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Geology of Dog Springs Quadrangle, New Mexico

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Abstract

Dog Springs quadrangle lies within the Gallinas Mountains of west-central New Mexico, approximately 30 miles northwest of the town of Magdalena.

The oldest rocks that crop out in the quadrangle are Triassic continental Chinle shales. Above the Chinle are the following sedimentary formations: Dakota(?), nonmarine Upper Cretaceous sandstone; Mancos, marine Upper Cretaceous shale; Mesaverde, nonmarine and marine Upper Cretaceous sandstone; and the Baca, Eocene(?) continental arkose. Overlying the Baca formation are the quartz latite tuffs of the Spears Ranch member and the rhyolite tuffs of the Hells Mesa member of the Datil formation. Resting on the Datil formation are the Santa Fe gravels and basalts; these in turn, are overlain by Recent gravels. Intruded into the section are basalt plugs and dikes of Pleistocene(?) age.

Structurally the area is characterized by broad-scale northwest trending, southeast plunging folds of Eocene(?) age, and broad-scale, northeast trending folds of Pleistocene(?) age. Several north trending normal faults of considerable displacement cut the sedimentary and volcanic rocks of the area.

Physiographic evidence suggests that the San Augustin Plains were once a topographic high and the source of the Santa Fe gravels.

Introduction

PREVIOUS WORK

The first published geologic work that included Dog Springs quadrangle was by C. L. Herrick in 1899. Herrick mapped all the sediments and the Datil volcanic rocks as Upper Cretaceous. In his text (1900, p. 342) he distinguished between the Fox Hills, the Chinle, which he called "red beds," and the volcanics, which he called trachyte and rhyolite intrusives.

In 1913 Dean E. Winchester made a reconnaissance trip up the Rio Salado. All the Upper Cretaceous sections described in his 1920 Oil and Gas Report were measured in Dog Springs quadrangle. The thicknesses for the Dakota(?) formation and the formation which he named Miguel, now recognized to be the Mancos and part of the Mesaverde, were measured on D Cross Mountain. The section for his Chamiso formation, now recognized as Mesaverde, was measured on the north flank of Blue Mesa.

In the summer of 1931, W. S. Pike investigated an area which he called McCarthy-Alamosa Creek. This area extended down from the north, at McCarthy, to Alamosa Creek, now called the Rio Salado, contrary to local usage. His map includes the northwest corner of Dog Springs quadrangle, and several of his most important sections were measured within the quadrangle.

Contiguous areas were studied by E. H. Wells (1919), V. C. Kelley and G. Wood (1946), and W. Tonking (1957).

METHODS OF INVESTIGATION

Field work in the area was done during the summers of 1952 and 1953. A total of 180 days was spent in the field.

The geology was plotted on contact aerial prints, which had an approximate scale of 2 miles to the inch, and was transferred subsequently to the United States Soil Conservation aerial mosaic of the quadrangle, which has a scale of 2 miles to the inch. All the contacts and stream patterns were then transferred to a sheet of tracing paper to make the finished map. Although there is a planimetric map of the area, it was felt that greater accuracy and usefulness could be obtained by using the photomosaic as a base.

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GEOGRAPHIC FEATURES

Location and Accessibility

Most of Dog Springs quadrangle is located in northwestern Socorro County and eastern Catron County, New Mexico. The quadrangle was designated as Datil 246 by the United States Soil Conservation Service in 1936. It has been named Dog Springs quadrangle after the springs of that name located in sec. 6, T. IN., R. 8 W. These springs are the best known water source in the area. The quadrangle has an approximate area of 225 square miles.

About 30 miles west of Magdalena on U. S. Highway 60 there is a sign pointing north to Dog Springs. The sign designates the only all-weather road which runs through Dog Springs quadrangle. Within the quadrangle several subsidiary trails branch from the main road, and these are shown on the accompanying map.

Physical Features

The Gallinas Mountains are an east-west trending range which passes through the lower one-third of Dog Springs quadrangle. The highest point of the range is Gallinas Peak (elevation 8,713 ft). From this promontory almost the entire quadrangle is visible.

The crest of the Gallinas forms a dividing line in the physiography of the region. To the south of the crest the rock surface slopes gently downward and passes beneath the bolson deposits of the San Augustin Plains. The southern mountain slopes are dissected by youthful canyons.

To the north the physiography takes on a wholly different aspect. The Gallinas drop abruptly from their crest, in cliffs up to 600 feet in height, into a series of sharply dissected, round-topped hills and ridges, some of which have pinnacles on their summits. These hills then descend rapidly as a series of declivities, some as much as 300 feet in height, to a gentle slope which terminates at the Rio Salado. Low sandstone cuestas extend through the gravels of the valley of the Rio Salado.

The northern one-third of the quadrangle is characterized by high, basalt-capped mesas, all of which have volcanic necks at their southern tips. The highest of these necks is D Cross Mountain (elevation 8,494 ft).

