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WAITE SANDS

GEOLOGICAL REPORT



BY

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NATIONAL PARK
SERVICE

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GEOLOGICAL REPORT ON WHITE SANDS NATIONAL MONUMENT

By Vincent W. Vandiver, Regional Geologist

INTRODUCTION

The White Sands National Monument is rapidly becoming one of the prime centers of interest among the Southwestern Monuments. It is estimated that approximately 34,000 people visited the area during the past year. I was informed that Mr. Gilbert Grosvenor, editor of the National Geographic Magazine, stated during his recent visit that he had observed three of the natural wonders of the world in the course of a few days; namely, Grand Canyon, the Carlsbad Caverns, and the White Sands. The inspirational features of the sands cannot be denied and this fact together with its being the only occurrence of gypsum sand in the world of much magnitude may eventually warrant the area being given consideration as a national park.

It is due to this increased interest in the White Sands and the fact that several theories have been advanced by geologists as to the source of the gypsum that I visited the area, in an effort to relate the best geological picture possible. There is considerable geological information in the literature on the Tularosa Basin and with this data at hand combined with the field studies made there appears to be little doubt as to the source of the main portions of the gypsum comprising the sands. Since only a short time was spent at the monument the following pages are necessarily largely a compilation, however, the data assembled is in the main from the publications of the United States Geological Survey and since this type of material was available there appeared little reason for spending time duplicating field studies completed previously.

LOCATION AND EXTENT

The Tularosa Basin, of which the National Monument is a part, lies between two of the most prominent mountain ranges of New Mexico, the San Andreas mountains on the west, and the Sacramento mountains on the east. This elongated synclinal basin is approximately 150 miles in length, has a minimum width of 60 miles, and covers an area of approximately 6,000 square miles. The most spectacular feature of the area is the granular gypsum comprising the White Sands, situated some 12 miles west of Alamogordo, in south central New Mexico.

Approach to the heart of the sands is over State Highway No. 3 which extends in a northeast-southwest direction connecting the towns of Alamogordo and Las Cruces. North-south U. S. Highway No. 80-85 to Albuquerque and El Paso is available at Las Cruces. U. S. Highway No. 54-70, running in the same general direction, may be had at Alamogordo for El Paso as well as points north. The Southern Pacific at Alamogordo is the nearest

approach by rail to the White Sands.

The deposit of gypsum is about 27 miles in length from north to south and averages around 10 miles in width, the greatest width being about 15 miles. (See Plate I for aerial extent.) Over 500 square miles are covered by the gypsum sands which probably average 50 feet or more in thickness. It has been estimated (8) that the deposit contains 15,000,000,000 tons by using 60 pounds to the cubic foot of gypsum, with much of the material containing no more than 2 or 3 per cent of impurity. It is interesting to note that the gypsum sands proper occupy only about 5 per cent of the total area of the Tularosa Basin.

The White Sands National Monument was created in January, 1933, and was formally opened to the public by Mr. Tom Charles, resident custodian, in April, 1934. The area comprised in the monument is 143,145.91 acres and negotiations are now being concluded for an extension to the south-east covering 1,640 acres, including a 200-acre lake, which is to be used primarily for a migratory bird refuge. The total area will therefore be approximately 225 square miles.

Roughly 40 per cent of the total deposit of gypsum in the basin is contained within the boundaries of the reserve area. On this basis and in consideration of the above estimate for the total amount of gypsum present there are 5,200,000,000 tons of almost pure gypsum within the monument leaving an estimate of 7,800,000,000 tons outside for public exploitation as desired. The average gypsum mined yearly in the United States for the five year period 1927-1931 amounted to approximately 4,300,000 tons (14). Should all sources be closed in this country and the consumption of gypsum required for domestic purposes be taken from the White Sands outside of the National Monument it is calculated that there is a supply available to meet the needs for over 1,800 years. Botkin (5) states that if all of the gypsum mines and mills in the United States were shut down for 1,000 years, a normal supply could be obtained in the sands' area outside of the monument.

HISTORIAL

The Tularosa Basin is rich in historical interest. The coming of the Spaniards in the sixteenth century and their contacts with the Pueblos and Apaches form many exciting chapters. The main route of travel in the early days was along the Rio Grande, the valley to the west, and that the desert, because of its lack of water and Apache depredations, made a deep impression upon the early travelers is certain since it was known as the Jornada del Muerto, or "Journey of the dead." Evidence still remains of the extension of the rule and religion of the Spaniards at Manzano and Gran Quivira. Gold placers and salt found in the alkali flats were early attractions to this area. Heavy wooden wheels of ox-carts and irons with which the oxen were shod have been observed along the old trails. The first real development in the area was the establish-

ment of Fort Stanton in 1835. The range wars of the 80's and the bloody events surrounding the activities of Billy the Kid all lend much to a fascinating historical picture.

PHYSIOGRAPHY

West of the Great Plains of New Mexico and Texas is a region of isolated mountain ranges with alternating plains or broad open valleys. The Pecos and Rio Grande rivers flow through several of these valleys, but in the region between these rivers there are valleys which are entirely inclosed by higher ground, thus having no drainage outlets. The Tularosa Basin, of which the White Sands is a part, is a typical example of such an inclosed basin.

A variety of topographic features occur in this elongated basin. Probably the most prominent to the average visitor are the buttes Cerro Tularosa, a few miles southwest of the town of Tularosa, and Tres Hermanos Peaks, near the southeast boundary of the monument. Fault scarps and innumerable shore line features are in evidence. Stream built slopes, terraces, alkali flats and an enormous exposition of dune building all contribute much to the attractions of the area to the observing person. In addition, along the northern portion of the basin are volcanoes and lava beds of intense interest and scientific importance.

Generally speaking the reserve within the boundaries of the National Monument consists of equal areas of gypsum sand dunes and alkali flats. In the southwestern portion there is an alkali lake covering six or eight square miles. The majestic peaks of the San Andreas and Sacramento Mountains, which limit the basin on the west and east respectively, rise to elevations of over 9,000 feet above sea level. The almost sheer vertical wall extending along the flanks of these mountains drops most abruptly in elevation for a distance of almost a mile to the plain level of the valley floor. The lowest altitude is in the vicinity of Lucero Lake with an elevation of around 3,000 feet above sea level.

CLIMATE

Meinzer (1) states that the climate of the Tularosa Basin is typical of the arid southwest. Generally the sky is clear and the atmosphere is dry and rare. In the main for both summer and winter the days are warm and the nights cool. Most of the rain is produced by condensation from local ascending currents of air and accordingly falls in a few heavy storms in midsummer.

