Water-Supply and Irrigation Paper No. 123 Series { B, Descriptive Geology, 66 / O, Underground Waters, 36

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

GEOLOGY AND UNDERGROUND WATER CONDITIONS

OF THE

JORNADA DEL MUERTO, NEW MEXICO

BY

CHARLES ROLLIN KEYES

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., July 15, 1904.

SIR: I transmit herewith a report by Prof. Charles R. Keyes on the geology and underground water resources of the Jornada del Muerto, in south-central New Mexico, and recommend that it be published in the series of Water-Supply and Irrigation Papers.

The work resulting in this report was done under the supervision of Mr. N. H. Darton, chief of the western section of the division of hydrology. It presents new and valuable information regarding the geologic structure of this large desert area and shows that the conditions are favorable for the extensive occurrence of underground waters which, to some extent, are available for irrigation and domestic supplies. The region is one of fine climate and fertile soil, and the development of its underground waters will afford the means for sustaining settlers at a number of localities.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

GEOLOGY AND UNDERGROUND WATER CONDITIONS OF THE JORNADA DEL MUERTO, NEW MEXICO.

By CHARLES ROLLIN KEYES.

INTRODUCTION.

Of the basin plains of southwestern United States the Jornada del Muerto, in south-central New Mexico, is, in many ways, one of the most

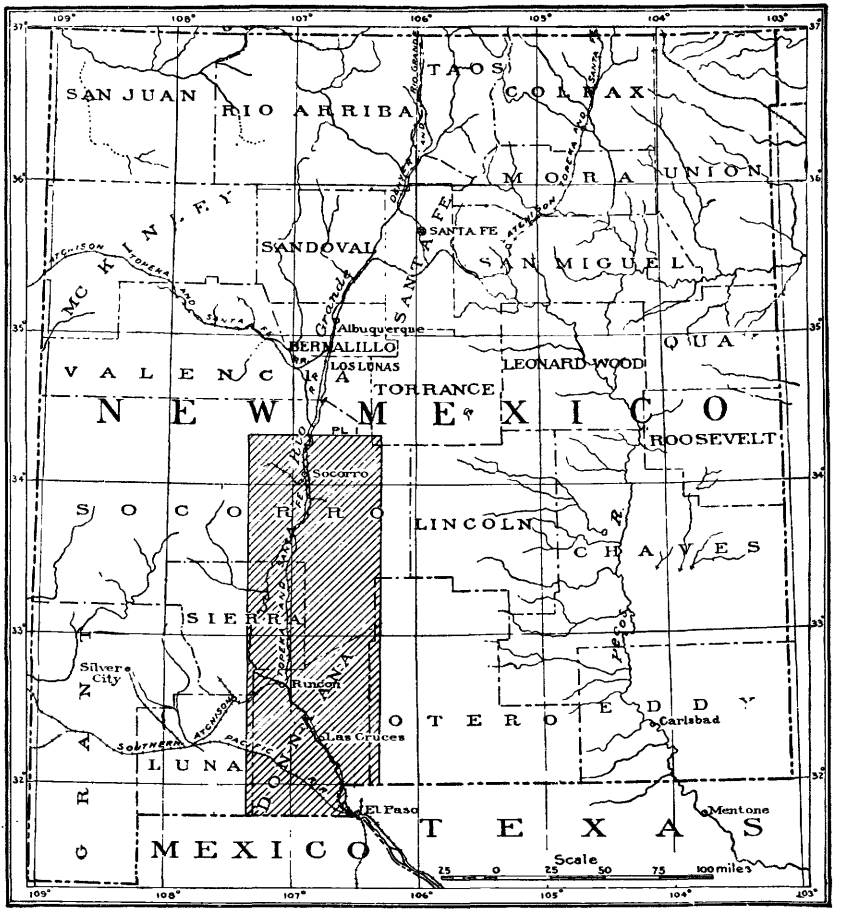


FIG. 1.—Location of the Jornada del Muerto.

remarkable. This plain is typical of a very large number of dry sandy plains which characterize the arid region and which show but

few signs of surface waters. As it is covered by loose, porous soils of unknown depth all the rainfall is quickly absorbed and the streams entering the plain from the mountains around the periphery soon sink below the surface.

In the long period that preceded the coming of the European the adjoining country was thickly populated by races highly skilled in agriculture and well trained in the art of irrigation, yet no one of the native peoples was tempted to settle upon this great strip of desert. For three hundred and fifty years after the Spanish invasion the Jornada lay in the beaten path of travel from Mexico northward. For 100 miles the famous El Paso and Santa Fe trail crossed its desert sands. In view of the horrors inspired by the trip across it from the time of Coronado to the advent of the railroad, the Spaniards who ventured within its borders might well be pardoned for calling it the "Journey of Death." The long white line of bleached bones of man and horse, which not so very long ago marked the trail, amply attested the fitness of the title.

Wallace[a] has described the Jornada in very somber though highly fanciful terms as follows:

> Near the southern boundary of New Mexico the Spanish explorers were opposed by a barrier of all on earth most to be dreaded—a shadeless, waterless plateau, nearly 100 miles long, from 5 to 30 miles wide, resembling the steppes of northern Asia. * * *
>
> The portion I speak of appears to have served its time, worn out, been dispeopled, and forgotten. The grass is low and mossy, with a perishing look—the shrubs, soapweed, and bony cactus writhing like some grisly skeleton; the very stones are like the scoria of a furnace. You vainly look for the flight of a bird, such as cheered the eyes of Thalaba in the desert; no bee nor fly hums in the empty air; and, save the lizard (the genius of desolation) and horn frog, there is no breath of living thing.
>
> Standing on the edge of the measureless waste, which is trackless as water, the first explorers might ask, "What is this strange ocean of sand, with its stillness more awful than any sea?"
>
> The spot I am trying to describe is the battle ground of the elements. In winter it is made fearful by raging storms of wind and snow. There men and animals have been frozen to death, their bodies left the lawful prey of the mountain wolf. From the primeval years the Apache has harried the hungry waste, hunting for scalps; and, besides the savagest of savages, it is now the favorite skulking place of outlaws, an asylum for fugitives escaping justice in old Mexico and Texas.
>
> In our times many a party cut off and many a traveler murdered makes good the name it bears, given by the first white men who dared its perils, Jornada del Muerto—"Journey of Death."

Repulsive as this picture is, it scarcely exaggerates the widespread impression which formerly existed concerning this country. Like much of the arid region, this district was considered waterless because no water appears on the surface. For three hundred and fifty years the traveler traversed this region without taking the trouble to dig beneath the surface of the plain for the moisture he so often longed for.

[a] Wallace, S. E., Land of the Pueblos, New York, 1888, p. 140.

GEOLOGIC SKETCH MAP OF THE JORNADA DEL MUERTO NEW MEXICO SHOWING THE UNDERGROUND WATER CONDITIONS

BY
CHARLES R. KEYES
1904

Scale of miles
10 5 0 10

Contour interval 250 feet

For sections along lines A-A, B-B, and C-C, see PL. II

LEGEND

- Unknown *(or overlain by Quaternary)*
- Tertiary *(partly overlain by Quaternary)*
- Cretaceous *(mostly overlain by Quaternary)*
- Red beds
- Carboniferous *(underlain by older sediments to the southeast)*
- Algonkian *granite and schist)*
- Acid eruptive rocks
- Basic eruptive rocks
- ----- Faults

BREUNER & KESSLER CO. PHILA.

Apparently it was not suspected that, owing to certain local peculiarities in the geologic formations, abundant water lay at comparatively shallow depths. In 1871 a well 160 feet deep was dug in the middle of the plain by a ranchero, John Martin, and cool, soft water was obtained in great quantity, so that his ranch became the resting place of every traveler crossing the desert.

The geologic conditions in New Mexico are less known than in any other region of equal size in the United States. With the exception of a few comparatively limited areas studied by the Federal surveys, but little detailed investigation has been undertaken. The geologists connected with the early Government surveys have given a general idea of the geologic formations, but the exact age and relations of most of the rocks remain to be determined.

GENERAL CHARACTER OF THE NEW MEXICAN PLATEAU REGION.

Among the most notable features of central and southwestern New Mexico are the broad desert plains, out of which the mountain ridges rise as abruptly as volcanic islands out of the sea. These plains are 20 to 30 miles wide, often 100 miles or more long, and at first glance appear nearly level. Closer inspection shows that they are basins inclined toward the center and devoid of marked drainage ways or drainage outlets.

With their usual keen distinctions of geographic features, the Spanish aptly call such an inclosed plain a "bolsone," meaning a purse. Of these plains a writer, who has brought their Spanish name into geographic usage, says:

> These plains or "basins," as they are sometimes called, are largely structural in origin. Bolsons are generally floored with loose unconsolidated sediments derived from the higher peripheral region. Along the margin of these plains are talus hills and fans of bowlders, and other wash deposits brought down by mountain freshets. The sediments of some of the bolsons may be of lacustral origin.
>
> It is essential in both the geographic and the geologic discussion to bear in mind the distinction between bolson plains and plateau plains. The plateau plains and the mountains are genetically related, the strata composing the one being bent on to or flexing out into the other. The bolson plains, on the other hand, are newer and later topographic features consisting of structural valleys between mountains or plateau plains, which have been partially filled with débris derived from the adjacent eminences. The plateau plains are usually destructional stratum plains. The bolson plains are constructional detritus plains filling old structural troughs. [a]

The distinction between the plateau plains and the bolson plains is as important as it is real. But the statement that bolson plains are constructional detritus plains in structural valleys does not convey a correct idea of the phenomenon, and, as generally understood, the term structural, as applied to these valleys, is very apt to be misinterpreted.

[a] Hill, R. T., Topographic Atlas U. S., folio 3, U. S. Geol. Survey, 1900, p. 8.

