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Gypsum Resources of New Mexico

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PURPOSE AND NATURE OF REPORT

This bulletin is designed to satisfy the growing demand for information concerning gypsum deposits in New Mexico and the possible utilization of known deposits of this mineral. An earlier study by Darton (1920), listing and summarily describing most of the large deposits in the State, is now out of print. Moreover, some smaller deposits of possible local value, not listed by Darton, have been located recently. The utilization of gypsum depends on many factors, which must be considered for each deposit and each locality individually.

This report is chiefly a reconnaissance survey of gypsum deposits in New Mexico. The large accessible deposits of possible large-scale economic use are emphasized, but small reserves that may be of local use are also noted. Most of the bedded gypsum is of middle Permian or Upper Jurassic age, whereas the gypsum dune sands and gypsite, formed from weathering of bedded or dune deposits, are of Quaternary age. Thick, relatively pure gypsum beds occur within 50 to 75 miles of the Rio Grande valley from the Rio Chama southward to Truth or Consequences; thinner beds crop out near the surface along the Pecos River from Acme and Roswell south to the New Mexico—Texas State line; and the extensive gypsum dune sands of the Tularosa Basin are not only a world-famous scenic attraction but include a huge reserve of pure gypsum that is outside the White Sands National Monument.

Areas of large gypsum deposits are serviced by the Atchison, Topeka *& Santa* Fe Railway from Lamy to Albuquerque and Belen, west to Laguna, east to Vaughn, and south to Engle; by the Southern Pacific Railroad from Vaughn and Ancho to Alamogordo; and by the Atchison, Topeka & Santa Fe Railway from Acme and Roswell to Carlsbad and Malaga. Paved State and Federal highways provide additional access to or near most of the major deposits.

PROCEDURE

Gypsum deposits known to be of large extent and purity were examined in the field, samples collected, and brief summary descriptions prepared for inclusion in this report. Large outcrop areas of possible economic deposits were examined at the more accessible points. Small deposits, deposits difficult to mine, and relatively inaccessible deposits have been described from published reports, unpublished and oral descriptions, or from cursory examination. Where possible, chip samples of gypsum beds were taken for chemical analyses. Many of the gypsum outcrops, however, are covered by a thick crust (in places tens of feet thick) of gypsite or by impure leached gypsum, or are well exposed only in impassable cliff faces; at these places only grab samples were collected.

Measurements or estimates of thickness of gypsum beds published by previous writers were found in many localities to be too optimistic; at least some of these thicknesses are of surficial crusts of gypsite and do not represent the actual thickness of the gypsum beds. The impure crust in many outcrops is seen indiscriminately to cover thin to thick beds of sandstone, shale, and limestone interbedded with gypsum beds. A 100-foot-thick outcrop band of gypsite may conceal several beds of gypsum totaling only 40 feet, whereas the remaining 60 feet is sandstone, shale, and limestone.

Gypsum deposits in north-central, northwestern, and central New Mexico were checked in the field by Robert H. Weber; the deposits in south-central and southeastern New Mexico were examined by Frank E. Kottlowski. The index map (pl. 1) was compiled by Kottlowski from all available recent sources: the Otero Mesa area from an unpublished map by Carl C. Branson, Oklahoma Geological Survey; the Sacramento Mountains from Pray (1952); the eastern Sacramento Mountains slope from Bachman (1954); the Caballo Mountains from Kelley and Silver (1952); the Sierra Cuchillo from Jahns (1955); the area east of Socorro from Wilpolt and Wanek (1951); northwestern New Mexico partly from Dane and Bachman (1957); the area west of the Pedernal Mountains from Read *et* al. (1944); eastern Torrance County from Smith (1957); the western Guadalupe Mountains from Boyd (1958) and Skinner (1946); Chaves County from King (1942); part of Eddy County from Hendrickson and Jones (1952); the area east of Carlsbad from DeFord and Riggs (1941); and the Carlsbad Caverns East quadrangle from Hayes and Gale (1957).

Outcrops shown on the index map of the Yeso and San Andres formations and the Whitehorse group (Chalk Bluff/Bernal) are restricted to those which appear to contain enough gypsum to be used commercially, whether locally or for out-of-State markets. South of the Whitehorse group outcrops shown in west-central Eddy County, the red bed—evaporite sequence grades into a carbonate rock facies; west and north of the Whitehorse group outcrops, the gypsiferous facies grades into a clastic red-bed facies. The San Andres formation contains noteworthy amounts of gypsum east of Chupadera Mesa, but only those areas in which gypsum beds are known to be at or near the surface are shown. North and northwest from the Yeso outcrops shown on the index map, the Yeso becomes chiefly a pale-red clastic sequence; thus outcrops near Tijeras, in the Sierra Nacimiento, on northern Glorieta Mesa, and near Las Vegas are not shown. In the Zuni Mountains, gypsum appears to be present in minable quantities only along the southern edge. Kelley, Rothrock, and Smalley (1946) reported no gypsum in the Yeso formation of the Gallinas Mountains area 15-20 miles north of Ancho.

PREVIOUS INVESTIGATIONS

H. N. Herrick (1904, p. 89-99) reported on New Mexico gypsum deposits in the first national survey of gypsum published by the U. S. Geological Survey. He noted the gypsum plaster plant of the Rock Island Cement and Plaster Company at Ancho, in Lincoln County; bedded gypsum along the Pecos Valley, on the north edge of Mesa Jumanes, near the Rio Chama and along the western and southern edges of the Nacimiento Mountains, east of the Sandia Mountains, east of Socorro, along the San Jose Valley, on the eastern slopes of Lucero Mesa, and in the San Andres, eastern Oscura, Caballo, and San (Fra) Cristobal Mountains; and the gypsum dunes in the Tularosa Basin.

Jones (1904, p. 235-244) discussed the origin of gypsum in New Mexico; referred to deposits at Jones Camp, Ancho, and White Sands; discussed processing of gypsum and gypsite at Ancho; and listed analyses of gypsite from Ancho and of gypsum dune sands from White Sands. A later report by Jones (1915, p. 46-47) made brief mention of the occurrence of gypsum in the red beds of New Mexico and in White Sands, cited the construction of plaster plants at Ancho, Acme, Elida, and Oriental, and repeated the earlier analyses.

Darton (1920, p. 161-186) described the gypsum deposits of the State in the second national evaluation of gypsum published by the U. S. Geological Survey. His report noted all major deposits and listed numerous estimated sections of the gypsum-bearing formations, both from outcrops and from wells. Plaster plants were in operation at Ancho, at Acme (Chaves County), and at Oriental (Eddy County) at that time. Darton listed three chemical analyses and the quantitative result of a fourth. The 60-foot-thick bed of Todilto gypsum near Rosario siding on the Atchison, Topeka & Santa Fe Railway along Galisteo Creek (sec. 5, T. 14 N., R. 9 E.) was reported to contain 96.22 percent gypsum. East of Senorita, southeast of Cuba, in secs. 12 and 13, T. 20 N., R. 1 W., outcrops of the Todilto gypsum were reported to be 54 feet thick and to be underlain by 50 feet of white crystalline Todilto limestone. An analysis of this gypsum by W. T. Schaller (Darton, 1920, p. 182) is: calcium oxide 34.24 percent, sulfur trioxide 46.61 percent, water 18.89 percent, insoluble residue 0.18 percent, and loss 0.08 percent. The gypsum is indicated as being about 97 percent pure, the remainder apparently being mostly calcium carbonate.

Darton (1920, p. 186) also indicated two previously published analyses of the gypsum dune sand from White Sands National Monument. The analysis by Arthur Gross (Brady, 1905, p. 529-530) showed 96.43 percent gypsum present from 33.30 percent calcium oxide, 44.85 percent sulfur trioxide, 0.82 percent chlorine, 3.32 percent insoluble, and 17.71 percent water (by difference). An analysis by W. J. Gies (MacDougal, 1908, p. 16) listed 30.9 percent calcium oxide, 44.2 percent sulfur trioxide, 2.7 percent silica, 0.4 percent iron and alumina, 20.8 percent water, and 1.1 percent loss, indicating 95.8 percent gypsum.

Stratigraphic relationships of the gypsum deposits have been described in numerous accounts of areal geology of the State. Meinzer noted the gypsum beds and dunes in and near the Estancia Valley (1911), and those of the Tularosa Basin (Meinzer and Hare, 1916). Darton (1922, 1928) described the Statewide extent and local occurrences of the gypsum-bearing formations. Bates et al. (1947) mapped and described the Permian formations in the Gran Quivira quadrangle. Most of the geologic studies of areas of gypsum-bearing beds describe the general pattern of outcrop and thicknesses.

Gypsum processors in New Mexico were listed by Bowles (1925, p. 56) as the Certain-teed Products Corp., at Acme (Chaves County), and the Globe Plaster and Mining Co., at Carlsbad (Eddy County).

ACKNOWLEDGMENTS

Robert A. Zeller, Jr. wrote the description of gypsum deposits in the Big Hatchet Mountains area. Charles 0. Parker & Co. made the chemical analyses listed in Table 1.

Miss Shirley Farrar assisted in preparing the index.

Properties and Origin of Gypsum

Gypsum is a naturally occurring hydrous calcium sulfate whose composition conforms to the chemical formula $CaSO_4 \cdot 2H_20$. It crystallizes in the monoclinic system as tabular, prismatic, or acicular crystals, among which swallowtail and cruciform penetration twins are common. Crystals cleave into rhombic fragments which may be cleaved very easily in one direction into thin, flexible laminae. The characteristic cleavage and low hardness (2 on the Mohs scale, hence easily scratched by a fingernail) serve to distinguish gypsum from other common minerals. It is only slightly soluble in water, but is readily dissolved by hot hydrochloric acid without effervescence.

Among the several recognized varieties of gypsum, the most abundant is rock gypsum, a massive, opaque, granular variety that constitutes most of the gypsum used by industry. Rock gypsum usually consists of about 85 to 95 percent hydrous calcium sulfate admixed with various impurities, and ranges in color from white to dark gray, and from red to brown, honey yellow, and pink. Alabaster is a massive fine-grained white, or lightly tinted, slightly translucent variety of rock gypsum valued for carving and other ornamental uses. Crystalline varieties of gypsum include selenite, the relatively coarse transparent rhombic, tabular, or platy cleavable form; and satin spar, an aggregate of fine, parallel fibrous crystals with silky luster and pearly opalescence.

Anhydrite, the anhydrous calcium sulfate ($CaSO_4$), is a common associate of gypsum. Although anhydrite may closely resemble rock gypsum, the greater hardness of anhydrite (3.5 on the Mohs scale, hence harder than a fingernail) and higher specific gravity (anhydrite 2.98, gypsum 2.32) usually serve to differentiate the two minerals. Under the petrographic microscope, the indices of refraction of gypsum (1.520-1.530) are lower than balsam, whereas those of anhydrite (1.571-1.614) are higher than balsam. The weak birefringence of gypsum (0.010) contrasts with the very strong birefringence of anhydrite (0.043). The rectangular cleavage of anhydrite is another point of distinction.

Although some of the earlier investigators referred to many outcrops of gypsum in New Mexico as anhydrite, no significant outcrop occurrences of anhydrite were observed in the course of the present study. As noted by Adams (1944), the Permian calcium sulfate beds appear to be largely gypsum within 500 feet of the surface, and anhydrite below 500 feet. Similarly, the present writers have cited the prevalence of gypsum in outcrops of the Jurassic Todilto formation, whereas anhydrite appears to predominate at depth. These observations lead to the conclusion that the gypsum that prevails in outcrops of Permian and Jurassic beds in New Mexico is largely a product of near-surface hydration of anhydrite. More detailed considerations of the gypsum-anhydrite problem are presented by Posnjak (1938, 1940) and Douglas and Goodman (1957).

The gypsum-anhydrite beds of New Mexico are largely chemical precipitates deposited as a result of evaporation of saline waters in ancient seas of Pennsylvanian, Permian, and Cretaceous age, and inland lakes of Jurassic, Cretaceous(?), and Cenozoic age. Minor occurrences have been noted in metalliferous hydrothermal veins, as replacements of limestone wallrocks and calcite gangue accompanying supergene oxidation of sulfide deposits, in veinlets and stringers deposited by ground water, and in tufa deposits of hot springs.

Brief mention should be made of the nature and origin of gypsite, that almost ubiquitous associate of gypsum outcrops. Gypsite is an earthy or cellular type of gypsum formed by the same processes as common caliche, and by leaching and recrystallization of gypsum outcrops. The earthy type is soft, impure, and admixed with variable amounts of clay, silt, and carbonates. It forms in soils in semiarid regions by evaporation of calcium sulfate-rich waters drawn to or near the surface by capillary action. Gypsum is soluble to the extent of one part in 400 to 500 parts of water. As a consequence, leaching of outcrops by rainwater tends to produce a crust of spongy cellular gypsite, which is partly a residue of the gypsum bed, and partly reprecipitated gypsum. Earthy gypsite coats gypsum outcrops, occurs as small lenses or surface crusts downslope from gypsum beds, and is part of the alkali crust of numerous depressions fed by gypsiferous waters. The cellular gypsite (fig. 4A), which has a characteristic hollow sound when struck by a hammer, may indiscriminately cover thin beds of limestone and clastic rocks interbedded with gypsum, but does not appear to occur at any considerable distance from gypsum outcrops.

Gypsum Deposits in New Mexico

STRATIGRAPHIC OCCURRENCE

Bedded deposits of gypsum, other than sparse lenses and nodules, occur in the Upper Pennsylvanian Panther Seep formation; in the Permian Abo—Hueco formation, Epitaph dolomite, Yeso formation, San Andres formation, Chalk Bluff formation or Whitehorse group, Castile formation, and Rustler formation; in the Jurassic Todilto formation; in Lower Cretaceous strata; in Tertiary red beds; and as Quaternary lake deposits. Quaternary gypsum dune sands occur in quantity in the Tularosa, Estancia, Encino, and Pifios Wells Basins.

PENNSYLVANIAN PANTHER SEEP FORMATION

The upper Pennsylvanian sedimentary rocks in the San Andres Mountains differ greatly from correlative beds in adjacent mountainous areas; they were grouped accordingly as the Panther Seep formation by Kottlowski et al. (1956, p. 42-47). Fusulinid faunas suggest that this formation is entirely of Virgilian age. In the southern San Andres Mountains and northern Franklin Mountains, the Panther Seep formation includes two gypsum beds. Gypsum is also reported in a similar litho-logic unit from the R. H. Ernest, Located Land Company No. 1 oil test (Otero County, sec. 20, T. 25 S., R. 7 E.) near Newman, north of the New Mexico—Texas State line, and in the northern Hueco Mountains (Hardie, 1958, p. 43-45). If the gypsum beds were once relatively continuous, they outline a basin of gypsum deposition about 50 miles north-south and 20 to 25 miles east-west. The gypsum crops out in the San Andres Mountains from Bear Creek north to San Andres Canyon, and in the northern Franklin Mountains in western foothills southwest of Anthony Gap. The latter outcrops have been quarried by the El Paso Cement Co. The upper, thick gypsum bed (or zone of gypsum lenses) is 65 to 100 feet thick in the San Andres Mountains, but only 10 to 35 feet thick in the northern Franklin Mountains, where in places it abruptly grades into gypsiferous limestone with large nodules of gypsum.

PERMIAN ABO-HUECO FORMATIONS

South of New Mexico Road 33, the route from Paxton siding to Piñon in south-central Otero County, outcrops of the Hueco, Abo, and Yeso formations are exposed on the west edge of Otero (Horse) Mesa. Abo red beds form an east-dipping cuesta at the base of the mesa, are about 170 feet thick, and are overlain by typical interbedded gypsum, pale-orange silty sandstone, and silty limestones of the Yeso formation. The Abo is chiefly of light-brown to dark reddish-brown and dusky-red hard siltstones and soft shales, with some lenses of sandstone and intraformational conglomerate. At the base of the typical Abo red beds is a 25-foot bed of gypsum; below the gypsum bed, typical Hueco limestones form low cuestas on the edge of the Tularosa Basin. The gypsum beds are an evaporate phase of the Abo—Hueco intertonguing and could be expected under such depositional conditions. The relatively thick gypsum bed continues to the south beneath Abo red beds but cannot be traced into the Hueco formation in the Hueco Mountains because outcrops are lacking. Darton (1928, p. 220) found a laterally correlative gypsum bed beneath red shale to the south near Owl Tanks (sec. 1, T. 25 S., R. 10 E.), although he believed that the clastic and gypsiferous beds of the Abo and Yeso pinched out southward and that the Yeso—San Andres limestones graded into Permian limestones that are now called upper Hueco or the Bone Springs formation.

Bachman and Hayes (1958) named this red-bed sequence, at the west base of the northern tip of Otero Mesa, the Otero Mesa member of the Yeso formation. The red beds were placed in the Yeso formation because they are underlain by gypsum beds. Obviously, however, they are not similar to the basal pinkish clastic rocks in the Yeso formation of Culp and Sand Canyons, about 5 miles to the north-northeast, as the Otero Mesa member was not recognized to the north by Bachman and Hayes. Unfortunately, the critical Abo—Yeso contact is covered within the 5-mile stretch from Culp Canyon south-southwestward, so that lateral walking out of the beds is impossible. The red beds appear more typical of Abo color and lithology than Yeso clastic beds and are, therefore, believed by Kottlowski to be an Abo tongue. Whether they are a time-equivalent of upper Abo red beds or lower Yeso units near Culp Canyon is a matter of conjecture that is not important unless one applies a strict time sense to the terms Abo and Yeso rather than a lithologicunit concept.

If the dark red beds of Otero Mesa are called an upper Abo tongue, perhaps the gypsum beneath the red beds should be labeled a lower Yeso tongue. The gypsum beds appear, however, to grade downward and are interbedded with gray shales and dolomitic limestones of the Hueco formation, and appear to be an upper phase of the Hueco rather than a lower part of the Yeso formation.

PERMIAN EPITAPH DOLOMITE

In the Big Hatchet Mountains of southwesternmost New Mexico, a dolomite unit within the 8,000-foot Pennsylvanian—Permian carbonate-rock sequence has been correlated by Robert A. Zeller, Jr. (personal communication) with the Epitaph dolomite (Leonard?) of southeastern Arizona. Gypsum beds in one area may be 200 to 300 feet thick, although exposed under thrust sheets; many thin to thick anhydrite beds were encountered in the Epitaph dolomite in the Humble State No. IBA oil test southwest of the Big Hatchet Mountains.

PERMIAN YESO FORMATION

Yeso is the Spanish word for gypsum, and the formation is aptly named as it contains the majority of the gypsum beds in the State. However, many of the beds are thin or include interbeds of pinkish clastics and silty limestones. The type section, southeast of Mesa del Yeso, 15 miles northeast of Socorro, is about 700 feet thick (Needham and Bates, 1948, p. 1658-9), including the basal Meseta Blanca member. Sandstone makes up 58 percent of the type section, shale and siltstone 20 percent, gypsum 12 percent, and limestone 10 percent. Near the type locality of the San Andres formation in the San Andres Mountains, the Yeso is about 1,580 feet thick, and sandstone composes 42 percent of the formation, gypsum 40 percent, limestone 17 percent, and shale only 1 percent.