The basin has a wide range of temperature, owing partly to differences of latitude, but chiefly to differences in altitude. The United States Weather Bureau reports that Alamogordo, with an elevation of 4,338 feet, had a maximum temperature over a period of nine years of 109°, a minimum temperature of 0° and an average annual temperature of

61°. These figures are in contrast to those of Cloudcroft with an elevation of 8,650 feet. Averages over a period of seven years for this point indicate a maximum of 83°, a minimum of -10° and an annual average of 43.2°.

Of considerable interest are the maximum and minimum temperatures taken in the sands area during April and July by Emerson (11) and have been recorded as follows:

Table I. Maximum and Minimum Temperatures

Dates	Position	Maximum °F.	Minimum °F.	Temp. Range °F.
April 2	Air	78	44	34
April 3	6" in Sand	56	48	8
April 4	Air	74	36	38
July 2	Air	100	58	42

As a supplement to these records comparative temperatures of sand and air were taken in both the alkali flat and the dunes on July 1 with the following results:

Table II. Temperatures in dunes and alkali flat in mid-summer

Location	Hour	Air °F.	In sun; on sand °F.	1 In. deep °F.	7 In. deep °F.
Alkali Flat	10:00 a.m.	93	108	93	77
Dunes	4:30 p.m.	99	108	99	81

Meinzer (1) summarizes the records of precipitation as follows: In the interior plain south of the lava bed the average annual precipitation is probably less than ten inches; near the margins of the plain it is approximately ten inches; in the mountain chain on the east side it increases with altitude, and near the crests of the highest ranges it exceeds 20 inches; in the mountain chain on the west side it also increases with the altitude but is on the average less than in the mountains to the east. The principal rainy season is in mid-summer, generally beginning near the close of June or in the first half of July and continuing into September. From 55 to 60 per cent of the precipitation occurs during this period.

The prevailing southwest winds are an important factor in the present location of the sands. Much has been written about the movement of the dunes in a northeast direction and one writer at least has gone so far as to estimate the date at which the gypsum sands will encroach upon the towns of Alamogordo and Tularosa. Unless one visits the area during one of their periodic dust storms it is difficult to appreciate the tremendous abrasive effects of the powerful wind currents and the enormous amounts of material carried in this manner.

VEGETATION AND ANIMAL LIFE

Studies of the vegetation of the White Sands were made in the spring and summer of 1934 by Emerson (11) and a summary of his findings are as follows:

2. Plants seem to be in the process of migrating from outside sources into the dunes with the possible exceptions of two endemics that may have originated within the area. Some species have entered only a short distance while others have migrated several miles.
2. No seedlings establish themselves except in the flats, between the moving dunes.
3. In the flats soil water is near the surface, the water table being between 2 and 3 feet deep with moist sand reaching almost to the surface.
4. Roots must absorb water from a saturated solution of calcium sulphate.
5. Even in the most luxuriant stands of plants there is a very slight concentration of nitrates and nitrites, thus raising the question of methods of nitrogen assimilation.
6. Seven species have the power to grow upward rapidly enough to survive encroaching sand. All of these produce adventitious roots when covered. At least 55 species are limited to the flats because they cannot elongate when covered.

The white color adaptation of the limited animal life of the White Sands presents an interesting story for study by the zoologist.

GEOLOGY

General

The sedimentary rocks of the Tularosa Basin consist of deposits of Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, Permian, Triassic, Cretaceous and Quaternary. Formations are present representing all ages of the Paleozoic sequence. (see Plate II). Igneous rocks are in evidence in widespread outcrops along the east flank of the San Andreas mountains and to a lesser degree along the west escarpment of the Sacramento mountains. They consist of pre-Cambrian granites and schists. Tertiary dikes and sills occur in isolated localities. Two lava flows of Quaternary age are a prominent feature in the northern part of the basin.

Cambrian

The basal formation of the Paleozoic in southern New Mexico is known as the Bliss sandstone of Upper Cambrian age. From the type locality in the Franklin mountains of Texas the formation thins out and is only six feet in thickness in the northern portion of the San Andreas Mountains. In the southern portion of this range the thickness averages around 100 feet. The limited exposure in the Sacramento Mountains shows a few feet of sandstone separating the granite from the El Paso limestone above. In the main it is a gray to brown sandstone, in part quartzitic, with upper slabby members in part glauconitic. The formation is unconformable on the granite or schist and grades into the El Paso limestone above.

Ordovician

The strata of this age is composed of the El Paso limestone, of Lower Ordovician, and the Montoya limestone of Upper Ordovician age. The El Paso limestone grades downward into the Bliss sandstone but is separated from the Montoya limestone by a break in sedimentation, representing Middle Ordovician time.

The El Paso limestone forms a prominent outcrop along the east front of the San Andreas mountains, where it is 300 feet in thickness in the southern part, decreasing to around 150 feet in the northern part of the range. It is a massive gray limestone, slabby in part, and containing considerable sand in the lower portions. Fossils are scarce.

The Montoya limestone is variable in thickness due to erosion and thins out in the southern part of the Oscura Mountains. In the San Andreas it consists of two members, an upper member containing alternating thin beds of limestone and chert, from 50 to 75 feet in thickness; and a lower member of dark massive limestone around 100 feet in thickness. Locally there is present a basal deposit of sandstone. In the Sacramento Mountains, southeast of Alamogordo, the two members mentioned above have been observed. Richmond fauna (Upper Ordovician) are present throughout the upper member.

Silurian

A small part of Silurian time is represented by the Fusselman limestone containing fossils of Niagara age. It ranges upward to around 200 feet in thickness in the San Andreas range and rests with an erosional unconformity on the Montoya limestone. Generally two members are present, an upper bed of hard dark massive limestone, and a lower bed of compact fine-grained limestone.

WHITE SANDS GEOLOGICAL REPORT (CONT.)

Sedimentary formations in the Tularosa Basin and Adjoining Ridges

AGE	FORMATION	CHARACTER	THICKNESS FT
QUATERNARY	: Wind blown de-	: Gypsum sands, dust and quartz	: 0 to 50' Ave.
	: posit	: sands.	
	: Stream deposits	: Chiefly red clay, gypsum,	: 100-
	: and other val-	: sand and gravel	: 1000 +
UPPER CRETACEOUS	: ley fill.		
	: Mesa Verde (?)	: Sandstone and shale, coal	: 630
	: formation	: bearing.	
	: Mancos (?) shale	: Shale; some sandstone; lime-	: 900
		: stone in lower part.	
TRIASSIC	: Dakota (?)	: Sandstone, massive, hard,	: 150
	: sandstone	: gray to buff.	
		: Red sandy shales with layers	
		: of brown sandstones and limy	: 340
PERMIAN*		: concretions.	
		: Upper part limestone and gray	
	: Chupadera	: sandstone; lower part gypsum,	: 1200-
	: formation	: soft red sandstone, then lime	: 1600
		: stone and gypsum	
		: Brown red sandstone and red	: 500-
PENNSYLVANIAN	: Abo sandstone	: sandy shales; thins towards	: 900
		: the south	
		: Limestone with beds of shale	: 2200-
MISSISSIPPIAN	: Magdalena group	: and sandstone; several sand-	: 2500
		: stone beds in lower part.	
DEVONIAN	: Lake Valley Ls.	: Coarsely crystalline limestone	: 0-
		: and limy shale.	: 150
SILURIAN	: Percha shale	: Gray shale	: 0-125
ORDOVICIAN	: Fusselman Ls.	: Limestone, massive, dark above	: 0-200
		: weathers white below.	
	: Montoya Ls.	: Massive limestone, cherty	
		: above, dark below, sandy at	: 0-200
CAMBRIAN		: base.	
	: El Paso Ls.	: Limestone; weathers light gray	: 0-350
		: slabby in part.	
PRE-CAMBRIAN	: BLISS Sandstone	: Sandstone, massive, gray	: 0-125
		: Granites and schists	

