

# GYPSUM DUNES AND EVAPORITE HISTORY OF THE GREAT SALT LAKE DESERT



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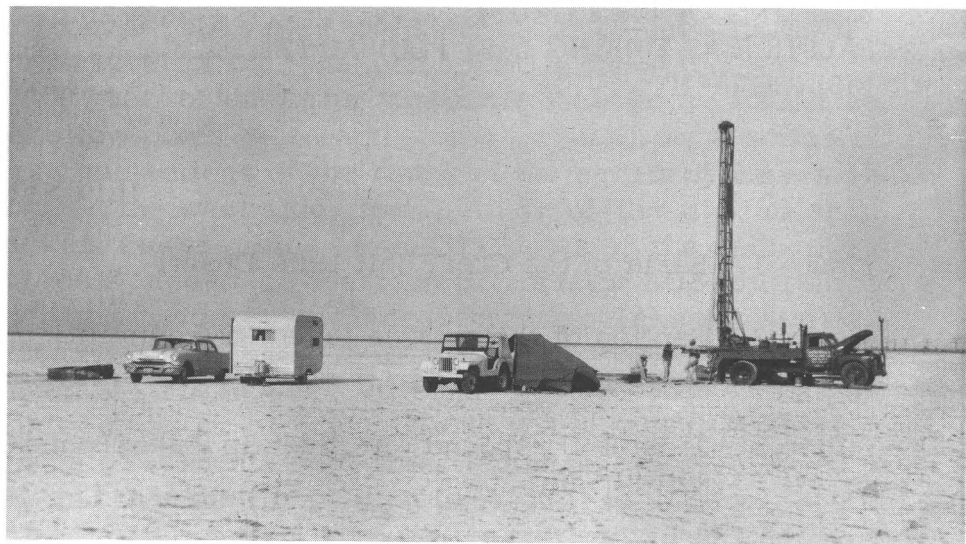
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# GYPSUM DUNES AND EVAPORITE HISTORY OF THE GREAT SALT LAKE DESERT

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Coring Through the Bonneville Salt Flats, 1960 (A. J. Eardley)



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# GYPSUM DUNES AND EVAPORITE HISTORY OF THE GREAT SALT LAKE DESERT

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## ABSTRACT

The Great Salt Lake Desert is a lake basin of about the same size and nature as that of Great Salt Lake, and the two are connected by a spillway or low pass about 25 feet above the present level of the lake (4195 feet). Events in the last 11,000 years of the desert basin are inferred from a series of shallow cores taken across the basin, from a series of measured sections of the banks of the canals of the potash works on the west side, from a study of the gypsum sand dunes on the east side, from  $C_{14}$  dates of the calcareous sediments, and from a consideration of isostatic adjustment and tilting incident to the disappearance of Lake Bonneville.

It is concluded that Lake Bonneville had desiccated to the high-salinity stage by at least 12,000 years ago, that the last carbonate sediments were deposited 11,000 to 10,000 years ago, and that the floor of the Great Salt Lake Desert basin had a gradient eastward through the spillway into Great Salt Lake until about 6,000 to 5,000 years ago. By this time the spillway site had risen sufficiently to develop closure in the Desert floor, and a few floodings from Great Salt Lake thereafter across the spillway into the incipiently closed Desert basin resulted in the salt now making up the Bonneville salt crust.

The salt crust first collected in the central part of the desert floor and later was shifted westward by rain water solution to its present site on the west side of the basin because of continued uplift on the east. At the time that the salt reposed in the central part of the basin, the eastern side had risen to the point that it began to suffer wind ablation and lost a layer of sediments, 10 to 15 feet thick, so that now the deposits at the surface are 25,000 years old. In the process

of ablation, the gypsum sand dunes formed. Evaporation at the surface of the plastic clays resulted in a capillary draw-up of the moisture, bringing with it sulphate ions. Probably associated with the capillary advance of the clay water were gypsum-producing bacteria, and myriads of sand-size gypsum crystals grew and are still growing in the top 3/4 inch or so of the clays. By further drying of the clay, these crystals are released to the wind and drift into dunes.

Likewise, while the salt crust was in the central part of the basin, the western side suffered ablation down to sediments having an age of 17,000 years. Gypsum dunes formed there also, but as the salt crust shifted westward incident to tilting, part of the gypsum dunes were bedded down by the salt and form an irregular layer under the salt. It has previously been supposed that the gypsum was an early precipitate of a lake that finally dried up where the salt crust now is.

## INTRODUCTION

The present report is an attempt to chronicle the post-Bonneville history of the Great Salt Lake Desert. The desert is a basin of the size and character of that of the Great Salt Lake but differs from it inasmuch as any lake waters that may have existed have dried up, leaving an extremely flat expanse of moist saline clays and a salt crust in the place of lowest elevations. See map of Figure 1.

The study concerns mostly the upper few feet of the clays that spread across the desert floor.

A series of shallow cores was taken along U. S. Highway 40 across the desert, and these, together with measured sections of several pits and canal banks, constitute the basic information. A number of  $C_{14}$  dates of the sediments illuminated the problems of correlation, and revealed areas of probable erosion in post-lake time. Crittenden's (1961) recent definition of uplift since Lake Bonneville began to disappear has made necessary the reconsideration of several previous postulates regarding, for instance, the spillway between Great Salt Lake and the Great Salt Lake Desert, the Gilbert beach, and the origin of the Bonneville salt crust. A theory is proposed for the origin of the gypsum sand dunes in the desert, and for the granular gypsum layer below the halite salt crust.

The research was done by means of a National Science Foundation grant to the writer and Donald L. Graf. Graf is concerned with the mineralogy and sedimentary geochemistry of the sediments; the present report is part of the writer's study of the past lake cycles and the climatic history of the basin.

## RESULTS OF CARBONATE RESEARCH

Dolomite and magnesite-bearing layers have been reported (Graf et al., 1961) in shallow cores from the Great Salt Lake Desert. These layers are indicated in Figure 2, and may be used for correlation purposes across the basin. Those that appear to correlate are connected by dashed lines.