In a carefully qualified sense the valleys occupied by the bolson plains might, perhaps, be considered structural valleys, but their history is very much more complex and very different from what might be suspected from casual observation.

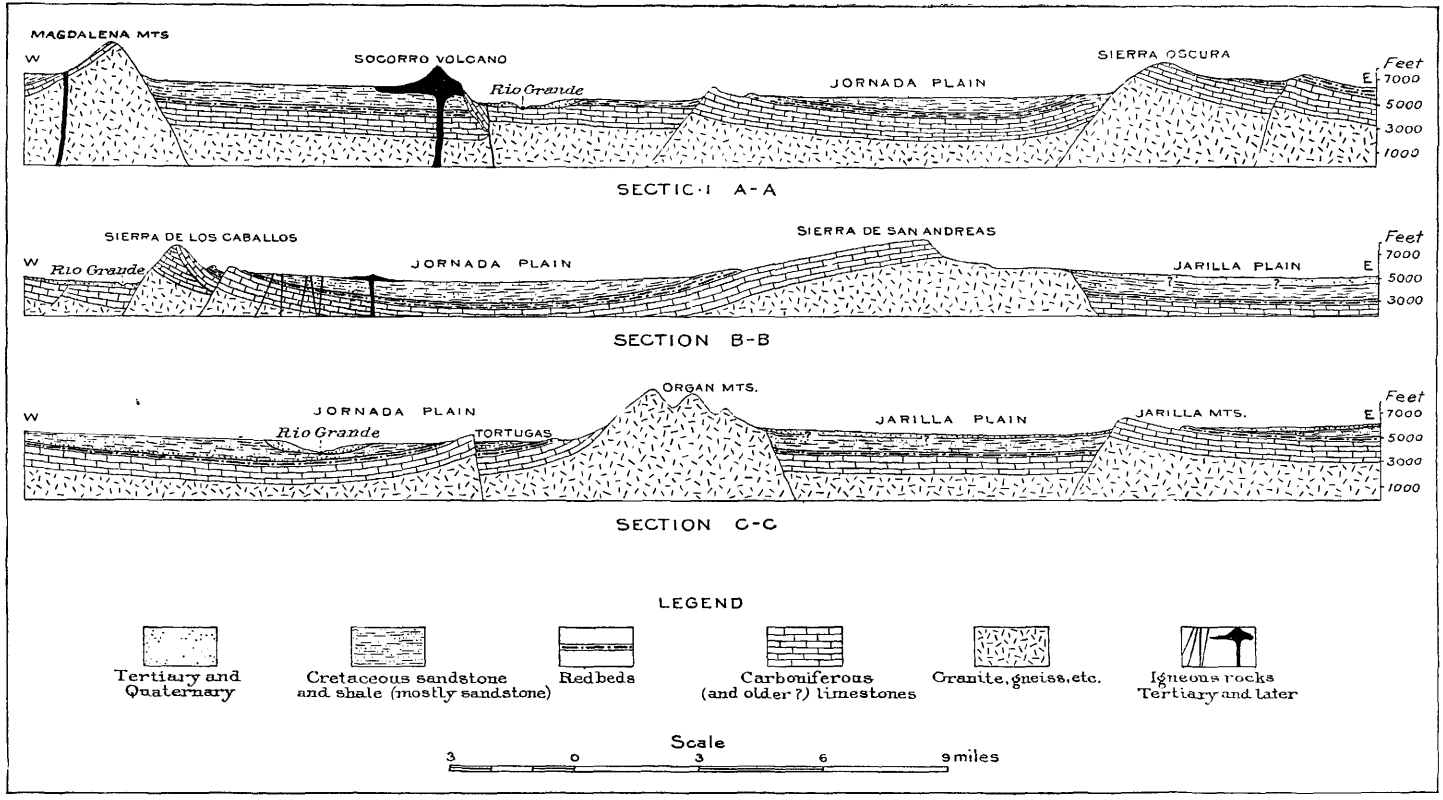
The alternation in central New Mexico of narrow mountain ridges and broad plains, of which the Jornada is a characteristic example, presents some features which are not easily understood until the regions both to the east and to the west are taken into consideration. In both directions the basin character of the bolson plains is soon lost. The plains become confluent and more continuous, and the mountain ranges more disconnected and finally isolated altogether. Farther on the plain alone persists without notable mountains. This condition continues on the one hand to the Gulf of California and on the other to the Gulf of Mexico.

At the beginning of Tertiary time the region between the two great gulfs south of what is now the Colorado line must have been a vast lowland plain with but faint relief features. A large part of this plain was on the beveled edges of Cretaceous and older strata, as is shown now in its remnants still clearly discernible. The Las Vegas Plateau, the Llano Estacado, the bolson plains of central New Mexico, and some of the less broken plains of eastern Arizona seem to belong genetically together. To the east and the west a broad submarine platform was formed from the sediments derived from the planing off of the central land area. When the general uplift of the region took place later in the Tertiary the great plain formed was partly a peneplain of destructional land origin and partly a constructional plain of marine origin.

In the uprising, however, faulting took place on a large scale, giving rise to the numerous monoclinal block mountains in the region now within the boundaries of New Mexico. There were various halts in the general uplift, and the Mesozoic and youngest Paleozoic beds were stripped off the mountain summits. Two or three times during halts in the uplift partial planation took place. With the progression of the uplift the mountain blocks finally became more and more tilted.

Between Tertiary and present time an enormous amount of erosion has taken place. The vast plain has been deeply dissected by the Canadian, Pecos, Rio Grande, and Colorado rivers—old, mountain-born streams. The valleys of these water courses are very wide and deep. On the east the Canadian flows 4,000 feet below the level of the old plain, the Pecos perhaps 2,500 feet, the Rio Grande about 1,500 feet, while the Colorado Canyon is a mile deep.

In the Llano Estacado the remnant of the great high plain has an area of 50,000 square miles. The bolsons are already beginning to give way to erosion agencies. In the valley of the Rio Grande nearly



CROSS SECTION OF THE REGION, ALONG LINES A-A, B-B, AND C-C, PL. I.

all traces of one old plain are already destroyed. The displaced intermontane basins like the Jornada, which adjoin the long Rio Grande Valley, are being deeply dissected wherever the great river touches the borders.

SURFACE RELIEF OF THE JORNADA.

GENERAL FEATURES.

The Jornada basin is roughly pear-shaped in outline, with the stem end at El Paso (see geologic sketch map, Pl. I). From this point the basin plain extends northward into central New Mexico, a distance of 200 miles. In width the plain expands to 30 or 40 miles.

Of late years only the central part of the basin has been called the Jornada del Muerto. As a physiographic feature the plain is unbroken from the Mesa Jumanes and the Cerro Montosa, which cuts it off to the north from the great Estancia bolson, to the canyon of the Rio Grande at El Paso. The Mesilla Valley is not a separate basin, as often reported, but a portion traversed by the Rio Grande, which enters the lower part of the plain.

In the central part the Jornada is a flat-bottomed basin, with borders turned abruptly upward on all sides like a miner's pan. Forming the rim are long, narrow mountain ranges which rise to heights of 2,000 to 3,000 feet above the plain. The floor of the basin slopes to the south. At the north end the altitude is about 6,300 feet, while at the southern extremity it is 3,800 feet. There is a descent of 2,500 feet in 200 miles, a rate of about 12 feet to the mile.

West of the Jornada, running its entire length, is the Rio Grande del Norte, which flows in a basin of its own. While at the north end the elevation of the Jornada is 1,600 feet above the river, at the southern limit where the stream cuts across the rim the height above the great water course is only about 100 feet. The river falls 1,000 feet in a distance of 200 miles; the fall of the plain in the same distance is 2,500 feet or more.

Viewed from the railroad the plain appears even and level, the only features breaking the smoothness of its general surface being isolated and irregular volcanic cones which follow down the middle of the basin for its entire length. These, however, are recent outflows on the surface of the plain and genetically do not interrupt its continuity.

Where the Rio Grande touches the Jornada, and where it traverses its southern part, the plain is deeply dissected. At the foot of the mountains the smooth floor of the basin passes into slopes deeply incised by arroyos.

In the main the rocks of the Jornada basin form a synclinal trough (Pl. II), but the dip of the beds is considerably greater than the slope of the land toward the center of the valley. As a result the beds are beveled, and toward the mountains on either side a thick

series of rocks is exposed wherever the surface gravels are removed. The basin is a destructional plain deeply covered by recent gravels and coarse deposits, with probably some lake sediments of limited extent.

Physiographically the bolson is very young. Erosion has as yet cut but little into the plain. The original constructional form of the present topographic cycle is everywhere in evidence. Only where the Rio Grande touches the borders of the plain have even the soft beds begun to wear out into lowlands.

Of the drainage little need be said. In general all waters flow toward the center of the plain and there are are no cross drainage ways. The numerous watercourses coming down from the mountains are quickly imbibed by the porous deposits and become "lost rivers." This is true also of the few small perennial streams as well as of the torrents which rush down the arroyos carrying only the storm waters.

On the west side of the basin the waters from the mountains do not drain out into the plains, but quickly disappear down deep canyons which debouch into the Rio Grande through gaps in the ranges.

In the central part of the basin are numerous shallow depressions into which the storm waters gather and form lakes of considerable size. Some of these retain their waters for several months and frequently through the year.

CENTRAL FLOOR OF THE BASIN.

As already stated, the Jornada presents the appearance of an almost level plain (Pl. III, *A*), slightly depressed in the middle. Closer inpection shows that the apparent smoothness is locally broken in various ways. The appearance of general evenness is due partly to optical illusion on account of the vastness of the field.