The upper beds of the Yeso formation are typically soft crosslaminated pink, orange, or yellow sandstone called the Joyita sandstone member. Beneath the Joyita member in south-central New Mexico is the Cafias gypsum member, which ranges from 50 to 115 feet in thickness from Mesa del Yeso southeastward to the northern Sacramento Mountains, and from 50 to 170 feet thick on Chupadera Mesa. The middle beds of the formation, the Tones member, include many thin to thick gypsum beds, but the lower Meseta Blanca sandstone is relatively barren of evaporites.

The base of the Yeso formation was originally placed by Lee (1909, p. 12) at the base of the first marine limestone above a considerable thickness of Permian red beds. In places, however, the basal limestones are seen to pinch out amid clastic beds, and in places there are gypsum beds beneath the lowest Yeso limestone. Further, a mappable sequence of pinkish apparently marine sandstone and siltstone below the marine precipitates appears more closely allied in origin to the Yeso than to the Abo, and contrasts strongly with the coloring and sedimentary features of the Abo red beds. This lower member of the Yeso, the Meseta Blanca member, is gradationally conformable on the darker red Abo beds.

In most of central New Mexico, the Yeso is overlain conformably by the resistant light-gray to yellowish-gray Glorieta sandstone. The contact in most sections is a gradational transition from pink and orange sandstone of the Joyita member to the light-gray and yellow sandstone of the Glorieta. In the southern Chupadera Mesa area, tongues of Yesolike gypsum, pinkish sandstone, and limestone occur in the lower part of the Glorieta sandstone, and the southward thinning of the Glorieta appears due to intertonguing with the Yeso formation. In the San Andres, Sacramento, and Caballo Mountains, the gradational contact between the Yeso and San Andres formations is placed at the base of a dominantly limestone sequence above a sequence of interbedded sandstone, limestone, and gypsum. Above the contact, in the upper part of the Yeso, or in the lower part of the San Andres formation in these southern ranges, there are in places one or several yellowish sandstones that have been referred to the Glorieta. Where traced along the outcrop in some localities, these Glorieta-like sandstones are seen to be tongues of differing areal and stratigraphic extent.

In north-central New Mexico, the gypsum beds of the Yeso formation pinch out amid a predominantly clastic sequence. Outcrops of the Yeso in the northern Zuni Mountains, Sierra Nacimiento, and foothills of the Sandia Mountains, on Glorieta Mesa, and near Las Vegas contain only thin (1-5 feet) lenses or laminae of gypsum. Southwestward from central New Mexico, the Yeso formation loses most of its gypsum, so that in the Sierra Cuchillo and the southern San Andres Mountains the Yeso formation consists of sandstone, siltstone, and limestone.

Regional study of the Abo, Yeso, Glorieta, and San Andres formations shows considerable lateral and vertical intertonguing of the formations, and it should be expected that the formational contacts cross time lines. Isopachous maps and lithofacies maps of the units will vary greatly, depending on the definitions applied to the formations and the contacts chosen.

The Briggs formation (Albritton, 1938) in the Malone Mountains of western Texas is a possible correlative of the Yeso; gypsum beds of the Briggs formation are quarried by the Southwestern Portland Cement Co. near Finlay, Texas, for use in El Paso.

PERMIAN SAN ANDRES FORMATION

At the type locality of the San Andres formation, west of Rhodes Pass in the San Andres Mountains, the formation is about 600 feet thick and consists of gray to dark-gray medium-bedded to massive fetid fossiliferous limestones. Yellowish silty calcareous sandstone lenses occur locally near the base and are possible southern extensions of the Glorieta sandstone. From the southern edge of Chupadera Mesa northward to Glorieta Mesa, the Glorieta sandstone thickens and is a prominent mappable unit. In much of central New Mexico, the San Andres formation has been thinned by post-Permian erosion to an average of 400 to 650 feet; northward, thinning of the marine facies is depositional, only about 20 feet of limestone being present on Glorieta Mesa, and 80 to 115 feet in the northern Zuni Mountains (Smith, 1954, p. 7-8). In the subsurface of southeastern New Mexico, Skinner (1946) reported 1,000 feet attributed to the San Andres formation, whereas Boyd (1958, p. 22) measured only 570 feet in the central Guadalupe Mountains.

In northeastern Socorro County, northeast of Mesa del Yeso and west and southeast of Mesa Redonda, thick gypsum beds are reported by Wilpolt and Wanek (1951) in the San Andres formation. Schmalz (1955) reported numerous gypsum beds in the San Andres formation of the Phillips Hills near Three Rivers, western Lincoln County. Jicha (1958, p. 15-17) noted numerous thick gypsum beds in the formation east of Mesa del Oro in south-central Valencia County. Gypsum is also a prominent component of the San Andres in the broad plains region extending eastward and northeastward from Chupadera Mesa, particularly in Lincoln and Guadalupe Counties. Outcrops were noted west of Carrizozo, near Ancho, and in the Vaughn area.

PERMIAN WHITEHORSE GROUP

Guadalupian back-reef beds of southeastern New Mexico above the San Andres formation are referred to the Whitehorse group by most petroleum geologists, and to the Chalk Bluff formation/group by the U. S. Geological Survey, although Bernal formation has been applied to stratigraphically similar beds in the area from Santa Rosa northwestward to Las Vegas. The Whitehorse group and correlative reefs crop out in the Guadalupe Mountains and adjoining foothills, with back-reef beds exposed along the Pecos Valley north from about Carlsbad. In ascending order, the formations of the Whitehorse group are: (1) Grayburg formation, (2) Queen sandstone, (3) Seven Rivers formation, (4) Yates sandstone, and (5) Tansill formation. The Queen and Yates are chiefly sandstone units, whereas the Grayburg, Seven Rivers, and Tansill include mostly dolomitic limestone and gypsum/anhydrite. Northwest of Carlsbad, there is a considerable amount of gypsum and red beds in the Seven Rivers formation; as described by Bates (1942), this red bed-gypsum sequence, about 440 feet thick along Rocky Arroyo, grades abruptly into limy dolomite in a southeast and south direction. Gypsum beds of the Seven Rivers and Tansill formations crop out in relatively accessible localities west of Carlsbad, and along the east side of the Pecos Valley from Carlsbad north to within a few miles of Yeso Arroyo in central De Baca County; poorly exposed gypsum beds of these formations also crop out west of the Pecos Valley on the long dip slope from the Sacramento Mountains. In places the gypsum beds are near or at the surface over large areas, and probably could be mined economically in shallow pits. The gypsum beds are relatively thin, grade laterally into dolomitic limestone and red beds, or in many localities pinch out abruptly. To the north and northwest, the gypsiferous beds grade into red-bed clastics named the Bernal formation.

PERMIAN OCHOAN SERIES

The Ochoan series is best developed in the Delaware Basin of southeastern New Mexico and west Texas (Adams, 1944). The series consists of, in ascending order, the Castile, Salado, Rustler, and Dewey Lake formations. The Castile formation was deposited only within the Delaware Basin and does not extend beyond the Permian boundaries of that basin. The formation consists of gypsum/anhydrite, calcite-banded anhydrite, halite, and minor amounts of limestone; the thickness is about 1,500 to 2,100 feet. The calcite-banded gypsum is characteristic of the formation; these typical banded calcium sulfate beds crop out along U. S. Highway 62-180 in the Yeso Hills just north of the New Mexico—Texas State line in southern Eddy County. Adams reported (1944,

p. 1604) that the calcium sulfate precipitates are gypsum within about 500 feet of the present surface but are anhydrite at depths below 500 feet.

The Salado formation consists chiefly of halite, with lesser amounts of anhydrite, potash salts, dolomite, magnesite, and some red to gray sandstone, siltstone, and shale. The Salado formation does not crop out in New Mexico, but there are a few poorly exposed patches of its gypsum beds to the south, in Texas, along the west edge of the Rustler Hills.

The Rustler formation rests unconformably on the older Permian strata, the Salado having been removed in many areas by solution before deposition of the Rustler. Adams (1944, p. 1613) noted two subdivisions of the Rustler in the subsurface; a lower sequence of sandstone, shale, dolomite, and anhydrite, and an upper anhydrite-gypsum unit. Outcrops of the Rustler formation in the Frontier Hills, 10 to 15 miles southwest of Carlsbad, and east of the Pecos River from the State line to northeast of Carlsbad, are chiefly of gypsum, dolomite, and red beds. The rocks are poorly exposed, except in some of the stream-cut bluffs, although in places relatively thick gypsum beds may underlie thin overburden.

The Dewey Lake formation consists of red beds—pale reddish-brown shales and orange sandstones. Gypsum occurs only as cement or veins.

JURASSIC TODILTO FORMATION

The Upper Jurassic Todilto formation is limited to northwestern and north-central New Mexico, having been deposited in a restricted lacustrine basin. The equivalent Pony Express member of the Wanakah formation occurs on the southwestern flanks of the San Juan Mountains in southwestern Colorado; to the northwest, in Utah, the Curtis marine facies is correlative, although deposited in a marine basin separated from that of the Todilto. The formation consists of dark-gray laminated limestone and gypsum, with laminae of limy shale. Gypsum occurs chiefly in the central one-third of the basin, overlying limestone beds. Contact with the underlying Entrada sandstone is locally gradational, as is the contact with the overlying Summerville formation. Where overlain by the Morrison formation, the contact is largely intergradational.

Outcrops of the Todilto gypsum beds occur around the southeast, east, and northeast sides of the San Juan Basin; along Galisteo Creek, near Rosario siding; southeast of Galisteo; on and near the Tejon Grant, east and northeast of Placitas; and in the Tijeras Basin, north of Tijeras. From the Mesa de los Viejos—Mesa Prieta area along the Chama River canyon south to San Ysidro, and from Mesita along Rio San Jose east to Tijeras and Lamy, the gypsum member of the Todilto formation is 50 to 100 feet thick and in many localities crops out in broad benches without overburden, or beneath a relatively thin overburden of the soft shales and sandstones of the overlying Summerville, Wanakah, and/or Morrison formations. The Todilto formation is an excellent stratigraphic marker of limestone and gypsum amid the repetitious sequence of sandstones and shales of the Triassic and Jurassic.

CRETACEOUS GYPSUM BEDS

In the Big Hatchet Mountains area of southwestern New Mexico, Robert A. Zeller, Jr., reported (personal communication) several thick beds of gypsum in the lower part of the Lower Cretaceous strata. The gypsum beds are at the top of a red-bed sequence, the Hell-to-Finish formation (Zeller, 1958), and just below massive to thin-bedded limestone of the U—Bar formation.

TERTIARY GYPSUM BEDS

Tertiary gypsum beds occur in the southern Robledo Mountains along Apache Canyon, 5 miles northwest of Las Cruces. Gypsum occurs as laminae, thin interbeds with reddish claystone and grayish latitic tuff, and as 1- to 10-foot-thick beds. This sequence of red beds, gypsum, and tuff includes a basal limestone-boulder conglomerate that is unconformable on Permian Hueco limestone and that grades up into an andesitelatite volcanic rock sequence of possible Miocene—Pliocene age. The gypsiferous tuffaceous red beds may be of Lower Cretaceous age, similar to the Hell—to—Finish formation of the Big Hatchet Mountains area, but appear younger, being less consolidated, less altered, and apparently conformable beneath mid-Tertiary volcanic rocks. This Apache Canyon unit includes lithologies similar to the Palm Park formation of the Caballo Mountains area, and to the Love Ranch formation of the San Andres—Organ Mountains; these latter formations are unconformable on strata ranging from Pennsylvanian to Upper Cretaceous in age.

QUATERNARY GYPSUM BEDS AND DUNES

Numerous gypsite crusts cover, or are adjacent to, outcrops of all the gypsum beds. The gypsite varies from gypsiferous soil to hard, crystalline, cellular layers, and is mostly a product of recent weathering of older gypsum beds or dunes. Wind-blown gypsum sands occur east of areas of extensive gypsum or gypsite outcrops but are present in quantity only in the Tularosa Basin, which contains the famous white sands of White Sands National Monument and adjacent areas, and in the Estancia, Encino, and Piños Wells salt basins of central and southeastern Torrance County. Quaternary (and late Tertiary?) gypsum beds occur in the Tularosa Basin, cropping out at the surface near Lake Lucero and beneath as much as 15 to 25 feet of reddish-brown clay and silt in the lower parts of the basin. Some of the massive structureless gypsum beds may have been formed as a calcium sulfate "caliche" by evaporation of near-surface waters that contained a large concentration of calcium sulfate. The gypsum beds bordering Lake Lucero, and those to the north around Alkali Flat, are well bedded and include laminae of silt and clay, suggesting their deposition as saline-lake beds. These gypsum beds are the source of the White Sands, which are the fourth-cycle deposits whose primary source was the Permian gypsum beds in the San Andres, Oscura, and Sacramento Mountains, the secondary source having been gypsiferous waters draining from the mountains into Lake Lucero and Alkali Flat. The white gypsum sands are broken particles of the gypsum lake beds, blown by the prevailing westerly winds into extensive dunes east of the gypsiferous playas.

AREAL DISTRIBUTION

Gypsum of potential commercial value crops out in all parts of the State, except the northeastern, west-central, and far northwestern portions. Deposits of considerable size and those near areas of possible large demand (irrigated valleys, cities, railroad sidings) are described in some detail, whereas the smaller deposits, and those remote from users, are noted only briefly.

NORTHEASTERN NEW MEXICO

Studies of northeastern New Mexico by Brewster Baldwin and numerous other geologists, have disclosed only nodules, laminae, and veinlets of gypsum, chiefly within the Todilto limestone and overlying Wanakah formation. No thick gypsum beds are exposed as surface outcrops.

NORTH-CENTRAL NEW MEXICO

Deposits of rock gypsum in the Jurassic Todilto formation in Rio Arriba, Sandoval, and Santa Fe Counties constitute some of the most important reserves in the State. Lesser deposits occur in the Todilto formation in Bernalillo County, and in the Permian Yeso and San Andres formations in Santa Fe and San Miguel Counties.

San Ysidro—Cuba Region

Massive gypsum in the Todilto formation crops out in a nearly continuous band along the western and southern margins of the Nacimiento Mountains in Sandoval County, where thicknesses ranging from 50 to 100 feet have been reported (Darton, 1920, p. 181; Kirkland, 1958, p. 25).

As shown by Wood and Northrop (1946), the outcrop, owing to the steep westward dip of the beds, is very narrow from the vicinity of Senorito Canyon, about 4 miles southeast of Cuba, southward to latitude 35°39.5' N. Folding along the footwall of the north-trending Nacimiento thrust fault is responsible for these attitudes. Southward from latitude 35°39.5' N. through the Ojo del Espiritu Santo Grant, and eastward across White Mesa, the dip flattens and the outcrop broadens to widths of nearly 1 mile. North-trending faults locally interrupt the continuity of exposure and terminate the surface extent of the Todilto formation at the eastern edge of White Mesa, 2 miles south of San

Ysidro, where it dips generally southward under cover of the Morrison formation. Northward from Senorito Canyon, exposures of the Todilto formation are patchy and of smaller extent, owing to the complexity of dislocations along the Nacimiento fault zone, and an extensive cover of late Tertiary to early Quaternary sediments.

Throughout its extent in this area, the Todilto formation consists largely of a massive white to pale-gray gypsum member above, with a thin member of thinly laminated gray to brownish-gray fetid shaly limestone at the base. The contact between the two members consists of a transitional zone of interlaminated gypsum and shaly limestone, which ranges from 25 to 40 feet in thickness on White Mesa (Kirkland, 1958, p. 26). Wood and Northrop (1946) state that thin beds of limestone also overlie the gypsum member. According to Kirkland (1958, p. 39-42, fig. 24), a gypsum-shale unit immediately overlies the massive gypsum. In sec. 18, T. 15 N., R. 1 W., this unit consists of 14 feet of red, reddish-brown, and green shales overlain by 31 feet of cyclicly interbedded coarsely crystalline gypsum and calcareous shale.

Most of the massive gypsum in this area appears in the outcrop to be of high quality. Darton (1920, p. 182) lists an analysis of a sample from west of the San Miguel mine showing 97 percent gypsum. A similar purity is indicated for a sample from near La Ventana (T. D. Benjovsky, 1946, unpublished report, N. Mex. Bur. Mines and Mineral Res.). Samples from White Mesa and the Ojo del Espiritu Santo Grant contained 95.0 and 97.8 percent gypsum respectively.

Although no anhydrite was recognized in the outcrop portions of the Todilto formation seen during the course of the reconnaissance for this report, an examination of drill cuttings from two oil well tests indicated that anhydrite is the major calcium sulfate mineral where the Todilto is protected by several hundred feet or more of bedrock cover. In Avila Oil Company's No. 1 Odlum, sec. 15, T. 15 N., R. 1 W., the Todilto was logged in the interval from 730 to 900 feet, most of which is shown by the cuttings to be anhydrite. Similarly, in Humble Oil and Refining Company's No. 1 Santa Fe B, the Todilto was logged at 1,150 to 1,244 feet, and the cuttings are largely anhydrite. Anhydrite was also identified by Kirkland (1958, p. 31) in cuttings from a prospect drill hole on White Mesa at a depth of 40 to 45 feet below the Todilto outcrop surface. The presence of anhydrite, and possibly some free sulfur, is also suggested by analysis No. 3, Table 1. One may conclude that anhydrite is the principal mineral constituent of the Todilto "gypsum" at depth in this area, and that the gypsum which prevails in the outcrop is a product of hydration under atmospheric or near-surface conditions.

In the San Ysidro—Cuba region, the Todilto formation is underlain by massive cliff-forming sandstone that is of prevailing red color in its lower portion, with a thin zone of pale-gray to yellowish-brown color at the top. This unit is now generally designated the Entrada sandstone (Wingate sandstone of earlier reports). The Todilto is overlain by shales, siltstones, and sandstones of the Morrison formation, the lower portion of which forms weak slopes above the gypsum. The gypsum-shale unit at the top of the Todilto is interpreted by Kirkland (1958, p. 44) as a zone of transition from the underlying evaporite sequence into the dastic sequence of the Morrison.

White Mesa deposit. White Mesa (actually a cuesta of gentle slope) derives its name from its nearly white caprock of massive gypsum, which constitutes most of the Todilto formation in this area. The main outcrop forms an arcuate band from 1/5 to 8/4 mile wide and 3 miles long in secs. 11, 13, 14, 15, 16, 21, and 22, T. 15 N., R. 1 E. The cuesta is bounded by a steep cliff facing the Rio Salado toward the north (pl. 2A) and has a gentle dip slope of about 4 degrees toward the south. A pair of north-trending faults, downthrown on the east, form the eastern limit of outcrop. The western margin is marked in part by a fault of similar trend, downthrown on the west, that dies out southward in an anticlinal fold. A fourth fault, downthrown on the west, offsets the central portion of the deposit (see fig. 1).