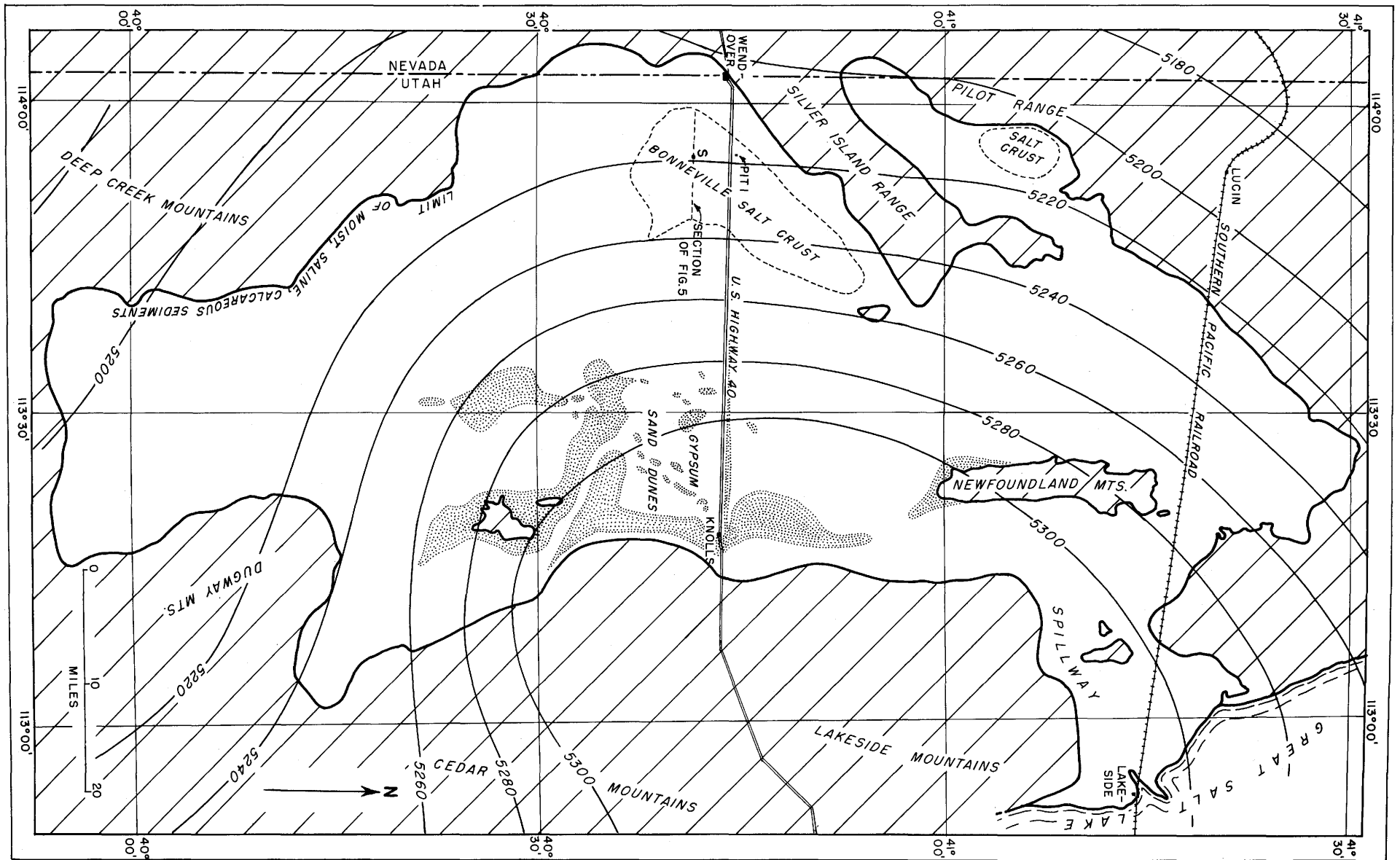


Figure 1. Basin of the Great Salt Lake Desert. Isobases are on the Bonneville beach and are taken from Crittenden (1961). Gypsum sand dunes are from Nolan (1927).

Other lithic characters are also used for correlation, such as oolitic sand and marly hard layers.

#### **C<sub>14</sub> DATES**

Graf et al. (1961) report a C<sub>14</sub> date of 11,300<sup>±</sup>250 years for the dolomite layer 10 1/2 miles west of Knolls, the sample coming from one foot below the surface. From C<sub>14</sub> dates of the sediments of Great Salt Lake and also here in the Great Salt Lake Desert basin, about one foot of sediments has accumulated in 500 to 1500 years. Therefore, at this locality the surface clays would have been deposited approximately 10,000 years ago.

Other C<sub>14</sub> dates from pits on each side of the basin were determined for the writer by the Lamont Geological Laboratory, and are shown on Figure 2. Those at the east side indicate that the surface calcareous sediments are 25,000 years old in contrast to 10,000 years in the central part. The first calcareous layer beneath the salt on the west side of the basin is 17,000 years old, and a bed about one foot below this is 25,000 years old. These dates from the west side of the desert were made on samples procured at station "S" of Figure 5, and the same layers approximately are presumed to be present at Pit 1, as shown in Figure 1.

#### **EVIDENCE OF EROSION IN POST-LAKE TIME**

The 11,000-year date has been considered by Broecker et al. (1959) to be in accord with many other dates in marking the end of glacial conditions and the beginning approximately of modern climates and Recent time. The Bonneville salt crust was considered to have been the last evaporation precipitate and to mark the demise of Lake Bonneville in the Great Salt Lake Desert (Eardley, et al., 1957). When the C<sub>14</sub> date was obtained, the writer concluded that the salt crust should rest on calcareous clays\* whose age would be 11,000 years,

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\*Clay is here used in the non-technical terminology of travelers on the salt flats, and by it is meant calcilutite with considerable silt admixed.

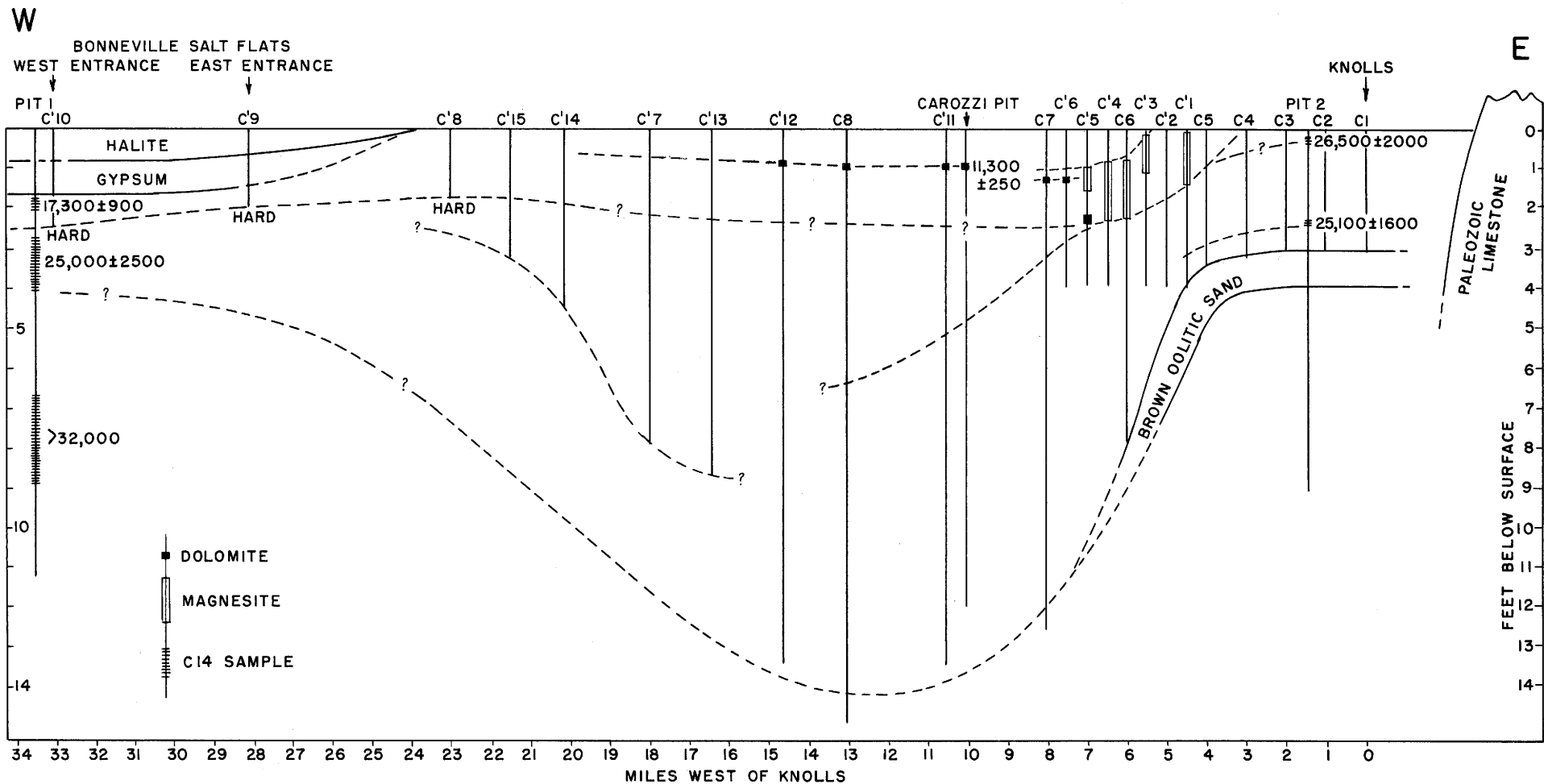


Figure 2. View facing northerly, Section of the surface layers of sediments of the Great Salt Lake Desert basin from the Bonneville salt flats to Knolls along U.S. Highway 40. Data on carbonates taken from preliminary work of Graf et al., 1961, especially for the carbonate minerals and chemistry of origin, and correlations will be better when this work is completed. Also certain oolite and pellet beds exist that have not yet been correlated.