Low conical hills of volcanic origin rise above the plain at various points throughout its entire length. Most of these are unnamed, but some of the larger ones, especially in the southern part of the basin, have received specific designations. Dona Ana Hills, San Diego Mountains, and Cerro Roblero may be mentioned.

All of these volcanic cones are very recent, and some of them still have their craters perfectly preserved. Extensive basalt flows extend from some of the cones, one of which, located south of San Marcial, covers more than 100 square miles. Several remarkably symmetrical cones occur west of Engle station, near old Fort McRae. These are about 200 feet in height, while the Dona Ana Hills, for example, are more than four times this elevation.

EASTERN RIM OF THE BASIN.

On the east side of the Jornada basin is a ridge which rises abruptly to a height of 3,000 feet above the plain. While there are a number of low passes through the ridge, no one of these is low enough to serve as a drainage outlet to the basin.

A. VIEW OF NORTHERN END OF THE JORNADA.

B. THE WHITE CLIFFS AT LOWER END OF ORGAN MOUNTAINS.

Shows Carboniferous limestone dipping west.

Through great faulting on the eastern side of the ridge the various mountain blocks have been tilted up so that the long back slopes form a part of the broad syncline of the region to the west.

Beginning at the south these blocks have received the name of Franklin Mountains, Organ Mountains, San Andreas Range, Oscura Range, and Chupadera Mesa. The last two ranges mentioned slope to the east instead of the west, the main fault passing between the Oscura and San Andreas sierras. Here two lofty fault scarps face each other, separated only by a comparatively narrow valley.

The characteristic aspect of the Franklin Range and the southern Organ Mountains is well shown by Peña Blanca (Pl. III, *B*). The main mass is composed of Carboniferous limestone and rises nearly 1,000 feet above the plain at the foot. The rugged character of the Organ Mountains is well displayed by the contour map of the region.

The great fault scarp of the Sierra Oscura is a mountain block rising about 3,000 feet above the plain. In the lower three-fourths the granites and schists occur, and the long back slope is a heavy plate of blue Carboniferous limestone nearly 1,000 feet thick. Farther northward the eastern rim of the Jornada is formed by the Chupadera Mesa, which rises in an abruptly westward-facing escarpment several hundred feet high. The view of the escarpment shown in Pl. IV, *A*, is from the plain at a distance of 2 miles. The face of the escarpment is composed of Cretaceous sandstones, but a short distance back from the crest the surface of the mesa is made up of Carboniferous limestones. The sharp hill in the left foreground is a huge trachyte dike which extends away from the observer across the mesa a distance of 12 miles or more.

With the exception of the extreme northern portion the entire run-off of the eastern rim flows down the limestone incline to the foot of the ranges, then over red shales into the sandstone area forming the floor of the basin.

Since near the eastern ridge there is no large watercourse such as the Rio Grande, which flows along the western rim, the surface at the foot of the mountains presents but little of the relief that occurs on the western border of the plain.

WESTERN RIM OF THE BASIN.

Like the eastern side of the Jornada, the western side consists of high ridges trending north and south and dipping toward the basin. Geologically the western rim is similar to the eastern and of about the same height. There is, however, this difference: The western portion is broken at several places and the Rio Grande has begun to make inroads into the plain. Toward the south that stream crosses a part of the plain, forming the Mesilla Valley.

The mountains forming the western boundary of the plain consist at the south of a number of rather low, unnamed ridges, lying on the

western side of the Rio Grande. The Cerro Magdalena, southwest of Rincon, appears to be the most important of the ridges which lie west of the river. The Sierra de los Caballos and Sierra Fra Cristobal are large ranges, comparable to those on the east side of the plain. Continuing northward is a long line of mountains from 8 to 10 miles east of the Rio Grande, which extend almost unbrokenly for a distance of 50 miles to the Cerro Montosa. All of these mountains have a conspicuous fault scarp marking their western flank.

At the north end of the Sierra Fra Cristobal, where for a short distance the Rio Grande breaks the rim of the Jornada, erosion is beginning to cut into the plain and considerable indentation has been already made. By headwater erosion the small drainage ways (dry except in time of heavy rains, which happen only a few times each year) are rapidly cutting into the border. The local drainage for a distance of nearly a quarter of the way across the plain is now turned in this direction, and when the driving rains come powerful corrasion takes place along these arroyos. The Rio Grande is 800 to 1,000 feet below the plain, and the gradient of the arroyos is over 100 feet to the mile.

Other important gaps permitting the drainage waters of the plain to enter the Rio Grande are at the northern and the southern ends of the Caballos Range, and in the center at Palomas Canyon. The runoff of the Jornada side of this entire range is allowed to enter the Rio Grande instead of flowing out onto the plain and there sinking beneath the surface. A strip of country 4 miles wide on the average and 20 miles long thus drains into the Rio Grande. This belt is faulted in many places. It is traversed by basic dikes and is altogether a rough country. The difference in elevation of near-by points is often as much as 300 feet. The canyons are numerous and labyrinthine, with high gradients. Mescal Canyon and Palomas Canyon are the two master drainage ways, into which all others empty before their waters cross the mountain axis and fall into the Rio Grande.

The tops of the hills in this rough strip are nearly all on a level, which is the same as that of the plain projected westward. Consequently, when viewed from the railroad train, at a distance of about 12 miles, the plain appears unbroken to the very foot of the mountains.

In some places, as at the north end of the Sierra de los Caballos, are extensive lava beds which were poured out on the surface of the plain. Mescal Canyon cuts through one of these sheets, displaying fine sections of the beveled Cretaceous sandstones and the overlying gravels which once constituted the floor of the plain and which now form the floor beyond the limits of the lava flows. The bottom of the lava sheet is on a level with the tops of the hills of the neighberhood, also showing conclusively that at the present time erosion has progressed sufficiently to intricately and deeply dissect the country, but not far enough to destroy the last remnants of the Jornada's sur-

A. ESCARPMENT OF THE CHUPADERA MESA.

B. PEÑASCO ROCK.

face lying in this belt. North of this Mescal Canyon lava sheet is another similar one, a detached mass, known as Elephant Butte, near which is a reservoir site which, owing to prolonged litigation, has become one of the best known in the country.

At the south end of the Sierra de los Caballos the Rio Grande enters the Jornada and cuts a deep trench diagonally across this plain to the south end of the Franklin Range at El Paso. The distance is 65 miles. In passing through the central part of the plain the stream encounters several groups of volcanic mountains, which are known as the San Diego Mountains, the Dona Ana Hills, Cerro Roblero, etc. This part of the river's course is a rather narrow canyon, the sides of which exhibit many benches at various elevations above the present level, showing that the lava flows acted as temporary dams. In this part of its course the real nature and relationships to the great bolson of the country adjacent to the river are so disguised that many of its features are apt to be misinterpreted.

At Mesilla the valley of the Rio Grande broadens out into a wide flood plain, known as the Mesilla basin. The Atchison, Topeka and Santa Fe Railroad follows the banks of the Rio Grande for the entire distance from Rincon, where it comes down from the upland plain, to El Paso. From Rincon southward the western rim of the Jornada, while still high, is not so sharply marked as farther northward.

NORTHERN RIM OF THE BASIN.

At the north end of the Jornada the rim of the basin does not present the high mountainous aspects of the sides. There is, however, a broadly curved line of hills marking the boundary (Pl. III, *A*). These are 500 to 800 feet high, and are produced by upturned strata. This chain of hills is broken through at a number of points by deep arroyos, whose storm waters are soon lost in the plain.

At one place, near the west side, a broad, flat-bottomed valley several miles in width opens out to the northward. It extends in that direction many miles and appears to be continuous with the floor of the Estancia bolson farther north. The deeply dissected Chupadera Mesa forms the northeastern wall of the basin.

Beyond the rim a considerable area is drained into the basin through arroyos. The principal one of these watercourses is located near the center of the north wall, and is known as the Arroyo Chupadera. At the point where it cuts the rim, in a deep canyon, is located the Ojo Chupadera.

SOUTHERN SIDE OF THE BASIN.

The southern side of the upland Jornada plain is a mountainous belt of country extending in long finger-like projections across the national boundary from Mexico. These are the northern ends of several Mexi-

can ranges, the principal one of which is the Sierra de los Muleros. At El Paso the Rio Grande has carved its way through the hard mountain rock, forming a narrow canyon only wide enough to permit the passage of the river. At this point the east ridge is the southern extremity of the Franklin Range, which here represents the eastern rim of the basin. The high mountain to the west of the river is said to be marked by benches to a height of 800 feet above the river level.

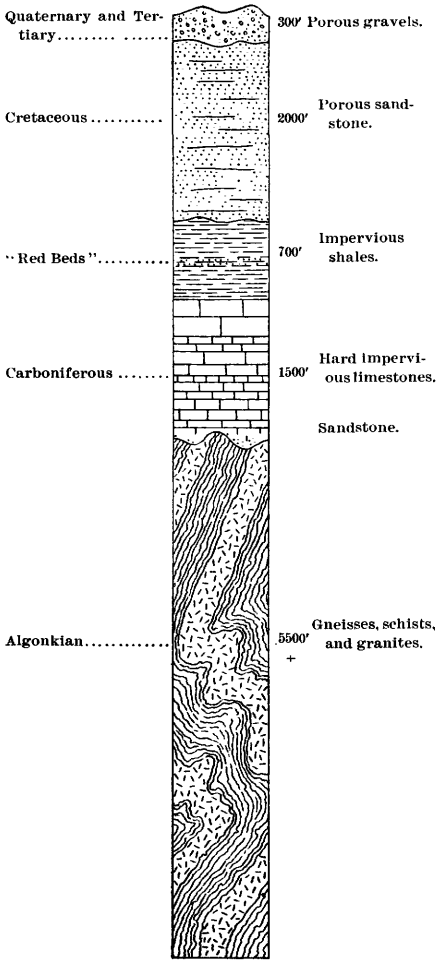


FIG. 2.—Geologic column.