The surface of White Mesa consists of barren hummocks of gypsum surrounded by shallow depressions that are floored with a few feet of crystalline gypsite and windblown gypsum sand (pl. 2B). In common with the previously described stratigraphic features of the formation in the surrounding region, the Todilto here consists of a basal laminated shaly limestone member that ranges from 6 to 12 feet thick (Henry Birdseye, personal communication, February 1958); a transition zone of interlaminated gypsum and thin shaly limestone 25 to 40 feet thick (Kirkland, 1958, p. 26); a massive gypsum member with a residual thickness of approximately 55 feet on the upper part of White Mesa; and an upper gypsum-shale unit that is transitional into the overlying Morrison formation (Kirkland, 1958, p. 39-42). The underlying Entrada sandstone forms steep cliffs, below which are landslide slopes of the Chinle formation.

The massive gypsum member of the Todilto formation, which forms most of the cuesta surface, appears to be of good quality, as is further indicated by analyses Nos. 2 and 3 of Table 1. Sample No. 2 consisted of drill-hole cuttings of the upper 55 feet of gypsum from the NW I/ sec. 13, T. 15 N., R. 1 E., with a calculated gypsum content of 95.0 percent. Sample No. 3 consisted of drill-hole cuttings of the entire residual portion of the Todilto formation (induding the basal limestone member and transition zone) from a location adjoining that of Sample No. 2. The calculated gypsum content of sample No. 3 is 92.3 percent; the higher CaO and CO_2 contents reflect inclusion in the sample of the basal limestone and transition beds, which undoubtedly would be excluded from any commercial operation designed to exploit the gypsum.

The deposit is readily accessible from the east side by a dirt road extending westward from N. Mex. Highway 44 about 2 miles south of San Ysidro. The total distance from the eastern margin of the deposit

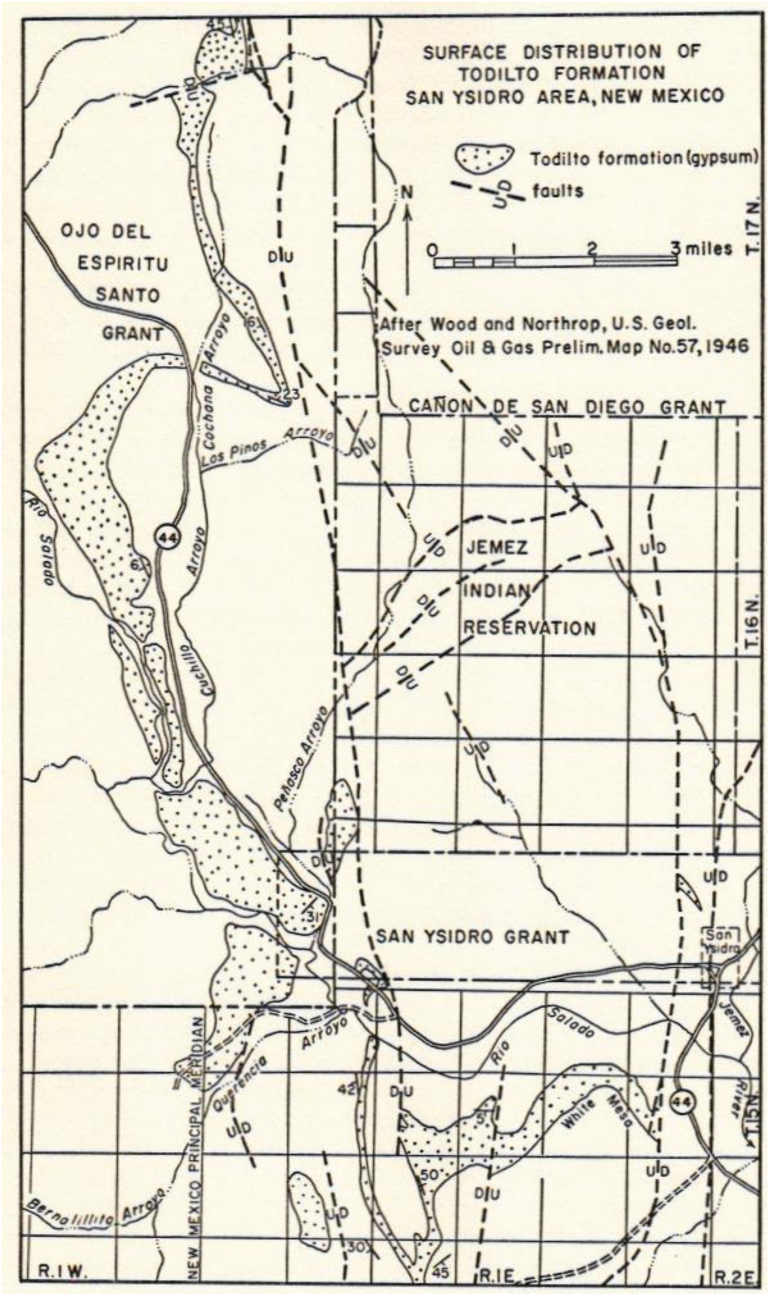


Figure 1

SURFACE DISTRIBUTION OF TODILTO FORMATION, SAN YSIDRO AREA to the nearest railhead at Bernalillo is approximately 23 miles via N. Mex. 44, an all-weather paved highway. Ease of access, coupled with the availability for open-pit mining of very large tonnages of good quality gypsum without overburden, makes this deposit one of the most promising for commercial development of those examined during the course of this survey. A small pit at the southeastern edge of the deposit has, according to Mr. Henry Birdseye (personal communication, February 1958), yielded a small-scale intermittent production of gypsite for agricultural use on nearby Indian Reservation lands.

At the time of the writer's visit (February 1958), the White Mesa deposit was being explored by rotary drilling on a large group of claims held by L. D. Lowery and H. L. Barbour, of the White Mesa Mining Association.

A press release (Albuquerque Journal, 9 June 1959) has announced plans for construction by the American Gypsum Co., of a gypsum-products plant immediately north of Albuquerque, scheduled to be in operation by late 1960. Products will include 100 million square feet of 3/8-inch wallboard and 15,000 tons of sheathing annually, in addition to lath rough, finish plasters, and agricultural gypsum. Raw gypsum will be obtained from a 1,180-acre site on White Mesa that contains measured reserves of 98 million tons and an additional 123 million tons available by stripping relatively thin overburden.

Deposits in Ojo del Espiritu Santo Grant. Massive Todilto gypsum is extensively exposed on the surface and cliff face of a gently west-dipping cuesta that extends from latitude 35°39.5' N. (southeastern corner of unsurveyed T. 17 N., R. 1 W.) southward for a distance of about 9 miles (see fig. 1). The outcrop reaches a maximum width of about 0.9 mile. The underlying Entrada sandstone forms a nearly vertical east-facing cliff along the eastern margin of the cuesta. The area is drained by the Rio Salado and its tributaries, which have cut the cuesta into 5 major segments that range in area from approximately 0.16 to 1.15 square miles.

Throughout most of its extent, the gypsum presents a nearly barren outcrop mantled by only a few feet of the usual cellular gypsite crust, local small patches of earthy gypsite and alluvial and windblown sands, and a very sparse vegetative cover of grasses, piñon, and juniper.

Most of the gypsum appears to be of good to excellent quality. It is largely white and crystalline. Beds containing thin reticulate seams of shaly limestone are more prominent in the lower than in the upper portion. The thin limestone member described previously is at the base of the gypsum sequence. Analysis No. 1 of Table 1 represents a grab sample from blocks thrown out during excavation of a pipeline trench in the extreme southeastern corner of the Grant. As calculated from the analysis, the gypsum content is 97.8 percent.

The accessibility of these deposits via N. Alex. 44, an all-weather paved road that closely parallels most of the belt of outcrop, coupled

A

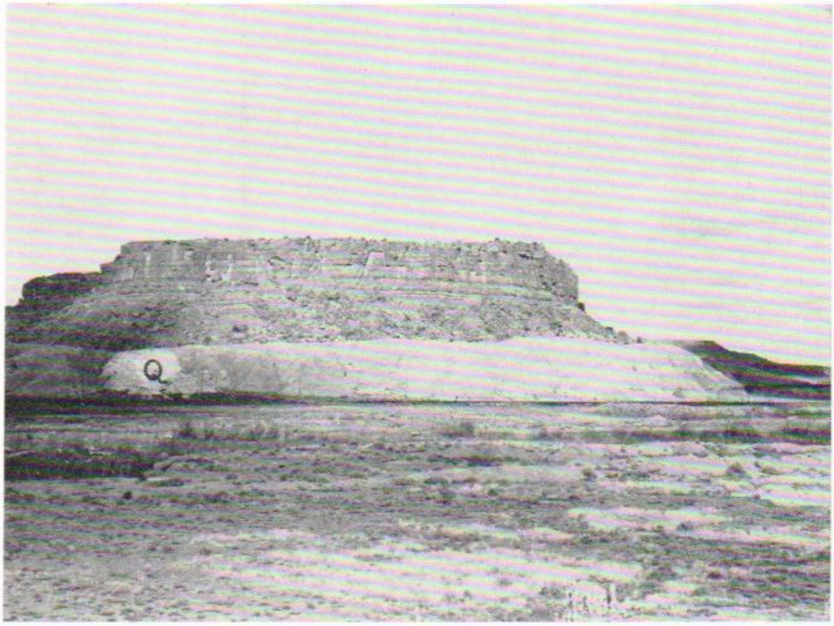
B

Plate 2

A. Northern face of White Mesa.

B. Eroded surface of massive gypsum in Todilto formation, White Mesa.

A



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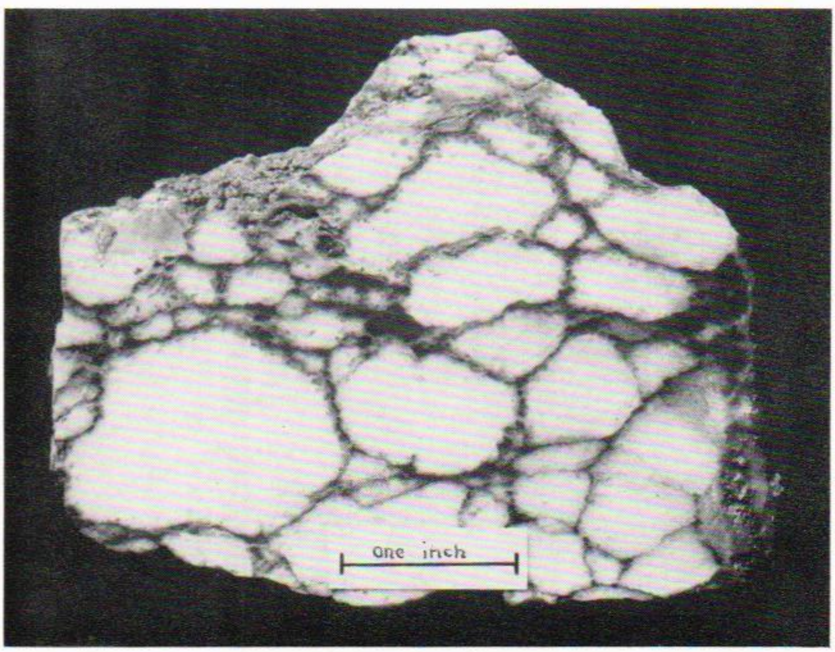
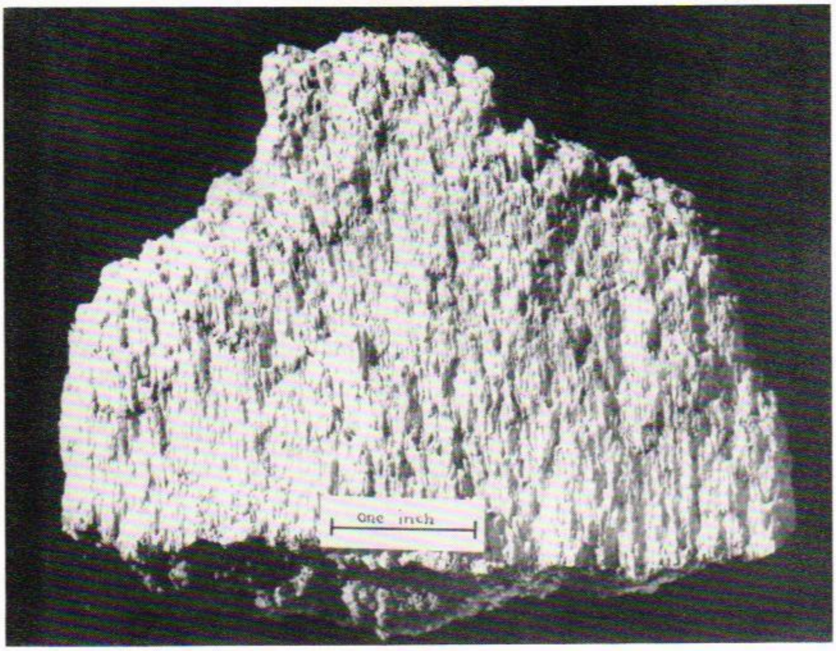


Plate 3

A. Mesita deposit.

B. Gypsum from San Andres formation, Vaughn quarry.



A

B

Plate 4

A. Crystalline gypsite, Mesa del Yeso.

B. Stabilized gypsum dune sands, Piños Wells Basin.

A

B

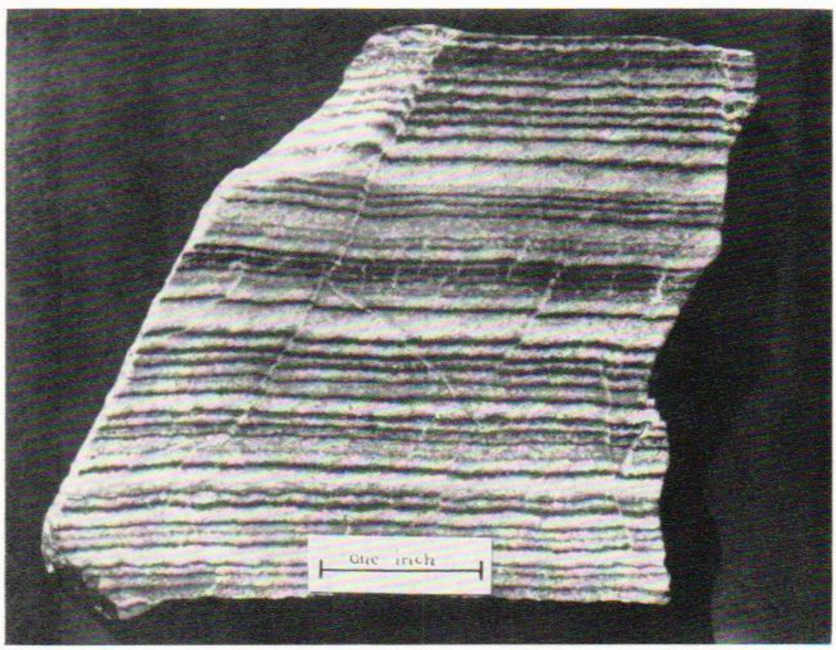


Plate 5

A. Gypsum sand dunes, White Sands National Monument.

B. Laminated gypsum from Castile formation, Yeso Hills.

with the very large tonnage of gypsum that could be cheaply developed for open-cut mining, will encourage their future exploitation. The nearest railhead, at Bernalillo, is about 30 highway miles from the southeasternmost segment of these deposits.

Gallina—Rio Chama Region

The outcrop belt of Todilto gypsum described from the San YsidroCuba region is interrupted by covered intervals northeast of Cuba. It reappears at the surface in the faulted tract southwest of Gallina in Sandoval and Rio Arriba Counties, encircles Mesa Prieta, and continues for a number of miles along both walls of the Chama River canyon, terminating against a fault several miles northwest of Abiquiu (Darton, 1920, fig. 33, pl. XXI; 1928, pl. 37).

Throughout most of the region, the gypsum is exposed largely in cliffs and steep slopes, only locally forming broad benches suitable for open-cut mining (Darton, 1920, p. 179-181). Thicknesses range from 50 to 65 feet, and the quality is reported to be high. An outcrop at Cerro Blanco, near Gallina, has produced a small amount of gypsum for local use (presumably as plaster for finishing interior walls of homes).

The remoteness of this area from centers of consumption and the lack of nearby rail transport facilities make it less attractive for commercial exploitation than deposits in the San Ysidro—Cuba region.

Galisteo Creek—Arroyo Tongue Region

Massive gypsum comprises the major portion of the Todilto formation in two narrow belts of outcrop southwest of Santa Fe, in eastern Sandoval and western Santa Fe Counties (fig. 2). One of these belts extends southward from near U. S. Highway 85 past Rosario siding, and into the Ortiz Mine Grant 4 miles west of Madrid. The other extends from the north bank of Arroyo Tongue southward and southeastward to its terminus 2½ miles southeast of Hagan. Smaller outcrops appear a short distance south and southwest of Placitas. According to Stearns (1953, p. 465), the gypsum in this region ranges from 40 to 60 feet in thickness.

At several localities, the gypsum forms low benches or cuestas of moderate dip, with little or no overburden, suggesting the possibility of low-cost, open-cut mining. Two of the more readily accessible deposits (Rosario and Tongue) are briefly described below. The geology of the area is discussed more fully by Stearns (1953).

Rosario deposit. Immediately adjoining milepost 859, near Rosario siding on the Atchison, Topeka & Santa Fe Railway, the Todilto formation caps a low cliff of red to buff Entrada sandstone. At this point, the gypsum member of the Todilto forms a bench dipping gently eastward, several hundred feet wide and barren of overburden; it then extends eastward under overlying siltstones, mudstones, and sandstones corre-

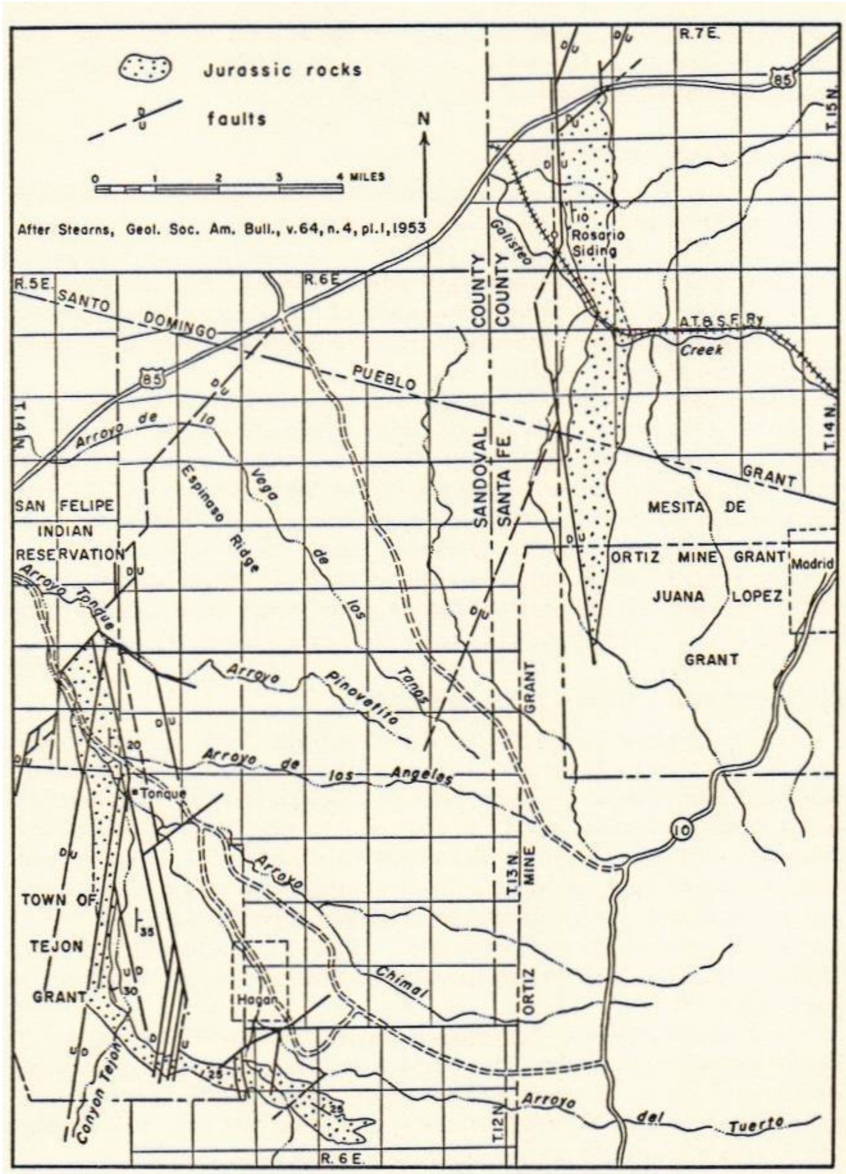


Figure 2

SURFACE DISTRIBUTION OF JURASSIC ROCKS, GALISTEO-TONQUE REGION lated by Stearns (1953, p. 465) with the Wanakah and Morrison formations.

