Lithium in Unconsolidated Sediments and Plants of the Basin and Range Province, Southern California and Nevada

GEOLOGICAL SURVEY PROFESSIONAL PAPER 918

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By HELEN L. CANNON. THELMA F. HARMS, *and* J. C. HAMILTON

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A study of the accumulations of lithium in
the evaporites, clays, freshwater limestones,
waters, and vegetation of open and closed basins

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By HELEN L. CANNON, THELMA F. HARMS, and J. C. HAMILTON

ABSTRACT

Geochemical and geobotanical sampling of 20 hydrologically closed and open basins in the southern part of the Basin and Range province shows contrasting lithium contents of their sediments, vegetation, and natural waters. These findings have significant economic and environmental implications. In hydrologically closed basins, where groundwater discharge is mainly by evapotranspiration, economic concentrations of lithium are of three types—as lithium chloride in evaporites and brines, in the crystal lattice of montmorillonitic clays, and in carbonate precipitates in hot-spring and lacustrine deposits. Along with potassium, boron, and halite, lithium compounds are precipitated at a late stage of evaporation. Sediments collected from low areas of closed basins contain 30–1,500 ppm lithium, whereas sediments from open, drained basins contain 20–150 ppm lithium.

Recycled concentrations occur in association with hot springs at the alluvium-playa contact, where lithium dissolved at depth is precipitated around hydrophytic plants and organic debris. The average lithium content of native vegetation sampled in closed basins is 100 times the content reported for average plants. The lithium content of halophytic vegetation is closely related to that of the soil, anomalous accumulations occurring in plants that also take up large concentrations of sodium chloride. Ground water contains 50 times more lithium than average municipal water supplies in the United States. Lithium is produced commercially from volcanic clays and, also, by brine evaporation in several closed basins; analysis of vegetation may furnish a means of prospecting for deep-seated lithium brines. Contents of as much as 3,000 ppm lithium were found in the ash of pickleweed (*Allenrolfea*) and in rushes rooted in hot springs. An average of 150 ppm lithium in the ash and 25.8 ppm in the dry weight of all plants that were collected in both closed and open arid basins is considerably higher than the average of 1.3 ppm in dry weight reported for plants growing in a nonarid climate. The high lithium content in well waters and vegetation of closed basins is probably beneficial, rather than harmful, to animals and man.

INTRODUCTION

The geochemistry of lithium in sediments and its absorption by plants in the arid basins of the Basin and Range physiographic province were studied after a broad geochemical study had found large amounts of lithium in the native plants of the basins. The importance of concentrations of lithium in plants is twofold: first, the plants may be of value as indicators of lithium-rich brines at depth; and second, the uptake of lithium by concentrator species of forage or produce may be of significance nutritionally to livestock and man. Therefore, we studied the plant-soil relationships in closed basins that are discharged by evapotranspiration and in open basins that are discharged by underflow through permeable beds at considerable depths to lower basins. Plants and sediments were sampled in 20 basins of California and Nevada (fig. 1), as time permitted, during 1963–67. Plants and the sediments in which the plants grew were collected in each basin from the lowest and wettest part of the basin, and, locally, suites of samples were collected from several chemical zones in the basin. Generally, the plants were salt-tolerant species—phreatophytes in the closed basins and xerophytes in the open basins. The flora and deposits of springs were of particular interest. Analytical data on eight elements are reported here, together with available water analyses.

COLLECTION AND TREATMENT OF SAMPLES

Branch tips and leaves were collected from the larger shrubs, and the above-ground parts were sampled from herbaceous plants. The samples were not washed but were dried in paper sacks and analyzed in the U.S. Geological Survey laboratories in Denver, Colo. Soil samples were air-dried and then sifted through an 80-mesh sieve. Plant samples were dried at 50°C, ground in a Wiley mill, and ashed in a muffle furnace at 500°C. Of the elements reported, magnesium and carbonate were analyzed by rapid rock analysis; calcium, sodium, and potassium by atomic absorption; sulfate by a colorimetric method; fluorine by selective electrode; and boron by emission spectrograph. The lithium content of each sample was determined by two methods—semiquantitative spectrographic analysis (Myers and other, 1961) and atomic absorption method (Ward and others, 1969). Determinations by atomic absorption for lithium in the plants were made by leaching 100 mg of ash in 2 ml of 6 *N* HCl and diluting the leachate to 25 ml before atomizing. Lithium detection limits are 10 ppm for the atomic absorption method and 100 ppm for the 6-step spectrographic procedure, which appears to be more reproducible for higher values. Therefore, the reported low values were determined by atomic absorption and the high values by emission spectrograph. A

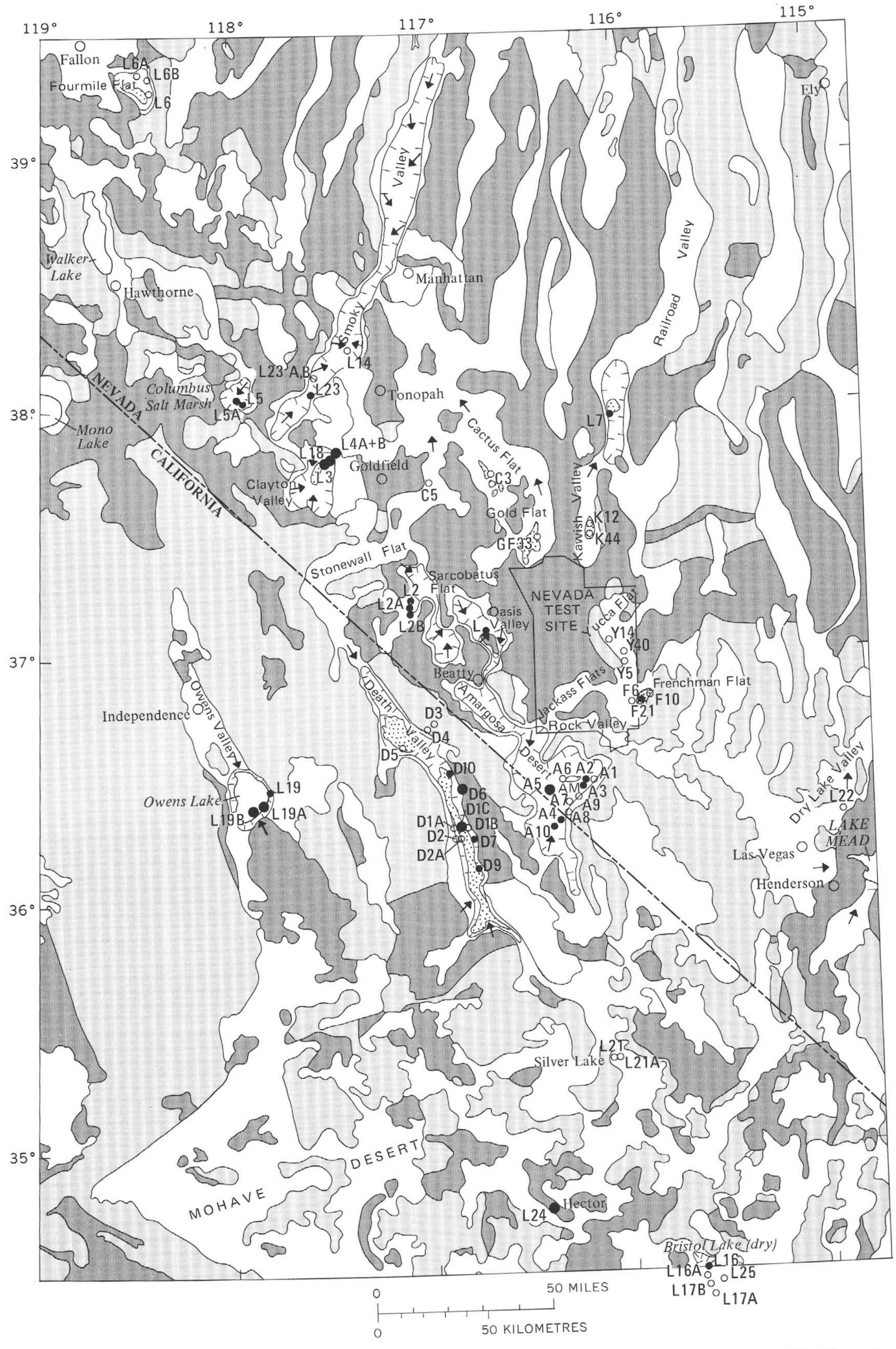

FIGURE 1.—Concentration of lithium in basin sediments, California and Nevada. Geology and base modified from Stose (1932). Map explanation is on facing page.

EXPLANATION

☐	Valley fill
▨	Sedimentary rocks – Largely Paleozoic limestones
■	Igneous rocks – Largely volcanic tuffs
⬭	Closed basin discharged by evapotranspiration
⬮	Playa
→	Direction of ground-water movement
	Lithium in sediment sample – In parts per million. Plants were collected at all sample localities
○	<100
•	100–300
●	>300
AM	Ash Meadows
C5	Station number

spread in lithium values was noted in high-sodium plants that were analyzed by both methods. Probably sodium masks lithium in determinations by atomic absorption to some degree but enhances the lithium values on the spectrograph.

Also presented herein are analyses of waters sampled by U.S. Geological Survey hydrologists; the samples were filtered, acidified, and analyzed chemically and by emission spectrograph in the Denver laboratories.

The senior author collected the samples, assisted at various times by Thelma F. Harms, Margaret E. Hinkle, and Mary Strobell. Analyses by emission spectrograph and atomic absorption were made in U.S. Geological Survey laboratories, Denver, Colo., and by rapid-rock analysis in Washington, D.C. Analysts were as follows:

Chemical analysis of plants and soils: M. E. Hinkle, J. B. McHugh, K. W. Leong, J. H. Turner, T. F. Harms, Clara Papp

Spectrographic analysis of plants and soils: J. C. Hamilton, Barbara Tobin, J. L. Finley, H. G. Neiman, B. N. Lanthorn, E. L. Mosier, L. D. Forshey

Rapid-rock analysis: Paul Elmore, H. Smith, S. D. Botts, Lowell Artis, J. L. Glenn, Gillison Chloe, D. Taylor.

Isaac Winograd, U.S. Geological Survey, provided helpful information concerning hydrological relationships.

GEOGRAPHY AND ECOLOGY OF THE BASIN AND RANGE PROVINCE

The Basin and Range province is characterized by a series of tilted fault blocks forming longitudinal, asymmetric ridges or mountains and broad intervening valleys. Weathering and erosion have lowered the mountain peaks and have filled the valleys with alluvium and products of volcanism to a depth of several thousand feet. The rocks range in age from Precambrian to Quaternary, but we are concerned here only with Pleistocene and Holocene basin-fill sediments interbedded with volcanic tuffs and basaltic flows, and with the gravel fans that surround the basins. During the several pluvial periods of historic time, those basins in which the alluvium overlies relatively impervious rock formations were filled with lake water to a considerably higher elevation than exists today. Basins that are not hydrologically closed drain through the underlying Paleozoic sedimentary rocks to nearby lower basins. The lowest closed basin is Death Valley, whose surface is 280 feet (85 m) below sea level. Large concentrations of salts have built up in the closed basins by processes of evaporation and transpiration; the composition of the salts varies from basin to basin depending on the source of the water and the geology of the recharge area. The climate is generally arid, and so surface waters are apt to be ephemeral; the depth to ground water in open basins may be several hundred feet. Which plant species can live in a particular basin is controlled by altitude, by water conditions, the total salt content, and the tolerance of various species for particular ions that may occur in very high concentrations. Hunt (1966) described the salt zones of Death Valley as a central area of chlorides ringed successively by sulfide and carbonate zones. Each zone has a characteristic flora. The plants of greatest significance as indicators of soil conditions and as accumulators of ions are woody shrubs of the Upper and Lower Sonoran plant zones. Open basins are generally populated by xerophytic plants except at springs along the mountain-basin contact. Closed basins are populated by phreatophytes (deep-rooted plants that depend on ground water for their water supply) on the basin proper and by xerophytes (plants adapted to dry conditions) on the peripheral gravel fans. Bare areas completely devoid of vegetation occur in the salt pan of Death Valley, playa muds of drier valleys, and on the steeper gravel fans. We sampled sediments of the bare areas in several basins as well as the soils in which plants were able to grow.

GEOCHEMISTRY OF LITHIUM

Lithium, a light metal, third in the periodic table, is widely distributed throughout the Earth's crust. It is used as a pottery glaze, as an absorbent in air conditioners, and as an ingredient of waterproof and high-temperature lubricants. The use of lithium in hydrogen bombs and of lithium flares accounts for some of the lithium that occurs at the Atomic Energy Commission's Nevada Test Site.

ROCKS

Lithium is concentrated in the silicates and aluminosilicates of acidic igneous rocks where it replaces magnesium, ferrous iron or aluminum; it is also present in pegmatite dikes where it forms independent lithium minerals, such as spodumene ($LiAlSi_2O_6$), and the lithium micas, such as lepidolite, which are the main ores of the element. Averages for lithium in igneous rocks have ranged from 22 to 65 ppm (Parker, 1967). Averages for sediments, calculated by Rankama and Sahama (1950) from Strock (1936), are 17 ppm in sandstones, 46 ppm in shales, and 26 ppm in limestones; contents of more than 100 ppm are reported for iron ores.

In a Russian study of the geochemistry of lithium in the sedimentary cycle (Ronov and others, 1970), 21,000 samples were analyzed. Lithium was found to concentrate in clays in which it correlates most strongly with aluminum. The results of the Russian study show that the behavior of lithium is the weathering zone is not dependent on the petrographic type of the initial rock, on the initial lithium content, or on the geologic age of the crust but is determined by the sequence of stages or the physiochemical conditions of weathering: the metal is usually concentrated finally in kaolinite. Lithium entering clay minerals differs from sodium, potassium, rubidium, cesium, magnesium and calcium by being firmly bound during the formation of the clay minerals but by ultimately being released during the disintegration of clays to form laterite.

Tardy and others (1972) showed that the retention of lithium in clay minerals of weathering is weak and on the same order as the initial content of the rock (<60 ppm); that the fixation of lithium is moderate in sedimentary clay minerals of detrital origin (<300 ppm); and that lithium is concentrated in new magnesium clay minerals formed under arid conditions in a carbonate or sulfate environment (as much as 6,000 ppm). The carbonates and sulfates that accompany the silicates, however, contain scant lithium (<30 ppm). Accordingly, the behavior of lithium can serve to distinguish in sediments the inherited clay minerals from newly formed clay minerals.

