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U. S. DEPOSITORY

LITHIUM

Nature's Lightest Metal

U. S.
DEPARTMENT
OF THE
INTERIOR
GEOLOGICAL
SURVEY

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LITHIUM

Nature's Lightest Metal

Lithium is the lightest of all metals, and has the highest electrical potential when used in batteries. Furthermore, it can be split to form tritium, an essential fuel element in the generation of power by fusion reaction. Because these new uses may play a major role in solving our energy problems, the U.S. Geological Survey has begun to search for sources of lithium.

The discovery of lithium is attributed to Swedish chemist, J. A. Arfvedson, who noted in 1817 that the mineral petalite contained an alkali metal with properties unlike either sodium or potassium. More than 30 years elapsed, however, before the element was isolated by Bunsen and Mattiessen (1855).

PHYSICAL AND CHEMICAL PROPERTIES

Chemical classification—Group I, alkali metal, highly reactive

Atomic number 3 **Atomic Weight** 6.94
(Only the light gases, hydrogen and helium, have lower atomic weights and numbers.)

Density 0.534 g/cm³
(Lighter than most wood, it floats.)

Oxidation potential $\text{Li} \rightarrow \text{Li}^+$
E-3.045 volts

Melting point 180.5°C

Ionic radius 0.68 Å

Isotopic abundance ^6Li , 7.4 percent; ^7Li , 92.6 percent

Electron configuration 2 electrons in inner orbit;
1 electron in outer orbit

Thermonuclear reaction $^6\text{Li} + n \rightarrow \text{T} + \text{He}$
(Lithium-6 plus a neutron forms tritium plus helium.)

EXCITING NEW USES FOR LITHIUM

In thermonuclear power generation

Ultimately lithium will be required in the electrical power generating plant of the future—the thermonuclear (fusion) powerplant. In a controlled thermonuclear reaction the two heavy isotopes of hydrogen, deuterium and tritium, react to produce very large amounts of energy. Deuterium can be recovered from natural waters, but tritium is obtained only by the neutron bombardment of lithium. Thus, tritium is obtained as a byproduct of the deuterium-tritium reaction if lithium is present in the thermal blanket surrounding the fusion reaction chamber. Although only a small amount of lithium is actually spent to form tritium, the thermal blanket may contain a large reserve of lithium so that it can serve the added functions of absorbing neutrons and providing a heat transfer agent to power a conventional steam generating plant.

Cover: Aerial view of Silver Peak, Nevada, showing a portion of the brine evaporating ponds in the foreground, the town of Silver Peak and the Silver Peak Range in the background.

In batteries for electric cars

Lithium metal and lithium salts have the greatest potential of any element for the manufacture of lightweight vehicle batteries capable of providing performance equal to that of the internal combustion engine. Prototype lithium batteries and fuel cells deliver more power per pound of battery because of lithium's high electrical potential and light weight. Various estimates of the number of electric vehicles that will be on the roads of the United States by the year 2000 range from 18 to 100 million. Besides the obvious advantages of being clean and convenient to recharge using a standard household electrical outlet, electric vehicles have the advantage for urban use that they do not pollute the air. True, the power must be provided by an electric powerplant that may be a source of pollution, but it will be much easier and more efficient to control emissions from a few large power plants than from millions of vehicles.

Isometric view of Oak Ridge National Laboratory (ORNL) Tokamak reactor. (U.S. Atomic Energy Commission report WASH-1239, p. 11).

In batteries for storage of off-peak electrical power

Part of the electrical power produced each day by generating plants is wasted because the plants operate continuously at the capacity required to supply power for periods of peak demand. Lithium batteries are being considered as a way to store the excess power produced during periods of low power demand. The power stored by such batteries during hours of low consumption could be returned to the system during hours of high consumption, thereby providing a significant saving in the amount of fuel consumed for electrical power generation.

In refrigeration and air conditioning systems

A significant saving in energy could be made if refrigeration and air conditioning systems were designed and manufactured to utilize the absorption refrigeration principle, which uses lithium bromide as the absorbent because of its low vapor pressure.

CONVENTIONAL USES FOR LITHIUM

In heat resistant glass and ceramics

When added to other ingredients in proper proportions, lithium compounds produce glass and ceramic products that have high strength and resistance to breaking when heated. Corning Ware is a typical example of heat resistant glass.

In special lubricants

Lithium-based greases are superior to greases based on other metals especially at temperature extremes and in water resistance.

Line diagram of a lithium/sulfur cell of the type that might be used in a battery to power electric vehicles. (Argonne National Laboratory report ANL-8075, p. 13).

In aluminum manufacture

Lithium carbonate, when added to the electrolytic cells used in the reduction of aluminum ore to metallic aluminum, decreases the electric power requirements and hence results in a significant economic saving.

In treating mental illness

Lithium carbonate is administered orally in the treatment and prevention of a variety of mental disorders, including manic-depression.

In cosmetics and paints

The lithium clay mineral, hectorite, is highly prized as a base in cosmetics, a thickener in oil-base paints, and as a clarifier in the brewing industry.