West of the Rio Grande the normal character of the great plain is greatly obscured by late protrusions of volcanic materials. Conspicuous cones rise out of the plain at many points, and extensive lava sheets cover the surface.

THE FORMATIONS.

GENERAL GEOLOGIC RELATIONS.

The geologic formations of south-central New Mexico comprise five very marked classes of rocks (see fig. 2). At the base is a great mass of crystalline rocks, chiefly granites, gneisses, and schists, with some metamorphic rocks which can not always be directly distinguished from the members of the fundamental complex. These crystalline rocks are, in greater part at least, Archean and Algonkian in age. The later Paleozoic rocks are widely distributed, and are mainly thick blue limestones, mostly of Carboniferous age, which form chiefly the crests and back slopes of many of the principal mountain ranges. A third class of rocks is found in the thick and extensive beds of massive yellow sandstones of Cretaceous age. Over all these indurated rocks lies a mantle of soft clays, sands, and gravels, largely deposited during the late Tertiary and Quaternary periods. Later than all of these are outflows of igneous rock which also cover many thousands of square

A. ELEPHANT BUTTE.

View taken from big bend in Rio Grande.

B. SOLEDAD CANYON, A MOUNTAIN ARROYO.

miles within the limits of New Mexico. The period during which these volcanic rocks were erupted extends from the early Tertiary down probably to within the time of the settlement of America by Europeans.

The stratigraphic relations of the several rock masses are represented in fig. 2. As will be noted, marked unconformities separate the different formations, the single exception being between the "Red Beds" and the Carboniferous. The geologic significance of these unconformities is of exceptional interest.

The thicknesses given are in all cases maximum measurements. The great thickness of the Tertiary gravels and the Cretaceous sandstones is found only in the middle part of the Jornada, and from this middle line there is a rapid diminution toward the eastern and western rims of the basin.

ARCHEAN SYSTEM.

In recent years geologic opinion regarding the crystalline rocks which underlie the great sedimentary succession in the New Mexico area has undergone some very radical changes, most of the extensive formations composed of granites, schists, gneisses, and slates, which form the core of many of the mountain ranges, being now classified in a later geologic age than the Archean.

It is thought that true Archean rocks are exposed only in the southern extremity of the Sangre de Cristo ranges within the boundaries of New Mexico. Possibly also some of the basement crystallines of the Mogollon and Burro mountains in western New Mexico and of the Sierra de los Caballos on the western rim of the Jornada may finally prove to be of Archean age. Even in these localities the areas which may be properly referred to the Archean are of limited extent.

ALGONKIAN SYSTEM.

Most of the mountain ranges of central New Mexico are huge tilted blocks, one side being a long slope and the other a steep face, originally a fault scarp. In the steep face a considerable portion of the basal part is often found to be made up of quartzites, micaceous and hornblendic schists, gneisses, and granites. The foliation of these highly metamorphosed rocks is usually nearly vertical. Where they are overlain by the basal quartzites and limestones above they are sharply beveled off, and the stratification of the sedimentary beds is nearly at right angles to the planes of lamination beneath.

For a long time it was thought that this crystalline complex represented the Archean. Late investigation has shown conclusively that many so-called "quartz veins" are in reality quartzites, and in thin section under the microscope this rock is seen to be of sedimentary character. Many of the dark-colored schists were without doubt originally basic intrusives, and some of the gneisses were granites

now profoundly sheared. These masses are frequently seen to be penetrated by later acid eruptives now forming vast irregular bodies and sheets of red granite, some of which probably are later than Algonkian.

These highly metamorphosed masses are referred to the Algonkian age. They are more or less mineralized in the various mountain systems, containing many of the extensive deposits of copper, iron, silver, gold, and some of the rarer metals. These rocks are well displayed in all of the ranges surrounding the Jornada plain.

The Algonkian rocks of the Grand Canyon section have not been recognized in New Mexico, and if they are represented it is not with the same characteristics and succession. It is possible, however, that more detailed study of the New Mexico field will disclose relationship to the Grand Canyon section. The main succession there is as follows: (1) Vishnu quartzite at the base, (2) Grand Canyon sandstone with interbedded and cutting basic eruptives, and (3) Chuar shales and limestones.

ROCKS OF EARLY PALEOZOIC AGE.

At present there is no reliable evidence that any of the lower Paleozoic beds are represented within the limits of the region under consideration. The great Cambrian, Ordovician, Silurian, and Devonian systems which are so extensively developed in other parts of the American continent have thus far not been observed in central New Mexico.

The Cambrian deposits, known elsewhere as the Tonto formation, and so well developed in the Grand Canyon district, may be represented in western New Mexico in some of the massive indurated sandstones. In central New Mexico, in the Sandia, Caballos, and San Andreas ranges, there is a massive quartzite 50 to 100 feet in thickness, the lower part of which is a conglomerate, but it is conformable with the overlying Carboniferous limestones. The quartzite member reposes upon the upturned edges of the Algonkian formations, indicating clearly that an enormous erosion interval separated the two. It would not be surprising if this erosion plane represents all except the latest Paleozoic sedimentation in other parts of the country. In some of the New Mexico mountain ranges this quartzite carries important copper deposits.

It was once believed that the formations subjacent to the great Carboniferous limestone were the metamorphosed beds of the lower Paleozoic; but this hypothesis does not now seem to have foundation.

CARBONIFEROUS SYSTEM.

The rocks of the Carboniferous system appear to be the only part of the great Paleozoic sequence that are represented in central New Mex-

A. ORGAN MOUNTAINS, NEW MEXICO, SHOWING BREAK OFF OR CHANGE IN TOPOGRAPHY.

B. VIEW SHOWING LOCATION OF CANAL LINE RUNNING ALONG SMALL RIDGES DIRECTLY BACK OF AGRICULTURAL COLLEGE.

ico. With the standard Carboniferous section for the American continent, as represented in the Mississippi Valley, the New Mexico sections do not as yet admit of detailed comparison.

The Carboniferous rocks of New Mexico are very important formations. They are found in most of the principal mountain ranges and in most localities they are important ore carriers. As guide horizons they deserve the fullest consideration in the location of all mineral deposits.

Four important formations belonging to the Carboniferous system have been clearly made out in the district under consideration. They are the lower Carboniferous, the middle Carboniferous, the upper Carboniferous, and the so-called Permo-Carboniferous. The three series of Coal Measures of the middle Carboniferous so enormously developed in the Mississippi Valley have not been differentiated in the West. They are, however, doubtless represented entirely by limestones.

The lowest series of the Carboniferous has been recognized in a number of localities. Among these places is one just outside of the area here mapped, in the vicinity of Lake Valley, which deserves special mention. Here has been found an extensive limestone series carrying a rich fauna identical with that of the lower Burlington limestone in Missouri, Iowa, and Illinois. Professor Herrick has also reported a similar lower Carboniferous from the east side of the San Andreas Range.

The great limestone sheets which cap the principal mountain ranges in south-central New Mexico, and which form their back slopes, are of upper and middle Carboniferous age. Immediately beneath these limestones is usually found a white quartzite which often passes downward into a coarse conglomerate. The quartzite with its coarse beds rests unconformably on the upturned edges of a metamorphic series, as already stated.

The great limestones are easily distinguished from all others of the region by their black and blue to gray colors, their peculiar compact texture, and the abundant characteristic fossils which they contain. The thickness of the formation is from 300 to probably more than 1,000 feet. They are everywhere massively bedded and some localities contain thick beds of very pure white limestone. In most of the principal mining districts the Carboniferous limestone carries important lead and silver deposits. The quartzite frequently carries copper.

In the Sandia Mountains, to the north of the district here described, several subordinate formations have been differentiated. The basal conglomerate and associated sandstones have been called the Sandia quartzite. The next member is a black limestone. According to the best available evidence derived from the contained fossils these beds correspond to the earlier Pennsylvanian of the Mississippi Valley.

The upper part of the great limestone formation—the blue to gray beds—contains an abundant fauna that clearly points to late Pennsylvanian age. In the Sandia Mountains this formation is called the "Madera" limestone. It forms by far the most important portion of the Carboniferous in all of the mountain ranges mentioned.

Above the great blue limestones of the Carboniferous there is an important sandstone, and then a sequence of shales and sandstones conspicuous for their remarkable red coloration. "Red Beds," they are generally called. These "Red Beds" are followed by other red beds scarcely distinguishable lithologically. The latter are believed to belong not to the Carboniferous, but to the Jurassic-Triassic.

The so-called Permo-Carboniferous red beds are found everywhere at the foot of the back slopes of the central New Mexico ranges. They are 200 to 1,000 feet thick, and often form a conspicuous feature.

In the Sandia Mountains the lower sandstone is called the "Coyote" sandstone, from Coyote Springs. There is an upper shaly member representing the Cimarron.

JURASSIC-TRIASSIC SYSTEMS.

There appears to be but small doubt that the upper part of the great formation long called the "Red Beds" belongs to a later geologic age than the Carboniferous, and the portion which occurs in New Mexico appears to be that termed in Kansas the Cimarron formation.

In New Mexico these beds are largely developed in the northeastern part in Cimarron, Canadian, and Pecos valleys, and in the central part in the Rio Grande Valley. The thickness probably is not greatly in excess of 500 feet.

CRETACEOUS SYSTEM.