not 17,000 years. He also anticipated that the moist, saline, calcareous sediments across the entire floor of the basin would be about 11,000 years old, not 25,000 as noted in Pit 2 on the east side of the basin. In an attempt to explain the older sediments at the surface on the east side and immediately under the salt crust on the west side, the units of the upper few feet across the basin were correlated as well as possible (Figure 2), and the result suggested that the younger beds had been removed by erosion along the east side, and possibly on the west side also before the salt crust was laid down there. The premise that erosion has occurred and that several feet of beds have been removed, particularly along the east side of the basin, will be examined in the following paragraphs.

#### **POST-BONNEVILLE ISOBASE AND TILTING**

Crittenden (1961) has recently confirmed the thesis of Gilbert (1880) that upward isostatic adjustments have occurred since Lake Bonneville started to fall. His isobases in the region of the Great Salt Lake Desert are shown in Figure 1. It will be recognized that tilting occurred across the basin, and that the east side has risen about 100 feet in reference to the west side. This is shown in Figure 3. One of the curves in the figure shows the present surface adjusted downward to the position it held at the time isostatic response to the disappearing lake started.

Erosion of the lake beds on the east side of the basin could not have started until the lake had entirely disappeared from the area, and as long as it was lower than the west side, it probably was covered with water. Since Knolls is approximately 15 feet higher today than the Bonneville salt crust, this amount of uplift has occurred since erosion started. Also the amount removed by erosion must be added to the amount of uplift since erosion began. This amount is judged to be about 10 feet, because the rate of sedimentation, according to C<sub>14</sub> dates, is about one foot per 1,000 years.

The total uplift of the east side of the basin over the left since Lake Bonneville disappeared is 100 feet, and inasmuch as about 25 feet has occurred since erosion started, then about 75 percent of the present amount of uplift predated the ablation stage.

## **GYP SUM SAND DUNES**

### **Distribution**

Gypsum sand dunes occur in fairly voluminous amounts along the east side of the Great Salt Lake Desert. Their distribution is shown on Figure 1, which has been taken from Nolan (1927). Since Nolan's mapping a new dune ridge has accumulated along the north side of U. S. Highway 40. It is the result of construction of a draft fence by the Western Pacific Railroad Company from Knolls westward in stages from 1940 to 1952.

### **Composition**

The composition of the dunes at Knolls has been described by Jones (1953). There they consist of 94 percent of medium, fine, and very fine sand of which slightly less than two-thirds is gypsum crystals and one-third spherical and rod-shaped oolites. Quartz grains are conspicuous in the very fine sand fraction and shell fragments of gastropods and ostracods were noted in the coarse, medium, and fine fractions (Jones, 1953). The dune ridge along U. S. Highway 40 consists of the same materials as Jones notes in the dunes at Knolls, and the great bulk of the grains are also as he notes, of the medium, fine, and very fine sand sizes. The proportions of these grain sizes varies considerably, however, from place to place, but in no systematic or meaningful manner as far as the writer could detect. The mechanical analyses were made by Vasyl Gvosdetsky.

### **Relation to Isostatic Uplift**

It will be seen that the distribution of the gypsum dunes corresponds approximately to the region of maximum uplift. Actually, some of the dunes extend south of the center of maximum uplift, but since the present direction of dominant drift of the sand is from north to south as attested by the dune ridge along the drift fence, it might be expected that the dunes would extend in this direction even though in some way tied in origin to the uplift.

### **Origin**

An examination of the surface of the moist saline flats, with the origin of the gypsum sand in mind, has yielded the following information. The upper 3/4-inch layer of the calcareous sediments on a normal stretch of the flats north of the drift fence is granular and slightly darker gray than the underlying beds. The granular character is imparted by numerous small gypsum crystals embedded in the plastic, moist, saline, calcareous clay. The crystals are of identical habit with the larger disc-shaped selenite crystals found buried in the bottom sediments of Great Salt Lake (Eardley and Graf, not yet published). The small crystals in the thin surface layer of the saline clays are closely akin to the crystals in the sand dunes, as may be seen in the photomicrographs of Plate 1.

The percentage of large crystals is greater in the thin surface clay layer, however, than in the dune sand. The very coarse and coarse fragments average 55 percent as against 9 percent in the dunes. Another difference is the slight rounding of the dune crystals and presence of cleaved fragments evidently of the disc-shaped crystals. These cleaved fragments give a prismatic appearance to half the grains in some samples. See the photomicrographs. If the dune crystals are derived from the surface clay layer, then it would be expected that the medium, fine, and very fine fractions would have been sorted out and concentrated, and that the crystals would have been somewhat rounded.