In air purification for submarines and spacecraft

Anhydrous lithium hydroxide is used aboard submarines and spacecraft to absorb carbon dioxide from the air required to support life.

In primary batteries

Lithium batteries for flashlights and small electronic equipment provide long life plus small size or twice the voltage of conventional cells.

OCCURRENCE OF LITHIUM

Although many lithium-bearing minerals are known, most are found only in certain rare pegmatites (coarse-grained igneous rocks) and in alteration zones of igneous rocks known as greisen.

1. Great Salt Lake, Utah.
2. Mono Lake, California.
3. Searles Lake, California subsurface brines.
4. Imperial Valley, California geothermal wells.
5. Clayton Valley, Nevada subsurface brines.
6. Smackover Formation oil field formation waters.
7. Yellowstone National Park geyser field.
8. Hector clay pit, Hector, California.
9. Kramer borate district, California.
10. Spor Mountain beryllium deposit, Utah.
11. Kirkland, Arizona lithium clay deposit.
12. Teewinot Formation clays, Jackson Hole, Wyoming.
13. West End and White Basin borate districts, Nevada.
14. Amargosa Desert clay deposits, Nevada.
15. Oil field formation waters in Devonian age rocks.
16. Kings Mountain pegmatite district.
17. Black Hills of South Dakota pegmatite district.

Lithium also occurs in clay minerals and shales as well as in desert lakes and underground brines of dry desert lakes. Common rocks, minerals, and sediments contain only trace quantities of lithium, generally less than 100 parts per million (ppm). Freshwaters generally contain less than 1 ppm; seawater contains an average of less than 0.2 ppm lithium.

Three lithium silicate minerals—spodumene, lepidolite, and petalite—as well as the lithium phosphate mineral, amblygonite, have been commercial sources. These lithium-bearing minerals occur in rocks where they are mixed in varying proportions with other minerals. To be of commercial value as lithium ore, they must be separated, in some cases by hand picking, from other minerals in the rock. In the United States, only spodumene is being

Map of the United States showing areas of anomalous lithium in waters and sedimentary rocks and lithium-bearing pegmatite mines.

mined as a source of lithium at present. Spodumene is especially desirable because of its high lithium content (about 3.75 percent), because it can be separated by a flotation process from other minerals in the rock, and because it can be treated to remove impurities and used directly in ceramics. Large pegmatite deposits of spodumene ore occur near Kings Mountain, North Carolina; near Bernic Lake in Manitoba, Canada; near Bikita in southern Rhodesia, Africa; and on other continents. Spodumene ore at Kings Mountain is estimated to contain about 0.7 percent lithium.

Twenty-five years ago, large crystals of spodumene were hand picked and separated from other associated minerals in the small pegmatite bodies in the Black Hills of South Dakota. Now at two large mechanized mines in North Carolina the ore is crushed and the spodumene is concentrated by flotation. The geologic occurrence of such deposits is so rare that the chance of finding additional

large deposits of the same type in other parts of the United States seems rather poor. Hence, if we are to increase the resources and production of lithium from the United States it will be necessary to search for other types of deposits. A brine deposit at Clayton Valley near Silver Peak, Nevada, containing commercial amounts of lithium provides a clue to the search for new sources of supplies in brines and in sedimentary rocks.

SELECTED LITHIUM-BEARING MINERALS

In pegmatites (primary igneous rock minerals)

Silicates

Spodumene (pyroxene group)

Lepidolite (mica group)

Petalite $\text{LiAlSi}_4\text{O}_{10}$

Eucryptite $\text{Li}(\text{AlSiO}_4)$

Holmquistite (amphibole group)

Phosphates

Amblygonite $(\text{Li}, \text{Na})\text{Al}(\text{PO}_4)(\text{F}, \text{OH})$

Lithiophilite $\text{LiMn}(\text{PO}_4)$

Triphylite $\text{LiFe}(\text{PO}_4)$

In greisen (high temperature zones of alteration in igneous rocks)

Zinnwaldite (mica group)

In veins with black manganese oxides and in altered rocks

Lithiophorite $(\text{Al}, \text{Li})\text{MnO}_2(\text{OH})_2$

In quartz veins and in the matrix of altered sandstones

Cookeite (chlorite group)

In clay beds of sedimentary origin

Hectorite (montmorillonite group)

Lithium-Rich Waters

Lithium-rich waters or brines occur in several different geologic settings, each of which probably represents a different process by which lithium is concentrated.

One setting is the closed desert basin or playa where salts are concentrated by evaporation. Lithium chloride is more soluble than sodium chloride (common salt) and remains in the residual brine after sodium chloride is precipitated by evaporation. Consequently, any closed basin where common salt is deposited may also have a high concentration of lithium. Examples include the Great Salt Lake in Utah, which contains an average of about 38 ppm lithium, and Searles Lake in southern California, where the brine in porous salt beds beneath the surface contains as much as 81 ppm lithium.