Lithium follows the pattern of magnesium and, in one mode of accumulation, is absorbed into the crystal structure of montmorillonite and illite (Mason, 1952). Lithium is not in an exchangeable site but is probably in the octahedral layer, substituting for magnesium (R. A. Sheppard and H. C. Starkey, written commun., 1972).

A second mode of lithium accumulation is in salt lagoons or basins where contents of lithium correlate negatively with those of aluminum but positively with those of magnesium, sulfate, and chloride; large concentrations of lithium occur in these evaporative basins (Ronov and others, 1970). Lithium not only is very soluble but is most easily displaced by ion exchange of all the cations and, hence, is a very mobile element that moves readily into and out of waters and sediments (Bear, 1964). In an evaporative basin, lithium may remain in solution until a late stage and then be precipitated along with sodium, potassium, and boron in the chloride and sulfate zones (Stewart, 1963). In several basins in the Western United States, lithium and potassium are commercially produced by evaporating the brines.

SOILS AND SEDIMENTS

Swaine (1955) reported 8 to 400 ppm lithium in soils. Steinkoenig (1915) reported 10 to 100 ppm in soil and 20 to 70 ppm in subsoil from 19 soils in 6 different areas of the United States. Recent U.S. Geological Survey studies in Missouri show a geometric mean of 21 ppm lithium for that State.

In the arid Basin and Range province, lithium is concentrated in hydrologically closed basins but not in open basins. In closed basins, soluble salts move upward to the ground surface, where they are further concentrated by evaporation and plant transpiration; in open basins the salts move downward to the ground-water table at depth and then laterally to a lower basin. Surface sediments (exclusive of alluvium) collected in our study contained 30 to 2,000 ppm lithium (median, 150 ppm) in 12 closed basins and 30 to 150 ppm (median, 50 ppm) in 8 open basins.

WATER

The lithium content of fresh water is considerably less than that of sea water (0.1 ppm), because lithium chloride is highly soluble and remains in solution in sea water more or less indefinitely. A median of 2 mg/l (0.002 ppm) lithium was stated by Durfor and Becker (1964) for municipal water supplies; some of this lithium may be sorbed by suspended clay. Thermal waters commonly contain large quantities of lithium leached as lithium chloride from rocks penetrated by the waters (Rankama and Sahama, 1950).

VEGETATION

Lithium is not known to be an essential plant nutrient, but its presence in all plants and its effect on plant growth suggests that lithium is necessary for plant growth and development. It exerts both stimulating and retarding effects on plant growth, depending on the concentration and on the plant species. According to Evans and Sorger (1966) at least one enzyme from a halophile is activated by sodium and lithium but not by potassium or rubidium. Those enzymes that are activated by potassium are not activated by lithium. After analyzing 680 plants from 68 families, Bertrand (1952; 1959) reported an average of 0.85 ppm in the dry weight of Monocotyledons and 1.3 ppm in Dicotyledons. Averages by Bertrand for some families are given in table 4. Robinson and others (1917) found an average of 0.3–0.42 ppm in dry weight of various classes of vegetation.

Borovik-Romanova (1965) analyzed 138 plants from 8 soil types by emission spectrography, using potassium chloride as buffer. She found that plants generally have an average content of 0.15 to 0.3 ppm, but plants rooted in saline soils contain 2 to 10 times that level.

Lithium accumulates first in the root and then moves into the older leaves where it becomes immobilized (Kent, 1941). High values were found in the dry weight of crops irrigated with water containing 0.1 to 0.2 ppm lithium; more lithium was concentrated in the leaves than in the roots (Bradford, 1966).

Vlasiuk and Okhrimenko (1967) experimented with various increments of lithium to determine effects on growth, development, and productivity of tomatoes and potatoes. The lithium was introduced as lithium sulfate in amounts of 0.1, 1.0, 2.0, 3.0, 10.0, and 30.0 ppm, and the experiments were repeated 6 times. Curves plotted on doses versus product weight are bimodal, with two optimal values—for tomatoes, 0.1 and 2.0 ppm; and for potatoes, 0.1 and 5.0 ppm. The reason for these double optima is unknown. In 1969 the same authors reported that lithium stimulates the photochemical activity of chloroplasts and chlorophyll content in tomato and pepper leaves, with a consequent increase in the yield. According to Borovik-Romanova (1965), lithium forms part of the protein fraction of the leaf, and lithium ions substantially stimulate the metabolism of protein and carbohydrate in the plant.

The amounts of lithium that stimulate growth and amounts that produce toxicity symptoms depend upon the tolerance of the particular species and the form of salt administered. Puccini (1957) reported that several lithium salts improved the growth of carnations, whereas lithium carbonate was toxic. Voelcker (1912) found any lithium salt to be stimulating to wheat in amounts of less than 20 ppm but to be toxic in amounts greater than 30 ppm in the soil; lithium nitrate was found to be the most toxic salt but nevertheless the most stimulating salt to growth when present in amounts less than 10 ppm. Plant species vary widely in their tolerance. Citrus trees are sensitive to lithium, and toxicity symptoms develop in citrus growing in California in areas where the lithium content of the soil is only 12 ppm (Bradford, 1966). Lithium contents in the tree reach 40 ppm dry weight or perhaps 400 ppm in the ash. Toxicity in avocado seedlings in pot culture was produced by the addition of 16 ppm lithium. Symptoms include necrotic spots in the interveinal leaf tissue and eventual browning and curling of the leaf margins. Meristem damage occurred in root tips of corn exposed to high lithium concentrations (Edwards, 1941).

Some plants, on the other hand, tolerate large amounts of lithium, and growth is stimulated when the soil contains considerable concentrations. The best-known such plant is tobacco, a member of the Solanaceae. Headden (1921), in plot experiments, found 496 ppm lithium oxide in the ash (or ±40 ppm in the dry weight) of *Nicotiana affinis* and 108 ppm in *Nicotiana tobacum* but only a trace in alfalfa grown in the same soil. A maximum value of 4,400 ppm (or ±750 ppm in the dry weight) was reported by Strock (1936) in tobacco ash. Borovik-Romanova (1965) found species of *Thalictrum, Adonis, Cirsium, Nicotiana, Salsola, Solanum, Ranunculus, Lycium, Atropa belladonna,* and *Datura stramonium* to accumulate lithium to an unusually large degree. She noted that the lithium content is highest in samples with high alkaloid contents, which also varies with locality and growing season. In recent years, lithium compounds have often been used in organic synthesis, and they may participate in the biosynthesis of alkaloids. Vinogradov (1952) described a lithium flora which includes *Thalictrum* (Ranunculaceae). Linstow (1929) reported *Lycium barbarum* of the Solanaceae to be a lithium indicator. *Lycium,* which is used in making jelly, was sampled on lands inhabited by the Pima Indians in Arizona; it contained 1,120 ppm lithium in the dry weight of the plant (Sievers and Cannon, 1974).

LITHIUM IN BASIN AND RANGE PROVINCE

HYDROLOGICAL RELATIONSHIPS

Two distinct types of basins occur in the Basin and Range province: hydrologically closed basins, in which the ground water is only discharged by evapotranspiration, and hydrologically open basins, in which the ground water is discharged by subsurface drainage through underlying sedimentary formations into a lower basin. Topography and surface drainage patterns in open basins do not necessarily coincide with the directions of ground-water movement. The Ash Meadows basin in the Amargosa Desert, for instance, drains several intermontane basins, all of which are hydrologically connected. The connection is effected by movement of ground water through the Paleozoic carbonate rocks that underlie the valleys at considerable depth (Winograd, 1962). The thousands of feet of fill in a closed basin act as an immense underground reservoir, constantly becoming more concentrated with salts as water is lost through evaporation at the surface and through transpiration by plants.

In a closed basin the composition of solutes depends largely on the reaction of natural waters with the particular lithologic units underlying that basin and occurring in its area of recharge. The composition is dependent on the simple solution of readily soluble compounds, as might occur in preexisting salt beds, and on hydrolysis of various silicate minerals, depending on their relative solubility (Jones, 1966). The end product of weathering in the Basin and Range province is generally montmorillonite and carbonates except that in basins fed by waters draining extensive mineralized areas sulfates predominate. Sodium bicarbonate waters are common in volcanic areas, and calcium-magnesium carbonate waters are common in areas of limestones. Mixed waters may have originated in tuffs and then been altered by traveling through limestones, or the sequence may be the reverse (Eakin and others, 1963). Secondary influences on the solute composition are concentration by evaporation and concentration by organic respiration and decay (Jones, 1966). The evaporative process involves a "continuous precipitation of salts in concentric zones from the edge inward according to their relative solubility: alkali-earth carbonates, then sulfates, then chlorides at the center." The chemical zonation of sediments and the typical plant species that are able to grow on each zone (generally identified by anion as carbonate, sulfate, and chloride zones) were studied by C. B. Hunt (1966; Hunt and others, 1966) in Death Valley, where he made on-site analyses of sediments and plants.

Lithium is reported to remain in solution until a late stage and to be precipitated with potassium and boron in the chloride zone (Stewart, 1963). Our sampling in Death Valley shows high values for lithium in both the sulfate and chloride zones; and Lombardi's (1963) analyses of springs in Saline Valley (west of Death Valley) show a similar concentration of lithium in high-sulfate water. Lombardi noted that in transit lithium is rapidly absorbed by clay in suspension. For example, the water of Vega Springs, Saline Valley, loses 98 percent of its lithium in flowing 2 miles (3.2 km) from spring to playa.

Lithium also is concentrated to a considerable degree in lacustrine montmorillonite clays of closed basins whose recharge is from volcanic rocks.

The amount of lithium concentrated in the brines from a large recharge area is considerable; a maximum of 1.62 percent lithium was found in the dried residue of Owens Lake water (Gale, 1915). The extraction of lithium, as well as potassium, from these large closed-basin reservoirs of brine is economically feasible; lithium chloride is currently being extracted from brines in several basins in Nevada and California.

Lithium concentrations in wells and springs are greater in chloride and sulfate waters than in bicarbonate waters and are significantly greater in closed basins than in open basins. Contents in springs and wells in southern Nevada, reported by B. P. Robinson and W. A. Beetam (written commun., 1965), Pistrang and Kunkel (1958), and Eakin and others (1963), range from 0.00 ppm lithium to 0.3 ppm, or 300 µg/l (table 1). Eighteen water samples from Amargosa Desert, a discharge area for several basins to the north, had a median lithium value of 105 µg/l, 50 times the median of 100 major city water supplies in the United States.

The contents of lithium and associated ions in basin sediments that we sampled are given in table 2. We conclude, as did the Russian scientists, that lithium is concentrated in residual chloride-sulfate brines of evaporative basins and also in evaporative lake clays close to volcanics.

LITHIUM UPTAKE BY DESERT PLANTS

Plants and soils were collected in relatively low areas of 20 basins in Nevada and California to study the uptake of lithium by salt-tolerant species (table 3).

Our analyses indicate (table 4) that native plants in the arid basins of the Western United States absorb much more lithium than do native plants in humid areas (Bertrand, 1952, 1959; Robinson and others, (1917). For the arid-basin samples, the median lithium content for 68 samples of dicotyledons is 150 ppm in the ash or 22.8 ppm in the dry weight, as compared with an average of 1.3 ppm in dicotyledons collected by Bertrand. A median content of 27 ppm lithium in dry weight of 47 samples of Chenopodiaceae from our desert collections is markedly higher than the average of 3.8 ppm found in Chenopodiaceae by Bertrand; except for *Atriplex polycarpa,* the median is higher (in lithium) than for plants sampled at the Nevada Test Site and Mohave Desert by Wallace, Romney, and Hale (1973). They found as much as 111 ppm lithium in the dry weight of *Atriplex polycarpa* and 176 ppm in *Lycium andersoni* in Rock Valley, which is hydrologically an open valley but which contains a

TABLE 1.—*Lithium, strontium, boron, and fluorine content (µ/l, ppb) in some waters of Nye County, Nev., and Inyo County, Calif., compared with 100 municipal water supplies in the United States*

[Data on municipal water supplies from Durfor and Becker (1964); data on Nevada Test Site and Amargosa Desert from B. P. Robinson and W. A. Beetam (written commun., 1965). ND, not detected]

	Water supply, 100 major U.S. cities		Open basins, Nevada Test Site (8 wells)		Closed basins, Amargosa Desert (18 springs, wells)	
	Median	Range	Median	Range	Median	Range
Lithium	2	ND- 170	20	13- 46	105	0- 300
Strontium	110	2.2- 1,200	40	32- 160	800	500- 7,700
Boron	31	2.5- 590	180	110- 280	420	90- 2,800
Fluorine	400	0 - 7,000	1,000	500- 2,400	2,100	700- 7,000
Hardness as $CaCO_3$ (Ca+Mg)	90,000	0 -738,000	45,000	8,000-116,000	119,000	26,000-482,000

TABLE 2.—*Maximum lithium concentrations (percent) in some basins of Nevada and California*

[Localities are shown in fig. 1]

Area	Maximum lithium in sediment or evaporite
Closed basins, discharged by evapotranspiration	
Amargosa Desert, Nye County, Nev., and Inyo County, Calif.	0.15
Big Smoky Valley, Nye County, Nev	.01
Bristol Lake, San Bernardino County, Calif.	.03
Clayton Valley, Esmeralda County, Nev	.05
Columbus Salt Marsh, Esmeralda County, Nev	.023
Death Valley, Inyo County, Calif.	.03
Fourmile Flat, Churchill County, Nev	.007
Hector, Mohave Desert, San Bernardino County, Calif	.20
Oasis Valley, Nye County, Nev	.015
Owens Lake, Inyo County, Calif	.08
Railroad Valley, Nye County, Nev	.015
Sarcobatus Flat, Nye County, Nev	.03
Median	0.03
Open basins, discharged by underflow	
Cactus Flat, Nye County, Nev	0.004
Dry Lake Valley, Clark County, Nev	.005
Frenchman Flat, Nye County, Nev	.015
Gold Flat, Nye County, Nev	.008
Kawich Valley, Nye County, Nev	.008
Silver Lake, San Bernardino County, Calif	.008
Stonewall Flat, Nye County, Nev	.007
Yucca Flat, Nye County, Nev	.007
Median	0.0075

sodium-calcium sulfate type of water unusual to the region. The source of the water is a sequence of volcanics (Schoff and Moore, 1964).