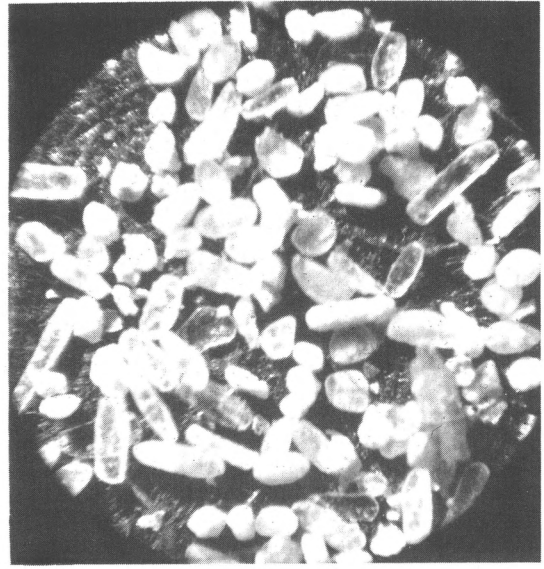
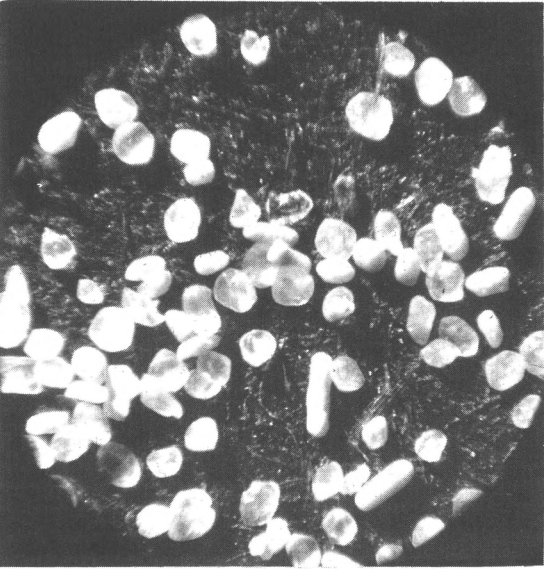
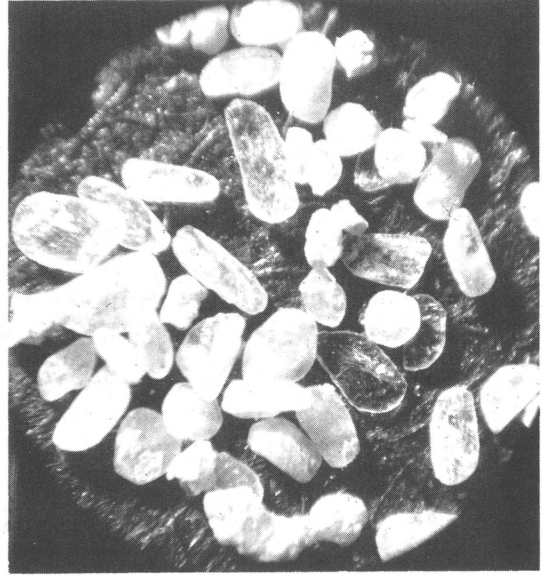
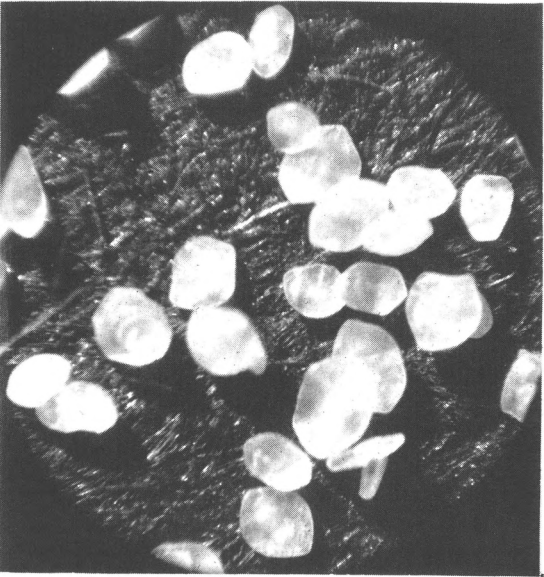
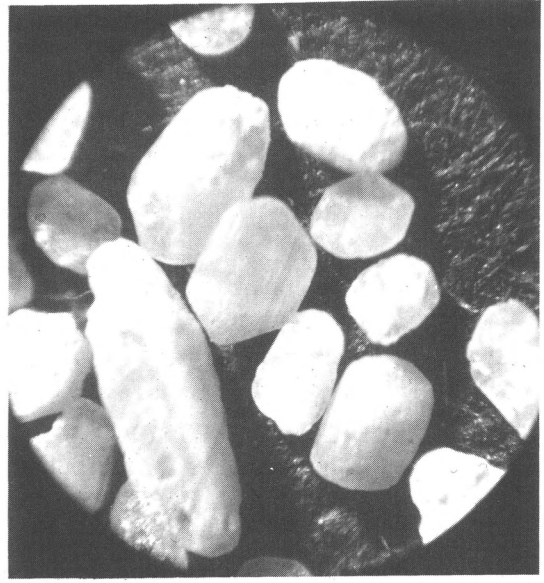
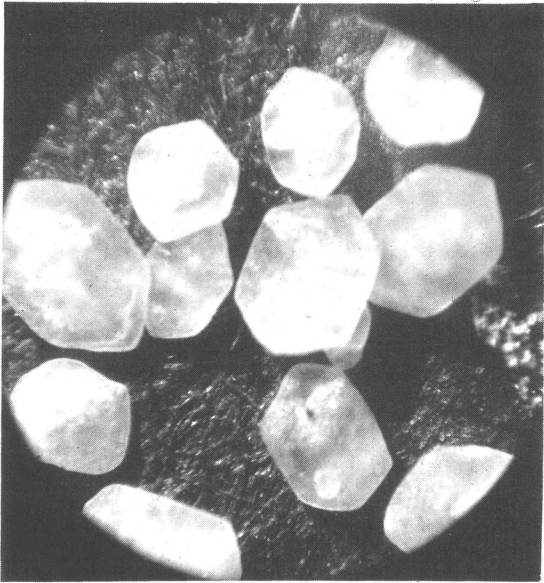


Plate 1

COARSE SAND SIZE	Crystals of gypsum growing in upper 3/4 inch of saline clay, north of U. S. 40, 6 miles west of Knolls		Crystals of gypsum in sand dunes along U. S. 40, derived from clays of sample on left. 6 miles west of Knolls. Note rounding of crystals. Compare with left.
MEDIUM SAND SIZE	Ditto above		Ditto above. Thin crystals are cleavage flakes of larger crystals. Cleavage and rounding occur in wind transportation. Compare with left.
FINE SAND SIZE	Ditto above. Plus brine shrimp pellets		Ditto above. Compare with left.

Plate 1. Photomicrographs of gypsum crystals in surface clay and in sand dunes, 6 miles west of Knolls.

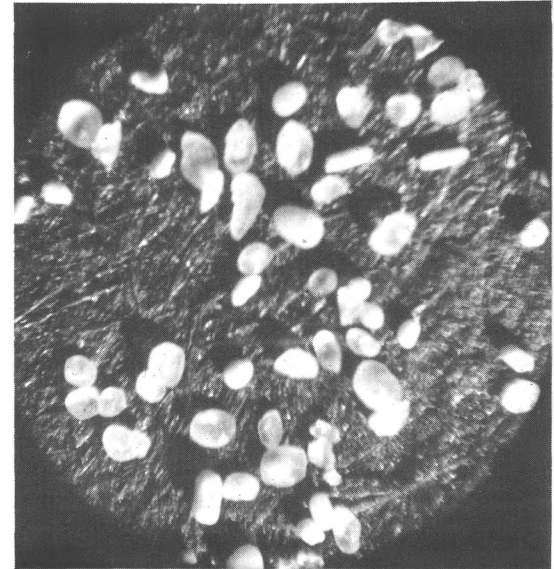
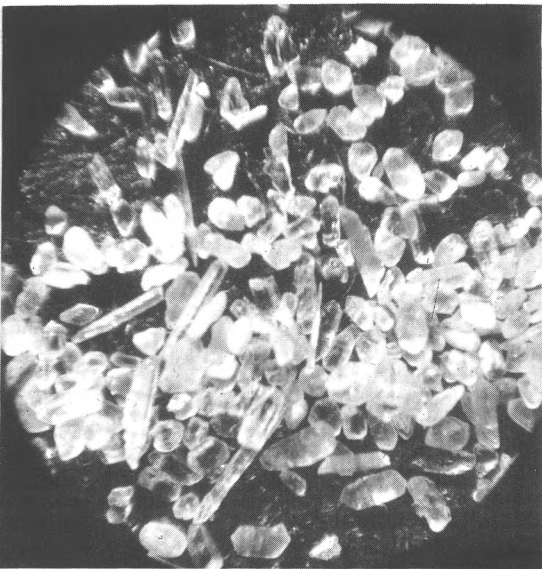
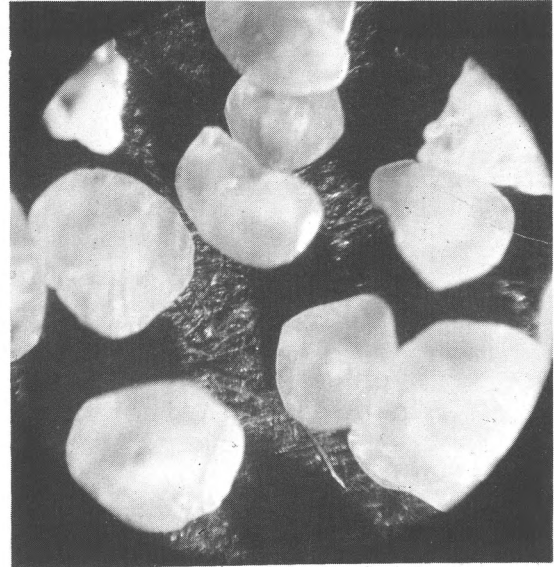
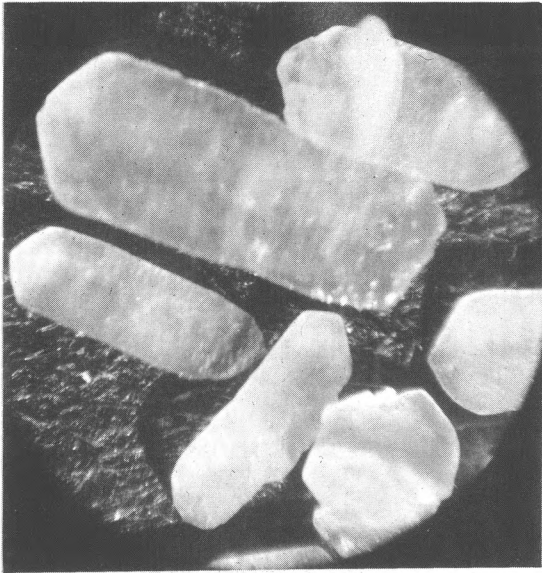