*The two formations of the Permian in this area comprise the Manzano Group.

Note: The stratigraphy as above indicated is from Winchester (9) with slight additions.

Devonian

A widespread deposit of black shale, known as the Percha shale, of late Devonian age, is present in southern New Mexico. Breaks in sedimentation separate it from the overlying and underlying formations. The formation consists of lower beds of fissile shales and upper beds of gray shale containing some liry beds with many fossils. These shales thin out in the northern part of the San Andreas mountains. They range in thickness upward to 125 feet.

Carboniferous System

It is the rocks of this system which we are primarily concerned since they contain thick beds of gypsun. They are widespread in this region occupying all parts of New Mexico except the higher portions of some of the uplifts, and here they have been removed by erosion.

Mississippian

The thick succession of limestones of the Magdalena group forms a prominent outcrop in the Sacramento and San Andreas Mountains. It is predominantly limestones, but interbedded sandstones and shales are present in all sections. In this area the thickness ranges upward to 2,500 feet. Locally the group may be divided into several formations, some apparently separated by unconformities, although as yet no faunal distinctions have been observed. In nearly all localities fossils occur in abundance.

Permian

The Permian is represented in the Tularosa Basin by the Manzano group comprising a thick succession with the lower member known as the Abo sandstone and the upper member represented by the Chupadera formation.

The Abo sandstone is made up of red beds of sandstone and sandy shale and ranges in thickness from 500 to 900 feet. The formation thins out in the southward extension of the Sacramento range and the Chupadera and Magdalena formations join in this direction in the vicinity of the Hueco Mountains. The Abo sandstone is apparently unconformable with the underlying Magdalena. In the western part of the state there are thin limestone beds near the base which have yielded fossils establishing the age of the formation as Permian. It is considered to be the equivalent of the Supai formation of the Grand Canyon section.

The Chupadera formation, so named from the Chupadera mesa in eastern Socorro county, is the uppermost formation of the Manzano group. It is generally separable into two members, the San Andreas limestone above and the Yeso formation below. These thick limestone beds with interbedded

deposits of gypsum and anhydrite attain thicknesses of 2,500 feet on the east slope of the Sacramento Mountains and this thickness is even greater to the south. It is from 1,200 to 1,600 feet thick in the Tularosa area.

The San Andreas limestone contains not only limestone but gray sandstones as well and to the south deposits of gypsum, anhydrite and salt, which become very thick in the south-central and southeastern sections of the state.

Representative sections of the Chupadera formation as indicated by Darton (8) are shown on the following plate III. The large amounts of gypsum present in this formation may be observed and this is a significant factor in any study of the White Sands. Many fossils are present in the Chupadera, which was originally regarded as late Pennsylvanian in age, but is now classed as Permian.

Triassic

The southern limit of the Triassic rocks in south-central New Mexico is not known. They have been traced southward to the vicinity of Tularosa but are absent under the Cretaceous outcrops 10 miles north of Organ. Thicknesses have been measured ranging upward to 340 feet in the Tularosa Basin. They are composed of red sandy shales with layers of brown sandstone and limy concretions.

Cretaceous

Outcrops of Cretaceous strata are present in the northeast portion of the basin, extending northward from Three Rivers, east of the lava flows. It is not unlikely that the Cretaceous underlies at least a portion of the basin to the south. Three formations have been tentatively identified as follows: The Dakota (?) sandstone, Mancos (?) shale and the Mesa Verde (?) formation. A maximum of almost 1,700 feet of Cretaceous section is exposed, composed of gray sandstone in the lower part, shale with some sandstone and limestone, followed above with sandstone and shale containing coal beds.

Quaternary

Sediments of this age are divided by Meinzer (1) into two groups, the Pleistocene and Recent. They consist of valley fill material and range upward to over 1,000 feet in thickness. The Pleistocene was deposited chiefly by streams, lakes and underground waters. It consists chiefly of red clay, gypsum, gravel and other sediments on the slopes. Gypsum was deposited at low levels, adobe clay at intermediate levels, and gravel and clay at high levels, with wind-blown gypsum and quartz sand present locally. Recent sediments consist of dunes deposited by the wind and consisting of gypsum sands and dust together with quartz

[illegible]

1. Well over 1000 feet in depth which did not reach bottom of unconsolidated fill. Located $1\frac{1}{2}$ miles west of Alamogordo. From Meinzer (1).

(From Darton) (3)

- II. Representative section west of the Henderson ranch in the southern part of T12S.
- III. Columnar sections of the Chupadera formation southwest of Oscuro.
- IV. Columnar section of the Chupadera east of Tularosa.

g-Gray
r-Red
y-Yellow
b-Brown
p-Pink

sands.

Igneous Rocks

Pre-Cambrian granites may be observed in an almost continuous band along the foothills of the San Andreas Mountains. Minor outcrops of granite are present at the base of the western escarpment of the Sacramento Mountains.

Two beds of Quaternary basalt occupy the basin west of Carrisozo. Both beds form thin sheets, probably less than 100 feet in average thickness, but in the vicinity of the craters they are several hundred feet thick. The lava came from a crater in Township 6 South, Range 10 East, and flowed south for a distance of about 50 miles. The flows consist of basalt of similar appearance and like composition. They are mainly black but locally reddish or brownish. The bulk of the lava flowed some distance before solidifying, lost most of its gases, became relatively compact, though its vesicular texture near the surface, shows that it cooled before all of the gas bubbles escaped. It is likely that the lava and cones were erupted along fracture planes which had produced zones of weakness in the strata.