The highest lithium contents in plant ash were found in *Juncus cooperi,* a rush, and *Allenrolfea occidentalis,* pickleweed, rooted in a hot spring on the east side of Clayton Valley. Most species that contained more than 400 ppm lithium in the ash are sodium chloride accumulators in which sodium may be absorbed and used in place of potassium. For certain species of *Atriplex,* sodium is an essential element (Brownell, 1965). The sodium plus potassium content in the plant appears to remain constant for the genus, but the sodium:potassium ratio varies with the species. Except for the hydrophytes *Juncus* and *Anemopsis,* the high-lithium plants are all halophytes from the Chenopodiaceae family (table 5). The relationship between the uptake of sodium and lithium in all the plants collected is as follows:

Percentage of sodium in plants	*Concentration ratio of lithium in plants:lithium in soils*
0–10	1.6
10–25	2
25+	2.55

The lithium content of native plants correlates well with the lithium content of the soils in which the plants were rooted (fig. 2) The correlation is better than might have been expected, inasmuch as only the top 5 inches of soil or evaporite were sampled, and the roots of the larger phreatophytic shrubs may extend to considerable depths and actually reach a deeper zone of chemical precipitate. The concentration ratio of lithium in plant to lithium in soil is greatly increased for sodium accumulator plants. A maximum concentration ratio of 10 occurred in samples of pickleweed and desertholly. Commonly, the ratio is also increased where the soils contain less than 100 ppm lithium. A plot of lithium in plants against calcium in soils shows no pattern that confirms an interference in uptake of lithium by the presence of high calcium as Epstein had reported (1960). A more detailed discussion of the distribution of lithium in soils and plants, by area, follows.

TABLE 3.—*Plant species sampled in Nevada and California*

Family	Genus and species	Common name
Chlorophytaceae	*Phormidium ambiguum* Gom.	Algae.
Ephedraceae	*Ephedra viridis* Cov.	Green mormontea.
Gramineae	*Distichlis stricta* (Torr.) Beetle	Saltgrass.
	Sporobolus airodes (Torr.) Torr	Dropseed.
Cyperaceae	*Scirpus olneyi* Gray	Olney bulrush.
Juncaceae	*Juncus cooperi* Engelm.	Cooper rush.
Capparidaceae	*Cleomella obtusifolia* Torr. & Frem.	Stinkweed.
Chenopodiaceae	*Allenrolfea occidentalis* (Wats.) Kuntze.	Pickleweed.
	Atriplex canescens (Pursh.) Nutt.	Saltbush.
	confertifolia (Torr. & Frem.) Wats.	Shadscale.
	hymenelytra (Torr.) Wats.	Desertholly.
	lentiformis (Torr.) Wats.	Big saltbush.
	linearis (Wats.) Hall & Clem.	Narrow leaved saltbush.
	torreyi (Wats.) Wats.	Torrey saltbush.
	parryi Wats.	Parry saltbush.
	polycarpa (Torr.) Wats.	Cattle spinach.
	spinifera Macbr.	Spiny shadscale.
	Eurotia lanata (Pursh.) Moq	Winterfat.
	Kochia americana Wats.	Greenmolly.
	Salsola kali L.	Russian thistle.
	Sarcobatus vermiculatus (Hook.) Torr.	Greasewood.
	Suaeda torreyana ramossissima (Standl.) Munz.	Bush seepweed.
	torreyana Wats.	Torrey seepweed.
	occidentalis Wats.	Western seepweed.
Compositae	*Bascharis glutinosa* Pers.	Seepwillow.
	Bebbia juncea aspera Greene	Rush bebbia.
	Franseria dumosa Gray	White bursage.
	Hymenoclea salsola T. & G.	White burrobush.
	Pluchea sericea (Nutt.) Cov.	Arrowweed.
Cruciferae	*Lepidium fremonti* Wats.	Fremont peppergrass.
Leguminosae	*Prosopis glandulosa* (Sw.) DC.	Honey mesquite.
Saururaceae	*Anemopsis californica* Hook.	Yerbamansa.
Solanaceae	*Lycium andersoni* Gray	Anderson wolfberry.
	L. pallidum Miers	Pale wolfberry.
Tamaricaceae	*Tamarix pentandra* Pall. or *gallica*	Tamarisk.

OPEN BASINS DISCHARGED BY UNDERFLOW

Many basins of the Basin and Range province are discharged by underflow and have been filled by clastic

TABLE 4.—*Lithium content (parts per million) in plant groups of the Great Basin, California-Nevada*

[Comparative data on analyses of plants growing in France from Bertrand (1959). P, phreatophyte; Ha, halophyte; Hy, hydrophyte; X, xerophyte; ND, not detected; <, less than; ∿, approximately]

	France	Great Basin, California-Nevada					
Order and family	Li average in dry wt.	Genus and species	No. of samples	Li in dry wt. Median	Percent ash in dry wt. Median	Lithium in ash Median	Lithium in ash Range
Lower plants							
Blue-green algae--	----	*Phormidium ambiguum* (P)-------	2	170.0	85.4	200	110- 300
Monocotyledons--------	0.85	Group average------------------	6	11	15.8	70	60-3,000
Cyperaceae--------	.4	*Scirpus olneyi* (Hy)-----------	1	54	15.5	350	----
Gramineae---------	.75	*Distichlis stricta* (P)--------	3	9.5	15.8	60	30-1,000
		Sporobolis airoides (Ha)------	1	12.6	15.8	80	----
Juncaceae---------	.89	*Juncus cooperi* (Hy)-----------	1	186	6.2	3,000	----
Dicotyledons----------	1.3	Group average------------------	68	22.8	15.2	150	<20-3,000
Capparidaceae-----	----	*Cleomella obtusifolia* (Ha)----	1	135	9.	150	----
Chenopodiaceae----	3.8	Family average-----------------	47	27	23.	120	<20-3,000
		Allenrolfea occidentalis (Ha)-	6	258	28.7	900	300-3,000
		Atriplex canescens (P)--------	2	18	20.	90	20- 150
		A. confertifolia (X)----------	6	6.7	16.8	40	30- 500
		A. hymenelytra (X)------------	2	124	31.2	400	300- 500
		A. lentiformis (P)------------	1	28.5	19.	150	----
		A. linearis (P)---------------	2	14.6	18.3	80	20- 150
		A. parryi (X)-----------------	4	22.8	21.1	108	30- 200
		A. polycarpa (X)--------------	4	25.5	17.	150	20- 300
		A. spinifera (X)--------------	3	14.2	12.9	110	50- 150
		A. torreyi (P)----------------	1	102	20.4	500	----
		Eurotia lanata (X)------------	1	16.5	11.	150	----
		Kochia americana (P)----------	1	6	24.8	20	----
		Salsola kali (X)--------------	1	ND	22.8	ND	----
		Sarcobatus vermiculatus (P)---	7	13.7	12.7	60	<20- 700
		Suaeda occidentalis (P)-------	1	43.5	29.	150	----
		S. ramossissima (P)-----------	2	67	22.3	300	100- 500
		S. torreyana (P)--------------	3	99.3	33.1	300	50- 700
Compositae--------	1.33	Family average-----------------	8	15.1	9.6	155	40- 175
		Baccharis glutinosa (P)-------	1	15	10.	150	----
		Bebbia juncea aspera (X)------	2	13.9	9.25	150	150- 150
		Franseria dumosa (X)----------	1	3.9	9.7	40	----
		Hymenoclea salsola (P)--------	2	26.6	15.2	175	150- 200
		Pluchea sericea (P)-----------	2	15.2	9.5	160	35- 300
Cruciferae--------	1.7	*Lepidium fremonti* (X)---------	2	4.45	7.8	57	40- 75
Leguminosae-------	.81	*Prosopis glandulosa* (P)-------	1	.39	3.9	10	----
Saururaceae-------	----	*Anemopsis californica* (Hy)----	1	25	16.7	150	----
Solanaceae--------	2.12	*Lycium andersoni* (X)----------	1	25.5	8.5	300	-----
		L. pallidum (X)---------------	2	∿4.2	7.7	∿55	<25- 100
Tamaricaceae------	----	*Tamarix pentandra* (P)---------	5	16	11.4	140	30- 300

TABLE 5.—*Maximum contents of lithium and sodium in some plants and basin soils*
[Analysts: Thelma F. Harms, B. N. Lanthorn]

	Plant					Soil			Plant ash to soil lithium ratio
	Lab. No.	Na (percent)		Li (ppm)		Lab. No.	Na (percent)	Li (ppm)	
		Ash	Dry weight	Ash	Dry weight		Dry weight	Dry weight	
Allenrolfea occidentalis (pickleweed)	D413057	29	10.1	3,000	1050	D413102	2.1	300	10
Juncus cooperi (rush)	D408136	22	1.4	3,000	185	D408181W	3.0	500	6
Distichlis spicata (saltgrass)	D413091	18	2.7	1,000	150	D413098	2.0	120	8.3
Suaeda torreyana (seepweed)	D413054	26	6.2	700	168	D413098	2.0	120	5.8
Sarcobatus vermiculatus (greasewood)	D408134	23	2.9	700	90	D408177W	4.7	300	2.3
Atriplex torreyi (Torrey's saltbush)	D411534	26	5.3	500	100	D413125	1.4	70	5.0
confertifolia (shadscale)	D405826	20	3.5	500	90	D405847	3.0	70	7.1
hymenelytra (deserthollly)	D412065	23	6.9	500	150	D412058	1.3	50	10

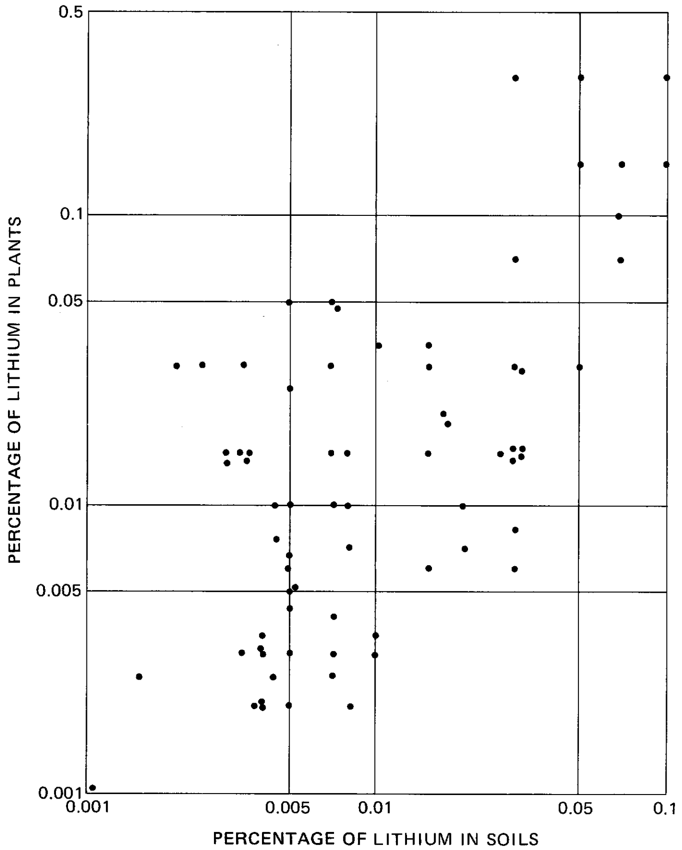

FIGURE 2.—Relationship between lithium in plants and that in soil.

materials of variable texture deposited from intermittent streams during torrential storms. The coarser materials are deposited on the higher parts of alluvial fans, and the fine silt and clay eventually reach the basin, where they are deposited in a thin layer over the playa as the water evaporates. Caliche, which is distributed in this type of basin through hundreds of feet of alluvium above the water table, probably is flushed out of the near-surface soils and is precipitated from surface water as it percolates downward through the beds; this contrasts with the upward capillary flow and near-surface deposition of caliche in closed basins (Johnson and Hibbard, 1957). In northern Yucca Flat, for instance, there is no caliche in the top 18 feet (5.5 m).

Alluvial basins discharged by underflow are not large reservoirs of water that are constantly being evaporated to brines; rather, they are undergoing a flushing action that prevents the buildup of salts. These basins can support lakes only if the underflow is considerably less than the recharge or if the sedimentation is such as to form a perched water table. Some such situation must have existed in the pluvial period in Gold Flat and Dry Lake Valley, as evidenced by old beaches, although the present ground-water table is several hundred feet deep (Eakin, 1963). Perched water appears to be close to the surface on the southern part of the Gold Flat playa, and many phreatophytes grow there. The soil contains 5.4 percent water-soluble sulfate, and a white efflorescence of salts coats the surface of the ground.

Analytical data for eight open basins are given in table 6; the sample localities are shown in figure 1.

The lithium content of sediments collected from hydrologically open basins was generally low, ranging from not detected to 150 ppm, with a median of 50 ppm and a mean of 54 ppm (table 6). The playas of open basins are largely composed of calcium-magnesium carbonate and clay; the surrounding sediments are sandy alluvium containing considerable caliche. The magnesium:lithium ratio is high. Boron contents are similar to those of lithium and range from 20 to 70 ppm. Probably no lithium or boron deposits of economic value can be expected in basins drained by underflow.

A maximum of 500 ppm lithium was found in a sample of *Atriplex confertifolia* from Stonewall Flat. This high lithium content, however, may be caused by contamination because neither the soil nor *Lepidium* collected at the same station contained much lithium; all three materials were collected near ground zero of a surface plutonium release which may have been accompanied by lithium flares. The 20 plant samples collected in open basins had a median content of 30 ppm lithium in the ash or 4.8 ppm lithium in the dry weight.

