, for which an arc is necessary, and the vapour must be rapidly chilled in order to prevent the reversal of the reaction with carbon monoxide, regenerating the oxide. In the original Radenthein

process this was done by a jet of compressed hydrogen, cooled to a very low temperature. The magnesium was precipitated as a very fine dust, which had to be melted by high-frequency current without exposure to air. Although much has been heard of this process, it does not seem to have had much success. The Permanente Corporation in California uses natural gas as the cooling agent. The dust is collected, mixed with oil to a dough and distilled. The Ford Co. uses oil as the quenching agent, and a pilot plant of the Dow Co. is using molten lead, from which the magnesium can be distilled.

Magnesite made from sea-water is proving a useful raw material for refractories. If calcined dolomite, a domestic British mineral, is used instead of milk of lime to precipitate the magnesium from sea-water, a double purpose is served and additional magnesium hydroxide obtained.

It should perhaps be mentioned that the production of magnesium metal and of magnesite in the years before the War exceeded the demand: many new uses for the metal will require to be found to absorb the output when peace returns.

Certain minerals reach the sea either from sewage or by the leaching out of cultivated lands. While these in the aggregate total far less than what is produced by denudation, they are of importance because they represent those constituents which are of primary value to man. One of these is phosphate, of which the mineral deposits are limited in amount and likely to become exhausted. Many of the agricultural soils of the world are definitely short of phosphate and their crop-bearing qualities impaired in consequence. It has been calculated that the sewage from 5 million people is equivalent to 17,000 tons of rock phosphate in a year and this quantity is equal to the amount of phosphate in the bones of the annual export of meat from New Zealand. The population of Great Britain discards as sewage yearly the equivalent of 150,000 tons of rock phosphate, most of which reaches the sea.

An estimate of the annual losses of phosphate from all sources to the sea in the United States amounts to the equivalent of 61 million tons of rock. The world's consumption of phosphate rock is said to be 18 million tons.

There is clear evidence that phosphate must be accumulating in the sea, unless it is somewhere being concentrated and deposited.

The chemist is already searching for materials capable of selectively absorbing and retaining substances present in small quantities in large volumes of water. Such base-exchanging materials are widely used in the softening of hard waters and make it possible to take a good deal of the salt out of sea-water, though not enough to make it drinkable by distressed mariners. What is wanted soon is a material which will extract the phosphates and concentrate them to an economic point; the discovery of such an agent should be feasible and may be imperative a generation or so hence.

The advantage of the sea as a source of minerals is that there is free access to it for any country which has a coast-line. Its use, therefore, comes under the fourth clause of the Atlantic Charter. The knowledge of its constituents and its exploitation in the service of man depends upon the progress of scientific inquiry.

The costs of pumping are less than those of mining; on the other hand, the ingredient desired, which may constitute 50 per cent of a land mineral, may be

present to the extent of much less than 1 in 1,000 parts of sea-water. A technique of handling large volumes at low cost has to be elaborated before the sea can become a source of minerals.

It is of interest that some plants and animals have the power of concentrating certain of the ingredients of sea-water. Iodine, for example, is present to the extent of 0.001 per cent, whereas the dry matter of deep-water seaweed such as *Laminaria* contains 0.5 per cent. Kelp, or *varech*, as it is called in France, has been used for many years for the commercial extraction of iodine, even though this practice cannot compete economically with the production of iodate from the caliche in Chile. Certain coral species are said to contain up to 8 per cent of iodine, and it is present here and in the bath sponge in the organic state as di-iodo-tyrosine.

To complete the story we should cite another natural organic halogen compound, Tyrian purple, the purple dye containing bromine derived from a mollusc, which was used to colour the togas of the Imperial Roman Emperors.

The seaweed moves lazily to and fro at our feet as the tide rises; we know what iodine signifies to us though we are without knowledge of what it means to the seaweed.