Meinzer (1) states that the younger lava flowed out upon the main body of valley fill (Pleistocene) and that it is clearly of less age than all except the most recently deposited parts of the fill. It was therefore erupted either in Recent time or very near the close of the Pleistocene. The older lava has been in existence several times as long as the younger but is much younger than the basin itself or the oldest valley fill. It was probably erupted late in the Pleistocene. The age of the younger basalt is at least several hundred years, but in all probability not more than a few thousand years; the age of the older basalt is probably at least a few thousand years and is perhaps several tens of thousands of years.

Structure

The regional structure of the Tularosa Basin is probably synclinal although most of the surface is covered by sand, lava and wash with critical data available only along the margins or from scattered well records in the interior. Cross sections on Plate IV by Darton (8) illustrate the structural features in so far as they are known. A hypothetical section across the basin by Meinzer (1) is also shown on this plate. Minor anticlinal structures are no doubt present in this large syncline. The San Andreas Mountains form a huge anticlinal uplift broken on the east flank by extensive faulting. The Sacramento Mountains have likewise undergone considerable faulting but principally along the west flank. The dominant feature or the prominent western escarpment is due in the main to an anticline, faulted in its higher portions, rather than to major faulting which is in evidence along the San Andreas scarp. The primary consideration in the structure of the Tularosa Basin is that it

is a large down faulted block between the San Andreas and Sacramento Mountains which gave rise to an inclosed basin, without drainage outlet, thus forming an ideal reservoir for the concentration of saline residues and the resultant gypsum sands.

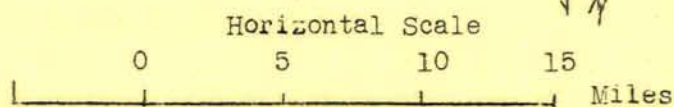
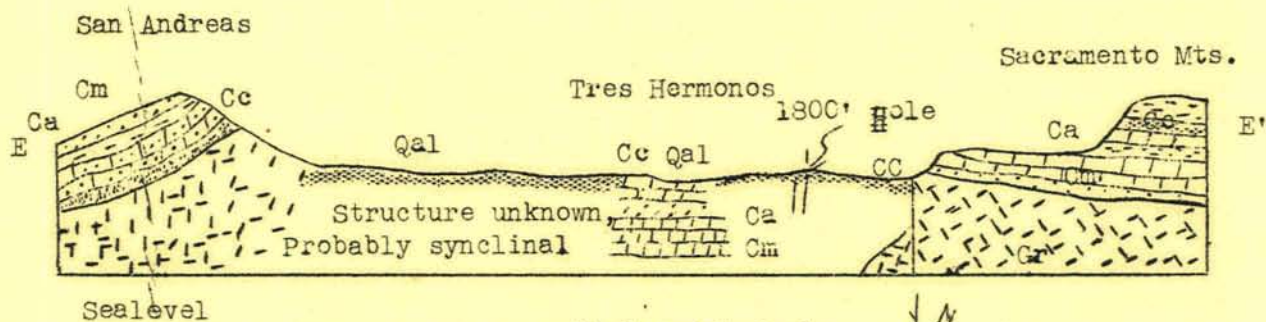
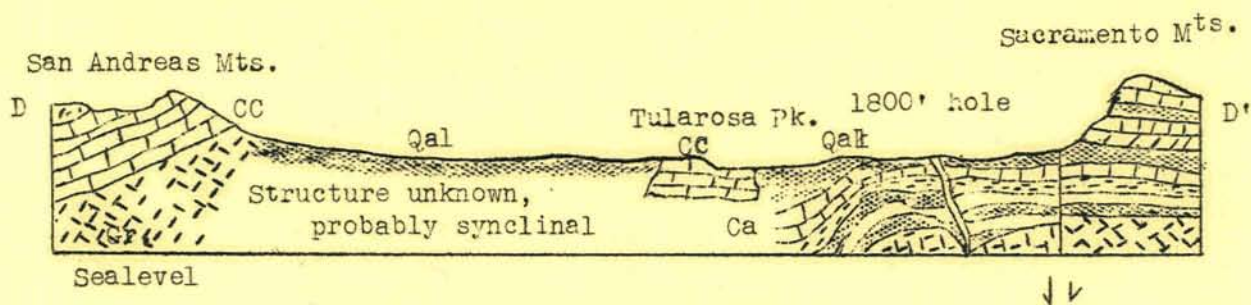
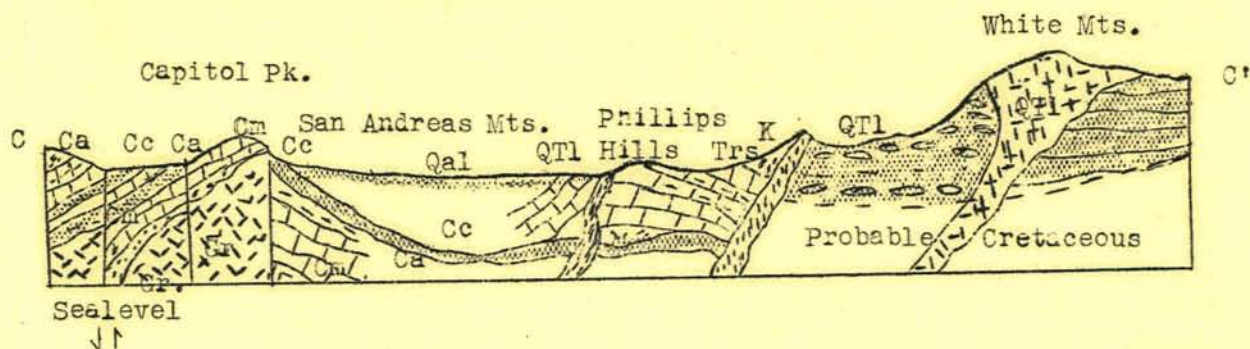
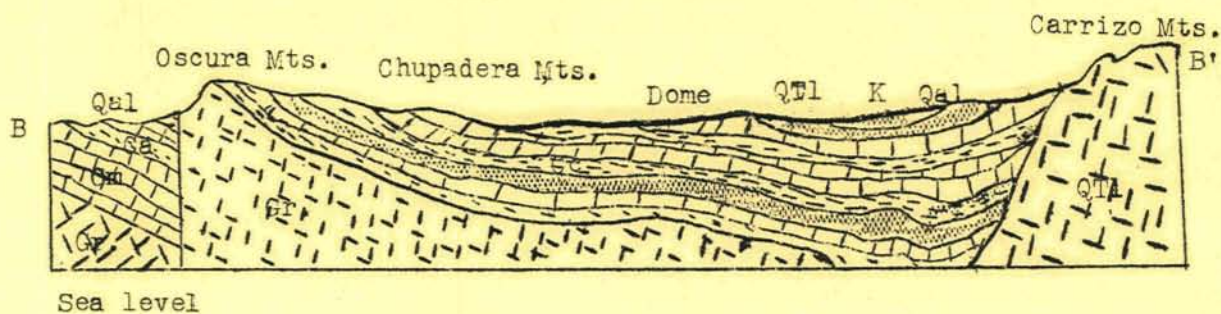
GEOLOGICAL HISTORY