Climate and Culture

Accurate climatic data are not available for Dog Springs quadrangle. Section 27 of the Climatic Summary of the United States gives data, however, for the towns of Datil and Magdalena, which are approximately equally distant from either side of the quadrangle. This source states:

	Datil	Magdalena
Average annual precipitation	12.97 in.	12.87 in.
Average annual snowfall	39.5 in.	21.1 in.
Average summer high temperature	81°F	83°F
Average winter minimum temperature	13°F	21°F
Overall high temperature	98°F	102°F
Overall low temperature	18°F	−21°F

The principal industry in the area at the present time is ranching. Some of the Navajos on the reservation in the northeast corner of the area dry-farm small patches of corn.

Descriptive Geology

GENERAL STATEMENT

Two distinctly different types of bedded sediments form the surface outcrop of Dog Springs quadrangle. The oldest rocks exposed in the area are the continental shales of the Triassic Chinle formation. These are overlain by three units of Upper Cretaceous age, the continental Dakota(?) sandstone, the Mancos shale, and the sandstones and shales of the Mesaverde group. The above units crop out only in the northern one-third of the quadrangle. To the south they are blanketed by a thick sequence of bedded tuffs and volcanic conglomerates, the Datil formation of probably Miocene age. Basalts and gravels of the Quaternary Santa Fe formation and later pediment and stream gravels unconformably overlie all the older rocks of the area. Several basaltic plugs and dikes of unknown age are also present.

TRIASSIC SYSTEM

Chinle Formation

The oldest unit exposed in Dog Springs quadrangle is the Chinle formation. This formation makes up the broad floor of Red Lake Valley in the northwest part of the quadrangle and also the floor of the small valley in the extreme northeast corner of the area. The Chinle formation was first described by H. E. Gregory (1916, p. 79) as follows:

> The Chinle formation consists of calcareous shales and sandstones including lenses and beds of varying horizons of limestone conglomerate. The strata are highly colored in pink, purple, gray, and brown, and eroded into badlands forms of singular beauty. Fossil wood is present in this formation and becomes unusually abundant at the various "fossil forests." Vertebrate remains collected at a number of localities fix the date of deposition of the beds. The Chinle is equivalent in part to the "Leroux formation" of Ward and the Dolores formation of Cross.

Gregory named the Chinle formation after Chinle Valley, in Arizona.

The Chinle is, for the most part, a red shale or mudstone, but core samples taken from a water well show that the shales and mudstones may be purple and blue as well as red. A bed of gray medium-grained quartzose sandstone crops out 150 feet below the top of the formation. This sandstone is thinly bedded, well consolidated, made up of angular grains, and cemented with calcite. It forms the tops of the small hummocks on the valley floors.

Regionally the Chinle formation is angularly unconformable with the overlying Dakota(?) sandstone. Although locally the contact appears conformable, the entire Jurassic section is missing, and well-developed structures, unconformable to those in the Upper Cretaceous strata, are present in the Chinle to the north and east of the quadrangle. On the eastern edge of Red Lake Valley the Chinle formation is in fault contact with the Crevasse Canyon formation, a part of the Mesaverde group.

Several lines of evidence point to the nonmarine, flood-plain origin of the Chinle shale. At the petrified forest in Arizona nonmarine vertebrate remains have been found with the fossil wood. The fine-grained nature of the shale points to flood-plain conditions at the time of deposition. The included sandstone bed may have been due either to a flood stage or a local rise in the source area, and hence furnished coarser clastic sediments.

CRETACEOUS SYSTEM

Upper Cretaceous rocks form the surface exposures in most of the northern one-third of Dog Springs quadrangle. The rocks belonging to the series can be split into two separate formations and a group, which in turn is broken down into two formations.

Dakota(?) Sandstone

The rocks making up the lowermost ledge which bounds Red Lake Valley on the west are typical of the Dakota(?) sandstone. This formation is called the Dakota(?) because of its stratigraphic relationships to the other Upper Cretaceous formations. Throughout the State of New Mexico the name Dakota(?) is used to signify the sandstone or sandstones at the base of the Mancos shale. Its exact equivalence to the type Dakota sandstone elsewhere is not implied.

The Dakota(?) formation consists of one bed of silica-cemented quartzose sandstone, which throughout the area is almost uniformly 20 feet thick. The grains of the sandstone are subrounded and poorly sorted. The sandstone is yellow on weathered surfaces, cream colored on fresh surfaces, and well consolidated. In places the formation contains lenses of silica-cemented conglomerate that are made up of subrounded quartzite pebbles and granules. This conglomerate at places contains iron oxide concretions. The Dakota(?) formation grades upward from a medium-grained into a fine-grained sandstone.

In general the bedding of the formation is regular, but locally channelling and crossbedding have developed.

The Dakota(?) formation is recognized easily by its stratigraphic position between the underlying red Chinle formation and the overlying gray-black Mancos shale. Owing to the incompetent character of the Chinle and the resistant nature of the Dakota(?), landsliding is common along the contact of the two formations.