Northward, the gypsum outcrop is topographically less prominent and at many places is covered by several tens of feet of gypsiferous, calcareous sands and silts of the Santa Fe group. It is cut off on the west by the north-trending Rosario fault, and on the north by a fault of northeastward trend. Patches of gypsum and white, locally yellow-stained, crystalline, very friable gypsite are present on the western (hanging-wall) side of the Rosario fault.

Southeastward from milepost 859, the Todilto closely parallels the railroad for three quarters of a mile and is covered by the fill of Galisteo Arroyo. It reappears and continues southward for several miles, finally terminating against the Rosario fault. The outcrop south of Galisteo Creek is characterized by a broader surface of low relief, owing to the flatter dip and less pronounced entrenchment of the drainage along the west edge of the outcrop.

The Todilto formation in this area consists of the usual thin limestone member at the base, succeeded upward by a transitional zone of gypsum with crenulate laminae and reticulate seams of limestone that grades upward into massive white gypsum with thin, widely spaced reticulate seams of limestone. The gypsum is 60 feet thick (Darton, 1920, p. 177).

The portion of the gypsum member above the transition zone appears to be of good quality. An analysis by A. A. Chambers showed a $CaSO_4 \cdot 2H_2O$ content of 96.22 percent (Darton, 1920, p. 177). A sample cut by T. D. Benjovsky in a waterworn crevice across the entire thickness of the massive gypsum was analyzed by R. A. Matuszeski, with the following results (T. D. Benjovsky, 1946, unpublished report, N. Mex. Bur. Mines and Mineral Res.):

	Percent
CaO	28.50
SO_2	40.21
Fe_2O, and Al_2O_3	tr.
SiO_2 and insoluble	2.64
MgO	0.13
H_2O (combined)	19.70
H_2O (free)	8.00
Total	99.18
$CaSO_4 \cdot 2H_2O$ (talc.)	93.3

The portion of the deposit adjoining the railroad southeast of Rosario siding is reached from U. S. Highway 85 by driving up the bed of Galisteo Creek, or following a poor trail along the south bank of the creek, for a distance of a little over 2 miles. Construction of an access road would be facilitated by the low relief of the area, although several arroyos must be crossed. Santa Fe is about 23 road miles to the northeast, and Albuquerque is about 39 miles to the southwest by all-weather paved highway. An 8-inch branch gasline of the Southern Union Gas Co. passes to the west of the deposit a short distance south of U. S. Highway 85.

According to a press release (Albuquerque Journal, 7 August 1959), the Kaiser Gypsum Co. has announced plans to build a gypsum processing plant adjoining the Rosario deposit. The plant is scheduled to go into production in June 1960, with an annual output of 120 million square feet of gypsum board. A mine production rate of 220 cars of crude gypsum per month is anticipated. Construction of a 1,500-foot spur track will provide rail transport from the plant to the main line of the Atchison, Topeka & Santa Fe Railway.

Tongue deposit. The stratigraphic sequence that includes the Todilto gypsum in the Rosario deposit is repeated by faulting in the drainage area of the Arroyo Tongue, about 10 miles to the southwest (fig. 2). Along the Arroyo Tongue, a short distance west and northwest of the ruins of Tongue Pueblo, gypsum crops out in a narrow bench tilted toward the east (fig. 3). The northern terminus, in sec. 1, T. 13 N., R. 5 E., is against a northeast-trending fault, downthrown on the northwest. Southward, the Todilto is covered by fill in the Arroyo Tongue and then emerges in a low, narrow ridge on the west bank. The outcrop continues southward through the Town of Tejon Grant; it then swings southeastward, disappearing under an apron of high-level gravels about 3 miles southeast of Hagan. As indicated in Figure 2, the outcrop is dislocated by numerous faults of northerly trend.

The northern segment of the deposit, in sec. 1, T. 13 N., R. 5 E., includes a complete section of the Todilto formation, which here dips eastward 15 to 25 degrees. It is underlain by Entrada sandstone and overlain by mudstones and sandstones of the Wanakah and Morrison formations. At the base of the Todilto is 6 to 8 feet of the characteristic thin-bedded limestone member, overlain by a transition zone of gypsum 6 to 10 feet thick, with interbedded, thin, crenulate limestone laminae. The gypsum member above the transition zone is largely massive and of good quality. It has a residual thickness of approximately 88 feet in the cliff face but appears to thicken markedly toward the east. The apparent thickening may be a result of repetition of the section by a probable fault of northerly trend, downthrown on the west; and/or a product of local deformation by flow of the incompetent gypsum. This may be the location of the section measured by Harrison (1949, p. 93), in which he gives the thickness of the gypsum as 242 feet.

The northern segment of the Tongue deposit is readily accessible via 3.4 miles of good improved dirt road southeastward from U. S. Highway 85. This portion of the deposit is within the San Felipe Indian Reservation, whereas its southward continuation is largely within the Town of Tejon Grant. An 8-inch branch gasline of the Southern Union Gas Co. passes 2.3 miles northwest of the northern tip of the deposit.

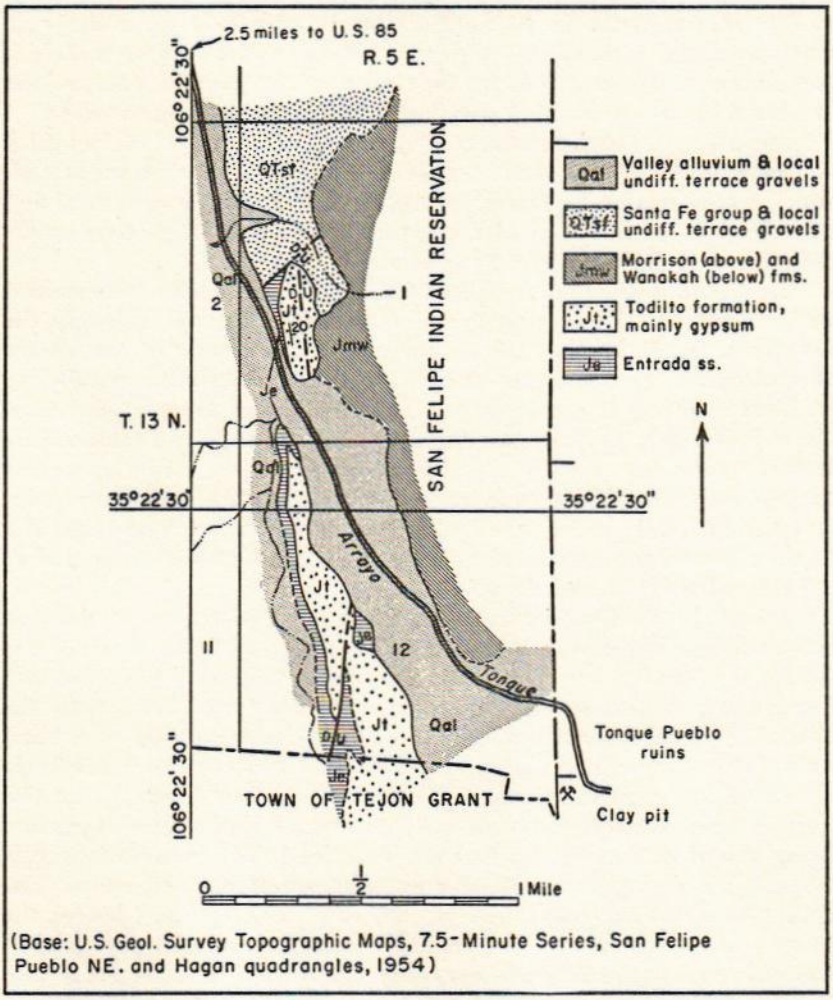


Figure 3
SKETCH MAP OF TODILTO FORMATION ADJOINING ARROYO TONQUE

Tijeras Basin

The southernmost exposure of the Todilto formation, east of the Rio Grande valley, is in a very narrow band along the western edge of the Tijeras Basin in Bernalillo County, about 17 air miles east-northeast of the center of Albuquerque. The Todilto formation here is very similar to that described for the Galisteo—Tonque region, consisting of a basal limestone member overlain by a massive gypsum member.

According to Darton (1920, p. 179), the gypsum is about 60 feet thick and may be traced "for about 5 miles to faults, which cut it off at each end." A cross-section by Darton (1920, fig. 32) shows the structural and stratigraphic relationships of the gypsum. The general geology of the area has been delineated by Read et al. (1944).

Cañoncito deposit. A complete section of the Todilto formation is well exposed in the western slope of a narrow hogback ridge in the SW¼ sec. 36, T. 11 N., R. 5 E., about half a mile east of the village of Cañoncito. The outcrop extends north-northeastward, paralleling N. Mex. Highway 10 on the east for roughly 2 miles. It swings eastward about half a mile south of San Antonito and is cut off by a fault a little farther to the east. Except at the southern tip of the ridge, exposures are generally poor, owing to a screen of thin slope wash, soil, and gypsite, and the generally dense stand of piñon and juniper. The rocks dip steeply toward the east in the southern segment of the outcrop, but appear to flatten toward the north.

Below the Todilto formation is a sequence of red to buff shales, siltstones, and sandstones of the Dockum group and Entrada sandstone. Above the Todilto are buff, pink, red-brown, and gray siltstones and fine-grained sandstones that have been variably correlated with the Wanakah and Morrison formations. The Todilto consists of a basal unit of thinly laminated dark-gray shaly fetid limestone 3 to 5 feet thick, and an upper unit of massive gypsum. The contact between the two units is sharp, the transition zone of interbedded limestone and gypsum being absent in the outcrop that was examined. The gypsum is largely white, with dark-gray to bluish-gray streaks and mottled zones. The darker portions are hard, fine grained, and alabastrine, whereas the purer white portions are soft, coarsely crystalline, and in part friable. Reticulate structure is much less conspicuous than in other areas, and is characterized here by dark seams only a fraction of a millimeter in thickness that contain little calcium carbonate.

Although the narrowness of outcrop and steep dip of the southern portion of the deposit will discourage commercial development for use in gypsum products, the ease of accessibility via paved highways (U. S. 66 and N. Mex. 10), and proximity to the plant of the Ideal Cement Co. (now under construction), should offer advantages for the utilization of the deposit in the manufacture of Portland cement. The silos of the cement plant, 5 miles to the south-southwest, are clearly visible from the ridge at the south end of the deposit. Recent prospecting is indicated by fresh bulldozer cuts. The quality of the gypsum appears to be high, although chemical analyses are not available.

Lamy—Glorieta Mesa Region

Outcrops of the Todilto formation in the vicinity of Lamy lack the massive gypsum so characteristic of the formation in the GalisteoTonque region. Thin beds of gypsum begin to appear at this latitude, however, in the Yeso and San Andres formations, increasing in thickness and stratigraphic frequency southward and southeastward. Darton (1920, p. 173) noted that "a thin bed of considerable value for local use outcrops in Jaspe Canyon 15 miles southeast of Lamy." This is probably the same locality as that in the southeastern corner of the Eaton Grant, where a stratigraphic section measured by Read et al. (1944, graphic section 41) shows a 30-foot sequence of gypsum or anhydrite immediately overlying the Glorieta sandstone, and another thin bed near the top of the Yeso formation. A thin bed of gypsum in the San Andres formation is also shown in a section measured on the slopes of Bernal and Chapelle Buttes near Bernal.

This region is so near the northern limits of evaporite deposition in the Permian sequence that possibilities for the development of commercially significant deposits appear very limited.

NORTHWESTERN NEW MEXICO

The northwestern quadrant of the State is largely deficient in gypsum deposits worthy of note, except along the eastern and southeastern margins of the San Juan Basin. The eastern belt is grouped with other deposits described previously in the section on north-central New Mexico; the southeastern occurrences are described below. These deposits include rock gypsum in beds of Permian and Jurassic age, and associated surficial gypsite of Quaternary age.

Mesita—Suwanee Region

The Todilto formation dips under the cover of younger rocks southward from White Mesa, near San Ysidro, but reappears 40 miles to the south on the southern flank of Mesa Gigante, in Valencia County. According to Darton (1920, p. 184, fig. 41), the gypsum is cut off on the southeast flank of Mesa Gigante by a north-trending fault, downthrown on the east (Correo fault of Kelley and Wood, 1946). From this fault westward, the Todilto gypsum crops out along the north side of the San Jose Valley for a distance of 16 miles, crosses the valley just west of Mesita (El Rito) Pueblo, and thins out a few miles to the south.

Additional exposures may be seen in the faulted area 1 mile north of Suwanee, south of Suwanee at the foot of Mesa Redonda, and around the margins of the low bench that extends southeastward from the mesa (fig. 4).

Mesita deposit. On the north bank of the Rio San Jose, directly opposite Mesita Pueblo (El Rito Pueblo of earlier reports), the Todilto formation forms a narrow cliff-bordered bench 60 to 80 feet high and 50 to 300 feet wide, surmounted by vertical cliffs of red-brown sandstone. Darton (1920, pl. XXII-B; 1928, pl. 27) illustrated this outcrop (also shown in pl. 3A). Where the Todilto crosses the San Jose Valley, half a mile northwest of Mesita, a gentle northward dip carries it under the cover of younger Jurassic sediments, valley fill, and a Quaternary basalt flow. It reappears again at the surface farther south and then thins out within a few miles. Half a mile south of U. S. 66, the thickness of the gypsum decreases to 1 foot (Silver, 1948, p. 77). As shown by Rapaport et al. (1952, map 6), the gypsum member also pinches out a few miles west of Mesita along a northwesterly line that passes about 2 miles west of Laguna. Northeastward from Mesita, the outcrop widens to a broader bench of gentle dip slope in the valley of the Arroyo Concho; then, rising in elevation above the valley floor, it continues to the southeast and east in a cliff-faced bench around the south side of Mesa Gigante. In secs. 14, 15, 22, and 23, T. 9 N., R. 3 W., gypsum forms a broad outcrop of considerable extent, dips northward at about 2 degrees, and attains a thickness of 95 feet (Kelley and Wood, 1946). The white to gray cliff line of this outcrop is clearly visible 1 mile to the northwest from U. S. 66 about 4 miles northeast of Correo. A section measured by Silver (1948, fig. 2, p. 72) on the west side of Mesa Gigante (sec. 12, T. 9 N., R. 3 W.) includes the following:

	Feet
Buff shale member of Morrison formation	
Todilto formation	
White gypsum, mottled gray, with clay laminations; 3- to 6-inch limestone beds in top 15 feet	95
Laminated gray limestone with white clay intercalations	6
Laminated light-gray limestone with calcareous clay and sandstone	6
Wingate sandstone	

At Mesita, the Todilto consists of 83 feet of gypsum, with an estimated 8 to 12 feet of thinly laminated shaly brownish-gray fetid limestone at the base. It is underlain by Entrada sandstone (Wingate of above section), which is pale gray to yellow in its upper part, and red in its lower part. Above the gypsum are slope-forming variegated and red silts, clays, and muds surmounted by a shear cliff of red-brown sandstone. This upper sequence is probably referable to the Summerville formation (Rapaport et al. 1952, p. 27-29, correl. diag. 3; Harshbarger et al. 1957, p. 39-42). The gypsum is largely white, and contains thin, irregular, subparallel and reticulate calcareous clay-silt seams throughout.

Immediately north and northwest of Mesita, in sec. 12, T. 9 *N.,* R. 5 W., the gypsum outcrop directly adjoins the north side of the main line and siding of the Atchison, Topeka & Santa Fe Railway (pl. 3A).

A quarry at the western end of the outcrop was worked some years ago by the Gallup American Coal Co. for crude gypsum used as a rock dust in its mines. Darton (1920, p. 119) reports quarrying of the gypsum here for the manufacture of plaster of paris. Two earlier analyses of samples from the east and west faces of the quarry give a mean calculated composition of 95.9 percent gypsum. A random chip sample, taken during the course of the present survey from the somewhat weathered quarry face, contained 95.6 percent gypsum (sample No. 4, table 1).

Except for scattered large boulders that have fallen from the sandstone cliff above, the outcrop is largely barren of overburden and would require little development for open-cut mining. The narrowness of the outcrop immediately adjoining the railroad limits the width minable by open-cut methods to a maximum of about 300 feet, but this increases locally within a few miles to the northeast, where accessibility is still good across the relatively flat floor of the Arroyo Concho valley. The area is also served by an all-weather paved highway, U. S. 66, which passes three quarters of a mile to the south of the outcrop. Although only a foot bridge across the Rio San Jose at Mesita provides access to this portion of the deposit and the railroad station of Rito, the narrow channel could easily be bridged by a short span for vehicular traffic. The El Paso Natural Gas Co.'s main 30-inch gasline passes 11/2 miles southwest of Mesita.

The deposit is situated on lands of the Laguna Indian Reservation, portions of which in secs. 6 and 7, T. 9 N., R. 4 W., and sec. 12, T. 9 N., R. 5 W., were reported in October 1946 (T. D. Benjovsky, unpublished report, N. Mex. Bur. Mines and Mineral Res.) to be under lease to E. C. Iden and Joseph Montag, of Albuquerque, New Mexico.