The formations of Cretaceous age are the most extensive surface rocks in New Mexico, as they probably cover more than one-half of the whole area. Both the upper and lower Cretaceous sediments are well represented, but the serial sequence has not yet been definitely made out. The Jornada is everywhere immediately underlain by these rocks and they are the principal water carriers. In Canadian and Pecos valleys, particularly around the western and northern borders of the Llano Estacado, a remarkable sequence of sands, chalky rocks, and clays lies above the "Red Beds." These strata, comprising the Trinity sands, Fredericksburg limestone, and Washita sands, are thought not to be present in the district here described, and the Cretaceous begins with a formation believed to be the Dakota sandstone. This formation is at least 300 feet in thickness in this region and its basal sandstone is one of the chief water reservoirs. While not generally recognized, except in northeastern New Mexico,

A. INTERNATIONAL RESERVOIR SITE, 2⅛ MILES ABOVE INTERNATIONAL DAM SITE.

B. RIVER BED AT INTERNATIONAL RESERVOIR SITE.

View taken from big bend in river.

it is probable that the Dakota is widely distributed and is to be found a short distance above the "Red Beds."

Although clearly differentiated in northeastern New Mexico in particular, the Colorado formation is not so well defined to the southward. It comprises, chiefly, shales with numerous bands of limestone and several thick sandstones.

Attaining a development of 1,500 feet in northeastern New Mexico, the Montana shales will doubtless be found to be well represented elsewhere in the Territory. Certain beds in the Jornada district are thought to be the equivalents of this formation. The shales are mostly gray and drab, becoming yellowish above and blackish below.

In New Mexico the beds generally referred to the Laramie formation are about 2,000 feet in thickness. The rocks are chiefly gray sandstones and shales, with numerous beds of coal. Most of the Cretaceous of the region between the San Andreas and Caballos ranges seems to belong to this age.

TERTIARY AND QUATERNARY SYSTEMS.

Eocene.—None of the sediments of the Jornada are as yet known to belong to the Eocene. In the bordering region of the Rio Grande Valley, however, there are large areas of gray shales and clays, reaching a maximum thickness of over 800 feet, which have been referred to the early Tertiary and are called the Puerco formation. A large vertebrate fauna has been obtained from them.

Later Tertiary.—The later Tertiary beds are widely distributed over the plateau region. In eastern New Mexico the Llano Estacado formation, over 100 feet in thickness, appears to belong to this age. A considerable part of the sands and clay deposits underlying the bolsons doubtless belongs to the Tertiary, though as yet they have not been differentiated from the other unconsolidated deposits.

Quaternary.—To this age belong such beds as the bolson gravels, the arroyo gravels, alluvium, and many deposits of talus wash, besides some lake deposits.

The unconsolidated gravels and other surface deposits covering the plain of the Jornada del Muerto are probably in great part of comparatively recent origin. This opinion is based on the belief that the beveled plain itself is of Tertiary age, and that consequently the present topographic features are of recent date. The rock waste brought down from the mountain slopes and carried out into the plain is of comparatively recent origin and its deposition is still in progress. Apparently during Tertiary time the relief was less marked than at present, and if any deposits were spread on the plain at that time they were at best very meager.

The present unconsolidated surface deposits are of diverse origin. For the most part they are river deposits. Some are wind borne. A

few of very limited extent may be lake deposits, but of this there is no direct evidence in the Jornada, though in other basins there is ample evidence of extensive lake beds. There are some irregular beds which may be the fine, light débris known as volcanic ash, derived from some of the many volcanic outbursts in the region in later geologic time. These superficial deposits do not appear to have near the enormous thicknesses that have been ascribed to them, but in places they are several hundred feet thick.

Most of the basaltic lava flows of the region doubtless belong to the Quaternary period.

ERUPTIVE ROCKS.

The eruptive rocks of the region are of three kinds. The most noteworthy are the surface flows of black basalt, which often cover many square miles. The great sheet which begins immediately south of San Marcial is perhaps the most extensive. It is of very late origin and lies on several hundred feet of soft materials. In the Rio Grande bluffs at San Marcial the lava capping is now 300 feet above the river. The bluffs at this point are nearly perpendicular and form a striking feature in the topography. This lava flow probably at one time dammed the river temporarily. Above the town terraces extend on either side of the river for many miles and gradually approach the water level in passing upstream.

Similar outflows from low volcanic cones occur at the northern end of the Jornada northwest of Ojo Chupadera. West of Engle station there are six or more low volcanic hills, none of them over 300 feet high, from which basalt flows extend for a distance of several miles. One cone 6 miles southwest of Engle appears to be the most important, as from it a broad tongue of lava extends a distance of 12 miles or more in a northwestward direction. This tongue is cut near its distal extremity by the deep Mescal Canyon. Four of these cones appear to be in a line running northeast and southwest. The rest are 5 to 6 miles apart.

Toward the north end of the line of volcanic cones there is one from which a broad sheet of lava extends into the Rio Grande Valley. Erosion has deeply dissected the river bluffs and has in several places isolated small areas of the original lava sheet which now form flat-topped hills rising several hundred feet above the stream. One of these isolated, lava-capped hills is widely known as Elephant Butte.

In the southern part of the plain, south of Afton, on the Southern Pacific Railroad, are similar lava flows covering many square miles of surface.

South of the Elephant Butte region the country is traversed by numerous basic dikes which are traceable for miles. So far as can be

TOPOGRAPHY OF THE FORT SELDEN ERUPTIVE AREA

From Las Cruces sheet 1900

1 0 1 2 3 4 5 miles

Contour interval 25 and 50 feet

1904

ascertained these dikes do not materially affect the water conditions, at least so far as obtaining ample water supplies from shallow wells. In some situations springs issue from the strata in the vicinity of the dikes.

Of much older date are the trachytic and rhyolitic masses constituting the mountains near the point where the Rio Grande enters the Jornada. The San Diego Mountains and the Dona Ana Hills are all of this class. They rise abruptly out of the nearly level plain and form conspicuous features of the landscape.

On the northern rim of the Jornada near Ojo Chupadera the rocks are traversed by numerous nearly parallel dikes of trachyte. These dikes are 200 to 300 feet wide, trend northeast and southwest, are 2 to 4 miles apart, and are traceable for miles across the country. In the vicinity of the dikes the rocks have been considerably disturbed, and at some localities the plane of intrusion appears to be a fault, as narrow belts of Carboniferous limestone are brought up into contact with Cretaceous sandstone.

STRUCTURE.

GENERAL CHARACTERISTICS.

In its general structure the Jornada bolson is a section of a peneplain—part of a vast Tertiary grade plain—formed on the beveled edges of Mesozoic and Paleozoic strata (fig. 3). Through comparatively recent deformation the boundaries of the present bolson have been defined by locally intensified mountain uplift.

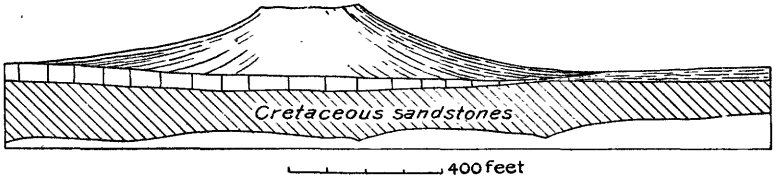


FIG. 3.—Mescal Cone resting on Cretaceous sandstones.

While in a general way the bolson under consideration is a broad, very shallow valley, and while with its rim abruptly upturned it has the appearance of a simple syncline, it is a district in which the synclinal structure has been developed at different times and under somewhat different conditions.

All the mountain ranges of central New Mexico may be considered as simple monoclinal blocks, so tilted as to present one steep side and an opposite side of more gentle slope. The crest and back slope of the different ranges consist chiefly of blue Carboniferous limestones. These limestones on the rim of the basin attain a thickness of over 1,000 feet, and are underlain by granites and gneiss.

In general structure, the ranges adjoining the great bolson plain of the Jornada del Muerto are of the characteristic mountain type known as the Basin Range structure. This feature is best illustrated by fig. 4, which is a cross section in an east-west direction transversely to the long axis of the bolson and embraces the mountain ranges on either side.

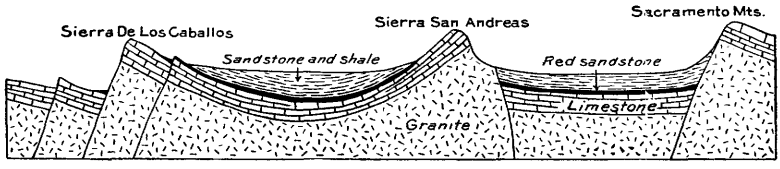


FIG. 4.—Basin Range structure of the Jornada.

In the various parallel bolsons and valleys which trend north and south through the high plateau region of New Mexico, the abrupt fault scarps on the sides face each other in some instances, while in others the longitudinal valleys are bounded by the long back slopes, giving the appearance of true synclines. The Jornada belongs in the main to the last-mentioned type. East of the Jornada is the great Jarilla bolson, a similar plain 150 miles long and 50 to 90 miles wide presenting opposed fault scarps on its longitudinal borders. To the west of the Jornada lies the Rio Grande Valley, which is similarly constructed, though now owing to the enormous erosior by the great stream the original plain effects are nearly obliterated. The general relations of the mountain blocks are more clearly represented in the cross sections in Pl. II. Near the mountains, especially on the west side of the plain, is a belt 3 to 4 miles wide, where the surface is trenched by intricately ramifying canyons, often several hundred feet deep, in which the formations are extensively exposed.

While the general slope of the plain toward the center is only 2° to 3°, the dips of the strata are often as high as 30° in the same direction, and in places they are vertical. On the beveled edges of the steeply inclined beds the plain gravels are laid down, and also broad sheets of basaltic lava, the latter spreading out from numerous low cones (see fig. 3).

The general synclinal character of the bolson holds good for only part of the Jornada. At its northern end the synclinal feature is completely lost. A monoclinal structure is present—steep on the western rim of the basin, but soon flattening out to nearly a dead level eastward to the foot of the Sierra Oscura, where there is a fault of 3,000 feet.

STRUCTURAL RELATIONS OF THE FORMATIONS.