TABLE 6.—*Percentage of lithium and associated ions in sediments and the ash of plants from open basins in Nevada and California*

[Stations shown in fig. 1. Analysts are named in introduction. N, not detected; Ma, element present in major quantity; X, xerophyte; P, phreatophyte; M, mesophyte; WSS, water-soluble salts The soil in which the sampled plant grew is listed directly below each plant]

Station No.	Sample	Lab. No. (D-)	Ash	WSS	Lithium		Magnesium		Calcium		Sodium		Potassium		Boron		Carbonate (as CO_2)	Sulfate (water-soluble)	
			(percent)		Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Soil	Plant	Soil
Frenchman Flat--$NaHCO_3$ ground water at depth 623-1,103 ft (190-336 m)																			
F6	*Lycium pallidum* (X)	403492	5.8	----	0.01	----	5.0	----	28	----	1.6	----	12	----	-----	------	----	0.19	----
	Sandy clay west of playa	403201	----	0.30	-----	N	-----	1.4	-----	4.0	-----	1.7	-----	2.9	0.01	------	2.4	-----	<0.01
	Lycium pallidum (X)[1]	412496	9.5	----	<.002	-----	1.5	----	33	----	.6	----	5.1	----	-----	<0.002	----	-----	----
	Playa clay	412501	----	----	-----	0.005	-----	2.0	-----	9.9	-----	.95	-----	2.3	.015	.003	----	-----	----
F10	Playa clay on east side (no vegetation)	411562	----	----	-----	.003	-----	3.2	-----	10	-----	.85	-----	2.0	-----	<.002	----	-----	----
	Atriplex linearis (P)	413078	16	----	.002	-----	7.0	----	9.0	----	.28	----	25	----	.015	------	----	.40	----
	A. spinifera (X)	413079	21	----	.002	-----	5.0	----	12	----	10	----	17	----	.02	------	----	.92	----
	Kochia americana (P)	413080	16	----	.003	-----	7.0	----	11	----	11	----	16	----	.07	------	----	.33	----
	Playa clay with plants	413115	----	----	-----	.004	-----	3.0	-----	10	-----	.8	-----	1.9	-----	.005	----	-----	.03
F21	Playa clay (no vegetation)	406182	----	.13	-----	.015	-----	3.1	-----	7.8	-----	.53	-----	2.7	-----	.002	8.1	-----	----
Yucca Flat--$NaHCO_3$ ground water at depth 670-1,539 ft (204-470 m)																			
Y40	*Tamarix pentandra* (P)	406532	14.1	----	0.003	-----	>10	----	17.6	----	4.0	----	8.2	----	0.07	------	----	1.7	----
	Atriplex canescens (P)	411573	23.0	----	.002	-----	.5	----	6.6	----	3.6	----	32.0	----	.01	------	----	-----	----
	North playa soil in cattle reservoir	411564	----	----	-----	0.004	-----	1.0	-----	2.0	-----	1.2	-----	3.0	-----	0.007	1.4	-----	----
Y5	South playa clay at crack 0-1.5 (no vegetation)	403218	----	----	-----	.007	-----	1.9	-----	3.7	-----	.74	-----	3.1	-----	.005	3.1	<.01	<0.01
	at 1.5-15 cm	403219	----	----	-----	.005	-----	1.9	-----	3.8	-----	.74	-----	3.0	-----	.003	2.9	-----	.23
	at 1 m	403220	----	0.10	-----	N	-----	1.2	-----	1.3	-----	1.3	-----	3.3	-----	.003	.15	-----	<.01
	Atriplex confertifolia (X)	403522	17.3	----	.003	------	2.0	----	13.1	----	10.6	----	14.4	----	.007	------	----	.55	----
	Sandy alluvium	403221	----	.15	-----	.005	-----	1.2	-----	2.8	-----	1.5	-----	3.2	-----	.003	1.1	-----	.02
Y14	*Lycium andersoni* (X)	408648	8.5	----	.03	------	2.0	----	25.2	----	.20	----	15.2	----	.02	------	----	.52	----
	Salsola kali (X)	408649	22.8	----	N	.0035	1.5	----	8.6	----	.35	----	27.2	----	.01	.003	----	.34	----
	Alluvium	118531	----	.08	-----	------	-----	.54	-----	1.3	-----	1.6	----	3.0	----	------	.15	----	.01
Kawich Valley--$NaHCO_3$ ground water at depth 660 ft (200 m)																			
K12	*Atriplex confertifolia* (X)	403585	11.7	----	0.0045	------	2.0	----	11.2	----	11.8	----	13.2	----	0.01	------	----	0.36	----
	Playa clay	403255	----	0.05	------	0.005	-----	1.3	-----	1.8	-----	1.5	----	3.3	----	0.005	0.55	----	0.17
K44	Playa clay (no vegetation)	405840	----	.76	------	.008	-----	1.8	-----	3.2	-----	.89	----	3.2	----	.005	2.2	----	1.3
Gold Flat--$NaHCO_3$, ground water at depth 230 ft (70 m)																			
GF33	*Kochia americana* (P)	405816	24.8	----	0.002	-----	2	----	8.8	----	24	----	15	----	0.02	------	----	0.49	----
	Suaeda occidentalis (P)	405817	29.0	----	.015	-----	1.5	----	3.8	----	31	----	9.4	----	.015	------	----	.68	----
	Silty sulfate zone	405844	----	2.1	-----	0.008	-----	1.5	-----	4.5	-----	1.3	----	3.2	-----	0.005	1.6	----	5.4
Cactus Flat--$NaHCO_3$ ground water at depth 110-443 ft (35-135 m)																			
C3	*Atriplex confertifolia* (X)	405822	10.5	-----	0.0035	-----	2.0	----	7.0	----	17	----	14	----	0.01	------	----	----	----
	Eurotia lanata (X)	405823	11.0	-----	.015	-----	2.0	----	7.0	----	1.1	----	16	----	.02	------	----	----	----
	Alluvium	405845	----	0.004	------	0.004	-----	1.0	-----	2.0	-----	2.0	----	3.0	----	<0.002	----	----	----
Stonewall Flat--altered $NaHCO_3$ ground water at depth 100-275 ft (30-85 m)																			
C5	*Atriplex confertifolia* (X)	405826	17.5	-----	0.05	-----	1.5	----	5.0	----	20	----	9.4	----	0.02	------	----	----	----
	Lepidium fremonti (M)	405827	5.3	-----	.004	-----	2.0	----	Ma	----	2.4	----	21	----	.03	------	----	----	----
	Alluvium	405847	----	0.1	-----	0.007	-----	1.0	-----	3.0	-----	3.0	----	5.0	----	0.003	----	----	----
Dry Lake Valley--ground water at depth >300 ft (>90 m)																			
L22	*Atriplex linearis* (P)	413074	15	-----	0.002	-----	7.0	----	15	----	0.26	----	21	----	0.02	------	----	0.65	----
	A. lentiformis (P)	413075	19	-----	.013	-----	10.0	----	9.2	----	12	----	17	----	.02	------	----	.77	----
	Playa sands	413112	----	-----	-----	0.005	-----	2.0	-----	9.4	-----	0.70	----	2.0	----	0.007	----	----	0.15
Silver Lake																			
L21	*Atriplex polycarpa* (P)	413090	13	-----	0.002	-----	7.0	----	6.0	----	16	----	16	----	0.05	------	----	0.46	----
	Sandy soil at playa edge	413124	----	-----	-----	0.007	-----	2.0	-----	3.4	-----	2.2	----	2.3	----	0.002	----	----	0.02
	Playa mud (no vegetation)	415475	----	2.0	-----	.008	-----	2.0	-----	3.8	-----	2.5	----	1.9	----	.007	----	----	.54

[1] Fluorine content of plant: 0.0063 percent.

TABLE 7.—*Percentage of lithium and associated ions in basin sediments, collected within 6 inches (15 cm) of the ground surface*

[N, not detected; number of samples shown in parentheses]

	Lithium		Magnesium		Mg/Li	Potassium		Boron	
	Median	Range	Median	Range	Ratio	Median	Range	Median	Range
Closed basins									
Lake clay (5) associated with volcanics--	0.07	0.03 -0.2	3.0	0.3 -11.0	43.	1.7	0.24- 2.4	0.005	0.002-0.015
Spring-deposited tufa and lake marls (8)-	.045	.003 - .20	2.85	.33- 5.0	63.	.73	.1 -18.0	.003	<.002- .03
Chloride zone (13)----------------------	.015	.0025- .03	2.0	.03- 4.0	133.	1.9	.8 - 2.4	.03	.015- .07
Sulfate-chloride mixed (9)-------------	.015	.003 - .03	1.7	.07- 5.0	113.	2.9	.24- 3.7	.05	N - .15
Black oozes in hot springs (6)----------	.01	.004 - .08	1.0	.70- 2.0	100.	1.12	.34- 3.0	.005	.002- .02
Carbonate zone (11)---------------------	.015	N - .03	1.0	.07- 4.8	66.	2.3	.24- 3.6	.015	N - .03
Playa clays, calcareous (7)-------------	.015	.006 - .023	1.3	.7 - 3.2	86.	2.45	2.3 - 2.6	.019	.005- .07
Alluvium (4)----------------------------	.003	N - .005	1.0	1.0 - 1.1	333.	3.0	2.8 - 3.5	.003	<.002- .005
Basin sands (6)-------------------------	.004	N - .017	1.5	.48- 3.0	375.	2.4	2.0 - 3.4	.005	.003- .2
Open basins									
Sulfate zone (1)------------------------	0.008	----------	1.5	---------	187.	3.2	--------	0.005	---------
Playa clays (12)------------------------	.005	N -0.015	2.0	1.0 - 3.2	400.	2.7	1.9 - 3.3	.005	<0.002-0.007
Playa sands (2)------------------------	.006	0.005 - .007	2.0	---------	333.	2.2	2.0 - 2.3	.004	.002- .007
Alluvium (4)---------------------------	.005	.004 - .007	1.0	.54- 1.2	200.	3.1	3.0 - 5.0	.003	<.002- .003

HYDROLOGICALLY CLOSED BASINS

Lithium is concentrated particularly in the evaporites, spring deposits, and lacustrine clays of closed basins. The maximum lithium concentration found in sediment and clay samples that were collected in 12 closed basins in Nevada and California ranged from 30 to 2,000 ppm. Samples collected from lacustrine clay deposits have a median concentration of 700 ppm lithium; spring-deposited tufa and lake marls, 450 ppm; those from the sulfate, chloride, and carbonate zones and, also, those from playa clays, which commonly contain considerable detrital calcium carbonate, contain 150 ppm; samples of organic black oozes in hot springs, 100 ppm; alluvium and basin sands from the fans that surround the basins, 30 and 40 ppm (table 7). Apparently lithium and boron differ in their geochemical behavior. Lithium becomes concentrated in lake clays, particularly those of volcanic origin and in spring deposits, whereas boron does not. A general increase for both lithium and boron content from the fans to the center of the basin is probably real, as shown by samples collected in Death Valley (fig. 1), although the content of a particular zone is not consistently high or consistently low.

A close correlation of lithium, boron, and potassium might be expected in view of their common volcanic origin and their precipitation at a late stage in brine evaporation. There is little zonal variation in the potassium concentrations of basin sediments, although the brines are highly enriched in potassium. However, the boron contents increase from 30 ppm in alluvium on the fans to 500 ppm in the sulfate-chloride zone in the central parts of the basins. Neither element is precipitated in quantity in the spring deposits. In evaporites, the boron content exceeded the lithium content, but in detrital sediments the reverse was found.

The magnesium content of the basin sediments varies widely because it occurs in residual dolomite that has been deposited in the carbonate zone and in the playas. Magnesium also occurs in sulfates and chlorides that have been precipitated from evaporite brines. The magnesium:lithium ratio varies from basin to basin, which affects the economic value of the deposits, a low magnesium:lithium ratio being most desirable. The ratio is lowest in collections from Owens Valley and is also relatively low in spring deposits and lake clays.

The amount of lithium found in the spring-deposited tufas and the marls of springs that occur at the alluvium-evaporite contact in these closed basins is much greater than the average content of lithium in marine limestones. The phenomenon probably reflects a secondary cycling in the basins, as lithium trapped in clays and other sediments may be easily returned to solution by thermal waters. Hot springs are highly charged with carbon dioxide, and so alkali carbonates precipitate around the orifice of a spring of low discharge due to evapotranspiration, respiration, and decay of marsh vegetation (Jones,

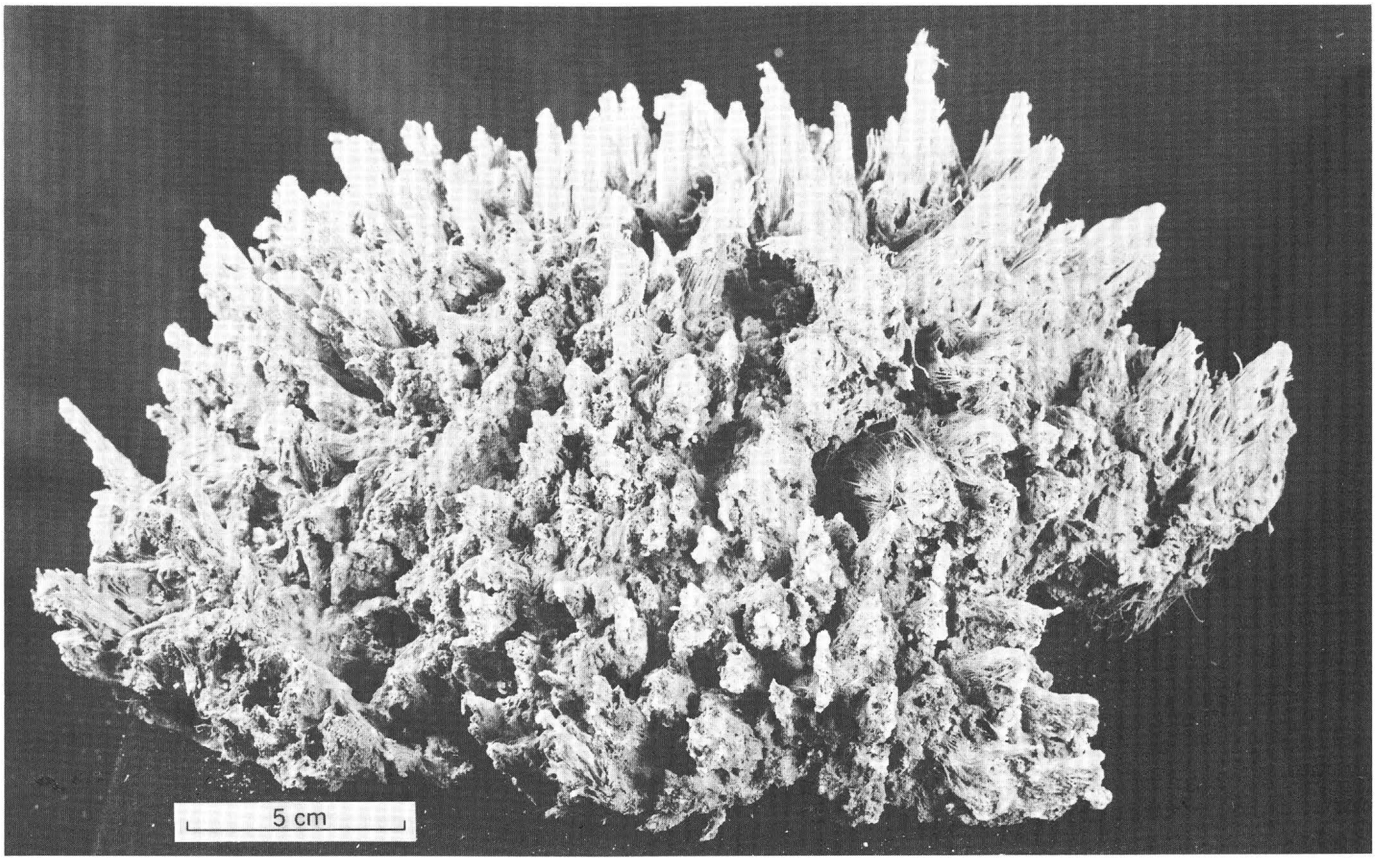

FIGURE 3.—Crown of rush killed by hot-spring precipitate, Clayton Valley, Sample from station L4B.