Suwanee deposits. The surface of the Todilto formation in the vicinity of Suwanee, a station on the main line of the Atchison, Topeka & Santa Fe Railway, is shown in Figure 4. In the northwest corner of the Antonio Sedillo Grant, about 1 mile north of Suwanee, small fault blocks of gypsum on the downthrown side of the Correo fault are cut by the Rio San Jose. Except for the small segment on the south bank of the river, access to these outcrops is difficult. Other small areas of outcrop occur in railroad cuts southeast of Suwanee, along the east side of Mesa Redonda, and a short distance southwest of the mesa. A more extensive area of roughly 1¼ square miles extends southeastward from Mesa Redonda across a surface of low relief mantled by gypsite and thin alluvium. A north-trending fault, downthrown on the east, marks the eastern margin of this outcrop. The southwestern margin is erosional, marked by contact with the underlying Entrada sandstone. As shown by Rapaport et al. (1952, map 6), this is approximately the southern limit of the gypsum member of the Todilto formation, and the limestone member pinches out a few miles farther south.

An estimated 14 feet of very thinly laminated limestone constitutes the basal member of the Todilto along the southwestern margin of the

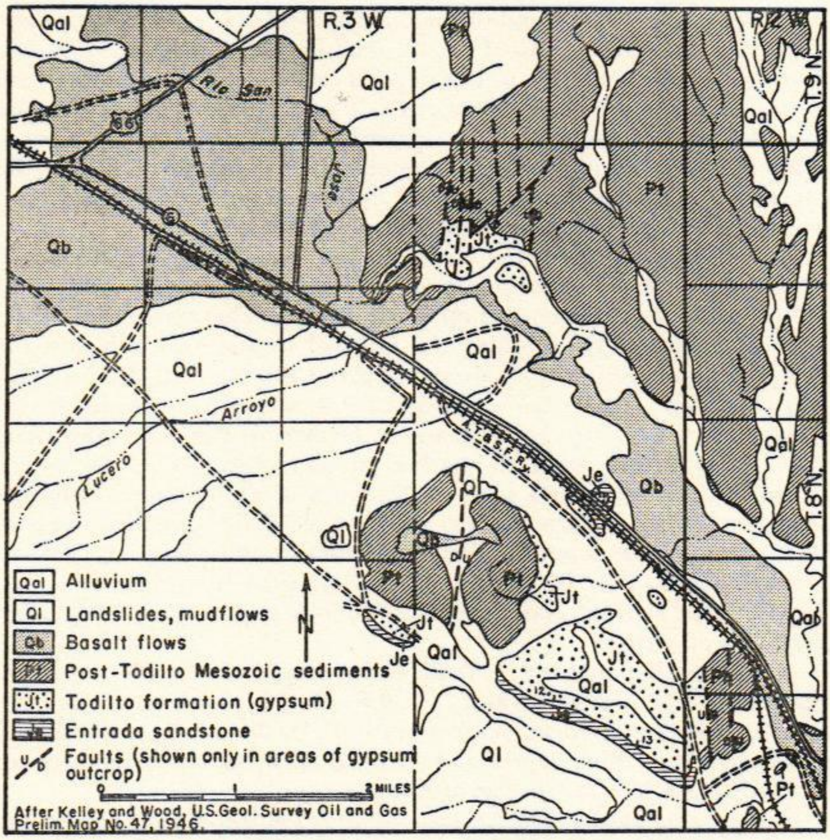


Figure 4

SURFACE DISTRIBUTION OF TODILTO FORMATION, SUWANEE AREA

main area of outcrop; it dips north-northeastward at a moderate angle. Here, the overlying gypsum has been largely stripped by erosion subparallel to the bedding; hence cross-sectional exposures are lacking. The residual thickness of gypsum increases northwestward to the foot of Mesa Redonda, where it is overlain by the Buff shale member of the Morrison formation (Kelley and Wood, 1946). Harshbarger et al. (1957, p. 39) correlated this unit with the Summerville formation. A complete measurable section of the Todilto gypsum was not seen in this area, but Kelley and Wood (1946) give it a thickness range of 90 to 110 feet.

A probably thin, but pervasive, cover of soft, pulverulent, pale-buff gypsite and local thin patches of sandy to silty Quaternary alluvium overlies most of the surface extent of the gypsum. The gypsite is moderately calcareous along the southwest margin, where only a few feet of rock gypsum overlies the basal limestone member. A sample of the calcareous gypsite (analysis No. 5, table 1) has a calculated gypsum content of 93.0 percent. Northward and northwestward from this locality, the carbonate content of the gypsite decreases. The gypsite probably originated from the same processes as the soft, pulverulent caliche so prevalent in the upper portions of the Tularosa Valley and on Chupadera Mesa.

Most of the gypsite may prove suitable for agricultural use. Its soft, friable character favors low-cost mining with simple earth-moving equipment and obviates the need for fine grinding. A sizable acreage of irrigated farm lands in the Rio Grande valley in the Los Lunas area is adversely affected with alkaline salts and could benefit from heavy applications of gypsum or gypsite. In July 1952, the Suwanee Gypsum Products Corp. began operations; since then, a small intermittent production of gypsite has been made from a shallow pit in the central part of the deposit. This was probably marketed for agricultural use in the Los Lunas area, 28 miles by paved road to the east-southeast. Production from what was probably the same deposit is reported for 1954 and credited to the White Eagle Gypsum Co., Inc. (Kelly et al., 1957, p. 757).

A large tonnage of rock gypsum could also be economically developed by stripping the thin cover of gypsite and alluvium from portions of the area. Rail transport is facilitated by the closeness of the deposit to the main line of the Atchison, Topeka & Santa Railway (siding at Suwanee). N. Mex. Highway 6, a narrow black-top road, parallels the railroad, connecting with U. S. 66 at Correo, and with U. S. 85 at Los Lunas. The main, 30-inch line of the El Paso Natural Gas Co. passes about half a mile to the southwest. These deposits are on lands of the Laguna Indian Reservation.

Mesa Lucero—Rio Salado Region

Beds of gypsum are widely distributed in the region that extends from several miles northeast of Mesa Lucero, in T. 8 N., R. 3 W., southward along the Lucero uplift to the north bank of the Rio Salado near Riley, T. 2 N., R. 3 W. (southern Valencia and northwestern Socorro Counties). Within this region, gypsum occurs at numerous intervals in a sequence of marine sediments some 1,300 feet thick. The gypsum-bearing rocks are all of Permian age and include representatives of the Yeso formation, Glorieta sandstone, and San Andres formation. Individual gypsum beds and continuous sequences of beds range from laminae a fraction of an inch thick to more than 100 feet thick.

Because of the relative difficulty of access to this area, which will deter its commercial development in the foreseeable future, these deposits were not examined nor sampled during the course of the present study. The following data are largely from published reports by Darton (1920), Kelley and Wood (1946), Tonking (1957), and Jicha (1958). The reader is referred to these sources for more detailed descriptions and illustrations of specific localities.

Beds along the eastern margin of the Lucero uplift have been complexly faulted and tilted. Locally, as in the Carrizo Arroyo area (Duschatko, 1953), plastic flow of gypsum has resulted in complex folding and thickening of the beds. Westward from this structurally disturbed belt, the Permian rocks show little deformation and dip west to northwest at low angles.

Darton (1920, p. 164, fig. 15) illustrated a section on the east slope of basalt-capped Mesa Lucero that includes a number of gypsum beds, the two principal ones being 80 and more than 100 feet thick, respectively. To the south, at the head of the Carrizo Arroyo drainage, the middle evaporite member of the San Andres formation contains 210 feet of gypsum, the thickest unit of which is 70 feet (Kelley and Wood, 1946, sec. 6). Farther south, in west Los Vallos (T. 4 N., R. 4 W.), Jicha (1958, p. 11-12) described a section of the Los Vallos member of the Yeso formation containing a number of gypsum beds 1.5 to 12.0 feet thick. The lower evaporite member of the San Andres formation in the Sierra Lucero is reported to consist of one-third or more gypsum in beds up to 40 feet thick (Jicha, 1958, p. 15). Still farther south, in the vicinity of Puertecito, individual gypsum beds reach a thickness of 25 feet in the Los Vallos member of the Yeso, and 40 feet in the middle evaporite member of the San Andres formation (Tonking, 1957, p. 10-11).

CENTRAL NEW MEXICO

Rock gypsum is an important component of several stratigraphic intervals in the Permian marine sediments constituting most of the bedrock outcrops of the region that extends across northeastern Socorro County, southern and eastern Torrance County, southwestern Guadalupe County, and northern Lincoln County. Gypsum beds are especially prominent in the Yeso formation throughout this region, become increasingly abundant in the San Andres formation in the eastern and south-central parts of the region, and have been noted in local outcrops of the Whitehorse group. Quaternary gypsum dune sands are present in three saline playa basins in Torrance County, and Quaternary gypsite is widely distributed in association with the other deposits.

Vaughn—Santa Rosa Region

Bedded gypsum in the San Andres formation, and possibly in the Whitehorse group, lies at or near the surface at a number of localities in Guadalupe County, from Vaughn eastward and northwestward to near Santa Rosa. This region, in common with much of the surrounding Great Plains portion of central New Mexico, is characterized by open grasslands of low relief with poorly integrated drainage, except near Santa Rosa, where surface drainage is into the Pecos River. A thin veneer of upland deposits of Tertiary and Quaternary age covers most of the region. These features contribute to the scarcity of gypsum outcrops, except in the walls of sinkholes, in railroad and highway cuts, and in Pintada Canyon, where stream erosion has cut well below the Plains surface and through Triassic sediments that overlie the gypsiferous San Andres and Whitehorse(?) beds west and southeast of Santa Rosa. Gypsum outcrops have been noted at Vaughn and Winkle, and near Aragon, Pastura, San Ignacio, and Puerto de Luna.

Vaughn deposits. Massive gypsum more than 20 feet thick is exposed in an abandoned stone quarry about three quarters of a mile northwest of Vaughn, in Guadalupe County. Rubble in the quarry floor conceals the lower portion of the gypsum sequence; hence the total thickness is unknown. The gypsum is massive and largely white in the lower portion, with reticulate limestone seams (pl. 3B), small selenite porphyroblasts, and some nodular limestone interbeds. Limestone impurities are less conspicuous in the midsection. The upper portion is gray to white and thinner bedded. A random chip sample from the quarry face contained 94.8 percent gypsum (sample No. 6, table 1). The gypsum is capped by 10 to 30 feet of limestone, which thins toward the east. The exposed rocks dip rather steeply westward toward a broad alluvium-covered sink, the collapse of which was probably responsible for the steep reversed dip. Other quarry pits adjoining on the northeast expose approximately 11 feet of gypsum, the base of which is covered, capped by 2 to 13 feet of hard, blocky limestone. The gypsum here is leached and very coarsely recrystallized in the lower part, consisting of a porous, friable, white, limonite-stained matrix studded with gray selenite porphyroblasts up to 1½ inches in length. The upper part is also white and limonite stained, but more cellular and friable, resembling a gypsite cap.

Additional outcrops of what are probably the same beds may be seen in the north wall of a small sinkhole a short distance to the southeast, adjoining the north side of the Southern Pacific Railroad. These beds are undoubtedly very near the surface for at least several miles northeastward along the north side of the railroad right-of-way. Blocks of gypsum thrown out of a railroad cut just southwest of Tony siding are of excellent quality.

Two beds of gypsum are exposed in the east wall of a sinkhole a quarter of a mile east of Tony siding. The lower bed has an exposed thickness of roughly (owing to collapse effects) 17 feet, but the bottom is not exposed. The quality is good in the lower part of the bed, whereas the upper part is impure. The lower bed is overlain by 8 or 9 feet of limestone, which is in turn overlain by 15 feet of gypsum that contains scattered large, gray, twinned selenite porphyroblasts. About 20 feet of limestone caps the upper gypsum.

The log of a drill hole at Tony shows a thick sequence of gypsum and interbedded thin clays from the surface to a depth of 170 feet (Darton, 1928, fig. 116).

These, and other more casual observations, point to the existence of a very large area north and cast of Vaughn in which gypsum lies beneath a thin cover of limestone and local alluvium. A program of test drilling would be required, however, to appraise the extent and quality of the gypsum and the thickness of the overburden. The area is readily accessible, with service by two railroads, the Atchison, Topeka & Santa *Fe* and the Southern Pacific. All-weather roads include U. S. 54, 60, and 285.

Ancho Area

Despite the prevalence of gypsum beds at moderate depth beneath the limestone-capped plateau surface that extends southward and southwestward from Vaughn to beyond Corona, exposures of gypsum are sparse except at the foot of the plateau in the vicinity of Ancho, in Lincoln County. Here, at a number of localities, gypsum in the San Andres formation and overlying correlatives of the Whitehorse group appears at the surface interbedded with limestone, shale, and clay.

Two groups of gypsum beds are exposed in the north face of a low hill at the northeastern edge of Ancho, where the upper beds and associated gypsite cap were quarried during the early 1900's for processing in a plaster mill. The gypsum includes white, gray, and thin dark-gray beds with sparse thin limestone laminae. The upper sequence is 30 to 35 feet thick, varies from fine to coarsely crystalline, and includes several beds containing abundant selenite porphyroblasts. A chip sample at approximately 1-foot intervals from bottom to top of the upper gypsum contained 96.9 percent gypsum, as shown in Table 1, sample No. 10.

The upper gypsum is overlain by thin-bedded limestones that form the caprock of the hill. The entire sequence has been folded and now dips toward the west. Toward the east, the gypsum beds extend beneath a thick section of red beds that could not be stripped economically to permit open-pit mining.

Herrick (1904, p. 90) noted that in 1902 the Rock Island Cement and Plaster Co. had a small testing plant in operation at Ancho. A large mill was then under construction. Gypsite ranging from 10 to 20 feet in thickness was being processed. According to Jones (1904, p. 240-243), a plant of 100 tons daily capacity was completed at the site in 1903. Later (Jones, 1915, p. 46-47), the plant was reported to be producing "cement plaster, plaster of Paris, stucco, dental plaster, etc." An analysis of the Ancho gypsite (Jones, 1915, p. 47) is as follows:

	Percent
Calcium sulphate	63.95
Calcium carbonate	20.04
Magnesium oxide	.89
Sodium chloride	.09
Silica	3.57
Oxides, iron, and aluminum	2.01
Moisture	9.45
Total	100.00

One may speculate as to whether the perfect total is a product of coincidence or intent!

Gypsum also crops out at a number of places in the hills north, east, and south of Ancho, and in a low bench west of Ancho. However, the structural complications presented by widespread fracturing, faulting, folding, and igneous intrusion, coupled with the apparent relatively low purity of many of the gypsum units, seriously limits the commercial potentialities of the area.

The accessibility of the area is good. Rail service is provided at Ancho by the Southern Pacific Railroad, and all-weather highway service by U. S. 54.

Mesa del Yeso Area

Bedded rock gypsum and accumulations of gypsite are widely distributed in the slopes of Mesa del Yeso and adjacent uplands and canyons about 12 air miles northeast of Socorro, in Socorro County. Outcrops of rock gypsum are generally poor and discontinuous, owing to disturbance by faulting, landslide effects, and the prevalence of thick gypsite caps that indiscriminately encrust interbedded gypsum, limestone, sandstone, and siltstone.

A number of generally thin gypsum beds with interbedded sandstone, siltstone, and limestone are distributed throughout the strati-graphic interval that comprises the Torres member of the Yeso formation in this area (Wilpolt et al., 1951). The overlying Cañas gypsum member consists largely of white gypsum with thin interbeds of siltstone and limestone. In Mesa del Yeso, the Cafias member is about 60 feet thick (Wilpolt et al., 1951, graphic sec. 6). A few miles to the southeast, at the type section of the Yeso formation, Needham and Bates (1943, p. 1658-1659) measured 52 feet of gypsum with thin pink silt partings (Cañas member), increasing in thickness southward and southeastward to 80 feet in southern Chupadera Mesa, and to 96 feet in Lomo de las Cañas. In Mesa del Yeso, the Cañas gypsum is overlain successively by the Joyita sandstone member of the Yeso formation, the Glorieta sandstone, and basal limestones of the San Andres formation, which form the caprock of the mesa.

A few miles to the north of Mesa del Yeso, the road is paralleled on the east by a narrow ridge of gypsum with thin limestone interbeds, which dips steeply westward into a fault of northeastward trend, down-thrown on the west. A pervasive crust of cellular, crystalline gypsite covers much of the ridge, obscuring the character and thickness of the underlying gypsum beds. As seen in one small outcrop, however, the gypsum is white, crystalline, and of high purity.

In general, the area seems to have very limited possibilities as a commercial source of rock gypsum, owing to the small extent of out-crops that could be mined by open-pit methods, and because of widespread structural deformation of the beds. Local accumulations of cellular, friable, crystalline gypsite (pl. 4A) might, however, be of value for agricultural use in the nearby irrigated farm areas of the Rio Grande valley. Locally, as at the northern foot of Mesa del Yeso, gypsite reaches a thickness of several feet, is without overburden, and could be excavated readily with earth-moving equipment. Pulverization to an acceptably fine particle size would be a simple process because of the highly friable character of the material. A surface-pit sample from this locality contained 96.5 percent gypsum (sample No. 9, table 1).

The area is reached by 14 miles of dirt road from a junction with U. S. 85-60 near Escondida, about 1.5 miles north of Socorro. Portions of this road are now in very poor condition. Lands from the south side of Mesa del Yeso northward are within the Sevilleta Grant.

Northern Chupadera Mesa—Mesa Jumanes Region

The northeastern segment of Chupadera Mesa is commonly referred to as Mesa Jumanes, although there are no topographic, stratigraphic, or structural differences that could provide a basis for separating the two. Within this region of southwestern Torrance County, beds of rock gypsum occur in both the Yeso and San Andres formations.

The Yeso formation is especially gypsiferous; near the southwest corner of Torrance County, gypsum comprises about 23 percent of the strata (Smith, 1957, p. 30-31). Outcrops of the Yeso formation form the lower slopes of the mesa escarpment and extend outward for some distance into the surrounding lowlands to the west, north, and east.

The San Andres formation makes up the upper cliffs and cap rock of Chupadera Mesa. Beds of massive white gypsum, interbedded with limestone and sandstone, crop out at a number of localities on the mesa surface. Many of these occurrences are too remote to be of economic interest under current market conditions.

Outcrops of gypsum in this region are generally poor and of small surface extent. However, those near main routes of transportation in the vicinity of Abo and Willard (described below) may offer some possibilities for local use.

Abo deposits. A moderately thick bed of gypsum crops out in the cliff that borders the prominent limestone-capped spur about three quarters of a mile south-southeast of the village of Abo. The gypsum is rather impure, gray to brown and red in color, and locally contains conspicuous red selenite porphyroblasts. It is embedded in a sequence of soft orange to red siltstones and sandstones typical of the Yeso formation. The cliff-line outcrop and the low strength of the overlying silt-stones do not favor commercial exploitation of the gypsum.

Lower beds of white to gray gypsum with thin limestone laminae form sparse small outcrops in a low bench at the foot of the cliff bordering Abo Arroyo on the south. The thickness is not readily apparent, but probably approximates 5 or 6 feet. The surface is largely covered by terrace gravels and/or alluvial and dune sands that are locally thin enough to be easily stripped.