The rim of the Jornada basin consists of limestones of Pennsylvanian age, which in the center of the synclinal trough lie beneath the sur-

A. ORGAN MOUNTAINS, NEW MEXICO, SHOWING A PORTION OF THE MOUNTAINS.

B. NATURAL DIKE NEAR ELEPHANT BUTTE.

face at a depth of more than 2,000 feet. Under these limestones are the crystalline schists and gneisses with intrusive granites. The formations to be considered with respect to the underground water conditions are those lying above the Carboniferous limestones and the overlying "Red Beds." These are the Cretaceous sandstones and the mantle of porous, unconsolidated deposits which everywhere cover the country occupied by this plain.

These several geologic terranes, embracing all between the basal crystallines and the loose surface deposits, recline upon one another without discordance in dip. It is possible that marked unconformities exist locally between some of the sedimentary rocks, but as yet no evidence of the existence of these conditions has been found.

DESCRIPTION OF CROSS SECTIONS.

The geologic cross sections of the Jornada are especially instructive in their direct bearing on the underground water conditions. Three of these cross sections (Pl. II) suffice to represent the general conditions. These are called the northern, middle, and southern cross sections, and their locations are indicated on the geologic map (Pl. I), although their extremities extend somewhat beyond the area shown on this map. Each of the cross sections is about 50 miles long. The vertical scale in feet is given at the side of the drawing, as are also the heights above sea level.

Northern cross section.—The northern section (section A–A on Pl. II), which may be called also the Socorro cross section, extends from the San Augustine Plains west of the Magdalena Mountains, through the old Socorro Volcano and the high range of hills on the east side of the Rio Grande, to beyond the Sierra Oscura. The Jornada lies between the last-mentioned range and the high hills bordering the Rio Grande on the east.

In this part of its extent the substructure of the Jornada plain is a monocline abutting against the Oscura Mountains. The latter rise abruptly out of the plain and for more than three-fourths of their height present crystalline rocks in the face of the escarpment they form.

Middle cross section.—The middle section (section B–B, Pl. II) may be called the Palomas section, since the famous Palomas Canyon which bisects the Sierra de los Caballos is in its line. This is the most typical cross section of the Jornada plain. It shows a simple synclinal structure, with profound faults on the opposite sides of the marginal mountain ranges in either direction.

On the Rio Grande side of the Caballos Range repeated faulting is indicated—the river occupying the minor fault block next to the great fault block of the main mountain ridge.

The highest part of the Caballos Range exhibits very clearly the evidences of a profound thrust plane, the geologic age of which greatly antedates the period of normal block faulting which gives the present characteristic aspect to the region. The Carboniferous limestones for three-fourths of the distance to the summit of the range stand nearly vertical. Erosion has beveled the edges of the upturned beds at angles of about 35°—the slope of the eastern side of range. This gives an appearance of great irregularity to the rocks, except at the top of the mountain, where horizontal beds cap the summit. The appearance is almost inexplicable until the existence of the fault thrust is recognized.

Immediately east of the western rim of the bolson and between the Sierra de los Caballos and Sierra Fra Cristobal are small lava cones 300 to 400 feet high, each of which has sent out a basaltic flow for several miles in all directions. These flows appear to cover some of the earlier mesa gravels, and they are probably early Pleistocene in age.

The gentle syncline of the Jornada is, perhaps, its most characteristic structural feature. It is to be noted, however, that this region is not a simple trough, but a syncline which has experienced repeated, or rather continued, upturning of its margins while the process of general base-leveling was going on.

In the San Andreas Range there is found a simple monoclinal block with profound faulting on the eastern flank of the range. From the foot another broad bolson plain extends to the lofty Sierra Blanca.

Southern cross section.—The Las Cruces section (Pl. II, section C–C) presents a number of features not displayed in the other two sections here mentioned. The Jornada continues to be a synclinal trough, but the Rio Grande has cut across the disturbed zone of the western rim and traverses the great bolson itself.

The Organ group of mountains, which forms a part of the eastern rim of the Jornada basin, is a mass of old crystalline rocks which, on account of special local conditions, has been thrust upward much more than any other part of the plain's periphery, and has been completely denuded of the sedimentary rocks, except at the very base of the range. Rising abruptly out of the plain half way between the Organ Mountains and the Rio Grande is Tortugas Hill, a small tilted limestone block.

SOME MINOR STRUCTURAL FEATURES.

The region to which this report relates exhibits many details of structure that probably are of sufficient interest to merit special notice here. Among the phenomena of this kind to be mentioned are faulting, jointing, folding, and fissuring. Most of the features are in the rim of the basin, and on the east slope of the Sierra de los Caballos are exemplifications of many interesting structural details.

Reversed faulting.—There is abundant evidence that while the present mountain uplifts are the products of normal faulting, this region has been subjected to some tangential pressure, causing overthrust faults. These occurred long after Carboniferous time, because they involve rocks of that age. Possibly some of the main lines of uplift of the present mountain ranges were initiated by the lines of weakness marked by the thrust planes.

In the Sierra de los Caballos the phenomena of reversed faulting are exceptionally well displayed. The east slope of the range presents some excellent examples on a small scale. One in which the throw is only 50 feet is represented in fig. 5.

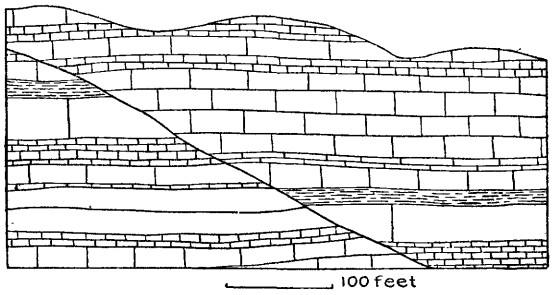


FIG. 5.—Small reversed fault in western rim of Jornada.

On the other hand, the immense thrust plane under the Caballos cone may represent a movement of one or more miles. It is clearly exposed, with relations shown in fig. 6.

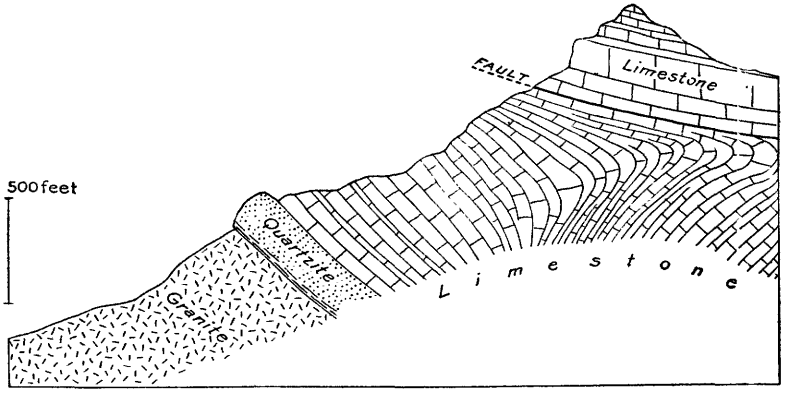


FIG. 6.—Caballos Peak and thrust plane.

The tremendous effects of the tangential pressure of this period are further indicated in Las Palomas Canyon, where the strata are greatly corrugated and folded.

Normal faulting.—The normal faults are of two series, of which the major produced the present monoclinal blocks forming the east

and west sides of the great basin. These have a throw of about 4,000 feet, and give the Basin Range structure to the region.

A minor series of normal faults trends at right angles to the axes of the mountain ranges. They were produced probably in the warping of the great limestone masses which form the main portions of the

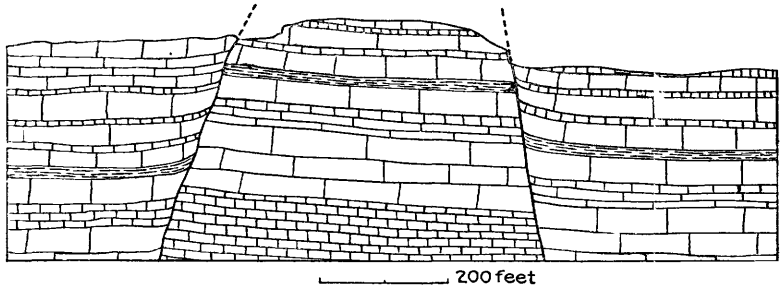


FIG. 7.—Normal faulting at Napoleon mine.

mountains. That some of these transverse faults, even those of comparatively small throw, affect great thicknesses of rock is shown by the fact that some of them are associated with true fissure veins of lead and copper ores. A cross section at the Napoleon mine is given in fig. 7.

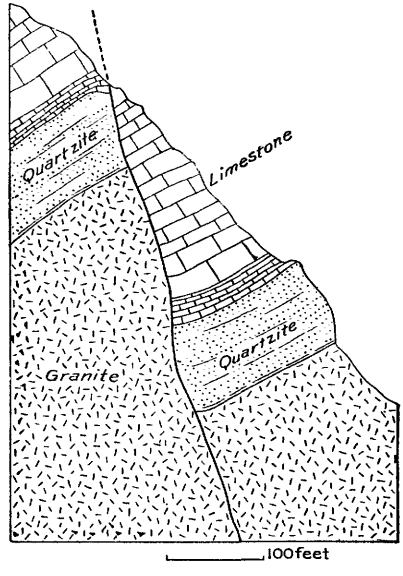


FIG. 8.—Normal faulting at El Capitan mine.

Another good illustration is at El Capitan mine, which is opened near the base of the unaltered sedimentary sequence, one side of the tunnel being the limestone and the other the crystalline complex (see fig. 8).

Another feature of faulting is associated with the basic dikes which extend for miles across the country east of the Caballos Range and near the volcanic cones already mentioned. In some cases the dikes do not appear to have disturbed the sandstones in which they occur, but simply spread apart the two walls. A good example is shown in Mescal Canyon, below the spring of the same name. This is represented in fig. 9.