Plate 2

COARSE SAND SIZE	Gypsum crystals from gypsum layer below halite crust, Pit 1, Bonneville salt crust.		Gypsum crystals in gypsum layer immediately below halite crust, Station S, canal bank, Bonneville salt crust.
MEDIUM SAND SIZE	Ditto above. Note cleaved fragments.		Ditto above. Note rounding of crystals.
FINE SAND SIZE	Ditto above. Note needle-like cleaved fragments and stubby brine shrimp pellets.		Ditto above. Note pellets and ostracode valves.

Plate 2. Photomicrographs of gypsum crystals from below halite layer, Bonneville salt crust.

Concerning the origin of the small gypsum crystals in the surface clays, it would appear that the moisture of the saline sediments is drawn to the surface as evaporation proceeds, and that a thin upper layer develops in which the small gypsum crystals grow. Eardley and Stringham (1952), in a study of the origin of the large selenite crystals, postulated a steady state condition toward calcium sulphate formation due to certain bacteria in the saline sediments. So also the presence of bacteria in the upper inches of the clays of the desert floor may be a necessary complement of the capillary movement of saline solutions to the surface in the formation of the small gypsum crystals in the top, thin layer. The sulphate ions are believed to come from the brine that saturates the clay, and the calcium ions are taken by the bacteria from the carbonates of the clay. Jones (1953) suggested that the gypsum crystals of the dunes come from the saline clays but did not note their actual occurrence in the surface clay layer.

Halite cement and thin crusts in some places on the gypsum dunes attest the presence of NaCl along with the gypsum, and so it seems that NaCl is also drawn up in solution and crystallized at the surface by evaporation. It is generally removed, however, by rain and snow, and hence does not concentrate as clastic particles like the gypsum crystals.

The area of uplift has a water table six to seven feet below the surface in the summer time, and hence the surface has a tendency to dry out. This provides not only gypsum crystals for wind drifting but also particles of calcite, various clay minerals, and the common minerals of airborne dust which settled into the lake during the time the sediments were forming. By wind ablation it is, therefore, postulated, that the upper 10 feet to 15 feet of sediments have been removed in the eastern part of the basin since it was elevated above the western part.

The moist saline clays are interlayered with beds of brine shrimp fecal pellets and oolites. The rod-shaped pellets are coated with calcium carbonate, and stubby pellets commonly form the nuclei of small round oolites. The nature of the

interbedding is shown in Figure 5. When ablation reduces the land surface, the pellet and oolite beds are exposed and contribute abundantly to the dunes.

### **Comparison with White Sands of New Mexico**

Extensive gypsum sand dunes occur in the Tularosa Basin of New Mexico. They are described by Talmage and Wooton (1937) as consisting of several varieties, including the glistening white, almost pure gypsum dunes of the White Sands National Monument. Dunes in other areas nearby are made up of various proportions of gypsum and quartz grains and in places are yellow. Gypsite hills in still other areas appear to be old dunes that have been cemented by the action of ground water and are now in various stages of dissection.

Talmage and Wooton state that the most widely accepted idea of origin is that the gypsum has been leached out of the Chupadera formation which underlies the valley or is in the mountains to the west, is brought to the surface of the playa valley by capillarity, is precipitated as gypsum crystals at the surface, and is then swept into dunes by the wind. They question this concept and propose that selenite crystals are and have been precipitated out of saline solution of Quaternary lakes that have occupied the Tularosa Valley, and that the large selenite crystals become embedded in the accumulating lake bottom silts, rather than forming a crust at the surface. Later, when exposed to erosion, the silts are dissected and countless numbers of large selenite crystals are laid bare and disintegrate to form cleaved fragments that form the grains of the dunes.

Neither of the foregoing ideas of origin of the White Sands of the Tularosa Basin is exactly like that proposed for the gypsum dunes of the Great Salt Lake Desert, but they both have elements in common with it. It would be intriguing to re-study the Tularosa dunes.

## **GILBERT LEVEL RECONSIDERED**

The Gilbert level of Lake Bonneville was described by Eardley et al. (1957) and is recognized at several places at elevations of 4,240 to 4,260 feet above sea level. The lake, according to postulate, was held at this level by the regulatory overflow spillway into the Great Salt Lake Desert. The position of the spillway is shown on Figure 1. Now, with the concept of tilting, the spillway must be reconsidered.

The spillway area has suffered almost maximum uplift, and since the isostatic adjustment, according to Crittenden's conclusions, is only about 70 percent complete, the spillway will continue to rise. The highest Gilbert beach recognized is a bar at Mills Junction at the northwest end of the Oquirrh Mountains (4,260 feet) which is at a point where isostatic uplift was 80 feet less than at the spillway. From this preliminary observation, it appears that the spillway could have had nothing to do with the control of the lake at the level where beaches have been noted and called Gilbert. Another cause for the stillstand of the lake at the Gilbert level must be sought.

## **DEVELOPMENT OF CLOSURE IN THE DESERT FLOOR**

The spillway at present has an elevation of about 4,220 feet. Assuming that at the beginning of upward adjustment of the crust that it was 100 feet lower (according to Crittenden's isobases), the spillway then stood at an elevation of 4,120 feet. Until it rose to an elevation of about 4,195 feet, the Great Salt Lake Desert would have drained by way of it into the Great Salt Lake basin at any time that it was not covered by lake waters. The rebound, then, at this stage would have been 75 percent of the present amount. Thereafter, drainage from the desert to the Lake probably was intermittent until another 15 feet of elevation had occurred, when the rebound was 90 percent of the total to date. The spillway was then at an elevation of 4,210 feet, which is the elevation of the lowest place in the desert floor at present. The desert

now for the first time began to develop topographic closure, and with another 10 feet of elevation of the spillway (that of the present) the desert attained a closure of about 10 feet.

The Great Salt Lake conceivably rose to the spillway elevation a number of times during the 75 to 90 percent of present rebound stage, and flooded or partly flooded the mildly closed and nearly flat desert with brine. It has been assumed that during this time the climate was approximately like that of the present, and that Great Salt Lake had shrunk approximately to its present volume and salinity. Since no streams of consequence flow into the Great Salt Lake Desert basin, the brine floodings probably dried up each time. The amount of NaCl in the Bonneville salt crust is only about 1/15 to 1/20 of that in Great Salt Lake (Eardley *et al.*, 1957), so the floodings presumably were not extensive.