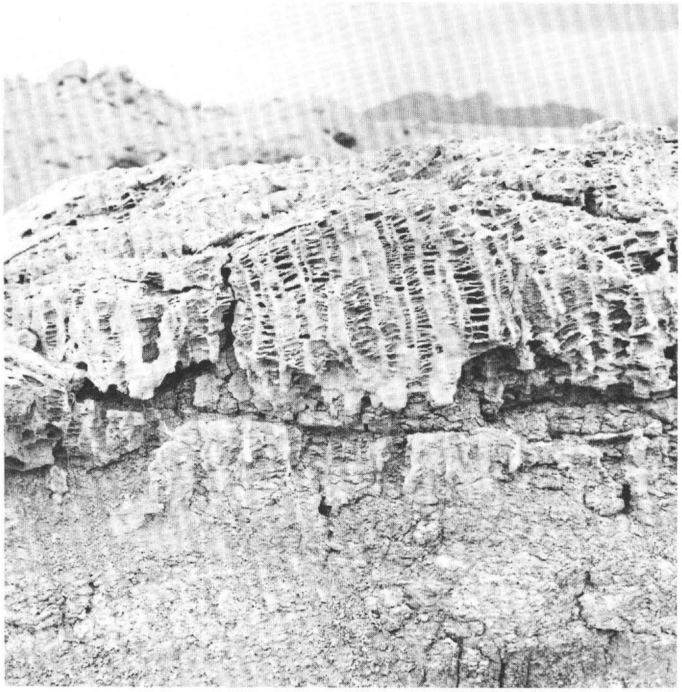

FIGURE 4.—Precipitate of biogenous origin occurring in place, Amargosa Desert. Sample from Station A5B.

1966). Such concentrations around the roots of rushes *(Juncus cooperi)* in a hot spring of Clayton Valley gradually kills the plants. These "fossilized" root crowns contain more than 1,000 ppm lithium (fig. 3). Lithium-rich lacustrine deposits of marl and clay commonly show a definite root-cast structure that suggests precipitation around plant debris and in old root casts in marls of Amargosa Desert (figs. 4, 5, 6).

Thus, the lithium content of many types of sediment is highest in closed basins discharged by evapotranspiration, particularly basins that receive recharge from several adjacent basins. Within a given basin, lithium is particularly concentrated in lacustrine deposits of volcanic origin and in biogenous deposits precipitated from thermal waters associated with these closed basins.

DEATH VALLEY

Death Valley is a closed basin from which no water escapes, as the floor of the valley extends 280 feet below sea level. Old shorelines mark the lowering by evaporation of Pleistocene Lake Manley, which was originally 600 feet (180 m) deep. Mineralized water has also been contributed yearly by freshwater rivers and by underflow from nearby

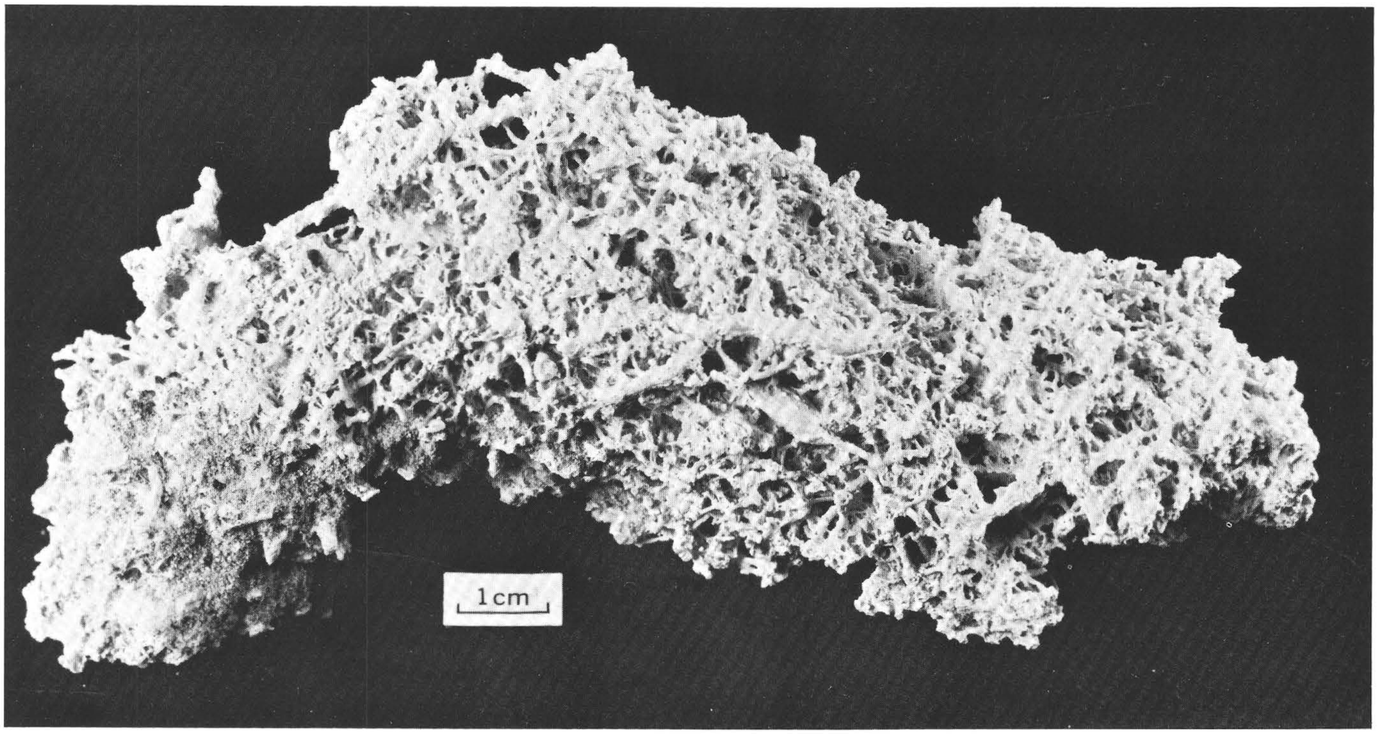

FIGURE 5.—Calcium carbonate precipitate on organic detritus, Amargosa Desert. Sample from station A5.

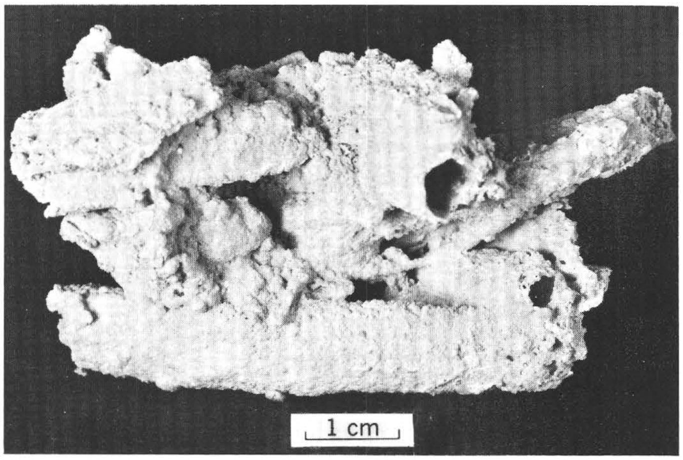

FIGURE 6.—Cast of former root or stem structure, Amargosa Desert. Sample from station A5A.

basins (Hunt and Robinson, 1960). Thus, lithium has been concentrated as a residue in the mother liquor in this evaporite basin from an enormous quantity of water and has been redistributed laterally through seasonal flooding and hot-spring action.

Discharge by evapotranspiration of this large quantity of water has resulted in a lateral zonation of salts characterized by chlorides in the center of the basins ringed successively by sulfates and carbonates. The carbonate and sulfate zones are commonly contaminated with salt (sodium chloride) during seasonal flooding. Groundwater conditions are rarely homogeneous to the depth penetrated by plant roots because permeable layers alternate with impermeable layers. The carbonate zone may be underlain by a caliche of sulfates, and so forth (Hunt and others, 1966).

Only bacteria grow in the chloride zone of the salt pan and fungi and algae in the sulfate zone (Hunt, 1966). Pickleweed *(Allenrolfea)* grows on the sand facies of the carbonate zone where the sands are impregnated with salt. Sixty percent of the ash of this plant is composed of sodium chloride, and mounds of exudated salt build up as high as 2 feet (0.6 m) around the base of the plant (fig. 7). Saltgrass *(Distichlis)*, which grows on the same sand facies, contains a lesser percentage of salt in the ash, but the true amount of salt in the plant is masked by the large amount of silica in the ash which affects all the percentage values. Arrowweed *(Pluchea)* absorbs large amounts of sulfate but little sodium chloride. Arrowweed is restricted to soils of less than 5 percent water-soluble salts and mesquite to less than 0.5 percent. Thus, mesquite (*Prosopis*) grows only around springs of relatively fresh water that issue along the contact between the alluvial fans and the salt pan. Xerophytes, such as desertholly (*Atriplex hymenelytra*), cattle spinach (*A. polycarpa*), and creosotebush (*Larrea*) cover the alluvial fans (Hunt, 1966).

Hunt (1966) reported the following percentage con-

FIGURE 7.—Pickleweed (*Allenrolfea*) on salt mounds in Death Valley. Mound beneath near bush is approximately 2 feet (0.6 m) high.

centration of major ions in the ash of some Death Valley plants:

Plant name and number of samples	Ca	Mg	K	Na	SO_4	Cl	CO_3 or PO_4 needed to balance cations	SiO_2
Xerophytes								
Atriplex hymenelytra (2)	6	2	7	26	4	25	30	...
Atriplex polycarpa (1)	11	6	8	14	4	14	40	< 5
Phreatophytes								
Pluchea (6)	11	4	10	12	23	8	32	...
Distichlis (6)	2	1	2	6	5	9	5	70
Juncus (2)	4	2	19	8	13	9	20	25
Suaeda (1)	3	5	9	20	8	20	35	...
Allenrolfea (12)	2	2	5	32	7	27	25	...
Atriplex linearis (1)	9	4	13	17	5	12	...	...

The relatively constant ratio of sodium to chloride in the plants suggests that the two ions are absorbed together. The correlation between lithium and sodium shown in our analyses suggests that lithium is adsorbed as a chloride.

Our samples in Death Valley came chiefly from the carbonate zone, the lower parts of the alluvial fans, and near springs so that we could study the uptake of ions by plants (table 8). The content of water-soluble salts in the soils that were collected at plant sample localities was higher in several instances than the tolerance limits reported for these species because the samples were of surface soils and included an efflorescent crust. The soils actually in contact with the plant roots (for example, mesquite) may be as much as 50 feet (15 m) below the surface.

In general, lithium contents in surface sediments of this evaporite basin decrease laterally from the center outward:

Chloride and sulfate zones	150–300 ppm
Carbonate zone	30–150 ppm
Alluvium and dune sand	35– 50 ppm

Anomalous amounts of lithium (300 ppm) were detected in the travertine deposits of Travertine Spring in Furnace Creek Wash, the sulfate sediments at Badwater, and in the sediment (as opposed to the halite pinnacles) of the salt pan or chloride zone (D1A). This concentration was found in the brown soft sediment below the polygonal hard crust of the streambed which meanders across the salt pan. The surface polygons of halite with upturned edges are hard enough to support a man's weight.

Lithium in the ash of plants that were collected in Death Valley ranges from 30 to 500 ppm in the ash, or 7.3 to 160 ppm dry weight. Plants containing high lithium correspond with high lithium in the substrate. The highest concentrations of lithium are in *Allenrolfea* (pickleweed), in *Atriplex hymenelytra* (deserthollv) and *Suaeda ramossissima* (seepweed) collected near the edge of the salt zone where the roots presumably are periodically contaminated with salt during floods. The blue-green algae at Badwater (sta. D8) in the sulfate zone (which is also high in sodium chloride) contained only 110 ppm lithium, a surprising low value considering the metal-accumulative ability of most algae.

AMARGOSA DESERT

The Amargosa Desert is not topographically closed; the Amargosa River flows into it from Oasis Valley in the northwest corner and out into Death Valley at the southeast corner. Nevertheless, little water is actually lost from the valley because the streambed is completely dry in the summer, when the temperatures and evaporation rates are high. Hydrologically, therefore, the basin is presumed to be closed and is characterized by a noticeable upwelling of ground water in many large springs; even that flow is consumed in the summer by evapotranspiration. The chemistry of Death Valley waters shows (Hunt and Robinson, 1960) that a certain amount of water from the Amargosa Desert is discharging by underflow into Death Valley. According to Winograd (1962), who studied the altitude of the piezometric surface of the semiperched Cenozoic aquifers in Yucca, Frenchman, and Jackass Flats, the ground water of these valleys moves downward into the underlying Paleozoic carbonates and discharges into the Amargosa Desert.