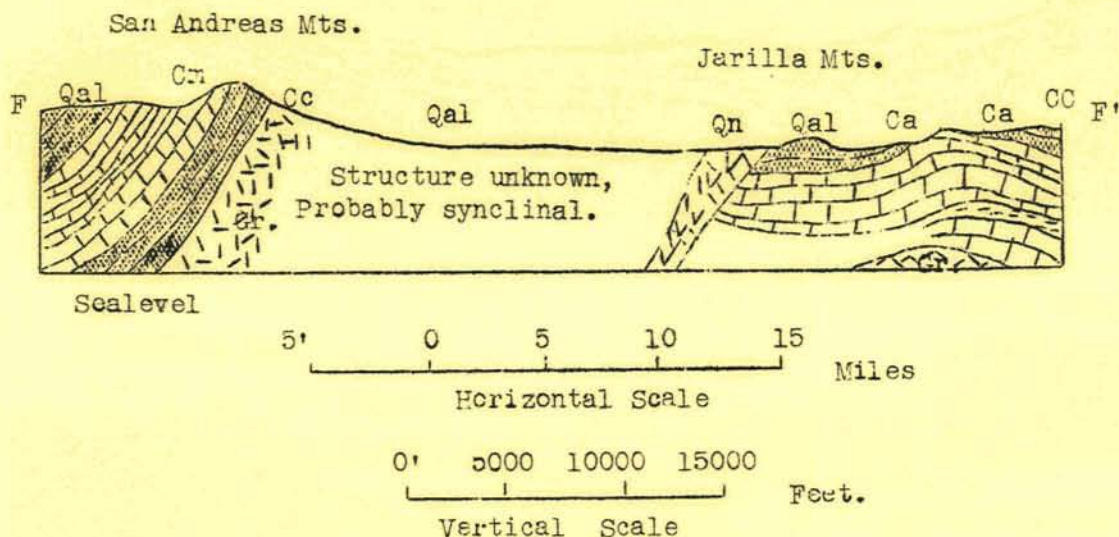
The Paleozoic (formations of Cambrian to Permian inclusive) deposition was preceded by a long era of erosion in which great thicknesses of rocks were removed exposing the granites of pre-Cambrian age. Generally the region was worn down to a level country. Quartzites are present to the north and south indicating the presence of clastic beds which at one time covered the granites. This long period of erosion marks the widespread unconformity upon which the Paleozoic sequence was deposited.

Paleozoic formations of New Mexico include the lower part of a series of various kinds of sedimentary rocks which have been upturned along the flanks of the southern extension of the Rocky Mountains. They also form in some instances extensive plain and plateau areas. The close of the Paleozoic is likewise marked by a widespread unconformity, although the lithologic variation of succeeding formations is not great, there is a distinct break in faunal characteristics distinguishing these sediments from those of the overlying Mesozoic strata.

Our principal concern is with the Permian, which marks the close of the Paleozoic, since the Chupadera formation of this period contains the thick deposits of gypsum and is generally regarded as the original source of the gypsum contained in the present sand dunes.

Western Texas and southern New Mexico contain one of the greatest sections of marine Permian known in North America if not in the world. Interior shallow seas from the Gulf of Mexico entered across this region extending over western Oklahoma and most of Kansas as well. Great deltas later restricted the waters of this large embayment and in their retreat they remained longer in southern New Mexico and western Texas than in the central portion of the continent. Thus, the Permian in this region attains a maximum thickness of over 7,000 feet. The gradual retreat of the sea with its intervening advances resulted in the deposition of great thicknesses of limestones in which was laid down thick layers of salt and gypsum. Evidence prevails that the area gradually became so arid, with evaporation exceeding precipitation, resulting in a vast dead sea eventually covering the central portion of the basin. During the Permian and the period following, the Triassic, desert conditions were probably more widespread than at any other time other than the present. Salt beds extend from Kansas to New Mexico and it has been estimated that they contain 30,000 billion tons of salt and would require the evaporation of more than 22,000 cubic miles of sea water with a salinity like that of the modern ocean.





Sections across Tularosa Basin and Chupadera Mesa. B, from north end of Oscura Mts to Carrizo Pk; C, thru Capitol Pk., San Andreas Mts. to Sierra Blanca of the White Mts; D, from San Andreas Mts east thru Tularosa Pk; E, thru Lake Lucero and Tres Hermanos Butte; F, east from the south end of the San Andreas Mts. thru the northern part of the Jarilla Mts. Qal, Porphyries; Cc, Chupadera formation; Ca, Abo Sandstone; Cm, Lake Valley and Magdalena limestones; CC, Bliss sandstone, El Paso, Montoya, and Fusselman limestones and Percha shale. From Darton (8).

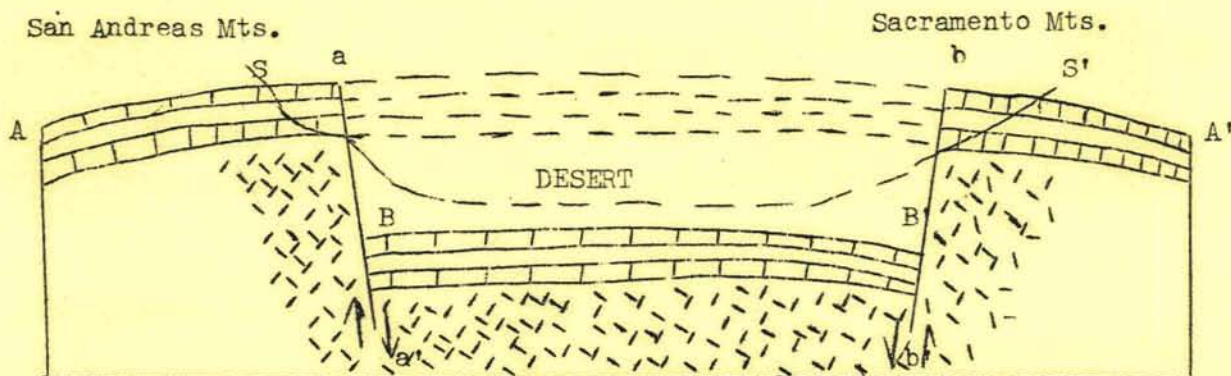


Diagram showing hypothetical structure of the San Andreas-Sacramento section. AA', including the broken lines, shows original structure of the arch; BB', present position of keystone part of the arch; aa' and bb' fault planes. Arrows show direction of movement; SS', present surface. From Meinzer (1).