The oyster concentrates copper, which is another material which may some day be scarce and have to be obtained from the sea. It has been estimated in the United States that 200 tons of copper are lost in sewage every year per million people, together with

50 tons each of such metals as manganese, lead, aluminium, and titanium.

There is an interesting organism, a holothurian or sea slug, found off the Cornish coast, which has the power of concentrating vanadium in its structure, though the quantity in the neighbouring rocks is very minute.

A balance sheet between land and sea is instructive as showing the loss each year of considerable quantities of the rarer minerals. They must either be accumulating in the sea and be available for recovery, or being deposited to form new areas of sedimentary rocks.

It is on record that for a whole month the very minute traces of gold in sea-water were recovered at the great plant which extracts bromine. The gold was there, but at a cost several, stated to be four, times its value, so that the mines of South Africa need not feel anxious.

Probably many experiments are in hand to extract coveted minerals from the sea. The chemist can do it, but at a cost which may not be competitive with a land source provided that this is accessible. The way to deal economically with large quantities has been shown. To solve such problems three things are essential: first, skilled chemists and chemical engineers, products of the universities; secondly, immense quantities of cheap electric power; and thirdly, a cheap source of heat. A country unable to provide any of these will fall behind in the race to produce even if it has 'free sea' available.

## OBITUARIES

### Prof. E. Fawcett, F.R.S.

THE death on September 22 of Edward Fawcett has taken away from British anatomy yet another outstanding personality. A fine figure of a man, his carriage was always firm and erect, even in old age; and this bodily vigour was the physical counterpart of a robust and active mind.

Born in 1867, he graduated M.B., C.M., at Edinburgh in 1889, and his interest in anatomy was already shown in his student days, for he was demonstrator of anatomy in the School of Medicine for two years before he qualified. He spent three years at the Yorkshire College, Leeds, and after this brief interlude proceeded to his permanent home in Bristol. In 1893, at the age of twenty-six, he was appointed professor of anatomy in University College, Bristol, and in that capacity he served until his retirement in 1934, when he was made emeritus professor. For a large part of that time (1905-34) he also served as Dean in the Faculty of Medicine. For practically forty years, therefore, he was associated with the Bristol Medical School as a whole, and the Anatomy Department in particular, and in the development of both he took an exceedingly active part. He was elected a fellow of the Royal Society in 1923.

As an anatomist Fawcett was held in high esteem by his colleagues. He was successively vice-president of the Anatomical Society of Great Britain and Ireland (1913), treasurer (1914-25), and president (1927-29). At the Budapest International Medical Congress (1909) he was president of the Anatomical Section.

From a review of an extensive list of published papers, Fawcett's work may be seen to fall, with

some overlapping, into four main periods. In the first period he was interested in bones and joints generally, but the interest gradually narrowed down to problems of bone growth and formation of epiphyses. This second or epiphyseal period passed over to the third, in which interest was focused more especially on the development of individual bones of the skull. This led, naturally, to the fourth and most important period, when he published his researches on the growth of the mammalian chondrocranium. It is the work done in this fourth period which constitutes his most important and fundamental contributions to biological science.

During 1917-23 he published in rapid succession detailed accounts of the primordial cranium of a number of mammals: *Microtus* (1917), *Erinaceus* (1918), *Poecilophoca* (1918), *Miniopterus* (1919), *Tatusia* (1921), *Xerus* (1923), and *Homo* (1923). All his work was marked by scrupulous honesty and an unremitting attention to detail. Both his histological and reconstruction work were of a uniformly high technical order.

Briefly to epitomize Fawcett's work, one may say that he enlarged our knowledge of the development and morphology of the bones of the facial skeleton, and made fundamental and extensive contributions to our understanding of the detailed anatomy of the mammalian primordial cranium. His researches under this head are classical, and will remain as a permanent contribution to vertebrate morphology. Various pieces of lesser work, such as those on the development of the clavicle, the epiphyses of the axial skeleton, and the ossification of the sacrum, also constitute a lasting addition to our knowledge of osteology.