Analyses of water from springs and wells (Walker and Eakin, 1963; B. P. Robinson and W. A. Beetam, written commun., 1965) show high calcium and magnesium in the ground water discharged largely from limestones in the northeastern part of the valley and high bicarbonate, sulfate, chloride, sodium, fluorine, potassium, and boron in waters recharged largely from tuffs in the western part of the valley (table 9). Water from Jackass Flats, which is unusually high in sulfate attributed by Schoff and Moore (1964) to hydrothermal alteration of volcanic rocks, contributes sulfate and probably lithium to the western part of Amargosa Desert. Water from a shallow well southeast of Allens Well and 2 miles (1.2 km) south of station A4 contains 0.30 ppm lithium and 2.8 ppm boron—the highest percentages recorded by Walker and Eakin for their 18 Amargosa water samples. According to Walker and Eakin, the boron content should be toxic to any but the most

TABLE 8.—*Percentage of lithium and associated ions in sediments and the ash of plants from Death Valley, Calif.*

[Stations shown in fig. 1. Analysts are named in introduction. N, not detected; X, xerophyte; P, phreatophyte; Ha, halophyte; Hy, hydrophyte; WSS, water-soluble salts. The soil in which the sampled plant grew is listed directly below each plant]

Station No.	Sample	Lab. No. (D-)	Ash	WSS	Lithium		Magnesium		Calcium		Sodium		Potassium		Boron		Carbonate (as CO_2)	Sulfate (water-soluble)		Chlorine
			(percent)		Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Soil	Plant	Soil	Soil
	At edge of salt pan, west of Devil's Golf Course																			
D1A	*Allenrolfea occidentalis* (Ha)	403640	27.5	----	0.035	-----	2.0	----	2.7	----	33.2	----	6.4	----	0.05	----	----	0.50	----	----
	Sediment mixed with halite	403338	----	2.8	-----	0.015	-----	4.0	----	7.8	-----	8.3	-----	1.7	-----	0.03	6.2	-----	1.72	28.5
	Salt pinnacle (no plants)	405463	----	----	-----	.02	-----	.07	----	.50	-----	35	-----	.8	-----	.07	----	-----	2.0	----
	Brown sediment between pinnacles	405464	----	----	-----	.03	-----	1.0	----	3.0	-----	20	-----	1.7	-----	.15	----	-----	4.5	----
	Streambed to salt zone	405465	----	----	-----	.03	-----	2.0	----	5.1	-----	15	-----	1.9	-----	.10	----	-----	9.4	----
D1B	*Atriplex hymenelytra* (X)	403642	32.3	----	.03	-----	1.5	----	5.4	----	31.3	----	5.4	----	.02	----	----	.71	----	----
	Suaeda ramossissima (P)	403641	22.5	----	.05	-----	1.5	----	3.2	----	31.5	----	6.4	----	.02	----	----	1.2	----	----
	Carbonate zone plus salt	403339	----	.85	-----	.007	-----	3.2	----	8.8	-----	3.1	-----	1.9	-----	.01	12.2	----	.44	----
D1C	*Atriplex hymenelytra* (X)[1]	412065	30.0	----	.05	-----	7.0	----	9.6	----	23	----	7.0	----	.03	----	----	----	----	----
	Alluvium	412058	----	----	-----	.005	-----	1.0	----	1.8	-----	1.3	-----	3.5	-----	.003	----	----	----	----
	Stovepipe Wells (spring)																			
D5	*Atriplex linearis* (P)	403649	16.8	----	0.015	-----	3.0	----	8.8	----	18.0	----	14.6	----	0.05	----	----	0.23	----	----
	Distichlis stricta (P)	403650	24.4	----	.003	-----	1.5	----	3.1	----	5.8	----	2.6	----	.03	----	----	.13	----	----
	Dune sand	413095	----	----	-----	0.0035	----	2.0	----	3.8	-----	1.1	-----	2.4	-----	0.015	----	-----	0.03	----
	Near Tule Spring																			
D2	*Pluchea sericea* (P)	403643	10.7	----	0.0035	-----	3.0	----	15.5	----	10.2	----	6.2	----	0.1	-----	----	0.76	----	----
	Prosopis glandulosa (P)	403644	3.9	----	.015	-----	5.0	----	20.8	----	1.0	----	19.2	----	.05	-----	----	.08	----	----
	Atriplex polycarpa (X)	403645	13.5	----	.015	-----	7.0	----	9.4	----	23.2	----	8.2	----	.03	-----	----	.19	----	----
	Sandy facies of carbonate zone	403340	----	1.05	-----	N	----	1.8	----	2.8	-----	4.2	----	2.5	-----	0.015	2.0	-----	0.91	----
D2A	*Atriplex polycarpa* (X)[2]	412066	16.0	----	.015	-----	7.0	----	7.3	----	23	----	6.5	----	.05	-----	----	-----	----	----
	Sandy carbonate zone	412059	----	----	-----	0.003	----	.7	----	7.0	-----	.75	----	2.0	-----	.005	----	-----	----	----
	1.7 mi (3 km) N. of Badwater, and 8 mi (13 km) S. of Badwater																			
D7	*Allenrolfea occidentalis* (Ha)	408644	25.5	----	0.03	-----	1.5	----	2.2	----	30.2	----	8.2	----	0.05	-----	----	4.2	----	----
	Sulfate zone plus salt	118528	----	38.8	-----	0.03	----	3.2	----	5.1	-----	9.7	----	2.7	-----	0.3	3.2	-----	5.9	16.7
D8	*Phormidium ambiguum*	408645	87.0	----	.011	-----	5.0	----	2.3	----	2.0	----	1.4	----	.02	----	----	.22	----	----
	Crust of gypsum	118529	----	5.7	-----	.007	----	1.4	----	18	-----	1.6	----	.41	-----	.02	1.0	-----	2.2	----
D9	*Allenrolfea occidentalis* (Ha)	408646	30	----	.03	-----	2.0	----	2.0	----	33.2	----	5.6	----	.03	----	----	1.9	----	----
	Spongy sulfate zone plus salt	118530	----	18.0	-----	.015	----	3.4	----	3.4	----	4.4	----	3.4	-----	.05	1.2	----	2.6	7.9
	Furnace Creek Wash, Travertine Spring																			
D6	*Anemopsis californica* (Hy)	403651	16.7	----	0.015	-----	5.0	----	5.6	----	12.1	----	27.0	----	0.02	-----	----	0.16	----	----
	Travertine deposit	403342	----	0.30	-----	0.03	----	3.3	----	17.7	-----	0.74	----	1.2	-----	0.003	20.4	-----	0.02	----
	Mud Canyon, alluvial fan																			
D3	*Franseria dumosa* (X)	403647	9.7	----	0.004	----	2.0	----	20.2	----	1.4	----	20	----	0.05	-----	----	0.22	----	----
	Hymenoclea salsola (P)	403646	9.1	----	.015	----	3.0	----	12.7	----	1.1	----	28.4	----	.07	-----	----	.14	----	----
	Alluvium at 2,000 ft elev. (610 m)	403341	----	----	-----	N	----	1.1	----	2.6	-----	8.1	----	2.8	-----	0.005	2.0	-----	0.01	----
D4	*Bebbia juncea aspera* (X)	403648	9.25	----	.015	----	6.0	----	14	----	.5	----	16	----	.3	-----	----	.13	----	----
	Alluvium at 1,000 ft elev. (305 m)	413096	----	----	-----	0.0035	----	1.5	----	3.8	-----	1.1	----	2.4	-----	.005	----	-----	.03	----
	Salt Spring																			
D10	Soft sediment (NaCl)	415466	----	2.0	-----	0.016	----	3.0	----	4.9	-----	2.0	----	2.3	-----	0.03	----	----	0.30	----

[1] Fluorine content in plant 0.0033 percent.

[2] Fluorine content in plant 0.0112 percent.

TABLE 9.—*Chemical constituents (parts per million) of some springs and wells in Amargosa Desert*

[Analyses from Walker and Eakin (1963, p. 33) and B. P. Robinson and W. A. Beetam (written Commun., 1965). Surface samples unless depth figure shown]

Name of spring, sample-collection date, station No.	Depth (feet)	Depth (metres)	Ca	Mg	Na	K	Li	HCO_3	SO_4	Cl	F	B	Dissolved solids	Hardness
Recharge largely from limestones														
Fairbanks Spring 10-27-64 (A7)	....	....	51	18	71	8	0.11	304	80	22	2.2	0.51	422	201
Point of Rocks (small spring) 10-26-64 (A9)	....	....	52	19	66	7.9	.1	306	70	21	1.2	.66	419	208
Point of Rocks (King Spring) 10-26-64 (A8)	....	....	42	19	68	7.9	.09	308	70	22	1.6	.45	416	208
Recharge largely from altered tuffs														
Southeast of Allens Well 8-18-52 (2 miles south of A4)	27	8.2	4.8	3.3	370	16	0.30	542	256	102	3.2	2.8	1,119	26
Death Valley Junction 8-29-52 (A10)	146	45	1.9	1.9	325	12	....	556	149	49	7.9	1.3	874	12
Ash Tree Spring 5-8-52 (A5)	....	....	16	4.8	53	7.9	*.45	160	37	7.2	2.8	.29	293	60

*USGS analysis of sample collected by H. L. Cannon.

boron-tolerant crops, and the fluorine content of 7.9 ppm at Death Valley Junction is too high to meet U.S. Public Health Service drinking-water standards. Lithium content was not reported for Death Valley Junction but is probably also high. Two phreatophytes collected near the well contained 200 ppm lithium and 116 and 140 ppm fluorine in the ash.

Although correlations are apparent for lithium and sodium, lithium and chloride, and lithium and boron in the waters, no consistent relationship between lithum and any other element can be demonstrated in the various types of sediments sampled (table 10). Plant and soil studies were made in relation to a playa northeast of Ash Meadows, springs issuing from limestones in the same part of the valley, a playa northeast of Allens Well, the well at Death Valley Junction, and the clay and carbonate deposits north of Death Valley Junction. The unnamed playa is a relatively wet playa with ground water at a depth of 5–6 feet (1.5–1.8 m) discharging from Paleozoic limestones. Several *Atriplex* species were sampled in sandy soil 600 feet (180 m) northeast of the playa (station A1). Also growing at the same station were the phreatophytes *Prosopis* (mesquite), *Atriplex canescens* (saltbush), and *Suaeda ramossissima* (seepweed) and the sulfur indicator *Lepidium fremonti*. No plants grew in the center of the playa, at station A2. Seepweed and shadscale were collected at station A3 where ground water stands at 6 feet (1.8 m) in depth in the clay pits. These clay sediments contained appreciable carbonate and sulfate and 200 ppm lithium. At four springs issuing from Paleozoic limestones (stations A6, A7, A8, A9) only a small amount of lithium was found in tufa deposits but as much as 150 ppm was found in organic mud in McGilivrays Spring. At the unvegetated wet playa northeast of Allens Well, the capillary fringe extends to the surface and is fed by water from the Paleozoic limestones; a maximum of 150 ppm lithium was found in the outcropping sandy carbonate facies. Of greater interest were the Pleistocene lacustrine clay and travertine deposits in the northwest part of the valley where the waters are of volcanic origin. There, clays contained as much as 1,500 ppm lithium; travertine or lacustrine limestones, as much as 700 ppm; and plants, a maximum of 300 ppm lithium. The area appears to be favorable for the commercial production of lithium salts.

The carbonates with the highest concentrations of lithium are clearly of biochemical origin (figs. 3, 4, 5) and probably reflect selective transpiration of particular elements by halophytes. Lithium has been shown to substitute for magnesium in the crystal lattice of the clays. Clays deposited or formed in saline lacustrine deposits commonly have relatively high lithium contents. Studies by P. D. Blackmon and H. C. Starkey (written commun., 1974) at the Pleistocene Lake Tecopa in the southern part of the Amargosa Desert showed the zeolitic rocks to contain 50–100 ppm lithium and montmorillonitic claystones to contain 100–800 ppm. A nearly pure separate of saponite from a claystone contained 0–34 percent lithium oxide.

OTHER CLOSED BASINS

Lithium and potassium have been commercially produced in Owens Lake and are being produced in Clayton Valley; halite, calcium chloride, and gypsum are being mined in Bristol Lake, and halite is being recovered at Fourmile Flat. In all these evaporite basins the brines are pumped from depth and evaporated to crystallize the salts. Lithium chloride and potassium are or have been produced from the remaining mother liquor in Owens Lake and Clayton Valley. Hectorite, a lithium clay, is being

TABLE 10.—*Percentage of lithium and associated ions in sediments and ash of plants from Amargosa Desert, Nevada and California*

[Stations shown in fig. 1. Analysts are named in introduction. N, not determined; X, xerophyte; P, phreatophyte; Ha, halophyte; WSS, water-soluble salts. The soil in which the sampled plant grew is listed directly below each plant]