In order to approximate the time of the 75 percent and 90 percent rebound stages, the history of lake level fluctuation and the viscosity of the subcrust must be considered. Since several chronologies of lake level fluctuations have been proposed, the writer has selected two rather different ones for analysis. The coefficient of viscosity selected for the subcrust for each must result approximately in a 70 percent isostatic recovery to date. The latest and probably most authoritative chronology based on field relationships is by Morrison (1961, a and b), and Richmond (1961), and is shown on Figure 4. Using a viscosity of  $10^{22}$  poises, the isostatic response was calculated by the writer's colleague, Melvin A. Cook, and is as shown in the lower curve.

A previous chronology based chiefly on  $C_{14}$  dates by Broecker and Orr chronology about 6,500 years ago, and the 90 percent rebound stage about 2,500 years ago. According to the Morrison and Richmond chronology, the 75 percent rebound stage would have occurred about 11,000 years ago, and the 90 percent stage about 6,000 years ago. The spillway, therefore, rose to the point of developing closure 2,500 or 6,000 years ago, depending on which chronology is accepted, and most of the salt now in the Great Salt Lake Desert basin was derived by overflow from Great Salt Lake

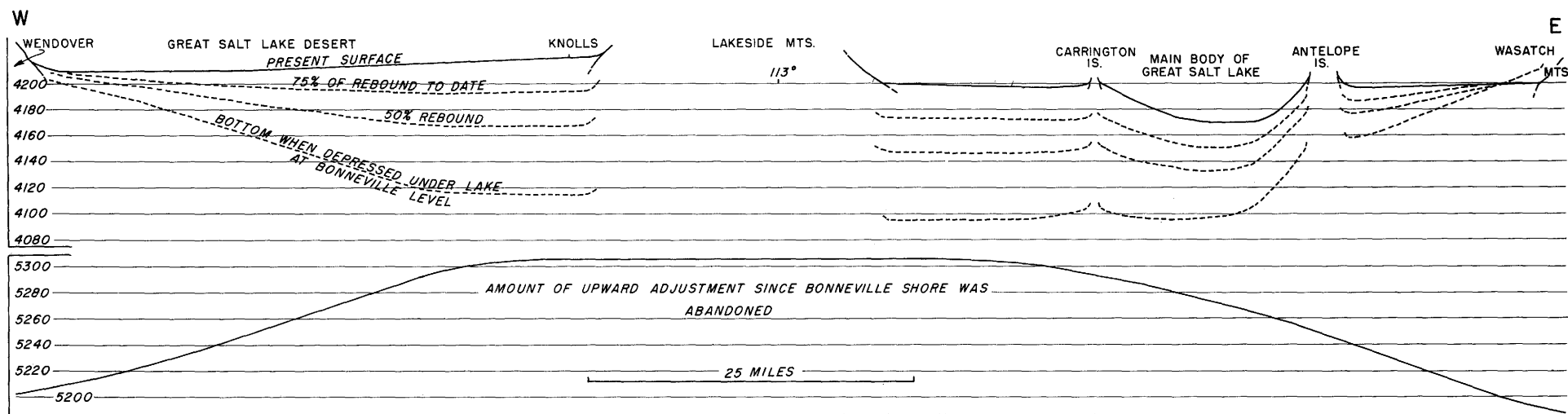


Figure 3. View facing northerly: Isostatic rebound of crust in Lake Bonneville basin taken from Crittenden (1961) and also position of lake bottom at different stages of rebound. Line of section from Wasatch Mountains to Longitude 113° is along latitude 41°N, and from Knolls to Wendover along U.S. Highway 40.

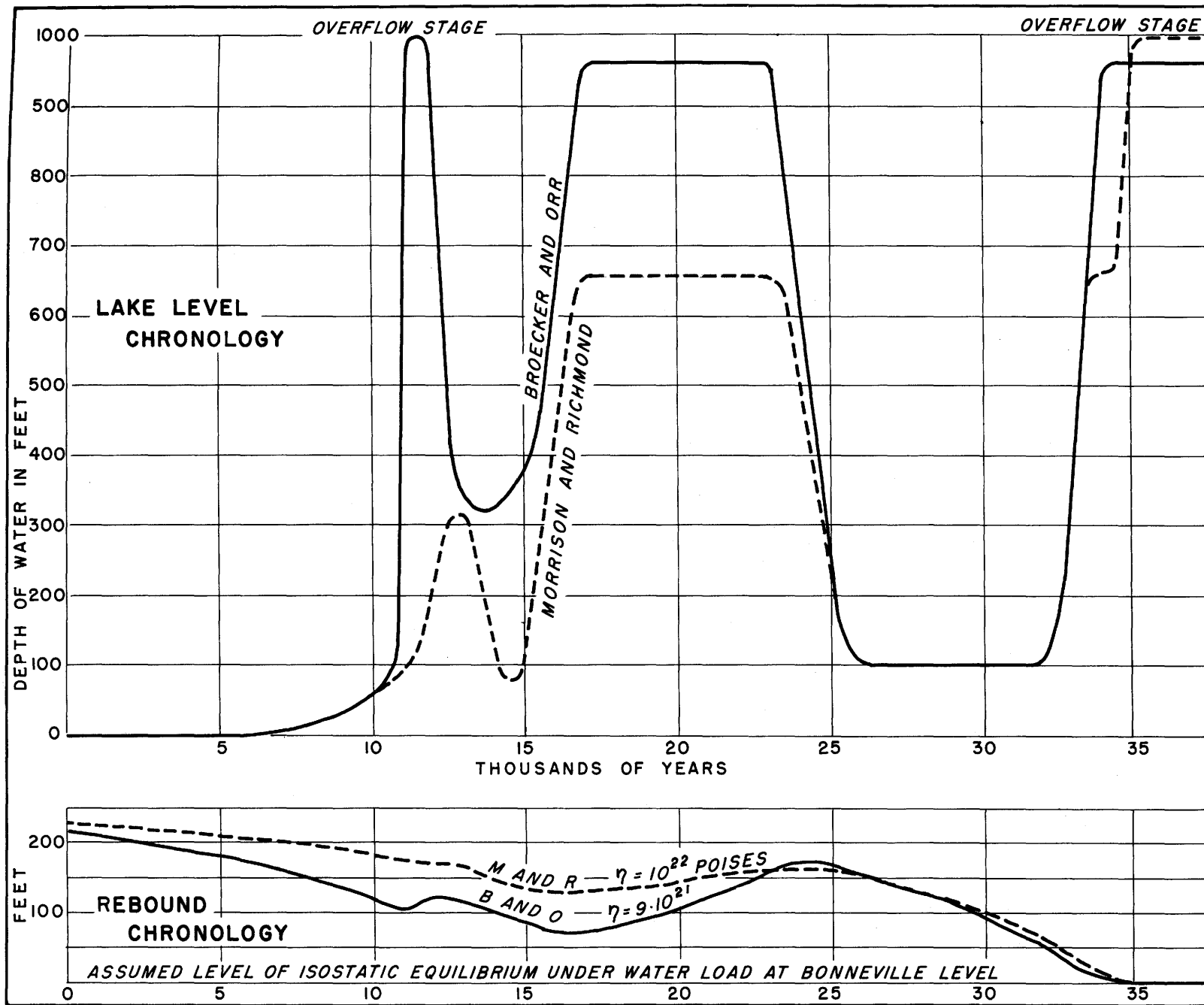


Figure 4. Chronology of isostatic rebound of crust in central part of Bonneville basin. Computed by Melvin A. Cook after data by Crittenden (1961).

in the previous period, extending back not further than 10,000 years ago. A lake had existed in the desert until about 10,000 years ago, and calcareous sediments were deposited in it until its desiccation.