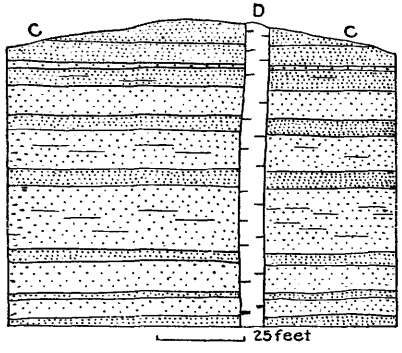


FIG. 9.—Basic dike in Cretaceous sandstone.

There are often springs issuing from the base of the canyon walls in the immediate vicinity of dikes of this description. It may be that the dikes act as dams for the underground waters and serve to pond them. On the other hand, some of these dikes greatly disturb the sandstones for a distance of several hundred feet. This is best illustrated by fig. 10.

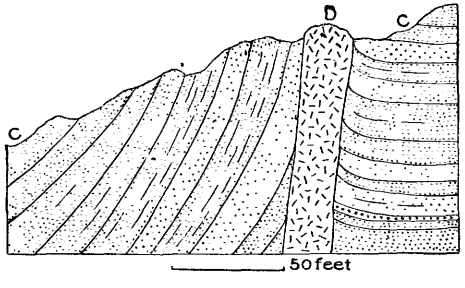


FIG. 10.—Basic dike disturbing level sandstones.

Still more prominent are some of the dikes on the northern border of the Jornada, east of the Ojo Chupadera. The relationships of the rocks are shown in fig. 11.

A similar dike is shown in Pl. IV, A, page 16. It cuts and upturns the Carboniferous limestones; but between the time of its intrusion and that of the deposition of the Cretaceous sandstones the whole region was elevated and beveled off.

In these cases the direct influence of the dikes in the local water storage underground is traceable. At various points springs issue from near the line of contact of the dike rock and sandstones. This

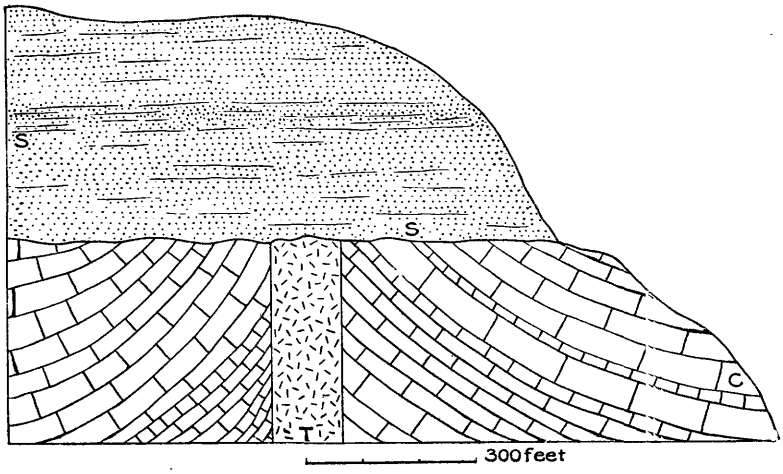


FIG. 11.—Acidic dike in Carboniferous limestones.

is especially noticeable wherever the rocks are slightly tilted. Reference will again be made to these various features in their bearings upon the local water supply.

UNDERGROUND WATERS.

GENERAL CONSIDERATIONS.

It will be seen from the foregoing description of the geologic relations that the Jornada del Muerto is underlain by extensive deposits of permeable materials. As the greater part of the rainfall sinks into these deposits, it is certain that they contain waters which are available for wells of greater or less depth. The appearance of a waterless waste which this plain presents loses much of its discouraging aspect to the settler when the real conditions are presented.

The peculiarities in geologic structure, composition and arrangement of materials, and climatic conditions of the Jornada are similar to those of the other bolson plains of the region, including western Texas. The observations of Hill[a] on the Texan area are so directly applicable to the area under consideration that several paragraphs are here quoted. He says:

> The influence of structure and imbibition is shown in the basin plains. Although unconsolidated, the rocks of the basin plains are alternations of porous and impervious beds, and hence are valuable artesian areas; by experimentation in boring in properly selected sites considerable water may be obtained. Nonflowing wells have

[a] Hill, R. T., Final Rept. Artesian and Underflow Investigation, U. S. Dept. Agric., pt. 3, 1892, p. 54.

been secured in many of the most unpromising plains, even in Death Valley; as furnishing water for stock, these wells are very important.

The geologic age of strata is of secondary importance in determining the occurrence of underground water. Approximately the same amount of rain falls upon a great diversity of country, some of which contains great stores of water, while other parts are entirely lacking in this essential. For instance, the mountains of the trans-Pecos region are mostly composed of hard, impervious rocks—compact limestones, quartzites, and eruptive rocks. Less than 1 per cent of the rain falling upon these rocks is absorbed, except such as finds its way into the structure by cracks and fissures or along lines of contact. As a result of this condition the water after every shower quickly flows down the slopes to the extensive flats which occupy the valleys between the mountain ranges. These flats, as well as the entire surface of the Llano Estacado, have a structure entirely different from the adjacent mountains, and are for the most part composed of loose, porous sands and gravels, so that every drop of rain that touches their surface is immediately absorbed and does not flow off in streams. This explains the utter absence of running water on the surface of these flats and its abundance stored in the structure beneath. Not only does this basin and plain formation imbibe all the rain which falls upon its surface, but the great torrents which pour down the mountain sides and canyons disappear immediately upon reaching the plain, being imbibed by its porous structure. The constant streams also which flow from the snow-clad peaks or mountain springs, such as the Seven Rivers, the Tularosa, and the numerous lost rivers of New Mexico and Texas, quickly disappear upon reaching the plain.

After the rain ceased an observer would be impressed by the fact that the representative rocks of the different areas exhibited capacities different not only for imbibing water, but also for transmitting it through their structure by percolation, and those rocks which imbibe the least water, like the limestones, porphyries, and quartzites of the Organ, the Guadalupe, and other trans-Pecos mountains, most slowly transmitted it, so that for days, perhaps months, springs and seeps flow from the crevices and contact plains of the high mountain slopes, keeping alive delicate ferns and rare plants. On the surface of the Llano, except where slight quantities of clay are mixed with sandy loam, in an hour or two there remains little evidence in the dry surface that a shower has fallen, the water having quickly penetrated to the depths beneath.

AREAL DISTRIBUTION OF THE WATER-BEARING BEDS.

By reference to the geologic map (Pl. I) the areal distribution of the several geologic formations will be seen. The greater part of the area is underlain by Cretaceous sandstone, which occupies the middle portion of the Jornada, probably four-fifths of the plains, and is more than 25 miles wide in places. On either side is a belt a mile or two broad of "Red Beds," chiefly impervious clays. Then come the Carboniferous limestones, forming the rim of the basin in a belt about 6 miles wide. Except in the Sierra Oscura and the Organ Mountains, the crystalline rocks are exposed on the bolson side of the area.

These various belts of formations extend in nearly parallel strips along nearly the entire length of the Jornada del Muerto district. Their proper recognition is necessary for an understanding of the hydrologic conditions to be expected in any particular part of the basin. This is especially true of the marginal portions of the area.

AREA OF WATER SUPPLY.

The most important feature to be taken into consideration in connection with the area of possible water supply is the fact that the collecting ground is not confined to the marginal mountains, as in many other regions, but the bolson imbibes all the water falling upon the surface. The underground reservoirs may be at different geologic horizons and at different depths from the surface, but, with the exception of a comparatively small amount of water which finds its way into the Rio Grande, all the rain finds lodgment in some part of the several porous formations.

As most of the mountain rock is hard and impervious, much of the rains run off the mountain slopes in torrents, which, as they spread out over the plain, are soon imbibed by the unconsolidated surface deposits. The arroyos of the Caballos Mountains carry streams 10 feet deep in time of heavy rainfall, flowing with terrific force and carrying away nearly all of the water, which is shed completely by the hard rocks on the mountain slopes. In the San Andreas Range these torrential waters are being stored for irrigation purposes in the adjacent plain below.

CLIMATIC CONDITIONS AFFECTING WATER SUPPLY.

As the Jornada is within the semiarid belt it presents characteristics not found in more humid regions. The total annual rainfall is about 12 inches, though in the mountainous rim, which rises 3,000 feet above the plain, the precipitation probably exceeds 15 inches a year.

The precipitation is mainly rain, but occasionally is in the form of snow, which covers the ground to a depth of 2 to 3 inches, but disappears in a few hours. Most of the rain falls during the months of July and August. Evaporation amounts to about 90 inches annually, and is facilitated by the dry air, high winds, and scant vegetation.

PERMEABLE STRATA.

One of the geologic peculiarities in the Jornada del Muerto is that it is in greater part overlain by unconsolidated porous deposits. These are the loose bolson gravels and sands which cover the underlying formations to considerable depth. Under fully two-thirds of the entire area of the plain the Cretaceous sandstones lie immediately beneath these bolson surface deposits. The next porous stratum is in the basal portion of the beds, where immediately above the Carboniferous limestones there often are beds of coarse sandstone.

There are, then, three distinct formations which permit the underground circulation of water. As these permeable formations extend throughout the whole Jornada, except a narrow belt around the mountainous rim, it is easy to understand the reason for the phenomenon of

a basin containing nearly 10,000 square miles, with an annual rainfall of 10 to 12 inches, yet having a total absence of running streams. Aside from the portion of rainfall which is evaporated, the whole of the annual precipitation is imbibed by the spongy surface formation, and percolates downward until it encounters some clayey layer or other impervious stratum.

WATER HORIZONS.