Station No.	Sample	Lab. No. (D-)	Ash	WSS	Lithium		Magnesium		Calcium		Sodium		Potassium		Boron		Carbonate (as CO_2)	Sulfate (water-soluble)	
			(percent)		Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Soil	Plant	Soil
	Clay pits N of Death Valley Junction, from Ash Tree Spring to ESE, Na_2HCO_3 ground water																		
A5	Lake clay with root casts	403349	----	0.25	------	0.15	------	11.0	-----	0.92	-----	1.1	-----	1.7	-----	0.01	0.04	----	0.04
	Limestone of biogenic origin	412759	----	.48	------	.07	------	3.0	-----	42.0	-----	.2	-----	.1	-----	N	-----	----	.09
A5A	*Atriplex spinifera* (X)	408130	10.7	-----	0.015	------	7.0	-----	25	-----	4.3	-----	3.7	-----	0.02	-----	-----	0.12	----
	Pinkish limestone	408171	----	1.46	------	.03	------	1.9	-----	32.6	------	.47	-----	.27	-----	.003	36.9	----	.26
	Lepidium fremonti	408131	10.4	-----	.0075	------	3.0	-----	14	-----	3.7	-----	19.4	-----	.07	-----	-----	1.64	----
	Casts on roots	408172	----	1.02	------	.03	------	2.7	-----	12.4	-----	.96	-----	2.4	-----	.03	12.6	----	.36
	Brown sulfate zone with crust	408173	----	11.0	------	.02	------	2.1	-----	2.9	-----	6.4	-----	3.7	-----	.1	5.9	----	2.58
	Cleomella obtusifolia (Ha)	413089	9.0	-----	.015	-----	5.0	----	6.6	-----	10	-----	18	-----	.03	-----	-----	1.2	----
	Calcareous soil	413122	----	.02	------	.015	------	3.0	-----	32.0	-----	.11	-----	.35	-----	.005	-----	----	.02
	Sulfate soil	413123	----	2.3	------	.028	------	5.0	-----	5.7	-----	2.2	-----	2.7	-----	.02	-----	----	2.3
A5B	*Distichlis stricta* (P)	408640	15.8	-----	.006	-----	.7	-----	1.3	-----	7.8	-----	2.2	-----	.03	-----	-----	.14	----
	Sporobolus airoides (Ha)	408641	15.8	-----	.008	-----	1.0	-----	2.3	-----	6.8	-----	1.7	-----	.02	-----	-----	.36	----
	Tamarix pentandra (P)	408642	14.5	-----	.03	-----	>10	-----	14.8	-----	10.3	-----	5.6	-----	.05	-----	-----	2.3	----
	Calcareous lake clay[1]	418525	----	.18	-----	.039	------	.96	-----	9.9	-----	1.7	-----	2.2	-----	.015	21.2	----	.03
	Limestone of biogenic origin	118526	----	.28	-----	.05	------	.33	-----	38.3	-----	.06	-----	.15	-----	<.002	35.4	----	.08
	Death Valley Junction, near spring																		
A10	*Tamarix pentandra* (P)[2]	412756	6.9	-----	0.02	-----	7.0	-----	8.4	-----	12	-----	19	-----	0.07	-----	-----	1.5	----
	Hymenoclea salsola (P)[3]	412757	21.4	-----	.02	-----	1.5	-----	1.4	-----	32	-----	8	-----	.015	-----	-----	1.4	----
	Atriplex parryi (X)	413088	25.0	-----	.02	-----	1.5	-----	4.6	-----	25	-----	3.4	-----	.20	-----	-----	.54	----
	Sandy soil	413121	----	0.50	-----	0.017	------	3.0	-----	6.0	-----	3.3	-----	2.7	-----	0.20	-----	----	0.50
	Playa NE of Allens Well (no vegetation)																		
A4	Brown carbonate layer with NaCl	403347	----	2.0	-----	0.015	------	3.4	-----	8.7	-----	2.2	-----	2.7	-----	0.015	10.2	----	0.41
	Salt crust	403348	----	80.6	-----	N	------	.4	-----	.78	-----	29	-----	3.2	-----	.05	9.4	----	19.5
	Playa NE of Ash Meadows; ground water at 5-6 ft (1.5-1.8 m), $CaMgHCO_3$)																		
A1	*Atriplex parryi* (X)	403652	21.6	-----	0.005	-----	0.005	-----	5.0	-----	17.6	-----	16.8	-----	0.007	-----	-----	0.12	----
	A. confertifolia (X)	403653	16.3	-----	.01	-----	.01	-----	7.0	-----	19.2	-----	12.4	-----	.007	-----	-----	.24	----
	Sandy soil at sta. NE of playa	403343	----	0.20	-----	0.005	------	1.1	-----	4.5	-----	1.7	-----	2.3	-----	0.003	4.4	----	0.01
	Atriplex parryi (X)	413087	27.0	-----	.015	-----	3.0	-----	8.8	-----	15	-----	8.4	-----	.02	-----	-----	.15	----
	Sandy soil	413120	----	-----	-----	.0035	------	1.5	-----	4.3	-----	1.3	-----	12.4	-----	.003	-----	----	<.01
A2	Playa crust	403344	----	1.5	-----	.007	------	3.2	-----	7.0	-----	2.3	-----	2.6	-----	.015	7.8	----	1.13
	Playa at 6 inches (15 cm) depth	403345	----	1.5	-----	.015	------	3.2	-----	4.8	-----	7.4	-----	2.5	-----	.03	10.4	----	.95
A3	*Suaeda ramosissima* (P)	403654	22.0	-----	.01	-----	2.0	-----	4.1	-----	27.9	-----	8.3	-----	.015	-----	-----	.72	----
	Atriplex confertifolia (X)	411477	38.6	-----	.0035	-----	1.5	-----	6.5	-----	21	-----	17.0	-----	.01	-----	-----	----	----
	Carbonate clay with SO_4	403346	----	.02	-----	.02	------	4.8	-----	8.4	-----	6.9	-----	2.2	-----	.03	15.2	----	3.65
	Efflorescence	411455	----	.01	-----	.01	------	3.0	-----	5.8	-----	16.0	-----	1.7	-----	.05	-----	----	----
	Fairbanks Spring, mixed $CaMgHCO_3$ and Na_2HCO_3																		
A6	*Tamarix pentandra* (P)	403655	9.5	-----	0.0065	-----	5.0	-----	13.3	-----	1.6	-----	16.8	-----	0.03	-----	-----	1.4	----
	Hard white calcareous clay	403350	----	0.45	-----	0.005	------	0.96	-----	9.9	-----	1.7	-----	2.2	-----	0.003	9.6	----	0.10
	Brown silty carbonate interbedded	403351	----	.15	-----	N	------	3.3	-----	38.3	-----	.06	-----	.15	-----	<.002	42.5	----	.01
	McGilivrays Spring, $CaMgHCO_3$, recharge in limestone																		
A7	*Bacharis glutinosa* (P)	411478	10.0	-----	0.015	-----	>10	-----	23	-----	0.91	-----	6.6	-----	0.15	-----	-----	----	----
	Black organic mud	411456	----	-----	-----	0.015	------	2.0	-----	10	-----	1.1	-----	1.5	-----	0.005	6	----	----
	Spring at trailer, $CaMgHCO_3$, recharge in limestone																		
A8	*Tamarix pentranda* (P)	411480	11.4	-----	0.01	-----	7.0	-----	14	-----	16	-----	9.0	-----	0.05	-----	-----	----	----
	Black organic mud	411457	----	-----	-----	0.0045	------	1.5	-----	19	-----	2.2	-----	1.5	-----	0.002	-----	----	----
	Point of Rocks Spring, $CaMgHCO_3$, recharge in limestone																		
A9	*Pluchea sericea* (P)	411479	8.3	-----	0.03	-----	3.0	-----	14	-----	16	-----	9.0	-----	0.15	-----	-----	----	----
	Calcareous tufa	411458	----	-----	-----	0.0025	------	2.0	-----	37	-----	0.15	-----	0.2	-----	<0.002	-----	----	----

[1] Chlorine content of soil 0.09 percent.

[2] Fluorine content of plant 0.0140 percent.

[3] Fluorine content of plant 0.0116 percent.

TABLE 11.—*Percentage of lithium and associated ions in sediments and the ash of plants from three closed basins in which economic quantities of lithium occur*

[Stations shown in fig. 1. Analysts are named in introduction. P, phyteatophyte; Ha, halophyte; X, xerophyte; Hy, hydrophyte; WSS, water-soluble salts. The soil in which the sampled plant grew is listed directly below each plant]

Station No.	Sample	Lab. No. (D-)	Ash	WSS	Lithium		Magnesium		Calcium		Sodium		Potassium		Boron		Carbonate (as CO_2)		Sulfate (water-soluble)	
					Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil
	Clayton Valley (Lithium and potassium produced commercially from chloride brines)																			
L3	*Sarcobatus vermiculatus* (P)	408134	12.7	----	0.07	----	0.5	----	6.8	----	23.2	----	14.6	----	0.015	----	----	----	0.38	----
	Sulfate soil under plant	408177	----	13.3	----	0.03	----	1.4	----	6.8	----	4.7	----	2.57	----	0.015	----	1.6	----	2.33
	Spongy chloride soil	408178	----	13.8	----	.03	----	1.4	----	3.0	----	6.1	----	2.24	----	.02	----	1.6	----	1.22
	Efflorescent crust	408179	----	88.6	----	.03	----	.24	----	1.8	----	35.0	----	1.3	----	<.02	----	.18	----	3.02
L4A	Soft brown lake clay (no plants)	415459	----	2.8	----	.03	----	1.0	----	3.3	----	2.9	----	3.2	----	.015	----	----	----	.10
	White efflorescent crust	415460	----	3.2	----	.05	----	1.5	----	3.3	----	2.8	----	2.8	----	.015	----	----	----	.24
L4B	*Allenrolfea occidentalis* (Ha)	408135	25.8	----	.15	----	1.0	----	3.6	----	31.5	----	4.5	----	.05	----	----	----	2.08	----
	Juncus cooperi (Hy)	408136	6.2	----	.30	----	1.0	----	4.6	----	21.6	----	4.8	----	.2	----	----	----	.4	----
	Algae in hot spring (Hy)	408148	83.8	----	.03	----	.3	----	33.4	----	3.6	----	3.6	----	.007	----	----	----	----	----
	Spring deposit between *Juncus*	408180	----	7.45	----	.03	----	.7	----	30.	----	3.0	----	3.0	----	.01	----	34.1	----	.50
	Spring deposit under *Juncus*	408181	----	9.51	----	.05	----	1.0	----	25.	----	3.0	----	3.0	----	.02	----	25.6	----	2.51
	Allenrolfea occidentalis (Ha)	413056	44.	----	.3	----	2.0	----	1.4	----	31.	----	3.4	----	.07	----	----	----	3.4	----
	Hot spring mud	413101	----	----	----	.01	----	1.0	----	23.	----	1.0	----	.85	----	.007	----	----	----	.18
L18	*Allenrolfea occidentalis* (Ha)	413057	33.	----	.3	----	3.0	----	1.0	----	29.	----	3.0	----	.05	----	----	----	1.8	----
	Brown soft soil with NaCl	413102	----	----	----	.03	----	2.0	----	3.9	----	2.1	----	2.4	----	.015	----	----	----	.16
	Owens Lake (Lithium and potassium formerly produced from chloride brines)																			
L12	*Scirpus olneyi* (Hy)	411481	15.5	----	0.035	----	1.5	----	4.2	----	15.	----	13.	----	0.7	----	----	----	----	----
	Mud in spring at playa edge	411459	----	----	----	0.01	----	1.5	----	7.8	----	1.45	----	2.5	----	0.007	----	----	----	0.65
	Atriplex torreyi (X)	411534	20.4	----	.05	----	.7	----	3.2	----	26.	----	11.	----	.03	----	----	----	2.2	----
	Sand at edge of playa	126550	----	----	----	.007	----	1.5	----	7.4	----	3.	----	2.0	----	.03	----	----	----	----
	Suaeda torreyana (P)	413054	24.0	----	.07	----	3.0	----	1.4	----	26.	----	8.2	----	.03	----	----	----	2.2	----
L19	*Distichlis spicata* (P)	413091	15.0	----	.10	----	1.5	----	2.0	----	18.	----	3.0	----	.15	----	----	----	.19	----
	Soil under evaporites in evaporating pan	413098	----	----	----	.012	----	3.0	----	9.2	----	2.	----	1.9	----	.015	----	----	----	.12
	Evaporites being shipped for B[1]	413099	----	----	----	.07	----	3.0	----	6.1	----	17.	----	.85	----	.05	----	----	----	.76
L19B	Soft spring mud with salts	415469	----	1.8	----	.08	----	3.0	----	11.0	----	2.5	----	1.9	----	.03	----	----	----	.15
L19A	Crystals in *Distichlis* plants	415468	----	44.	----	.01	----	1.5	----	3.5	----	10.	----	1.7	----	.1	----	----	----	15.
	Spring mud with algal scum	415467	----	.7	----	.004	----	.7	----	2.8	----	2.8	----	3.1	----	.1	----	----	----	.17
	Hector (Lithium clays being mined (hectorite))																			
L24	White carbonate lithium clay being shipped	415473	----	1.0	----	0.20	----	7.0	----	22.	----	1.1	----	0.24	----	0.003	----	----	----	0.01
	Darker clay surrounding white nodules	415474	----	1.6	----	.07	----	3.0	----	20.	----	1.5	----	.85	----	.002	----	----	----	.03
	Shale underlying volcanic flow	415476	----	.3	----	.005	----	.3	----	.80	----	4.2	----	2.4	----	.01	----	----	----	.01

[1] Chlorine content of soil 1.4 percent.

mined in the Mohave Desert. Analyses of samples from three closed basins from which lithium has been produced are given in table 11.

In Clayton Valley playa sediments consisting of 5–20 feet (1.5–6 m) of clay impregnated with halite and gypsum overlie beds of crystallized halite and saturated brine

(Meinzer, 1917). Brines that contain 12 percent sodium and 3 percent potassium are currently being pumped by the Foote Mineral Co. from a depth of 500 ft (150 m). Lithium contents of the brine were not ascertained from company geologists, but a magnesium:lithium ratio of 1 was mentioned. The percentage of lithium in the brine can then be assumed from the available analyses for magnesium in the brines to be at least an order of magnitude higher than that of sediments sampled at the surface. The highest lithium value in a surface soil analyzed by the Foote Mineral Co. was 1,200 ppm. Our surface sediment samples averaged 300 ppm lithium. Lithium-rich precipitate around the roots of *Juncus* in the hot spring on the east side of Clayton Valley contained 500 ppm lithium; a *Juncus* root crown (fig. 3) contained 3,000 ppm. Water-soluble sulfate has been concentrated from 0.50 percent in the spring mud to 2.51 percent in mud around the roots of a *Juncus* plant (sta. L4B). Hunt (1966, p. 34) reported 13 percent total SO_4 in the ash of *Juncus;* the plant described above contained 0.4 percent water-soluble SO_4.

The water of Owens Lake is a dense brine containing halite, soda, borax, and other salts. The dried residue analyzed by Stone and Eaton in 1905 contained 38.09 percent potassium, 1.62 percent lithium, and only 0.02 percent magnesium (Gale, 1915). The mother liquor still constitutes a large proportion of the mass, permeating the entire thickness of crystallizing salt.

Mud in the bottom of the old evaporating pans at Owens Lake contained only 120 ppm lithium; evaporite, which is dug and trucked only for boron payments, contained 500 ppm boron and 700 ppm lithium. Plants collected at several stations contained 350 to 1,000 ppm lithium.

A high-lithium clay, hectorite, is mined at Hector, east of Barstow from lake beds close to volcanic flows from Mount Pisgah (Foshag and Woodford, 1936). The pure mineral contains 1.1–1.2 percent Li_2O. The material being shipped is a white talclike clay that occurs in nodules and contained, in our sample, 0.2 percent lithium. The surrounding impure clay matrix contained only 0.07 percent. The hectorite resembled structurally the clay being mined in Amargosa Desert (A5) and shown by our analyses to contain a considerable amount of lithium.

Analyses of samples from seven other closed basins are given in table 12. On the Bristol Lake playa, rock salt (sodium chloride) is mined by the Leslie Salt Co. from a 6- to 7-foot-thick bed, which is covered by a similar thickness of mud over an area of about 4 square miles. In the recovery method, calcium chloride is precipitated from brines believed to be the mother liquor of the evaporative basin. The abundance of calcium chloride in this basin is unique for basins of the Basin and Range province. The calcium chloride is believed by Gale (1951) to have originated in the basaltic flows from Bagdad crater, which have in Holocene times separated Bristol Lake from Bagdad Lake to the northwest. Lithium is not mentioned in Gale's report. Polygonal salt crust in evaporating pans sampled during our study (sta. L25) contained only 20 ppm lithium. A sample of the playa carbonate mud overlying the salt contained 300 ppm lithium, and *Atriplex linearis* rooted in the carbonate near the toe of the volcanic flow contained 150 ppm. Gypsum and oolitic surface material 350 feet (100 m) onto the barren playa from the south edge also contained scant lithium. The surface alluvium at the south edge of the lake was low in lithium, but desertholly and cattle spinach collected there contained 300 ppm lithium.