The exposures mentioned above are chiefly in secs. 28 and 33, T. 3 N., R. 6 E. Intermittent outcrops extend eastward and southward for several miles, but these were not examined in the course of the present reconnaissance.

Although this area does not appear especially favorable for large-scale production of gypsum, its proximity to a paved highway, U. S. 60, commends it for local use. Rail service is provided by the Atchison, Topeka & Santa Fe Railway. A potential market depends to a large extent upon the possible installation of a portland cement plant near Scholle, which has been under consideration by the Permanente Cement Co. A local source of raw gypsum should be advantageous to a plant of this type.

Deposits near Willard. A narrow belt of gypsum outcrops in the Yeso formation extends along the northern and eastern foot of Mesa Jumanes a few miles south of Willard. In sec. 31, T. 4 N., R. 9 E., massive gypsum approximately 100 feet thick forms the basal portion of the mesa escarpment, overlain by several hundred feet of sandstone that forms the mesa rim. The gypsum is rather impure and contains silt and limestone laminae. The outcrop here is narrow and cliffy, offering little opportunity for open-pit mining.

Lower beds of gray to white gypsum are very poorly exposed in small patches on the old floor of Lake Estancia a short distance to the north. The thickness and lateral extent of these beds could not be determined because of the pervasive, though thin, cover of silt and sand. The quality appears to be good, however, and it is possible that a series of shallow exploratory cuts or borings might disclose a fairly sizable tonnage.

Outcrops of the upper gypsum sequence extend southeastward around the northeast side of Mesa Jumanes, where it forms a narrow bench that widens toward the south. Farther south, the gentle southward dip of the beds carries them beneath the cover of high-level Quaternary alluvium. Although white, pure, coarsely crystalline beds constitute a part of the section, the gypsum is generally impure and contains thin interbeds and lenses of limestone, siltstone, and sandstone. The surface of the bench is mantled by only thin patches of soil and slopewash to the north, the overburden increasing southward.

Outcrops along the eastern side of the mesa are readily accessible from N. Mex. Highway 42, which parallels them on the east. At Willard, about 8 miles to the northwest, there is a railhead on the Atchison, Topeka & Santa Fe Railway and a junction with U. S. Highway 60.

Estancia, Encino, and Piños Wells Basins

These are all centrally drained basins, in the lowest portions of which are wind-scoured depressions containing saline playa lakes and ponds. The Estancia Basin (Valley) is by far the largest of these, with a north-south length of about 50 miles, a width of 12 to 30 miles, a drainage area of about 2,000 square miles, and a floor area of about 900 square miles (Smith, 1957, p. 42). The Encino Basin has a drainage area of about 240 square miles, and the Piños Wells Basin about 180 square miles (Smith, 1957, p. 80, 84). The two smaller basins are separated from the Estancia Basin, to the west, by a drainage divide formed by a broad upland of Precambrian crystalline rocks, the Pedernal Hills. On the basin floors are accumulations of wind-deposited clay, silt, and sand scoured from the playa beds during low-water stages. Locally these deposits include gypsiferous dune sands. The geology of the region and local area is described and illustrated by Meinzer (1911) and Smith (1957).

Estancia Valley deposits. Gypsum is a significant, though proportionately variable, constituent of a series of narrow dune ridges that closely border the eastern margins of the many saline playas clustered in the southeastern portion of the Estancia Valley, in Torrance County. The distribution of gypsum dunes is concordant with the day hill area of Meinzer (1911, pl. 1), which has a north-south length of 16 miles and a maximum width of a little more than 6 miles. As indicated by Meinzer, these deposits consist largely of windblown clay scoured from the existing playa salt basins, but they also contain a considerable proportion of silt-size material and local accumulations of gypsum sands. Under conditions of lower rainfall, which would promote more thorough winnowing of the dune deposits by wind action, extensive gypsum dunes of a character and purity approaching those of the White Sands might have been formed.

The dunes reach local heights of over 100 feet above the underlying sequence of laminated lake-bed days and silts from which they have been excavated. The majority are, however, 50 feet or less in height. The more gypsiferous of these consist largely of buff-colored selenite cleavage flakes with intermixed and occluded clay and silt. They are largely stabilized by a slight cementation with calcite and gypsum, a soft caliche crust, and a sparse to moderate cover of bunch grasses.

Although the portions of these deposits that were examined are far inferior to the deposits of White Sands and Piños Wells, no thorough reconnaissance of the area was made. It is possible, accordingly, that a more thorough search might disclose sands of higher quality.

The southern third of the area is readily accessible and adjoins, or is within a few miles of, major highways and railroad lines. The most southerly exposure is in sec. 1, T. 3 N., R. 9 E., along the southern and eastern margins of a small playa. This area is readily accessible from N. Mex. Highway 42, about 7 miles southeast of Willard. At Willard, there is a junction with U. S. Highway 60, and a railhead on the Atchison, Topeka & Santa Fe Railway. The western edge of the gypsum dune tract is about 31/2 miles east of Willard, adjoining U. S. 60 and the railroad right-of-way. The accessibility of the dune tract decreases northward from U. S. 60.

Encino deposits. Deposits in the Encino Basin, in Torrance County, include both Recent gypsum dune sands and bedded rock gypsum of Permian age. The gypsum dunes are essentially identical with those described for the Estancia Valley, but of much more restricted extent. They are best developed along the eastern border of the present playa, in secs. 27 and 34, T. 5 N., R. 14 E., where they form a narrow irregular ridge only a few hundred yards in width. The western face of this ridge has been scoured by wind erosion into steep cliffs, exposing laminated lake-bed clays and silts beneath a maximum thickness of 75 or 80 feet of crossbedded gypsum sands. As in the deposits of the Estancia Valley, the dune sands are weakly cemented and quite calcareous, and contain variable proportions of silt and clay.

The area is readily accessible from N. Mex. Highway 3, about 3 miles south of Encino, via 1.7 miles of dirt trail that extends eastward from the highway past the south edge of the playa. N. Mex. Highways 3 and 60 join at Encino, at which point there is also a railhead on the Atchison, Topeka & Santa Fe Railway.

Several beds of rock gypsum crop out in the low bluff at the southern edge of the old lake floor 5 miles south of Encino. The outcrop crosses N. Mex. 3 in an east-west direction. The main gypsum bed ranges from 4 to 6 or 8 feet in thickness, is fairly pure and white, with gray streaks below, and has an irregular zone of medium- to coarse-grained recrystallized gypsum at the top. This bed is overlain by a few feet of gypsite and sandy soil that cap a broad, flat bench bordering the old lake shoreline. Interbedded red to pink siltstone and thinner beds of gypsum make up the rest of the exposed sequence. A similar sequence is exposed in bluffs on the opposite side of the lake floor to the north-northwest. These beds are probably a part of the Yeso formation.

Piños Wells deposits. Recent gypsum sand dunes are developed especially well in an irregular tract several miles long and roughly half a mile wide along the eastern margin of the present-day playas that occupy the central part of the basin (E1/3 T. 3 N., R. 13 E., Torrance County). The principal accumulation is an irregular transverse dune ridge of northward trend that locally reaches heights of more than 100 feet above the present lake floor. A series of longitudinal spur dunes, on the lee side of the main ridge, slope gently eastward to the level of the surrounding earlier lake floor. Both the transverse and longitudinal dunes are stabilized by weak cementation, a thin gypsite crust, and a moderate cover of bunch grasses and sparse shrubs. Wind scour is currently excavating a series of narrow, steep-walled blowout channels and miniature bad lands in the western face and crest of the main ridge (pl. 4B). The channels are elongated in an east-west direction, paralleling the trend of the longitudinal dunes, which are probably products of this process. Small, currently active longitudinal to irregular dunes are scattered across the lower planed surface that slopes gently westward from the foot of the transverse ridge to the present playa floor.

The stabilized dune sands consist of thin cleavage flakes of buff-colored selenite, and sparse smaller grains of quartz and rock fragments. Cementation and interlocking of grains are sufficient to permit the formation of vertical to slightly overhanging walls and miniature bad-lands pinnacles in the blowouts, yet so friable as to yield to wind scour. The active dunes tend to be much paler gray buff and finer grained. Analysis of a grab sample from a stabilized longitudinal dune showed 80.9 percent gypsum; from an active dune near the present playa, 77.4 percent gypsum (table 1, samples Nos. 7 and 8).

There is clearly a very large tonnage of readily available gypsum sand in these deposits that could be mined easily with ordinary earth-moving equipment. The sand could be used without further preparation for agricultural purposes, but most markets for this product are at some distance from the deposits. Required truck haulage would be approximately 9 miles to the Southern Pacific Railroad and U. S. Highway 54, 2 miles southwest of Duran. Six miles of this distance is on the improved dirt road connecting Duran and Piños Wells, and 3 miles is on unimproved dirt ranch roads and trails.

WEST-CENTRAL NEW MEXICO

A single known outcrop of gypsum occurs in west-central New Mexico south of the Zuni Mountains and west of Puertecito; this gypsum outcrop is on the south edge of Horse Mountain, in east-central Catron County, and is near the top of the Yeso formation. Subsurface studies by Foster (1957) show essentially no evaporite beds north of lat. 35° N., but thick Permian anhydrite beds in the subsurface near, and west-northwest of, Quemado.

SOUTH-CENTRAL NEW MEXICO

Gypsum in south-central New Mexico occurs in the Panther Seep, Abo, Yeso, and San Andres formations, in Tertiary volcanic red beds, and as Quaternary gypsum beds and dunes.

White Sands

The more spectacular gypsum sand dunes of New Mexico occur within White Sands National Monument, covering almost 115 square miles as individual and coalescing dunes 10 to 50 feet high (pl. 5A). The average thickness of the dune sand is nearly 20 feet above a relatively stable, partly consolidated "sandstone" base 10 to 20 feet thick. Outside, and almost entirely north of the Monument, the gypsum dunes cover 131 square miles. Solid rock gypsum (specific gravity, 2.32) weighs 145 pounds per cubic foot. The gypsum sands have less than 25 percent pore space; thus should average about 110 pounds per cubic foot. The gypsum sands north of the Monument average about 20 feet thick, so that there are more than 3.93[1] billion tons of relatively pure gypsum available for commercial use, although lying within the White Sands Missile Range. As the United States uses about 11 million tons of gypsum each year, this is a 3½-century supply for the nation.

South of the White Sands National Monument, from 2 to 4 miles northeast of U. S. Highway 70, in the NW¼ sec. 9, T. 19 S., R. 6 E., and in the N1/2 sec. 31, T. 18 S., R. 7 E., there are two small patches of dune sand. These patches, 0.07 and 0.30 square mile respectively, may contain about 11 million tons of gypsum, sufficient for extensive local use. They lie, however, within the White Sands Missile Range.

Areas (pl. 6) covered by relatively pure, thick (10 to 50 feet) gypsum sands are tabulated as follows:

	IN MONUMENT (square miles)	OUTSIDE MONUMENT (square miles)
T. 14S.,R.6 E.	0	0.31
T.14 S., R. 7 E.	0	2.22
T.15 S.,R.6 E.	0	18.75
T.15 S., R. 7 E.	0	30.52
T.15 S., R. 8 E.	0	15.11
T.16 S., R. 5 E.	0	1.38
T.16 S.,R. 6 E.	0	23.61
T. 16 S., R. 7 E.	0	36.00
T.16 S., R. 8 E.	0	2.80
T.17 S., R. 6 E.	11.92	0
T. 17 S., R. 7 E.	29.33	0
T.17 S., R. 8 E.	0.42	0
T.18 S., R. 5 E.	12.55	0
T.18 S., R. 6 E.	34.27	0
T. 18 S., R. 7 E.	20.18	0.30
T. 19S.,R. 5 E.	1.37	0
T. 19 S., R. 6 E.	4.94	0.07
Total	114.98	131.07

North of the thick, pure gypsum dunes is at least 190 square miles of scattered to continuous eolian dunes that are composed chiefly of gypsum mixed with quartz and other mineral and rock grains. Typical of this impure gypsum sand are dunes crossed by N. Mex. Road 52 in the SE¼ sec. 21, T. 14 S., R. 8 E. As seen under the binocular microscope, the sand is fine to medium grained; the grains range from ½ to ½ mm, with 75 percent in the ¼- to ½-mm size. The sand consists of 75 percent gypsum as tabular, subangular to rounded, frosted grains; 5 percent angular, equant quartz grains with fresh surfaces; 5 percent reddish-brown subangular orthoclase/microcline; 5 percent subangular

1. A layer of gypsum sand 1 foot thick and 1 mile square weighs about 1,533,000 tons.

to subrounded white calcite and gray to brown limestone/dolomite; and 10 percent two-mineral or rock grains, including hornblende, actinolite, quartzite/siliceous sandstone, andesite, andesite tuff, siliceous rhyolite, obsidian(?), diorite, chert, epidote/olivine, and some mica schist.

The purer gypsum sands are medium to coarse grained. The grains, cleavage flakes of selenite, range from 1/4 mm to 1 mm; they are sub-rounded to subangular, tabular, faceted, and frosted, and have a dull luster, with rough surface relief. More than 99.5 percent are of whitish gypsum. Some scattered gypsum crystals are stained reddish brown. There are a few grains of clear angular quartz, and some white to light-gray sugary crusts of calcite grown on gypsum grains. The chemical analysis of a channel sample from a 37-foot dune is shown in Table 1, sample No. 16.

South of the White Sands dunes are older dune sands, partly consolidated, occurring as low ridges and indistinct mounds; the sand is chiefly gypsum mixed with quartz and reddish silt. Many of these older, stabilized dunes are capped by calichelike, massive to earthy gypsum. South and southeast toward the Jarilla Mountains, the eolian sands become more quartzose. These older gypsiferous sands show that Lake Lucero is a mere remnant of a larger saline playa that extended southward to include the dry flats of Parker Lake, East and West Dry Lakes, Davies Tank, and Old Coe Lake. Present intermittent streams draining to these southern lake beds transport very little calcium sulfate inasmuch as gypsum beds are not exposed on the east sides of the Organ and southern San Andres Mountains. The source of the gypsum of these playas, as well as of Lake Lucero and Alkali Flat (fig. 5), and of the gypsum dunes (both active and stable), was, and is, the Permian Yeso gypsum cropping out in the San Andres and Sacramento Mountains. The Permian gypsum beds thin to the south in the San Andres Mountains so that only laminae occur south of Dead Man Canyon (lat. 32°50' N.); also, drainage of the gypsiferous strata south of Sulfur Canyon (lat. 33° N.) is to the west, into the Jornada del Muerto.

Lake Lucero and Alkali Flat are usually flooded by the summer rains that wash down from the San Andres Mountains; the intermittent streams from the Sacramento Mountains, such as the Rio Tularosa, do not reach the western (lowest) side of the Tularosa Basin, being blocked and swallowed by the sand dunes. Calcium sulfate derived from the Permian gypsum is reprecipitated as gypsum crystals around the edges and on the flats of the playas, forming an annually *renewed* source of gypsum sand available to the restless westerly winds. Much of the present dune sand may have accumulated just after the latest Pluvial (wet period, 12,000 to 24,000 years ago), when the whole west-central part of the Tularosa Basin, the area below 4,000 feet altitude, was probably an intermittent lake, called Lake Otero by Herrick (1904) and others.

Around the present playas, and beneath as much as 15 to 25 feet of reddish-brown silt in areas as far east as Alamogordo, bedded crystalline to massive gypsum crops out. In places, as near Lake Lucero, this is the bedded gypsum precipitated upon seasonal drying of the saline lakes. In other localities, the massive gypsum resembles a calcium sulfate caliche; i.e., deposited by evaporation of surface and underground waters containing a high concentration of calcium sulfate. In places the bedded crystalline gypsum grades laterally into crossbedded partly consolidated gypsum "sandstone" and may have been formed by recrystallization of gypsum sand. These gypsum beds are somewhat less pure than the eolian gypsum sand but are a potential source of commercial gypsum; billions of tons are available beneath thin overburden.

Caballo Mountains

Outcrops of gypsum in the Yeso formation occur chiefly on the east side of the Caballo Mountains in south-central Sierra County. The gypsum occurs as thin to thick (1 to 20 feet) beds that decrease in thickness and number southward. Considerably more gypsum occurs in the Yeso formation in the Fra Cristobal Mountains, 15 miles north-northeast of the northern Caballo Mountains. The Yeso gypsum is mined in an open pit in the east-central part of the Caballo Mountains (sec. 16, T. 15 S., R. 3 W.; sample No. 14, table 1) by the Associated Materials Co., of Las Cruces. In and near the mine, the gypsum (plus interbeds of siltstone and limestone) is as much as 25 feet thick; it includes massive to laminated light- to dark-gray gypsum, with some gray and reddish-orange porphyroblastic beds. The chemical analysis shows about 99.4 percent gypsum.

In the southeastern part of the range, prospect pits (sec. 2, T. 17 S., R. 3 W.; sample No. 15, table 1) in the upper Yeso outcrops cut a 25-footthick band of gypsite, exposing gypsum in 1- to 5-foot-thick beds interbedded with limestone and limy siltstone. Most of this gypsum is of the gray and reddish-orange porphyroblastic type. The chemical analysis shows about 97.4 percent gypsum, with 1½ percent silica and probably more than 1 percent magnesium carbonate.

Outcrops of the Yeso formation on the southwest side of the Caballo Mountains, near Apache and Green Valleys (northeast of Garfield), expose only laminae and thin beds of gypsum. These outcrops are only 2 to 4 miles from U. S. Highway 85. The band of Yeso that crops out along the east side of the Caballo Mountains, although 4 to 10 miles from the railroad, can be reached from U. S. Highway 85 and the Rio Grande valley via Elephant Butte at the north or Rincon on the south, a 20- to 40-mile trip on secondary roads.

Nogal Canyon

An isolated outcrop of the San Andres and Yeso formations occurs on the southeast edge of the San Mateo Mountains along Nogal Canyon (sec. 3, T. 9 S., R. 4 W.), southeast of Glorieta ranch. This is one of the pre-Tertiary sedimentary rock exposures on the edge of the Datil-

Mogollon volcanic plateau that give an idea of the buried pre-Tertiary rocks that may be present beneath the volcanic extrusives. Gypsum occurs only as laminae and veinlets; most of the Yeso is of rust-brown siltstone, dark-gray wavy-bedded limestone, silty limestone, and some yellow to light-gray silty sandstone.

Sierra Cuchillo

Jahns (1955) reported 750 feet of the Yeso formation in the Sierra Cuchillo east of Red Hill Pass along N. Mex. Road 52. The formation consists of variegated sandstone and siltstone, with dark-gray limestone and dolomite abundant in the upper part; gypsiferous beds are rare and thin. Beds attributed to the San Andres formation total 1,360 feet in thickness and are chiefly dark-gray limestone, with subordinate silty limestone and reddish-brown siltstone and sandstone. Evaporite beds are conspicuously sparse.