As the basin was finally filled to sea level, streams converged in the low lands, depositing hundreds of feet of red mud and sands. There are occasional zones of gypsum present in the red beds which are evidence of a temporary return of marine waters and of partial evaporation at least.

It is believed that a connection was maintained with the marine waters of the Gulf through most of the Permian and that additional salt waters were supplied to the lagoon areas as evaporation proceeded in depositing the saline residues. Such a supposition is almost imperative since Twenhofel (15) states that to precipitate a ten-foot bed of gypsum over the entire extent of a basin, water to a depth of 14,000 feet would be required. It would seem very improbable that waters of a basin so deep ever reached the degree of concentration that they deposited gypsum, and that upon consideration of the immense thicknesses of gypsum and salt beds, it becomes obvious that exceptional conditions made them possible. A thickness of 1,200 feet of anhydrite in a west Texas well may be used to illustrate the time element involved in deposits of this type. The anhydrite contained banded layers apparently marking seasonal deposition and suggests that from 150,000 to 300,000 years were required to form same.

The great Appalachian Mountain chain was formed during Late Paleozoic with the culminating movements occurring during the Permian. The important points to bear in mind in connection with the history of the Permian in southern New Mexico is the existence of a shallow sea in Early Permian, the partial inclosure and breaking up of this sea into lagoon areas which produced large saline deposits, and finally the deposition of the red beds by streams in shallow lakes over large sections.

Permian history is of much importance to the National Park Service in the southwest. The Carlsbad Caverns have been formed in limestone of this age. Kaibab limestone of the Permian forms the rim rock at Grand Canyon. Dune sands of the Permian make up the Coconino formation as exposed in Walnut Canyon and the erosional features of the Kaibab limestone above formed ideal homes for the cliff-dwellers. Gypsum formed during this period has now come to rest, or perhaps rather to migrate, in the beautiful White Sands.

In the Tularosa Basin area sediments of the Triassic and Cretaceous of the Mesozoic era were deposited on the Permian. They consist mainly of shales and sandstones and are widely distributed in the Rocky Mountains. At or near the close of the Cretaceous the great mountain making movements of the Rockies took place. The rocks were broken and faulted and the region generally was raised above the water. The basin began to assume a more definite character. During successive periods erosion on a large scale tended to reduce the ranges to a peneplain. Great thicknesses of Mesozoic and Carboniferous strata were removed. A regional upward during late Cenozoic (probably Pliocene) has given

the Rockies their present height and the differential erosion of the uplifted peneplain has brought about most of their rugged relief.

Above the Cretaceous in this area are the loosely consolidated sediments of the Quaternary. Valley fill deposits over 1,000 feet in thickness have been deposited by streams, lakes and underground waters. Much gypsum was certainly carried down from the overlying formations and concentrated in the inclosed Tularosa Basin. Saline residues were thus deposited, redissolved and redeposited over and over again, even up to the present this process is going on. The most recent deposit is the gypsum sand dunes which have been formed through the action of wind on the concentrations of this material in the alkali lake area.

Fossils

Fossil bones and teeth of a mammoth are said to have been found in Section 28, Township 14 South, Range 6 East. I visited the locality but was unable to find anything but some fragmentary bones. It would probably be well to later work over the entire alkali flat and along Salt Wash in an effort to determine if important fossil remains are present. If such is the case a connection might be made with the present monument area in order to include the fossil exhibit. The intervening land so far as is known at present is worthless.

What I have termed the external molds of plants are plentiful in the White Sands. My interpretation of this process, which I am not at all sure is correct, is that the gypsum crystallized around the plant forms and adhered to the structure and became more or less hardened, the organic material of the plant decayed leaving an internal core, thus forming the external molds now visible in the sands. Samples of this material have been forwarded the Washington office. These molds as I have termed them are to be sure very recent and in fact are being formed at the present time. They will make an interesting exhibit for the future museum of the White Sands.

GYPSUM

The evidence points, according to the writer's belief, that the original gypsum and salt deposits of the Chupadera formation are derived from precipitation in bodies of water, cut off from the sea or in embayment areas extending landward, or lakes or playas, with successive replenishment by waters flowing into same and consequent evaporation. Factors are present which indicate that in most cases such substances are precipitated under arid conditions. That evaporation takes place at a powerful rate in such areas is evidenced by the fact that 28 inches of water has been taken from the alkali lake during the month of July by this process.

Saline Residues

WHITE SANDS GEOLOGICAL REPORT (CONT.)

ANALYSES OF WATERS

	N. W. PART (Surface)	LAKE SOUTH SIDE (10' Hole)	NORTH OF NEAR SURFACE	FLATS NEAR SURFACE
	%	%	%	%
Total soluble matter	9.50			
Calcium (Ca)	.07	.06		
Magnesium (Mg)	.52	.08	1.22	2.46
Sodium (Na & K)	2.29	1.88	9.88	7.62
Carbonate (CO ₃)	.01	.02		
Sulfate (SO ₄)	2.54	1.76	2.87	4.25
Chloride (Cl)	3.29	.94	16.82	15.78

ANALYSES OF SURFACE MATERIAL

	LAKE EDDY PROSPECT (Surface)	FLAT AT NORTH END (Surface)	(1-5 Feet)
	%	%	%
Total Soluble Matter	62.95	4.73	3.16
Calcium (Ca)	.49	.34	.12
Magnesium (Mg)	.40	.05	.03
Sodium (Na & K)	18.43	1.23	1.00
Carbonate (CO ₃)	.02	.01	.01
Sulfate (SO ₄)	40.27	1.27	.65
Chloride (Cl)	.60	1.72	1.35

Note: Tables are from Meinzer (1).

PLATE V

Some of the most important substances termed as saline residues are rock salt, gypsum and anhydrite. As water is evaporated the salts are precipitated and deposited. The least soluble salts are naturally precipitated first and these would include calcium carbonate and iron oxide if present. Gypsum separation follows and it is usually associated with anhydrite deposition. Sodium chloride (or common salt) is precipitated after the gypsum and following the bitter salts of sulphates and chlorides of potassium and magnesium, which are usually among the last to separate out of solution. The latter are so soluble that they are not always deposited when salt and gypsum are formed. It has also been observed that whenever these saline residues are precipitated they are likely to be redissolved unless they are protected against solution by water. When they are preserved muds and clays often form an impervious cover which serves as a means of protection.

Twenhofel (15) states that the chief processes involved in the formation of these saline residues is the evaporation of water in which constituent materials are dissolved, although some of them, as gypsum, may be precipitated by chemical reactions without evaporation, and some occurrences have resulted from the freezing of water. In some instances they are also formed through replacement of other substances, gypsum replacing limestone probably being the most common example. Also that so far as these substances are the result of the evaporation of water they develop either through the evaporation of sea water, the waters of lakes and playas, or of waters brought to the surface by springs or capillary action.