Accordingly, the history of the desert floor may be reviewed as follows: The youngest sediments of the Great Salt Lake Desert floor became exposed to the atmosphere about 10,000 years ago (the main episode of reduction and desiccation of Lake Bonneville had already occurred) and a faltering drainage developed from the Desert basin through the spillway to the lake. Thereafter, as the spillway was elevated sufficiently so that closure developed in the Desert, the bottom sediments nearly everywhere were subject to erosion. It seems likely that they remained too wet in the central part of the basin to be removed by the wind, but around the periphery some of the calcareous saline clays and silts were removed, and as previously described, gypsum sand dunes formed.

#### **SHIFTING OF THE SALT CRUST**

With the concept of tilting of the Great Salt Lake Desert basin and the development of closure must come a consideration of the history of the salt crust. It was previously noted that the calcareous sediments directly under the crust are 17,000 years old, whereas it was anticipated that they should be of the age of those in the central part, namely; about 10,000 years old. An east-west section across the Bonneville salt crust is shown in Figure 5. It has been compiled from sections measured by Donald L. Graf along the canal walls of the potash operations of Bonneville, Ltd. Accepting the  $C_{14}$  dates as correct, the relation may possibly be explained by viewing a shift of the salt from an original place of precipitation. Accordingly, the last site of carbonate precipitation is visualized to have been in the central part of the basin where the 11,000 year date was obtained. Here presumably was the site of the first floodings from Great Salt Lake in the Desert basin, and the first precipitation of a salt crust. At the time, the west side was high and possibly suffered some windablation. Possibly also scattered gypsum sand dunes accumulated there. As tilting

continued and the surface finally came to grade westward, the rains and snows dissolved the salt and moved it westward in the direction of tilt. Granular or crystalline gypsum has been noted under the salt in several places, and the section of Figure 5 shows its somewhat irregular extent. The crystals are shown in Plate 2 and are similar to those found growing in the surface clays. The similar size range and the unusual crystal habit point to an origin in the surface clay layer nearby. Therefore, possibly the gypsum under the present salt crust originated as low scattered dunes which are now bedded down by the halite.

The correlations of the pellet lenses in Figure 5 suggest an erosional hiatus below the salt, and according to the previous considerations, this is necessary for the formation of sizable gypsum dunes.

The writer until now had presumed the salt crust to have been precipitated in place, with the gypsum thrown out of solution before the halite in the final drying up of the brine. The gypsum in the Great Salt Lake Desert, however, posed a problem because if a brine, like that of Great Salt Lake, were evaporated to dryness, no gypsum would result. According to the above proposed theory of flooding from Great Salt Lake to the Great Salt Lake Desert, there is no obvious reason why the composition of the Desert lake should be much different than Great Salt Lake. If, however, the gypsum layer originated as sand dunes, then the problem of origin by precipitation from the brine disappears.

#### **SALINE LAKE DURING LAST PLUVIAL (?)**

The carbonate sediments cored by the hand sampler prove to have the aspects of saline, if not brine, deposits. The fecal pellets of the brine shrimp are abundant to depths of 10 feet or more, and undoubtedly indicate accumulation in rather salty water, if not water approaching NaCl saturation. The plastic dolomite, calcite, aragonite, and magnesite sediments described by Graf et al. (1961) are considered to have been precipitated out of fairly salty water. However, since the C<sub>14</sub> dates indicate an age for some of

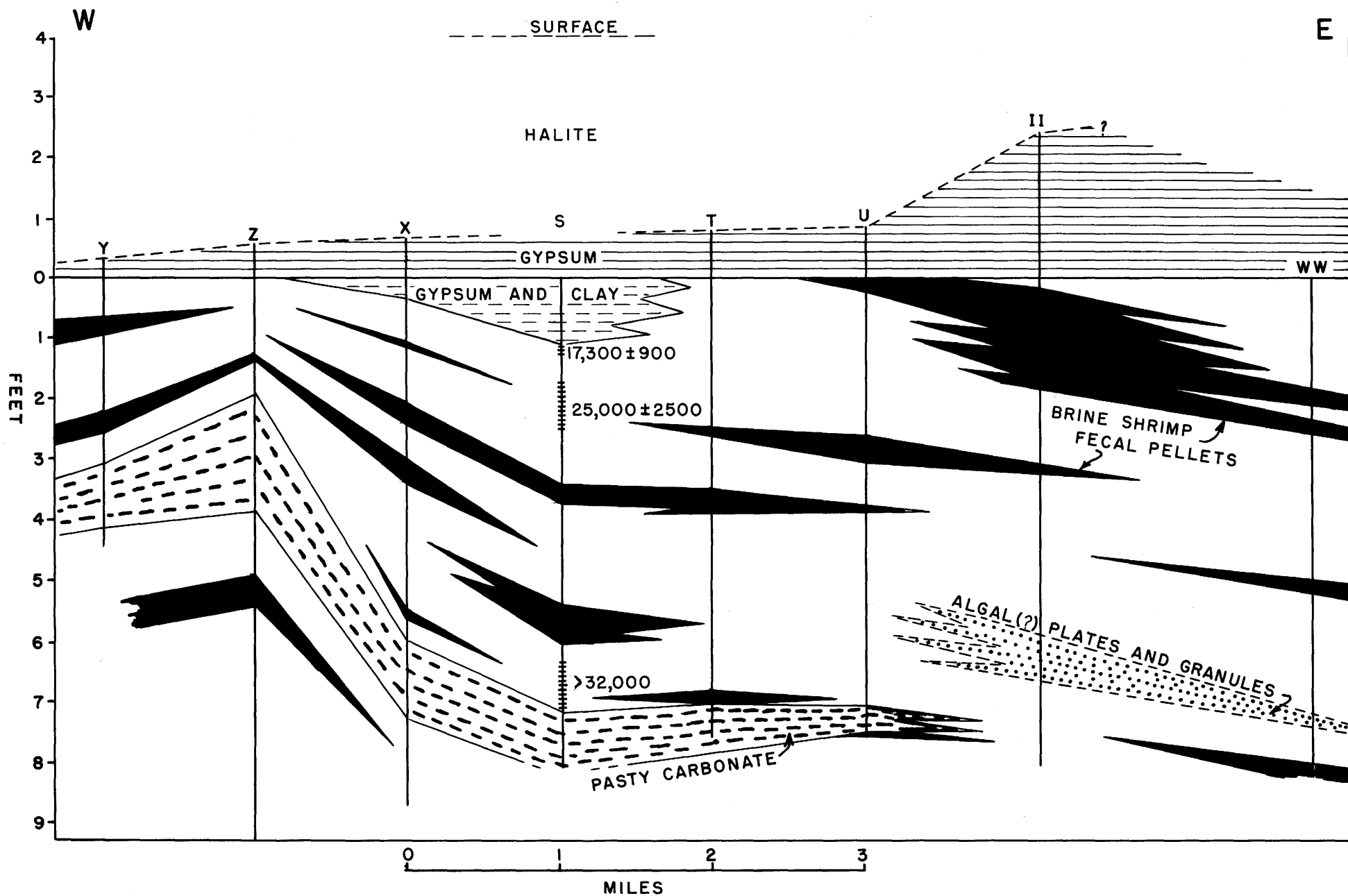


Figure 5. East-west section of the Bonneville salt crust and calcareous sediments immediately beneath. The vertical lines are measured sections on the banks of the canals of the potash facility of Bonneville Ltd. The original surface of the top halite layer is mostly destroyed or covered by the potash workings. Line of section shown on Figure 1.

the sediments during the last highwater stage of Lake Bonneville, one wonders why they are not freshwater deposits.