San Andres Mountains

Numerous thick gypsum beds occur in the Yeso formation in the western part of the northern and central San Andres Mountains. North of Rhodes Pass (traversed by N. Mex. Road 52), the Yeso is about 1,580 feet thick and includes about 635 feet of gypsum. In the upper part of the formation, the Callas member consists of 235 feet of gypsum, with thin interbeds of limestone and sandstone near the base. In the west-central part of the range, west of Hembrillo Pass, the Yeso is 890 feet thick and includes about 175 feet of gypsum; the Cañas member is not identifiable, having pinched out southward or graded laterally into limestone. In the southwestern part of the San Andres Mountains, near Ash Canyon and Love ranch, no gypsum occurs in beds attributed to the Yeso formation, which at that point is only 324 feet thick.

The gypsum ranges from massive and coarsely crystalline to laminated and aphanitic. Many of the gypsum beds are folded or contorted and covered in part with cellular gypsite, so that recorded thicknesses may not be accurate. Gray gypsum containing large reddish-orange gypsum porphyroblasts appears confined to the Cañas gypsum member. Most of the thick gypsum beds crop out on steep slopes capped by ledges of limestone; any large tonnages would need to be mined underground, although considerable quantities could be quarried along the strike. Within a few miles of the road (N. Mex. Road 52) from Engle eastward through Rhodes Pass and Rhodes Canyon, there are millions of tons of gypsum. Some of the westernmost outcrops are west of the White Sands Missile Range.

In the southwestern San Andres Mountains, from San Andres Canyon south to Bear Creek, two gypsum beds occur in the uppermost part of the thick Pennsylvanian strata. These gypsum beds are in the Panther Seep formation (Kottlowski et al., 1956) and crop out as light-gray bands along east-facing slopes below cliffs of basal massive limestones of the

Hueco formation. Near Love ranch, the upper gypsum unit is 65 feet thick, with minor laminae of limestone and calcareous siltstone; 4 miles to the north, northwest of Ash Spring, the bed is 80 feet thick and appears to thicken to 100 feet nearby. The lower gypsum bed includes laminae of silty limestone and averages 25 feet in thickness. The strata dip westward 15 to 35 degrees, complicating any underground mining that would be needed to extract large tonnages. Not only are these gypsum outcrops within the White Sands Missile Range, but most of the area is also in a U. S. wildlife refuge.

Southern Chupadera Mesa

Along U. S. Highway 380, the Yeso and San Andres formations crop out on the southern edge of Chupadera Mesa. Most of the gypsum beds occur on steep slopes, so that only narrow strike-bands could be mined by open pits; in places, however, some of the gypsum beds are near or at the surface over areas of several acres and could be strip-mined inexpensively. Near the pass over Chupadera Mesa, the Cañas member of the Yeso formation is 150 to 190 feet thick and forms a wide belt of outcrops on top of upper cuestas of the Torres member limestone beds. The Cañas gypsum is white to light gray on fresh fracture, with beds of reddish-orange porphyroblastic gypsum near the top; outcrops are mostly covered by earthy to cellular gypsite; numerous thin (2 to 24 inches) interbeds of silty limestone and soft calcareous sandstone are exposed in freshly cut gullies. Above the Cañas gypsum member is the soft pinkish-orange sandstone (with thin interbeds of gypsum and limestone) of the Joyita sandstone member, the uppermost unit of the Yeso formation beneath the soft yellowish silty Glorieta sandstone. A chip sample (No. 11, table 1) of the Cañas member, collected in sec. 8, T. 6 S., R. 7 E., is composed of 98.6 percent gypsum.

Thin to thick gypsum beds occur within the medial Torres member of the Yeso formation. A grab sample of one of the lower beds (No. 12, table 1) shows 98.4 percent gypsum, with almost 1 percent silica.

Phillips Hills

The Phillips Hills are a small eastward tilted fault block uplifted on the northeast side of the Tularosa Basin (Valley), below and west of Sierra Blanca. The crest of the hills is capped by San Andres limestone; gypsum beds in the Yeso and San Andres formations crop out along the west and central parts of the uplift. U. S. Highway 54 is 3 to 7 miles from the gypsum outcrops. The Southern Pacific Railroad parallels the highway; Oscura siding and North siding are 4 to 7 miles from the gypsum beds. The Phillips Hills are on the east edge of the White Sands Missile Range, 1 to 2 miles west of the east border.

Numerous gypsum beds occur within the Yeso—San Andres section (Schmalz, 1955) and crop out for 5 miles along the north to northwest strike. The gypsum beds are poorly exposed, being concealed, along with interbedded dark-gray limestone, by earthy gypsite bands. At most places, the strata dip eastward at low angles (5 to 16 degrees) but in a few places are almost horizontal or dip gently to the west. Along some of the broader canyons, several acres of gypsum could be uncovered by stripping a thin overburden of soil and limestone, but in most places large deposits would require extensive deep stripping or underground mining. There are reports of pure, white gypsum beds 50 to 100 feet thick, but these outcrops are more than half covered by cellular gypsite; narrow cuts of parts of the beds show some interbedded limestone and siltstone. A chip-channel sample (No. 13, table 1) from a more than 20-foot-thick bed near the top of the section in sec. 21, T. 10 S., R. 8 E., was 98.1 percent gypsum.

Sacramento Mountains

The Yeso formation crops out from northeast of Tularosa southward to far beyond the southern Sacramento Mountains. The upper part of the formation and the lower part of the San Andres limestone are exposed for many miles in the valleys that drain east and southeast from the crest of the Sacramento Mountains. West of the crest, the upper slopes of the westward facing escarpment of the range are carved from the soft beds of the Yeso formation. In the higher, west-central part of the range, the Yeso formation, and particularly the gypsum beds, are mostly covered by slope wash, landslides, and soil supporting heavy vegetation. The broad belt of Yeso outcrops extends from the low foothills 2 miles east of Salinas siding (11 miles north of Tularosa), southeastward along the edges of the mesa bordering lower Rinconada Canyon, along Tularosa Canyon near Bent and Mescalero, and then southward just below the crest of the Sacramento Mountains to the southwest edge of the range, where the upper part of the Yeso forms the lower slopes, and the lower Yeso caps Otero Mesa.

As described by Pray (1952), the Yeso formation in the western Sacramento Mountains is about 1,300 feet thick and consists of pale-red, pink, yellowish, or gray sandstone, limestone, siltstone, shale, and gypsum. The pale-red elastic and gray gypsum beds are lenticular, with the amount of red beds and gypsum decreasing southward in proportion to an increase in carbonate rocks. Near Bent, in an outcrop along Tularosa Canyon where traversed by U. S. Highway 70, R. C. Northrop and Pray (Pray, 1952) noted only about 160 feet of relatively pure gypsum within the 1,300 to 1,400 feet of Yeso exposed. The thickest gypsum unit occurs 300 to 400 feet below the top of the formation; it is about 60 feet thick, with thin limestone and silty shale interbeds near the top. Although coated with gypsite, the gypsum beds are fairly well exposed on the steep, bare slopes around Bent, and to the south and northwest of Bent, but would need to be mined underground to obtain any considerable tonnages.

Southward from Bent, west of Cloudcrof t and along the upper part of the Sacramento River canyon, the Yeso gypsum beds are mostly covered on the steep, heavily forested slopes of the central Sacramento Mountains. The Yeso beds are exposed continuously on the southwestern edge of the range (between the Sacramento River and the heads of Grapevine and Culp Canyons) and above Otero Mesa. Here Pray (1952) measured 1,240 feet of Yeso strata containing only 90 feet of gypsum; except for a 6-foot gypsum bed near the middle of the formation, the gypsum is in thin to thick beds interbedded with dolomitic limestone and gray to pink shale of the basal 150 feet. Ranch roads from Tularosa Basin into Grapevine and Culp Canyons are blocked by the continuing northward expansion of the McGregor Firing Range, so that this area is relatively inaccessible.

Otero Mesa

From the southwestern Sacramento Mountains southward to the Hueco Mountains, the low (200 to 800 feet high) west-facing Otero Mesa is capped by limestones of the medial Yeso formation, and several lenticular gypsum beds crop out on the steep slopes of the escarpment above Abo red beds. Gypsum beds are concentrated near the base of the Yeso; several may be 10 to 20 feet thick but have laminae and thin interbeds of pinkish siltstone and dark-gray dolomitic limestone. Outcrops are poorly exposed, owing to cover by cellular gypsite. The lower part of the Yeso section is lithologically similar to that measured by Pray (1952) in the southwestern Sacramento Mountains 7 miles to the north-northeast of the Piñon road (N. Mex. Road 33).

Below and west of the upper west-facing escarpment of Otero Mesa, there are in many localities two lower west-facing east-dipping cuestas: (I) a lower, westerly cuesta capped by limestones of the Hueco formation, and (2) a medial cuesta capped by dark reddish-brown to light-brown crossbedded sandstones herein referred to the Abo red beds, following Pray and Otte (1954) and others. This unit is lithologically similar to the upper Abo tongue of Pray (1952) and consists of about 170 feet of dark reddish-brown, dusky-red, and light-brown resistant siltstones and soft shales, with some lenses of sandstone and intraformational conglomerate, and in the lower part, a thin whitish to purplish marly limestone. Below this red-bed sequence, and above limestones typical of the Hueco formation, is a 25-foot bed of impure gypsum overlying about 50 feet of poorly exposed thin-bedded light-gray to gray silty limestones which contain thin interbeds of gypsum and gray to reddish shale. Bachman and Hayes (1958) believed that the red bed sequence was a part of the Yeso formation and named it the Otero Mesa member, suggesting that the Yeso rests on the Hueco on the west side of Otero Mesa. The gypsiferous unit below the 170 feet of red beds, on the basis of lithology and stratigraphic sequence, appears more likely to be an evaporite phase of the Abo—Hueco intertonguing than a Yeso tongue beneath Abo-like red beds.

The Abo-Hueco gypsum is exposed on the gentle slope at the base of the cuesta capped by Abo-like silty sandstones, and could be mined in open pits over a considerable area. The gypsum beds in the Yeso formation, although apparently purer, crop out on steep slopes above the red beds and below the rim of Otero Mesa, so that the production of any considerable tonnages would require underground mining. Almost the entire area of Otero Mesa, however, is within the McGregor Firing Range and is closed to the public.

Hardie (1958, p. 43-45) mapped the northern Hueco Mountains, in southwestern Otero County, a few miles west of the southern remnants of Otero Mesa. Along the western edge of the range, he found a bed of gypsum, 25 to 75 feet thick, within a 1,200-foot sequence of pale reddish-gray to olive-gray shale and dark-gray limestone occurring unconformably below the Hueco limestone. These shale-limestone beds may be correlative with the Panther Seep formation of the San Andres Mountains. The gypsum is thin bedded, with thin brown clay partings, and in places highly contorted. The outcrops are about 15 miles east of Newman, which is located on U. S. Highway 54 and the Southern Pacific Railroad and is only 10 miles from the city limits of El Paso, Texas. The gypsum beds, however, are cut off from the highway by a part of the Fort Bliss Firing Range.

Rio Hondo and Rio Ruidoso Valleys

The upper beds of the Yeso formation and the lower part of the San Andres formation crop out in and along the many valleys draining east and southeast on the eastern dip slope from the Sacramento Mountains crest to the Pecos River. The Rio Hondo, Rio Bonito, Rio Ruidoso, and the Rio Peñasco are some of the major tributaries; along the upper reaches of the streams, thin beds of gypsum in the upper part of the Yeso formation are poorly exposed. Locally a few acres of thin (2 to 10 feet) gypsum may be available for open-pit quarrying, but in most localities any large tonnage would require underground mining.

Southern Robledo Mountains

Along Apache Canyon, in the southern Robledo Mountains 5 miles northwest of Las Cruces, gypsum beds occur within the basal part of the Tertiary volcanic sequence. Some of the gypsum beds are 1 to 10 feet thick, but there are also many laminae and veinlets of gypsum amid the interbedded reddish to gray calcareous claystone, shale, and silt-stone; gray silty limestone; and gray to purple latitic tuff. Basal beds, unconformable on the Permian Hueco limestone, are of limestone-cobble conglomerate in a matrix of gypsiferous reddish-brown clay; lenses of limestone-pebble conglomerate, volcanic sandstone, and breccia tuff occur in the lower part of the unit. The volcanic red-bed and gypsum sequence grades upward into a series of andesite-latite tuffs, tuff breccia, and flows of possible Miocene-Pliocene age.

As shown on the map (fig. 5), the gypsum-bearing volcanic red beds crop out along Apache Canyon for about 2 miles west of Apache Dam, in the S½ sec. 31, T. 22 S., R. 1 E., and the E½ sec. 36, T. 22 S., R. 1 W. Near Apache Dam, on the south side of the canyon, there is a fairly persistent pure gypsum bed 2 to 4 feet thick, that could be strip-mined over 3 to 5 acres by removing 10 to 40 feet of soft overburden. A channel sample (No. 17, table 1) of this bed from the SW¼ sec. 31 contains 90.4 percent gypsum, 21/2 percent silica, and about 3 percent calcium carbonate. The gypsum is gray to white; typically it is coarsely crystalline and medium gray, with whitish laminae and stringers. Thin beds and laminae of gypsum in the reddish shale are red. Near the junction of secs. 31 and 36, lenticular beds of gypsum are numerous and in places coalesce to form 15 feet of 80-percent gypsum interbedded with reddish clay. These beds dip 15 to 35 degrees to the south, are cut by faults with small displacements, and are drag folded. Only small areas could be quarried in open cuts, and the adjoining clays and tuffs are too soft to permit extensive underground workings.

In the E¼ sec. 36, west of the CCC dam, several lenticular 1- to 4-foot-thick gypsum beds crop out; westward and northward in the central and NE¼ of the section, the gypsum beds are covered by terrace gravels and slope wash, or, to the north, are not present in this basal volcanic-lacustrine unit.

In 1956, a third dam was built across Apache Arroyo—a large earthen dam across the mouth of the arroyo in NEI,4 sec. 32, T. 22 S., R. 1 E. The gypsum outcrops can be reached from the Picacho-Shalem road by driving up Apache Canyon, but one must go over or around 2 or 3 dams, and through the mud flats behind each dam. Operations during the rainy season would be impossible.

Northern Franklin Mountains

Gypsum beds occur in the upper part of the Pennsylvanian strata of the Franklin Mountains, within lithologies that appear correlative to the Panther Seep formation of the San Andres Mountains. In the low foothills southwest of Anthony Gap, Wolfcampian fusulinids *(Pseudoschwagerina?)* are present in massive Hueco limestones (basal?) about 125 to 200 feet above the upper gypsum horizon. About 250 feet above the gypsum are limestones speckled with tiny (1 mm or less) *Staff ella huecoensis;* the latter limestones are similar to fusulinid-bearing ones in the lower Hueco of Powwow Canyon, the type Hueco formation in the Hueco Mountains. Below the gypsum beds (apparently about 30 feet, although the interval is covered, and there is a change in dip), a lightgray-weathering limestone bed yielded *Triticites,* a type suggesting uppermost Virgilian age. Beds below the gypsum are of interbedded siltstone, shale, silty sandstone, and limestone, lithologies similar to those of the Panther Seep formation. Above the upper gypsum are thin-to medium-bedded gray limestones interbedded with dark-gray shales,

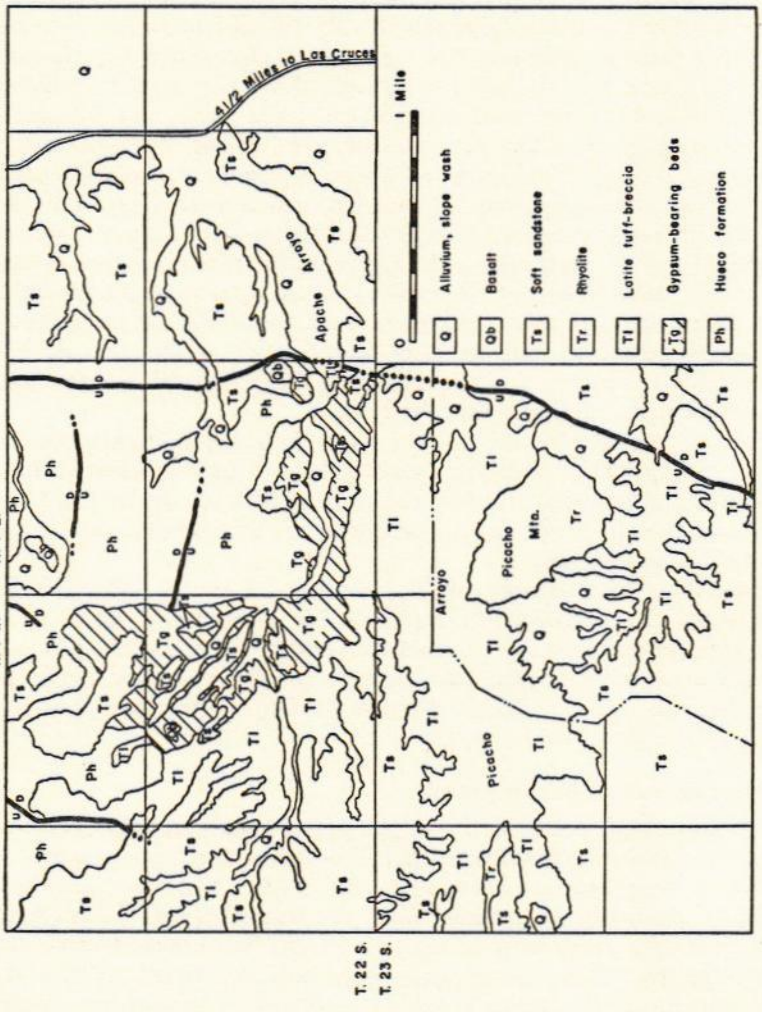


Figure 5
APACHE CANYON AREA, ROBLEDO MOUNTAINS

also suggestive of the Panther Seep, but yellowish-brown to tan sandstones present below the Hueco in the San Andres Mountains were not seen near Anthony Gap.

There are two gypsum horizons southwest of Anthony Gap, a quarter of a mile north of the New Mexico—Texas State line. The upper, thicker, more persistent gypsum has been quarried by the El Paso Cement Co., now the Southwestern Portland Cement Co. Where exposed in the abandoned quarry (NW¼NW¼ sec. 33, T. 26 S., R. 4 E.), the gypsum is 35 to 40 feet thick, dips 20 to 23 degrees to the south, and consists of medium-gray to medium dark-gray laminated medium-crystalline gypsum. The gypsum is overlain by thin-bedded gray limestones interbedded with dark-gray shales, a poor roof ("back") for underground operations. The gypsum bed has been explored to the east-southeast by prospect pits; it thickens and thins eastward, ranging from 10 to 20 feet in thickness, and includes in places limestone beds totaling as much as 2 feet thick. In one prospect cut, the gypsum horizon is dark-gray limestone with large nodular lenses of gypsum. The argillaceous beds below the upper gypsum bed are covered in most places by slope wash or pediment gravels, but in one gully a lower gypsum bed, 5 to 10 feet thick, is exposed about 100 feet below the upper, thicker gypsum horizon.