The water horizons in the three formations above described are as follows: (1) At the base of the bolson gravels, (2) at the base of the Cretaceous sandstones, and, locally, (3) at the base of the "Red Beds." These are the horizons from which artesian flows are most likely to be obtained. There are, however, other minor horizons in the bolson gravels and sands and Cretaceous sandstones, to which wells may be sunk to secure ample water supplies.

The depth to which it is necessary to bore in order to reach the base of the bolson gravels and sands, which form the first of the principal artesian horizons, varies greatly. The thickness of these gravels has manifestly been greatly overestimated, as all recent data indicate that they probably nowhere exceed a thickness of about 150 feet.

Shumard,[a] one of the pioneer scientists, who traversed the Jornada in 1856, makes the following statement:

> Wherever examined, the surface formation was found to consist of detritus of rock débris, in all respects the same as those composing the neighboring mountains from which it was doubtless mainly derived. The precise thickness of this deposit could not be very accurately determined, as only a few natural sections were observed and these only near the base of the mountains. In two localities its observed thickness was nearly 500 feet.
>
> Geologically speaking, the Jornada del Muerto may be considered as notl ing more than a single trough composed mostly of limestones, sandstones, and shales, and covered to the depth of 500 or 600 feet with loose detritus.

There is no place along the Jornada in which there is a section of bolson gravels showing any very great thickness. As these gravels slope down from the marginal mountains, the first inference would naturally be that the incline was produced by filling up by the gravels on a level plain. This is not the case, for the gravels lie on a sloping surface and their thickness is not great along the slopes, as might at first glance be expected.

Waters from wells sunk in the Cretaceous sandstones are especially satisfactory. Most of the waters of the Jornada del Muerto now in use are "hard," as they often contain relatively large amounts of lime in the form of the carbonate and the sulphate, but the actual amounts of these compounds is surprisingly small when the source of the water is considered.

[a] Shumard, G. G., Structure of the Jornada del Muerto: Trans. St. Louis Acad. Sci., vol. 1, 1858, p. 341.

Some analyses of waters from an adjoining bolson, the Estancia plain, which presents almost identical geologic conditions, illustrate the point. These results of analyses are introduced for the reason that they represent even more extreme conditions than those in the Jornada. The analyses were made by Prof. F. C. Lincoln, of the New Mexico School of Mines.

Chemical analysis of well water at Stanley, N. Mex.

[In grains per United States gallon.]

Probable compounds:	
Organic and volatile matter	3.644
Silica	6.892
Alumina and ferric oxide	4.555
Calcium carbonate	4.163
Calcium sulphate	1.938
Calcium chloride	.000
Magnesium carbonate	3.052
Magnesium sulphate	.000
Magnesium chloride	.000
Potassium carbonate	.000
Potassium sulphate	2.973
Potassium chloride	.000
Sodium carbonate	.000
Sodium sulphate	2.708
Sodium chloride	4.194
Total solids	34.119

Chemical analysis of water of spring-fed lake at Estancia, N. Mex.

[In grains per United States gallon.]

Probable compounds:	
Organic and volatile matter	2.125
Silica	1.682
Alumina (with ferric oxide)	.666
Calcium carbonate	6.120
Calcium sulphate	8.332
Calcium chloride	.000
Magnesium carbonate	.000
Magnesium sulphate	.000
Magnesium chloride	4.463
Potassium carbonate	.000
Potassium sulphate	6.556
Potassium chloride	.000
Sodium carbonate	.000
Sodium sulphate	.000
Sodium chloride	2.371
Total solids	32.315

WELLS OF THE JORNADA DEL MUERTO.

The wells of the region are of three classes, viz, shallow dug wells, deep drilled wells, and flowing wells.

The first important well in the Jornada del Muerto was sunk by John Martin in 1871. He dug a hole 160 feet deep in the middle of the plain and found a plentiful supply of good water. From that time onward Martin's ranch became the stopping place of every party crossing the then dreaded basin.

During the more than thirty years which have passed since the first well was dug a large number of wells have been sunk in nearly every part of the region. They rarely go down more than 50 to 75 feet, and the water is raised chiefly by windmills.

When the location is selected with consideration of topographic and geologic conditions, it is quite likely that there are but few spots in the Jornada which would not furnish adequate supplies of water for all purposes to which the surrounding country is adapted. Most of the wells are now dug in the mesa gravels, but where they are in the Cretaceous sandstones there is apparently a larger flow, due probably to the more homogeneous texture and more uniform porosity of the formation.

It is probably unnecessary to mention in detail the various dug wells, as they are so numerous and the phenomena presented are so much alike everywhere within the area. Practically nothing has been done to develop water supplies by means of deep wells, though the conditions appear favorable for abundant water from this source. The only serious attempt to sink a deep well within the limits of the Jornada appears to have been at a point a short distance northwest of Engle, a station on the main line of the Atchison, Topeka and Santa Fe Railroad, on the high plain about halfway between San Marcial and Rincon. Engle is 300 feet above the first-named station and 700 feet above the second.

This well was drilled by the railroad company to a depth, as reported, of 1,200 feet. A good artesian flow was obtained, but the water was unfit for locomotives. The casing was withdrawn and the hole plugged at a depth of about 150 feet, where softer water is obtained. This water does not rise to the surface, but has to be pumped about 50 feet. The discharge goes into a large reservoir and is then piped to the station, about 2 miles distant. The present water supply appears to be obtained from the base of the mesa gravels. At a depth of 1,200 feet this boring probably failed to reach the base of the Cretaceous sandstones, the horizon in which artesian flows of good water may be expected.

A number of shallow wells are practically flowing wells. They have been dug near springs in some cases, and when properly curbed the

overflow is conducted through iron pipes farther down the valley. Such, for example, are some of the wells near the foot of the Caballos Range.

QUALITY OF THE UNDERGROUND WATERS.

In the arid regions the waters are so generally spoken of as "alkali waters" that many persons suppose that this character is the prevailing one. In most cases, however, the underground waters of such bolsons as the Jornada are often sufficiently good for domestic use. The so-called "alkali," which often appears as a thin white coating in places where the water has evaporated, in most cases consists chiefly of common salt. Of the large number of well waters examined from the Jornada comparatively few were found to be unpalatable and, with a few exceptions, all were excellent for stock and for domestic purposes.

RÉSUMÉ OF UNDERGROUND WATER PROSPECTS.

The geologic conditions of the Jornada indicate that the most important water-bearing stratum lies at the base of the Cretaceous sandstone. How extensive this stratum is can only be determined by a few properly located drill wells; but all available data lately collected go to show that this water supply should be very considerable.

Since the trough of the basin pitches southward about 12 feet to the mile, it is questionable whether the artesian conditions extend beyond the southern half of the region. The deep well and a number of shallow wells in the sandstone near Engle indicate that artesian conditions exist at least that far north.

The dips in the synclinal trough of the Jornada are such that the main water-bearing stratum lies from 1,000 to 2,000 feet beneath the surface in the center of the valley, but rises rapidly on each side until at a distance of from 10 to 12 miles on either side the water horizon reaches the surface under the gravels. The probable distance that it is necessary to drill in order to penetrate the principal water stratum may be thus estimated approximately. Moreover, there is another important and easily recognizable horizon which serves as a guide plane beyond which no one should go in his search for flowing water. The impervious "Red Beds" underlie the yellow sandstones of Cretaceous age and effectually prevent water from sinking lower. This important fact should always be borne in mind in sinking deep wells, and it is also believed to be useless to seek for water in the "Red Beds." When the drill penetrates these beds sufficiently to establish their identity the boring should be abandoned.

There are also local conditions that interfere with the artesian flow. Some of these obstructions have already been considered at length, but they should be regarded as of but limited extent and when met with a locality should not be condemned on account of a single failure.

The water-bearing stratum at the base of the mesa gravels is less clearly defined than that at the base of the Cretaceous sandstone. It is not likely to furnish flowing wells except in a few favored localities. Its main value is in furnishing the water supply for shallow, dug wells. Another point to be taken into consideration in connection with the water horizon of the mesa gravels is that in many places impervious clays separate the gravel beds. This brings important water-bearing levels much nearer the surface than would be ordinarily expected.

It is now a well-known fact that in the Mesilla Valley, where the Rio Grande traverses the Jornada plain, there is a vast underflow, from which water may be pumped in great volume for irrigation. As the Cretaceous sandstones rise near the surface in the Mesilla Valley, it is possible that a part of this underflow may be derived from the artesian stratum at the base of the Cretaceous sandstone, but it is here mainly in the Quaternary gravels filling the valley.

IRRIGATION.

Regarding the possibilities of the Jornada as a district for irrigation by well waters much might be written. It is possible that by systematic development many thousands of acres may be reclaimed for agricultural purposes. From artesian wells or even deep-drilled wells where pumping would have to be done, the outlook appears favorable for the irrigation possibilities. It is estimated that eventually at least one-tenth of the region should be brought under cultivation. The waters of the Rio Grande can be made available for the irrigation of large areas and the Elephant Butte reservoir at the end of the Sierra Fra Cristobal, now in contemplation, will bring an extensive portion of the flood plain under irrigation.

By the construction of reservoirs in the mountain arroyos along the elevated margin of the plain, many local areas may be brought under cultivation. Some of these reservoirs have already been planned or are under construction. Their success will certainly encourage many others to be built, and eventually a large strip of country bordering the mountain ranges, which at present is mostly used as grazing land, will thus be irrigated.

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O

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 123.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of the United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

Most of the above publications may be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they may be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are allotted to every member of Congress, from whom they may be obtained, free of charge, on application.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they may be had at prices slightly above cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they may be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the sixty-sixth in Series B, and the thirty-sixth in Series O, the complete lists of which follow (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

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Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

AUGUST, 1905.

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