On Sarcobatus Flat, the sediments of the soft brown carbonate zone that are impregnated with halite contained 300 ppm lithium, but greasewood ash contained only 150 ppm. Lesser amounts in both plants and soils were found in samples from Fourmile Flat (where halite is mined), Big Smoky Valley, Railroad Valley, and Oasis Valley. Samples of gypsiferous sediments collected near an old borax works in Columbus Salt Marsh contained only 30 ppm lithium but contained 10,000 ppm boron. *Atriplex spinifera* growing on them contained 150 ppm lithium and 1,500 ppm boron. The barren playa muds 500 feet (150 m) beyond the borax works contained 280 ppm lithium and 1,500 ppm boron. Seemingly, lithium is not associated directly with halite and borates but has a rather spotty distribution pattern in the basins, owing to sources of volcanic activity, to thermal hot springs, to adsorption on clay, or to subsequent flooding and subsurface movement of the solutions.

PLANT PROSPECTING

The analysis of plants for assessing lithium contents in brines in the Great Basin might be a useful prospecting tool in those areas where brines occur at depth and surface soils are relatively low in lithium. The lithium contents of plants growing in two plant societies in closed basins may indicate lithium concentrations at depth. First, hot springs at the contact of alluvium with basin sediments are apparently dissolving lithium at depth and the hydrophytes, such as *Scirpus olneyi* and *Juncus cooperi,* are absorbing and concentrating large quantities of lithium in plant tissues. Second, phreatophytes, such as *Allenrolfea, Distichlis,* and *Suaeda,* that are tolerant of and absorb large quantities of sodium chloride and grow in the chloride and sulfate zones also are tolerant of and absorb large quantites of lithium chloride. Xerophytic species of *Atriplex,* even though they may be lithium accumulators, have shallow root systems adapted to collecting surface water rather than ground water and, therefore, do not reflect lithium deposits at depth.

No symptoms of lithium toxicity were identified in plants, nor were useful indicators identified. *Lycium* is definitely an accumulator of lithium and may even be an

TABLE 12.—*Percentage of lithium and associated ions in sediments and the ash of plants from other closed basins in Nevada and California*

[Stations shown in fig. 1. Analysts are named in introduction. N, not detected; P, phreatophyte; X, xerophyte; WSS, water-soluble salts. The soil in which the sampled plant grew is directly below each plant]

Station No.	Sample	Lab. No. (D-)	Ash	WSS	Lithium		Magnesium		Calcium		Sodium		Potassium		Boron		Carbonate (as CO_2)	Sulfate (water-soluble)	
			(percent)		Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Soil	Plant	Soil
	Bristol Lake (salt (NaCl) produced commercially)																		
L16	*Atriplex linearis* (P)------------	411575	21.5	-----	0.015	------	0.5	----	8.6	----	21.0	-----	12	----	0.015	-----	----	-----	----
	Playa mud--------	411565	----	-----	-----	0.01	----	2.0	----	5.6	----	1.3	----	2.3	-----	0.005	1.5	-----	----
L16a	Carbonate overlying chlorides	413104	----	-----	-----	.03	----	1.5	----	16.0	----	2.1	----	1.6	-----	.007	----	-----	----
	Limestone underlying flow-----	415470	----	4.4	-----	.004	----	.2	----	15	----	1.5	----	1.1	-----	<.002	----	-----	2.1
L17	*Atriplex hymenelytra*----------	413060	27	-----	.03	------	5.0	----	10	----	15	----	11	----	.05	-----	----	1.5	----
	A. polycarpa (X)-	411576	19.4	-----	.03	------	1.0	----	7.4	----	18	----	14	----	.03	-----	----	-----	----
	Alluvial fan, south side-----	411566	----	-----	-----	<.0025	----	1.0	----	3.4	----	2.0	----	3.0	-----	<.02	1.2	-----	----
L25	Oolitic gypsum (no plants)----	415471	----	54	-----	.005	----	.07	----	25	----	.95	----	.24	-----	N	2.1	-----	14
	Polygonal evaporite crust (no plants)----	415472	----	90	-----	.002	----	.03	----	1.4	----	34	----	.33	-----	N	2.0	-----	15
	Columbus Salt Marsh (borax previously produced commercially)																		
L5	*Atriplex spinifera* (X)-------	408137	7.2	-----	0.015	------	5.0	----	12.8	----	12.2	----	15.6	----	0.15	-----	----	0.24	----
	Soft sand with sulfate and borates--------	408182	----	12.5	-----	0.003	----	1.4	----	5.2	----	6.0	----	2.6	----	1.0	3.8	-----	4.3
	Soft brown gypsiferous soil (no plants)----	415455	----	7.0	-----	.015	----	.7	----	3.5	----	3.8	----	2.9	----	.2	----	-----	2.2
	Playa sediment (no plants)----	415456	----	8.4	-----	.028	----	.7	----	3.2	----	5.0	----	3.0	----	.15	----	-----	2.0
	Railroad Valley ($NaHCO_3$ water)																		
L7	*Sarcobatus vermiculatus* (P)--	408139	13.7	-----	0.0025	------	1.0	----	5.6	----	28.2	----	11.8	----	0.01	-----	----	0.30	----
	Suaeda torreyana (P)-------	408140	9.2	-----	.005	------	1.0	----	4.8	----	25.2	----	13.6	----	.02	-----	----	.55	----
	Sandy soil, brown----------	408184	----	0.37	------	N	----	0.48	----	2.1	----	1.8	----	3.4	----	0.005	1.2	----	0.02
	Playa mud with sulfates-------	408185	----	7.5	------	0.015	----	1.7	----	6.1	----	4.4	----	2.4	----	.007	3.5	----	2.1
	Big Smoky Valley ($NaHCO_3$ water)																		
L14	*Sarcobatus vermiculatus* (P)---	408643	16.3	-----	0.007	------	0.7	----	8.9	----	20.2	----	12.2	----	0.03	-----	----	0.28	----
	Playa mud (water at 43 ft (13 m))	118527	----	4.4	------	0.008	----	1.6	----	3.8	----	1.2	----	2.6	----	0.007	1.6	----	0.15
L23	*Sarcobatus vermiculatus* (P)---	413059	16.0	-----	<.002	------	1.5	----	3.2	----	25	----	9.0	----	.05	-----	----	.75	-----
	Atriplex parryi (X)-------------	413058	11.0	-----	.003	------	2.0	----	5.2	----	20	----	8.2	----	.05	-----	----	.31	-----
	Sandy soil with NaCl------------	413103	----	-----	------	.01	2.0	2.0	----	2.9	----	3.6	----	2.6	----	.07	----	----	.54
	Hard playa mud (no plants)-----	415457	----	3.3	------	.006	----	1.0	----	3.6	----	2.5	----	2.6	----	.007	----	----	.01
	Sandy clay (no plants)-----	415458	----	.4	------	.009	----	1.0	----	4.0	----	3.5	----	2.4	----	.07	----	----	.21
	Fourmile Flat (halite mined)																		
L6	*Sarcobatus vermiculatus* (P)---	408138	9.7	-----	0.0025	------	0.7	----	7.4	----	19.8	----	15.8	----	0.015	-----	----	0.28	-----
	Chloride 500 ft (150 m) onto playa----------	408183	----	5.9	------	0.007	----	2.2	----	2.9	----	4.9	----	2.2	-----	0.05	2.6	----	0.40
	1-4 in. chlorides 4,400 ft (1,320 m) onto playa---	415453	----	1.8	------	.0035	----	.7	----	4.5	----	3.6	----	2.4	-----	.07	----	----	.08
	Sediments in slough near edge	415454	----	8.8	------	.0025	----	.5	----	3.2	----	6.5	----	2.4	-----	.10	----	----	.54
	Sarcobatus Flat (altered $NaHCO_3$ water at depth 0-5 ft (0-1.5 m))																		
L2	*Sarcobatus vermiculatus* (P)---	408133	5.0	-----	0.015	------	1.5	----	23.2	----	5.5	----	5.9	----	0.03	-----	----	0.06	-----
	Brown carbonate zone------------	411479	----	1.6	-----	0.03	----	1.0	----	6.2	----	2.0	----	3.6	-----	0.02	5.7	----	0.07
	Soft dembo in playa edge------	415461	----	3.2	-----	.02	----	1.0	----	6.0	----	3.1	----	3.2	-----	.03	----	----	.55
	Hard playa mud (no plants)-----	415462	----	2.2	-----	.015	----	1.5	----	5.5	----	2.4	----	3.1	-----	.03	----	----	.18
	Oasis Valley (drains into Sarcobatus Flat; $NaHCO_3$ water at depth 0-5 ft (0-1.5 m))																		
L1	*Sarcobatus vermiculatus* (P)---	408132	7.5	-----	0.006	------	1.5	----	8.0	----	22.4	----	8.8	----	0.015	-----	----	0.16	-----
	Brown carbonate zone with NaCl--	408175	----	2.3	-----	0.015	----	0.96	----	2.6	----	3.0	----	3.0	-----	0.01	2.3	----	0.18
	Efflorescent crust of NaCl---------	408174	----	46	-----	.01	----	.30	----	1.3	----	>35	----	3.0	-----	.02	5.9	----	.47

indicator of lithium but it cannot grow in soils of high salt (sodium chloride) content.

Plants would not be useful in prospecting for high-potassium brines, because nutrient elements, such as potassium, that are required by plants in large amounts in normal physiological processes are not generally accumulated to any great extent. The plant absorbs only the amount needed regardless of the amount in the soil unless the quantities available are extremely high. As the particular species of plants that grow in the chloride and sulfate zones use sodium in place of potassium even when the latter is available, no correlation between plant contents and brines would be expected.

HEALTH ASPECTS OF LITHIUM

Little is known concerning the long-term effects of lithium deficiency or excess on health or disease of domestic animals or man. Claims for the efficacy of lithium in the treatment of gout, diabetes, and epilepsy have not been substantiated. Probably the most promising use for lithium in medical practice arises from its profoundly tranquilizing effect on manicdepressive patients (Cade, 1949; Schou, 1959). In Texas, a strong negative correlation exists between lithiumintake, as indexed by concentrations in drinking water, and admission rates to State mental institutions (Dawson and others, 1970). According to Lawrence Razavi (written commun., 1970), lithium stabilizes chromosomes by shortening the amplitude of helical polymers, including DNA. Although the concentrations cannot be compared with those used in medical treatment, one might conclude that relatively high levels (20–100 μg/l) of lithium in drinking water as might be encountered in the Basin and Range province would be beneficial in improving chromosomal quality and cell membrane strength.

The well-known negative correlation between water hardness and cardiovascular mortality can be explained statistically by lithium concentrations concomitant with water hardness (Voors, 1971). Biological evidence that low levels of lithium provide a protective effect against atherosclerosis is accumulating.

No cases of toxicity from naturally occurring lithium have been reported; indeed, increasing evidence suggests several beneficial effects.

SUMMARY

Lithium contents average 22–655 ppm in igneous rocks, 17 ppm in sandstone, 46 ppm in shale, and 26 ppm in limestone. During weathering, much of the released lithium is trapped in montmorillonitic clays; but lithium that reaches the sea tends to remain in solution as the highly soluble compound lithium chloride (average, 0.1 ppm). From 8 to 400 ppm lithium have previously been reported in soils.

Both open and closed basins occur in the Basin and Range province; hydrologically closed basins are discharged by evapotranspiration, and open basins are discharged by underflow to basins of lower hydraulic head. The median lithium content for 100 major municipal water supplies of the United States is 2 μg/l; that of 18 springs and wells of the Amargosa Desert, a closed basin, is 105 μg/l. Thermal hot springs are a common source of lithium in geochemical processes, and more lithium is contained in sodium bicarbonate water originating in tuffs than in calcium-magnesium bicarbonate water originating in the Paleozoic limestones. A further concentration of lithium takes place by the evapotranspiration of brines contained in closed basins that drain a large recharge area and that were occupied by lakes in Pleistocene time. The percentages of lithium in the brines along with potassium, bromine, boron, and halite are of economic value in several areas. Further investigation of lacustrine clays in closed basins, particularly in the Amargosa Desert, may reveal lithium concentrations of economic value.

In an evaporative basin, lithium may remain in solution until a late stage and then be precipitated along with sodium, potassium, and boron in the chloride and sulfate zones, although lithium is readily adsorbed by clay minerals in lacustrine deposits and also precipitated in marls of biogenous origin. Sediments collected for our project contained maximum values of 70–2,000 ppm lithium in 12 closed basins and maximum values of 40–150 ppm in 8 open basins.

Median contents of lithium in the type of sediments in closed basins were: lacustrine clays 700 ppm lithium; hot-spring travertines 450 ppm; sulfate-chloride, and carbonate zones, 150 ppm; playa clay, 150 ppm; and alluvium, 30 ppm. Lithium may be concentrated in amounts greater than 1,000 ppm in hot-spring deposits where lithium is dissolved at depth, pumped to the surface, and precipitated around the roots of hydrophytes.

Lithium is reported to be toxic to most cultivated plants at concentrations as low as 30 ppm in the soil, and for citrus plants, as low as 12 ppm. Vegetation generally contains about 1 ppm lithium in the dry weight; a maximum concentration of 4,400 ppm has been reported in the ash (or ±750 ppm in dry weight) of healthy tobacco. In the Great Basin, pickleweed and rush containing 3,000 ppm in the ash grow without apparent damage in soils containing 300–500 ppm lithium. A median of 150 ppm in the ash or 22.8 ppm in dry weight of higher plants collected from these basins is considerably greater than the average of 1.3 ppm in dry weight found by Bertrand.

The lithium content in the vegetation correlates well with that of the soil (as shown in fig. 2) except at levels of less than 100 ppm; at lower levels, the greater relative content in plants suggests that lithium is essential to plants. The species of plants that accumulate the greatest amounts of lithium are largely from the Chenopodiaceae family, and most lithium accumulators also take up large amounts of sodium chloride. The analysis of hydrophytes in springs at the alluvium-basin sediment contact and of halophytes growing in the chloride and sulfate zones of closed basins may be useful in evaluating the economic possibility of lithium extraction from brines.

The high lithium concentrations in water and vegetation of hydrologically closed basins may have a beneficial effect on the health of both lower animals and people living in the Basin and Range province.

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