Saline residues commonly present in the lower portions of the Tularosa Basin, or the alkali flats, are sodium chloride (common salt), sodium sulphate (glauber salt, also called "ice" and erroneously called "soda"), magnesium sulphate (epsom salt), sodium bicarbonate (baking soda), sodium carbonate (washing soda), calcium sulphate (gypsum), and calcium carbonate (limestone). Plate V on a following page taken from Meinzer (1), shows the composition of water from the narrow portion of the lake and from a ten-foot hole on the south side; also, of the surface material at the Eddy soda prospect; and similar data on waters and soil at the head of the alkali flat about 35 miles further north. There is evidently a larger ratio of chlorides to sulfates in both the waters and the surface materials at the north end of the flat than in the lower lake region. Possibly this may be accounted for by the fact that the drainage is in this direction and precipitation dies out to the south.

It is generally agreed that in humid regions soluble substances, which may be formed by the weathering of rocks, are quickly washed out of the soil passing into the drainage system and finally carried to the sea. In arid regions there is not sufficient rainfall to perform this function and in the case of an inclosed basin it would not be possible. The salts therefore remain in the soil, at times of rainfall they are dissolved into solution, and in times of dryness when water draws to

the surface, or is evaporated they are left, forming the white incrustation on the soil known as alkali, a common feature of the lower sections of the Tularosa Basin.

Varieties of Gypsum

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) occurs in several different forms. There is the amorphous or microcrystalline variety which includes anhydrite and is commonly known as rock gypsum or alabaster. This is the type that frequently occurs in thick beds. The microcrystalline variety of gypsum is known as selenite. It commonly occurs as individual crystals in clays and as veins and bands in the clay beds associated with rock gypsum. Gypsite is an earthy form of gypsum. Satinspar, a variety with fibrous structure, is commonly found in veins, but is not present in the White Sands area.

Anhydrite is an anhydrous calcium sulphate, CaSO_4 , containing sulphur trioxide 58.8 and lime 41.2. Crystals are rare but when observed are thick tabular and of the orthorhombic system. It is characterized chiefly by its cleavage which is in three directions at right angles to each other. The hardness is 3-3½ and specific gravity is 2.9.

The hydrous calcium sulphate known as selenite, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, is composed of sulphur trioxide 46.6, lime 32.5, and water 20.9. It occurs in tabular or diamond-shaped crystals of the Monoclinic system. There is cleavage in three directions and with a hardness of 2 it may be scratched with the finger nail. Specific gravity is 2.32. Luster is usually vitreous, sometimes silky. Ordinarily its color is white, gray; sometimes various shades of yellow, red, brown, etc., from impurities. This variety occurs along the west side of the lower alkali lake in great profusion. Various crystals were observed more than a foot in length and this probably represents the average although Talmage (6) mentions crystals reaching a maximum length exceeding four feet.

Gypsite is a massive granular earthy form of gypsum containing impurities. There is a belt of gypsite hills to the west of the White Sands proper. They appear to be old dunes that have been compacted and cemented through the action of water. Satin spar is fine and fibrous with a silky luster.

Origin of the White Sands

Sands are occasionally but rarely composed of gypsum. Deposits occur west of Duran, New Mexico, near a series of depressions or shallow lakes filled with gypsiferous materials. To the east of these lakes mounds of sand dunes occur of the same character as the White Sands. There is no known deposit of the same magnitude as the White Sands of Alamogordo, however.

Much has been written about the origin of the gypsum deposits at this locality. It is generally conceived that the original source of the gypsum is the Chupadera formations, but the question is to whether the gypsum came from the rocks as they were eroded from the ranges surrounding the basin, or if they were carried upward by waters under hydrostatic pressure from below and precipitated at the surface. From the vast quantities of gypsum that must have been washed into this basin and from various observation as processes which are at present in progress and which will be described later I am inclined to lean toward the former view, and see no reason to complicate the picture by elevating large quantities of gypsum, when a normal simple explanation is forthcoming.

It would seem well to mention some of the various opinions expressed:

Meinzer (1): The gypsum is derived from the gypsum beds in the Pennsylvanian rocks outcropping in the mountains. Since it is comparatively soluble it was brought to the low interior of the basin chiefly in solution in the surface and underground waters, and was re-deposited when these waters evaporated, either from desiccating lakes or from springs or wet areas fed from underground sources. The deposits thus formed have been altered and further transported by repeated resolution and redeposition and by wind work.

Betkin (5): According to this explanation, which differs from that heretofore given by geologists, an enormous deposit of large crystals was formed in sediments over a long period of time, the sands being a comparatively recent and rapidly formed product resulting from wind erosion and weathering of the materials of the dry lake bed. East of the lake outliers of coarse wind-blown crystals capped by vegetation show by their bedding that high dunes of this material recently existed in the region.

Talmage (6): Origin has been ascribed largely to the action of ground water bringing up gypsum in solution from beneath the valley. Field investigation shows: 1. The importance of ground water in transporting gypsum to the area where the active dunes exist has been overestimated. 2. That importance of ground water in the formation of the large selenite crystals and the importance of these crystals as the ultimate source of part of the White Sands has been underestimated. 3. Reworked by wind and weather, rather than ground water, has been directly responsible for material in the active dunes.

Russall (7): Underlying the Tularosa Basin are beds of Permian limestone and sandstone, between the layers of which are interspersed thick beds of gypsum. Boring made in recent

Years reveals that the gypsum is hundreds of feet below the present valley floor and that water is encountered at depths of a thousand feet or less.

The nature of the sedimentary rocks above the water bearing sands is favorable to upward seepage. As the water on its upward course passes through the gypsum deposits, it dissolves that material and carries a rather full load to the surface. The limestone through which the solution passes is not readily soluble; very little in addition to the gypsum is carried by the rising water. When evaporation takes place at the surface a fairly pure crust of gypsum is deposited, which, under action of the atmosphere, crumbles to form crystalline grains.

Hills and mountains surrounding the Tularosa Basin contain gypsum, and it is evident that some of the deposit is brought from this source by surface waters that feed it to the large natural evaporation pan at the south end of the sands. Whether the source is the deeply buried beds or the visible deposits in the mountains, the processes of evaporation, crumbling and drifting with the wind are the same.

Darton (8) and Winchester (9): The gypsum has been brought to the surface by a seepage of water, probably from the underlying Chapadera beds, and deposited on the surface in crusts, which have crumbled to sand and in the course of many centuries have been piled by the wind into great dunes covering many square miles.