Chemical analysis of a chip-channel sample (No. 18, table 1) from the abandoned quarry is composed of 93.8 percent gypsum, with almost 3 percent silica, and at least 2 percent calcium carbonate. The steep dip of the beds, the erratic thickening and thinning, and the poor roof have retarded further development of the gypsum by the Southwestern Portland Cement Co. This company's present supply of gypsum (since 1937) is obtained near Finlay, Texas, from gypsum beds in the Permian Briggs formation.

SOUTHWESTERNMOST NEW MEXICO

In the southwestern corner of New Mexico, south of lat. 32° N. and west of long. 108° W., Robert A. Zeller, Jr. (personal communication, 1958) reported that gypsum beds occur at two localities, both in Big Hatchet Peak quadrangle. One occurrence is of gypsum in the Lower Cretaceous; the other is in Permian strata.

Outcrops of the Lower Cretaceous gypsum are exposed in the foothills south of the Big Hatchet Mountains, in a gully near the center of the NW¼NW¼ sec. 10, T. 32 S., R. 15 W., and in another gully in the NW¼SW¼SW¼ sec. 3, T. 32 S., R. 15 W. At least two beds of gypsum were found interbedded with red shale, red sandstone, and marine calcarenite in the uppermost part of the Hell-to-Finish formation and below the limestones of the U-Bar formation. The maximum combined thickness of the two gypsum beds is about 60 feet, and they have been traced at the surface for about a quarter of a mile. These gypsum beds appear to be of high purity but are in rather isolated country to be of commercial interest.

The Permian gypsum is exposed on the southwest edge of the Big Hatchet Mountains in numerous gullies tributary to the short valley near the corner common to secs. 20, 21, 28, and 29, T. 81 S., R. 15 W. The gypsum is interbedded with dolomites correlative with the Epitaph dolomite of southeastern Arizona (Gilluly et al., 1954). Gypsum is exposed over an area of about 23 acres, its thickness being estimated at 200 to 300 feet. The gypsum is contorted, and its thickness may be due to plastic flow at the base of a series of overthrust sheets. Gypsum was not seen elsewhere in the Epitaph dolomite of the Big Hatchet Mountains, but many thin to thick anhydrite beds were encountered in the Epitaph dolomite in the Humble State No. 1-BA oil test, southwest of the Big Hatchet Mountains.

The gypsum is banded and includes some 6-inch beds of dolomite. Claims were staked in the area by M. T. Everhart and R. K. Meyers in 1953. Analyses of 3 grab samples run by Farm Service Laboratory, El Paso, are as follows:

No.	CaO	SO_3	ARSENIC	SODIUM (water soluble)	SULFUR TRIOXIDE EXPRESSED AS GYPSUM ($CaSO_4 \cdot 2H_2O$)
1.	32.30%	44.25%	0.05%	trace	95.25%
2.	32.98	46.65	0.10	trace	100.05
3.	33.14	44.45	0.25	trace	95.50

There is a large amount of this Permian gypsum that can be quarried in open *pits,* and the quality is good enough for at least agricultural use. The area is low on the southwest side of the Big Hatchet Mountains and could be made accessible by building 6 miles of road across sandy-clayey flats and gravel fans, due west from N. Mex. Road 81. The nearest railroad siding is at Hachita, on the Southern Pacific Railroad, 32 miles by road from the outcrops. Possible markets for agricultural gypsum are the irrigated farms in the Playas Valley, 5 to 20 miles away; in the Animas Valley, north of Animas, 66 miles by road; and in the Deming area, 77 miles by road from the gypsum outcrops.

SOUTHEASTERN NEW MEXICO

Thin to thick gypsum beds of Permian age crop out in many localities of southeastern New Mexico and have been quarried for plaster near Acme and Oriental. The Pecos "diamonds," euhedral quartz crystals, occur in gypsum beds of the Whitehorse group. Sufficient tonnage of gypsum for agricultural or industrial use is available, and in many areas can be quarried in shallow open pits with removal of thin overburden. A quarry and calcining plant are planned near the Yeso Hills to mine and process gypsum from the Castile formation.

Pecos Valley

Gypsum beds within the Permian Whitehorse group crop out along the Pecos Valley in several areas from Santa Rosa southward to the Arroyo Yeso, and almost continuously south from the Arroyo Yeso to Carlsbad. Outcrops near Acme (Tansill formation?) are of light-gray crystalline gypsum, 1 to 6 feet thick, interbedded with red beds and obscured by gypsite cover. Typical sections (Seven Rivers formation?) are well exposed east of Roswell, where U. S. Highway 380 cuts the bluffs on the east side of the Pecos Valley, and to the south at Bottomless Lakes State Park. The gypsum beds are 1 to 5 feet thick and are interbedded and interlaminated with red beds (shale, fine-grained sandstone, and siltstone), some greenish shales, and thin-bedded gray limestones. Many of the gypsum beds are of white, high-purity gypsum; others are laminated and banded, with some contorted laminae. Thin laminae and bands are orange to reddish brown in the gray to whitish beds. Parts of the Whitehorse group in this area total 20 feet of 80-percent gypsum, with thin interbeds of red beds. On low benches and the relatively level slopes rising toward the High Plains, there are many areas several to tens of acres in extent where gypsum could be strip-mined.

On the east side of the Pecos Valley, and on gentle slopes east of the valley proper, east of Artesia and Hagerman, there are extensive outcrops of gypsum (Tansill formation) with only thin cover of eolian sand, soil, or red beds. Outcrops in the bluff along the east side of the valley are chiefly of limestone and red, green, and gray mudstone, but above the bluff are many thin to thick gypsum beds. Much inexpensively strippable gypsum is present.

To the south, toward Carlsbad, gypsum (Seven Rivers formation) is well exposed on the northeast side of the McMillan Escarpment, above Lake McMillan, in the canyons cutting the escarpment. Near the base of the hills are several gypsum beds, 10 to 20 feet thick, partly covered by gypsite and soil, and overlain and interbedded with thin-bedded dolomite and pinkish claystone. Much slumping and landsliding have occurred, owing to solution of the gypsum and washing away of the softer clastic beds. Along the northeast edge of the Seven Rivers Hills, near their base, several gypsum beds of the Seven Rivers formation, 1 to 5 feet thick, crop out interbedded with pale reddish-brown claystone, green and yellowish-brown platy sandstone, and tan to yellowish-brown argillaceous silty calcic dolomite. Some of the gypsum almost resembles "granite," being coarsely crystalline, gneissoid, and light gray speckled pink.

Southeast of Carlsbad, at Red Bluff—Rustler Bluffs, and along other nearby bluffs of the Pecos River, the Rustler formation crops out and includes gypsum beds, 10 to 30 feet thick, tan to light-gray silty calcic dolomite, yellowish to reddish limy sandstone, and pale reddish-brown shale. The gypsum beds are poorly exposed, but there are areas where acres of gypsum could be strip-mined beneath thin soil, partly consolidated gravels, or soft red beds.

Yeso Hills

The Yeso Hills are crossed by U. S. Highway 62-180 a few miles north of the New Mexico—Texas State line. Outcrops of the Castile formation are predominantly of gypsum, with interbeds of banded limestone and limy siltstone. The gypsum ranges from white, high-purity, coarsely crystalline gneissoid beds to gypsum laminated with calcite (pl. 5B). Much spongy cellular gypsite covers the outcrops, and numerous small caves are developed along joints in the gypsum. Sequences predominantly (90 percent) of gypsum appear to be 20 to 50 feet thick and could be quarried inexpensively in open pits. Chemical analysis of non-banded Castile gypsum (sample No. 20, table 1; sec. 28, T. 26 S., R. 24 E.) reveals 97.4 percent gypsum and probably about 2 percent calcium carbonate. In contrast, the laminated gypsum (sample No. 19, table 1) is made up of 92.0 percent gypsum and almost 8 percent calcium carbonate.

A quarry in the NE¼ sec. 14, T. 26, R. 24 E., exposes a lens of selenite gypsum in the Castile formation; the beds (crystalline laminae) are contorted and grade from almost clear selenite to cloudy selenite with twisted and warped twinning planes, and then into coarsely crystalline laminated gneissoid gypsum. Pratt (1954) noted the association of this selenite lens with nearby lamprophyric dikes, as well as with low scarps suggestive of fault lines.

The gypsum beds of the Castile formation in the Yeso Hills are to be mined by Claude Huckleberry, who estimates that his property contains 14 million tons of 97-percent-pure gypsum. The gypsum will be calcined near the quarry and then trucked 145 miles to El Paso to the gypsum wallboard plant of the Dura-Bond Gypsum Co. An estimated 200 tons of calcined gypsum will be trucked to El Paso daily. The wallboard plant was scheduled to be in full production by late 1959. (Newspaper release, El Paso *Times,* March 12, 1959.)

Chemical Analyses

Table 1 lists the principal oxide components of 20 samples of gypsum and gypsite collected during the course of the present survey. Anhydrite and gypsum contents were calculated from the analyses.

Calculated values for anhydrite are based on satisfaction of the formula $CaSO_4$ (41.9 percent CaO and 58.81 percent SO_3). The SO_3 content of each analysis was used as the basis for the calculations. In most cases, this left a surplus of CaO that probably is combined largely with CO2 and Mg0 in calcite or dolomite. Three samples (Nos. 12, 14, and 15 of table 1) showed small deficiencies of CaO, which may be due to the presence of free sulfur, other sulfates, or analytical errors.

Gypsum contents shown in Table 1 are the sum of calculated anhydrite and combined water from the analyses, adjusted to total 100 percent with the impurities listed. None of these satisfy the ideal formula for gypsum, $CaSO_4 \cdot 2H_20$ (79.07 percent $CaSO_4$ and 20.93 percent H_20), because of a shortage of water. The shortages may be attributable to loss of part of the combined water during drying of the samples; the presence of anhydrite, hemihydrate, or intermediate compounds in the samples; or analytical errors. According to Posnjak (1938, p. 247), the transition point of gypsum to hemihydrate is at 97°C, which suggests that at least a part of the water deficiency has resulted from losses in drying.

Although an attempt was made to obtain representative portions of each section sampled, no one sample can be assumed to represent an entire deposit. The analyses listed should be considered only as approximations of the composition of the respective deposits. An accurate appraisal of the variations in composition and average composition of a particular deposit will require a carefully planned program of sampling at regular intervals throughout its extent.

Uses and Industrial Preparation

Gypsum is an essential component of a wide range of commercial products, as indicated in Table 2. Although the total value of these products in 1955 was more than $319 million, much of this accrued from processing and fabrication costs. Crude gypsum is in reality a low-priced commodity that is of value only where it can be mined economically and transported to the consumer at low cost.

UNCALCINED GYPSUM

Uncalcined gypsum constituted 22 percent of the total gypsum utilized in the United States in 1955. The bulk of this was used as a retarder in portland cement. For this purpose, raw gypsum is added to the cement clinker, before grinding, in amounts of 85 to 100 pounds of gypsum per ton of clinker (about 10 pounds per barrel of finished cement). Most plants now specify that the gypsum must contain a minimum of 92 percent $CaSO_4 \cdot 2H_20$, but lower grades may be acceptable. "Pebble" gypsum in the size range of about 3/8 inch to 1½ inches is usually required. Some plants, however, accept only finely ground gypsum.

Agricultural use of uncalcined gypsum depends largely upon its value for improving alkaline soils. Some nonalkaline soils that are deficient in calcium and/or sulfur may benefit from applications of gypsum, which supplies both of these plant nutrients. The sulfur content is particularly beneficial to alfalfa and leguminous plants. Gypsum may also free fixed potassium, or make other essential elements that are present in the soil in insoluble form more readily available to growing plants.

Many alkaline soils of fine texture tend to be relatively impermeable to air and moisture, hard and cloddy when dry, and sticky when wet, owing to the deflocculation of clay particles by adsorbed sodium ions. Such soils may also contain toxic (to plants) concentrations of sodium carbonate. The presence of sodium-saturated clays and/or excess free sodium carbonate characterizes the black alkali soils that have plagued farmers in many irrigated districts in the Western United States. Gypsum added to black alkali soils will displace adsorbed sodium ions and react with sodium carbonate to produce the less toxic and more readily water-soluble sodium sulfate. Subsequent flood irrigation and leaching of the soluble salts are essential steps in the reclamation process. White alkali (saline) soils also respond favorably to treatment with gypsum, which counteracts the tendency of the soils to "freeze up" toward the end of the leaching operation. In some cases, gypsum has proved useful in improving the tilth and structure of soils that have been damaged by

TABLE 2. GYPSUM PRODUCTS IN THE UNITED STATES, 1955
(From Larson and Jensen, 1958)

USE	SHORT TONS	VALUE TOTAL	VALUE AVERAGE
Uncalcined:			
Portland-cement retarder	2,225,781	$ 8,725,863	$ 3.92
Agricultural gypsum	678,332	2,298,831	3.39
Other uses'	33,995	411,000	12.09
Total uncalcined uses	2,938,108	11,435,694	3.89
Industrial:			
Plate-glass and terra-cotta plasters	67,664	931,528	13.77
Pottery plasters	49,744	966,578	19.43
Orthopedic and dental plasters	9,454	345,972	36.60
Industrial-molding, art, and casting plasters	84,159	1,589,972	18.89
Other industrial uses'	88,098	2,503,005	28.41
Total industrial uses	299,119	6,337,055	21.19
Building:			
Plasters:			
Base-coat	1,799,219	26,846,683	14.92
Sanded	594,275	13,159,252	22.14
To mixing plants	7,977	90,422	11.34
Gaging and molding	165,168	2,844,306	17.22
Prepared finishes	12,470	823,646	66.05
Roof-deck	385,094	5,666,736	14.72
Keene's cement	54,496	1,270,518	23.31
Other plasters [3]	19,673	2,144,539	109.01
Total plasters	3,038,363	52,846,102	17.39
Prefabricated:			
Lath	2,274,258	71,340,593	
Wallboard	4,439,093	165,899,184	
Sheathing board	131,235	4,671,953	
Laminated board	2,032	100,479	
Formboard for poured-in-place gypsum roof-deck	53,836	2,001,467	
Tile	200,174	4,690,950	
Total prefabricated	7,100,628	248,704,626	

1. Includes uncalcined gypsum for use as filler and rock dust, in brewer's fixe, in color manufacture, and for unspecified uses.
2. Includes dead-burned filler, granite polishing, and miscellaneous uses.
3. Includes joint filler, patching, painter's, insulating, and unclassified building plasters.

improper tillage, and in maintaining a favorable structure in soils that are in good condition.

Rates of application will depend upon the amounts of adsorbed sodium and free sodium carbonate in the soil, the chemical composition of the irrigation water, the permeability of the soil, and the crops to be grown. A minimum of 2 to 3 tons of high-grade gypsum per acre has been recommended for reclaiming the average black alkali soil (Dregne and Chang, 1952). Applications of 500 pounds of gypsum per acre every second year usually will provide protection against further alkali damage. Additional information on methods of application, and local recommendations, can be obtained usually from County Agricultural Agents and district offices of the United States Soil Conservation Service. The following references give fuller discussions of the subject than seem appropriate in this report: Dregne and Chang (1952), Kelley (1951), McGeorge (1945), Rollins (1951), and Ver Planck (1952).

There is a sizable market for low-cost agricultural gypsum in New Mexico. Chang and Dregne (1955, p. 2) state that "there are few irrigated areas in the state [New Mexico] where salt and sodium accumulation is not a present or potential problem." According to Harry Maker, State Soil Scientist, U. S. Soil Conservation Service (personal communication, June 1958), large acreages of alkaline soils in the Rio Grande valley, Tucumcari, Deming, and Animas irrigated areas would benefit from treatment with gypsum. The Socorro Soil Conservation District alone is reported to contain 23,313 acres of alkaline and heavy clay soils that would require 5 to 10 tons of gypsum per acre for improvement of tilth and reduction of excessive alkalinity (J. E. Reeves, U. S. Soil Conservation Service, personal communication, May 1958).

The preparation of agricultural gypsum for market requires only that the material be in a pulverized state for ease of application and speed of reaction. More than trace amounts of sodium salts and boron are undesirable, but these have not been recognized in the gypsum deposits of New Mexico. Rock gypsum sources would require crushing and pulverizing facilities. Pulverulent gypsite deposits could supply a suitable mine-run product, although removal of nodular aggregates by screening might be desirable in some cases. Friable crystalline gypsite caps, such as those in the Mesa del Yeso area, pulverize easily with relatively simple equipment. Gypsum dune sands could be used as mined without further preparation.

Agricultural usage does not require high-purity gypsum, but the value to the consumer is directly proportional to the calcium sulfate content. Nearby low-grade sources may permit savings in transportation, mining, and preparation costs that more than offset the advantages of high purity offered by other deposits.

CALCINED GYPSUM

Calcined gypsum products constituted the bulk of the consumption of crude gypsum in the United States in 1955, aggregating 78 percent of the total. The principal products, in terms of both tonnage and value, were prefabricated wallboard and lath, followed by building plasters. Industrial uses were of relatively minor importance. Tonnages consumed and the total values of products are outlined in Table 2.

Calcining of gypsum is the controlled elimination of part of the chemically combined water by heating crude gypsum in kettles, rotary kilns, or autoclaves. For most purposes, the resulting product approximates calcium hemihydrate ($2CaSO_4 \cdot H_2O$), which has the valuable property of recombining with admixed water and rapidly setting to a stonelike substance that has the composition of gypsum. Most processes require that the crude gypsum be crushed and ground prior to calcining. The calcined product is known as stucco, calcined plaster, or plaster of paris. It may be used in this form for some purposes but is usually reground in tube mills. Various additives designed to control the rate of set, consistency, bonding strength, and other properties permit tailoring of the final product to a wide range of use specifications.

The numerous small plants that formerly supplied calcined gypsum products to local markets have in recent years been replaced by a few large-company operations with integrated facilities for mining, crushing, grinding, calcining, fabricating, and marketing. The construction of a modern calcining and wallboard manufacturing plant involves capital expenditures of from one to several million dollars, which effectively eliminates the small operator with limited financing from this field of endeavor. The producer of crude gypsum alone is largely limited to portland cement manufacturers and agricultural gypsum consumers for market outlets for his product. Even in these fields, it is difficult to compete with the low-cost crushed and ground gypsum supplied by plaster and wallboard manufacturers. In areas, however, at some distance from existing producers, which at present includes essentially all of New Mexico, the development of local sources might provide savings in transportation costs which would more than offset any differential in f.o.b. prices.

CHEMICAL USES

Increasing attention is being focused on gypsum as a possible source of sulfur and calcium compounds for industrial use. Under conditions of equal availability, anhydrite is given preference over gypsum because of its higher sulfur content. The manufacture of sulfuric acid from gypsum and anhydrite has proved commercially successful in sulfur-poor Europe, but current processes are not competitive in the United States, where elemental sulfur is more readily available. The production of cement, ammonium sulfate, lime, hydrated lime, and other compounds has also been shown to be technically feasible.

The continued depletion of known reserves of elemental sulfur, even at the present rate, coupled with technological improvements in extractive processes, will undoubtedly shift gypsum into a position of increasing importance as a chemical raw material in the future.

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