Lithium is also concentrated in certain waters and brines associated with petroleum. For example, a number of wells that produce oil from Arkansas, Pennsylvania, Michigan, and Utah yield brine with unusually high concentrations of lithium. Concentrations as high as 500 ppm lithium have been reported. In some areas, lithium is probably dissolved out of salt beds and other rocks associated with the salt deposits. The chemical composition of these waters is too complex, however, to be explained by a simple solution mechanism, and several alternatives have been suggested that involve filtration through beds of shale and chemical reaction with various minerals in the rocks.

Unusually high concentrations of lithium are also associated with certain hot springs, geysers, and mineral deposits that form from hot waters. This third mechanism for lithium concentration in geothermal waters may be related to subsurface boiling. The waters probably dissolve lithium from a large volume of rock near a heat source deep within the Earth. The heat provides energy to cause deep circulation of ground water capable of dissolving the more soluble constituents—including lithium—from the rocks with which the water comes in contact. The dissolved salts may be further concentrated by boiling and the escape of steam. Such waters may emerge at the surface as hot springs or they may mix with other waters before reaching the surface. Deeply circulating hot water may account for the high concentration of lithium in the Clayton Valley subsurface brine near Silver Peak, Nevada. There lithium is recovered commercially from brines that contain an average of about 300 ppm lithium.

Lithium-Rich Sedimentary Rocks

In the normal cycle of rock weathering, erosion, and deposition to produce a sequence of sedimentary rocks, there is little or no opportunity for lithium to be concentrated. Any lithium taken into solution is probably carried out to sea where it is widely dispersed.

One notable exception is the closed basin where there is no opportunity for lithium to escape. Lithium accumulating in the water of such a basin may be concentrated by evaporation to such an extent that it can react with the sediments to form lithium-rich rocks. Lithium-rich geothermal water or lithium-rich water associated with petroleum could react similarly and would not necessarily be restricted to closed basins. Certain clay minerals, manganese

oxides, phosphates, and possibly some magnesium or iron-rich carbonates are the most likely components to react with lithium and form lithium minerals. Hectorite is a lithium-bearing clay mineral that occurs in the Mojave Desert of California and in parts of Nevada, Utah, Arizona, and Wyoming. None of these occurrences are presently regarded

as commercial sources of lithium, but this situation could be changed by the development of an inexpensive method for extracting lithium from the clay. Pure hectorite now commands a high price for use in cosmetics and for other uses where its unusual physical properties are desired. Lithium-rich manganese oxides, phosphates, and carbonates have not

View of lithium-bearing magnesite (light colored band) in the Horse Spring Formation of late Tertiary age near the head of the Overton Arm of Lake Meade, Overton, Nevada.

View of Searles Lake, California.

View of the hectorite mine in the Mojave Desert of California, showing the removal of the basalt that overlies the light colored clay bed in the bottom of the pit.

yet been recognized in sufficient quantity to be considered as sources of lithium. All of these types of deposits are under investigation and are potential sources of lithium.

Elements Associated With Lithium

One way to search for lithium is to examine those areas known to contain elements associated with lithium elsewhere. For example, lithium clays have been reported in association with the borate deposits of the Mojave Desert. Upon examining other borate deposits in Nevada we find a similar association. Bromine-rich brines in the Smackover Formation of Arkansas also contain lithium; so bromine-rich waters elsewhere should be examined. Lithium clays are associated with beryllium-fluorite deposits near Spor Mountain, Utah. Similar deposits in Alaska should be examined. These three examples correspond to the three different geologic settings in which we find lithium-rich waters, and they may represent three different geochemical systems.

View of beryllium mine at Spor Mountain, Utah, showing one of the minor faults that served to concentrate minerals including lithium in volcanic ash of late Tertiary age.

THE LITHIUM RESOURCE PROBLEM

Resources of lithium that have been identified in the ground include about 1.5 million tons in pegmatites and 2.6 million tons in brines. Of this total of more than 4 million tons that have been identified, however, probably less than 1 million tons is actually recoverable and can be expected to reach the market by the year 2000. About one third of the recoverable lithium will be required for conventional uses leaving the remaining two thirds for the new energy-related uses, including batteries for electric vehicles. This is less than the anticipated requirements for batteries, but the shortage could probably be made up from imports. If our domestic resources are exhausted by the year 2000 however, the development of thermonuclear power in the early decades of the next century could be seriously limited. Lithium is a unique element with unique properties and the well being of the United States as an industrial nation may well hinge on our ability to supply enough lithium to fuel thermonuclear powerplants at that time.

THE OUTLOOK FOR LITHIUM

The prospect of a large-scale increase in the demand for lithium in batteries and in thermonuclear power production requires that we look ahead far enough to know whether the increase in demand can be met by an increase in supply. As with most mineral commodities, a lead time of several years is required to develop a new deposit, even after it has been discovered. Additional lead time must be allowed for a commodity like lithium because so little is known about its occurrence and distribution in nature. A program of exploration for new deposits well in advance of the demand will help to ensure a stable price and a steady growth in lithium resources and will be of benefit to the American public as well as to the lithium industry. The U.S. Geological Survey is studying this problem and is actively searching for new types of deposits of lithium—nature's lightest metal that packs more power per pound.

(from material supplied by James D. Vine)

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

Thomas S. Kleppe, Secretary
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