Richard (12): The basin thus enclosed (Tularosa Basin) has no visible outlet and as evaporation exceeded precipitation we find the waters becoming loaded with the salts above mentioned. Into this great lake was poured the waste of mountains, rocks, gravel, mud, sand, etc. Centuries later the great abyss had been filled with these sediments made up principally of the detritus of the Permian formation or Red Beds, and highly impregnated with the salts of gypsum. At the time this great lake had practically been filled there were no White Sands.... The White Sands originated from the waters of this vast lake which lies to the west.... As the wind sweeps rapidly over the surface of the saturated brine waters of the lake tiny wavelets are developed at the crests of which instantaneous crystallization of the crystal gypsum takes place; that is to say, a crystal of gypsum is born and this tiny crystal is at once swept eastward by the force of the wind and ledges on the shore. Thus there is in time built upon the shore a long line of crystals which in time develop into a larger quantity and finally become a white sand

dune... In order to prove the final theory of origin a small boat was pulled out into the lake from the East shore on a fairly windy day. A canvas tarp was so arranged to catch the particles of gypsum as they were crystallized from the crests of the waves and born forth by the wind. Examination showed these to be true crystals of gypsum and of course put the origin beyond all dispute and contention. (The latter point proves nothing to the writer as gypsum dust is prevalent everywhere when there is a strong wind blowing in the basin. I would not be surprised to see granules in the mechanism of a Brunton compass even though it be enclosed in a leather case upon passing through one of these storms.)

Brady (13): Describes the White Sands and region in general; associates the White Sands and dry climate with volcanic eruption. Lava is said to have diverted the assumed ancient river to another valley. Mentions Spanish legend that valley was "inhabited by prosperous people before the eruption destroyed river and brought about present desolation."

My idea as to the origin of the White Sands may be summarized as follows:

1. The Chupadera formation contains the only known source for the large quantities of gypsum now present in the Tularosa Basin.
2. Gypsum was precipitated from the evaporation of waters and deposited in thick beds in the Chupadera formation of Permian age. This process was made possible due to the prevailing arid conditions where bodies of water were cut off from the sea, probably by deltas, or in embayments extending landward, or in shallow lakes or playas, with the water supply being replenished periodically by successive advances and retreats of the sea.
3. Mountain making movements, at or near the close of the Cretaceous, with faulting and folding on a large scale, resulted in the formation of the Tularosa Basin somewhat as we see it today.
4. The Chupadera formation and overlying rocks were elevated around the margins of this Basin, thus being more susceptible to rapid erosional processes. In the Basin proper the Chupadera and overlying rocks were in a down-faulted block with several thousand feet of displacement. The Basin was probably not inclosed at this time which permitted great quantities of weathered materials to be carried away to the sea. Later movements closed the Basin and permitted no visible drainage outlet for the rock debris or saline substances carried in solution by the waters. A large lake was formed as is evidenced by the terraces which may be observed at the present time. Evaporation processes concentrated the waters and saline residues came into prominence under these ideal

conditions. The Chupadera formation was being rapidly covered by valley fill material until now it is over 1,000 feet below the valley floor in places.

5. As the shrinkage of this large lake took place great areas of the outcropping Chupadera was eroded on the margins (see sections Plate IV). The thick beds of gypsum were broken up and the material carried in solution to lower levels and deposited. At several periods at least crystals of selenite were forming on a large scale in this lake bed. Photos show the stratified gypsum laid down in this lake bed as well as the terraces containing the selenite crystals.

6. As the lake dried up and became an alkali flat, winds had an opportunity to start their work of transportation. The gypsum terraces and the selenite areas were subjected to weathering and as the material was broken up and reached the stage to be moved by the winds, the granules were carried to the east side of the lake and deposited, due to the prevailing southwest wind. The White Sands occur along the east side of the old lake bed and must have come mainly from the area once occupied by the lake. If the source is from the underlying Chupadera beds, which may barely be possible for a small percentage of the sands, then why do the sands not cover more of the basin as the Chupadera formation underlies most sections as evidenced by drill holes?

7. Various stages of this process of the formation of the sands may be observed at present. Since it can be seen I see no reason to resort to an underground source which process cannot be seen. There is a gradual gradation of materials between the old lake bed and the White Sands proper now present on the surface. Selenite crystals, gypsum terraces, coarse yellow crystals forming dunes with finer gradation eastward, intermingled with gypsite hills and some of the older dunes showing cross-bedding and now more or less cemented, and finally, the White Sands proper, free from fine silt which has been carried onward by the winds. The gradational zones mentioned are not sharply defined but overlap and intermingle and it is doubtful if they could be mapped to satisfaction without considerable time being spent in the area and even then test hole drilling would probably be necessary with considerable generalization as a final result.

8. Crystals now being precipitated in the flats forming crusts is a normal sequence since the whole area is saturated with gypsum, but it seems hardly probable that this could be a source for the large volume of gypsum sand and at the same time there must be a starting point since this feature was evidently not in progress until the dunes were well under construction and the area to the east of the old lake bed did become saturated with gypsum.

Movement of the Sand Dunes

I know of no proper records as to the rate of migration of the sand

dunes to the eastward. Now that the Park Service have made a National Monument in the area exact measurements should be made. MacDougal (4) mentions an advance of about one mile in 20 years. From local reports this estimate is much too large. At the southeast corner 10 to 20 feet per year is said to be more nearly correct. There is the possibility of correlating the rate of migration with the age of the yuccas. Richards (12) estimates that the sands will move into Alamogordo in 4097 A.D., and would reach Tularosa about 6151 A.D. I do not believe that he considered the amount of gypsiferous material remaining in the old lake bed to be transported or that the fact that the elder dunes become more or less cemented with transportation processes not so easily involved. At any rate the residents of the above mentioned towns have little to fear for some time nor need the Park Service take out protection in lands to the east in order to have White Sands for a monument in later years.

Road Building

I believe that present visitors are missing one of the most interesting features of the monument in that no road is available to proceed into the area of the old lake bed. In certain seasons travel may be made over most any section of the alkali flat. The road could easily be constructed along the west margin of the sands which would permit travel at all times. This would afford an opportunity for the public to obtain a better picture of the source of the gypsum now present in the White Sands. Mirages, a closer view of the San Andreas Mountains, etc., would lend much to the merits of such a development. Those factors notwithstanding the idea that it would be pulling away from the "picnic practice" now prevalent in the scheme of things. The geological story could be related in a much more satisfactory manner after or during a visit to this area.

Tom Charles, resident custodian, is a live wire booster for the White Sands and is doing much good work for the Park Service. All possible assistance was supplied by him during my visit. Ben Daugherty and Barry Mohun, Jr., of the park staff, accompanied me on several trips and their presence was badly needed at times especially in the digging out process. Mr. Mohun, as well as Dr. Talmage, of the New Mexico School of Mines, supplied negatives for a number of the photos attached for which acknowledgement will be made later. White Sands is an area that the Park Service can justly be proud and my visit was indeed most delightful.

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