It would appear that the 11,000 year old central basin clays should grade downward into freshwater deposits, and that perhaps saline deposits would again set in having an age of about 25,000 to 33,000 years (Figure 4), but regardless of age, viz.: 17,000 years, 25,000 years, or greater than 32,000 years, the sediments all appear to have originated in a saline environment. One could suspect an error in the C<sub>14</sub> dates, but without much support, because previous C<sub>14</sub> dates of the carbonate sediments of Great Salt Lake have proved consistent with themselves and with geological relations and interpretations. It remains a mystery why there are no freshwater sediments at shallow depths in the Great Salt Lake Desert when high Lake Bonneville terraces are vividly present on the nearby mountains. It leaves the writer to suspect that some major element in the Pleistocene and Recent history is unrecognized.

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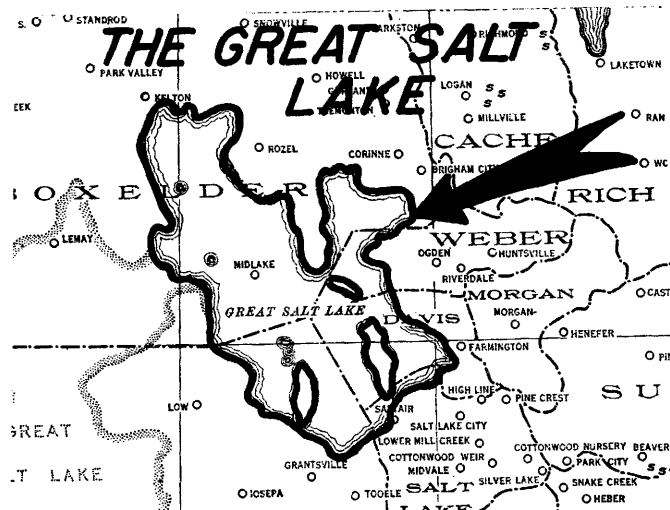
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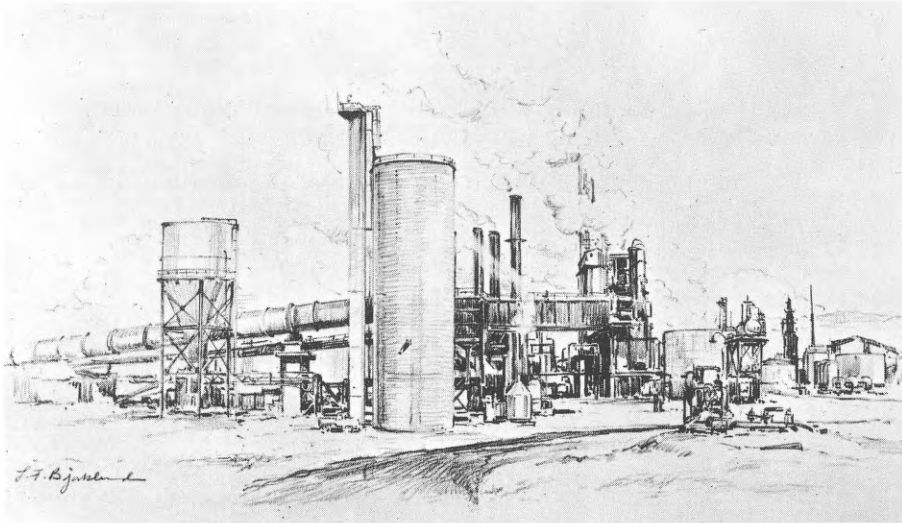
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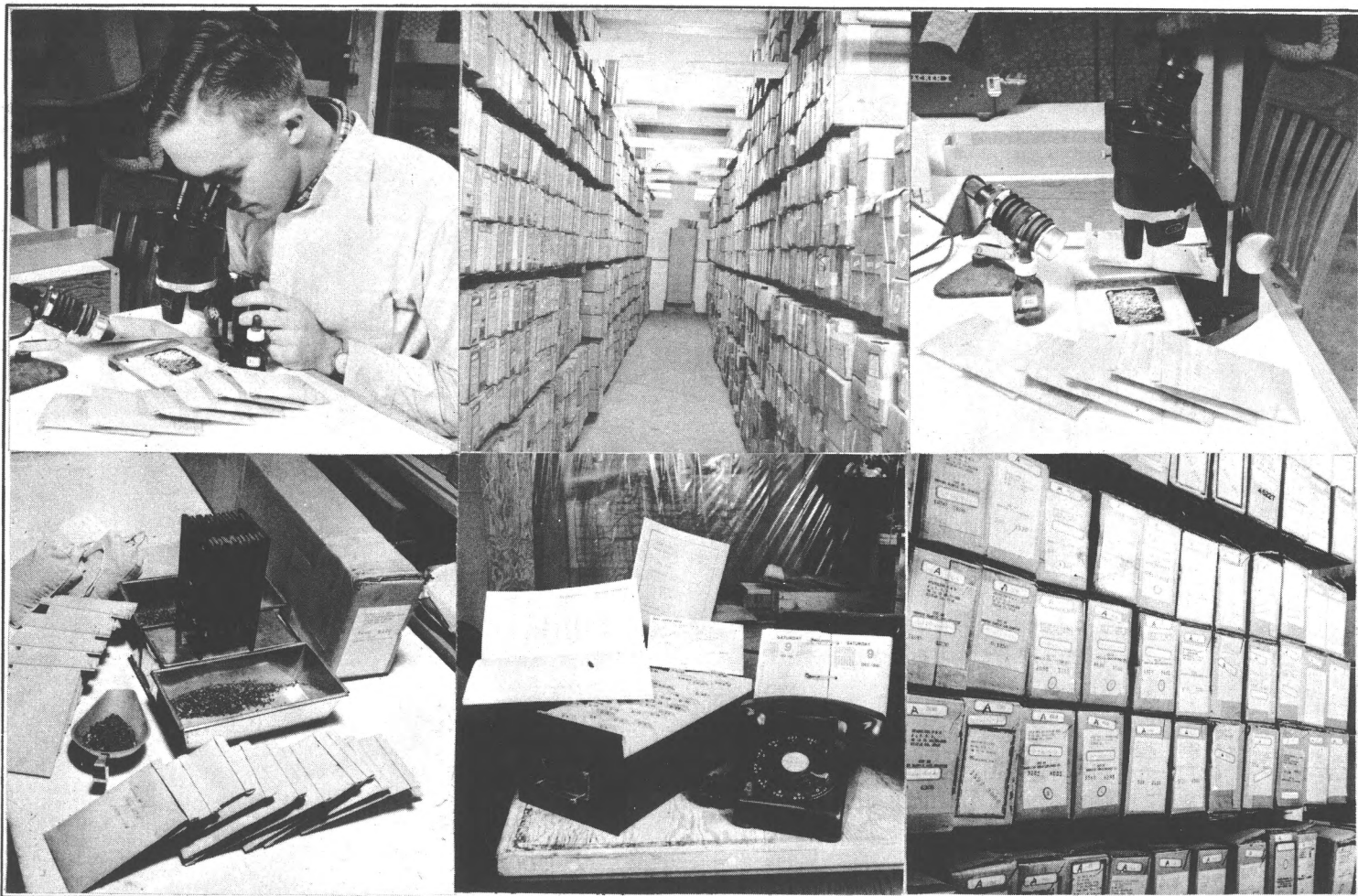
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