Mancos Shale

Exposed on the east slope of D Cross Mesa are two identical, thick, slope-forming shale units separated by a bed, 25 feet thick, of ledge-forming sandstone. These shale units and the sandstone between them are mapped as the Mancos shale.

Cross (1899-b, p. 4), who named the formation, says concerning the Mancos:

> . . it is an almost homogeneous body of soft, dark-gray or nearly black, carbonaceous clay shale, . . . The Mancos is therefore a lithologic unit which it is necessary to recognize in the mapping of this region. It is limited below by the Dakota sandstone and above by the lowest sandstone of the Mesaverde formation of alternating sand-stones and shales. . . .this lithologic unit embraces the Colorado group and a part of the Pierre division of the Montana group.

Sears *et al. (1941,* p. 109), working in the San Juan basin, state further:

> The upper limit of the Mancos shale in the southwestern part of the San Juan Basin, near Gallup, has been placed "at the bottom of the massive sandstone that forms the crest of the west ridge of the Hogback. Thus limited, the formation consists mainly of dark-gray, somewhat sandy marine shale."

The Mancos, then, as defined and used by geologists signifies a lithologic unit comprised mostly of shale.

In Puertecito quadrangle, east of the quadrangle described here, Tonking (1957) placed the Mancos-Mesaverde contact at what is here called the Tres Hermanos member of the Mancos shale, thereby including in the Mesaverde the thick shale unit above the Tres Hermanos.

Shale Members

The upper and lower shale members of the Mancos are so nearly identical that it is expedient to describe them together. Both are slightly sandy carbonaceous gray shale, Both shales are highly fossiliferous, gypsiferous, and calcareous. Lentiles of sand occur in the two shales.

The units are best exposed on the flank of D Cross Mesa, where the lower shale member is approximately 90 feet thick, and the upper shale member is approximately 190 feet thick.

Tres Hermanos Member

The sandstone bench cropping out above the Dakota(?) sandstone on D Cross Mesa was called "Tres Hermanos" by Pike (1947, p. 65). Tonking (1957) mapped this sandstone in Puertecito quadrangle and found that it pinched out to the east in that quadrangle. Field evidence in Dog Springs quadrangle shows that the Tres Hermanos sandstone must also pinch out to the west near the boundary of the two quadrangles. Farther west, at D Cross Mesa, it is again present. This sandstone apparently is lenticular.

The origin of the name Tres Hermanos is obscure. As Pike (1947, p. 32, footnote) pointed out:

> One or more sandstones near the base of the Mancos at various localities in New Mexico have been called "Tres Hermanos." The term seems first to have been applied by Herrick and Johnson (1900b) in describing the geology of the Albuquerque sheet, but no type locality was given. Their original type locality is probably a mile east of Tres Hermanos Buttes, three volcanic necks in Alamosa Creek valley, in sec. 26, T. 3 N., R. 7 W., where sandstones occur in a similar stratigraphic position.

The Tres Hermanos member is a well-layered quartzose sandstone that is almost uniformly 25 feet thick. The sandstone is yellow on weathered surfaces, yellowish cream on fresh surfaces. The grains are frosted, well sorted, and cemented by silica. Some of the layers within the sandstone unit are fine grained, whereas others are medium grained.

Pike (1947, p. 32, 36, 65, and 93) mentions that the Tres Hermanos may be a tongue of the underlying Dakota(?) sandstone, although he found no field evidence to support this statement. Lithologically the Tres Hermanos is more nearly similar to the overlying Mesaverde than it is to the underlying Dakota(?). The Dakota(?) has been described as nonmarine in other parts of the State; the Tres Hermanos is probably of marine origin. Hence, the Tres Hermanos sandstone appears genetically to resemble the Mesaverde group more than it does the Dakota(?) formation.

The Mancos conformably overlies the Dakota(?) sandstone and is conformably overlain by the Mesaverde group.

Mesaverde Group

The "Mesaverde" group was first described by Holmes (1875, p. 248 and 252) and was named by him from a typical exposure on Mesa Verde, Montezuma County, Colorado. He divided the group into a "Lower Escarpment" sandstone, 180 feet thick, a "Middle Coal Group," 624 feet thick, and an "Upper Escarpment" sandstone, 200 feet thick.

It is doubted that Holmes used the term "group" in the restricted sense of present-day stratigraphic nomenclature, as he subsequently used the term "Middle Coal Group" for a unit within the "Mesaverde Group." However, various geologists have designated the Mesaverde as both a group and a formation. Following the usage of Allen and Balk (1954), the Mesaverde will be treated as a group in the present report. It seems consistent to treat the Mesaverde rocks as a group because many of the units are continuous for great distances.

The division of the Mesaverde into formations or members has been carried out in different ways by various authors. Allen and Balk (1954) give an excellent summary of the nomenclature used by various authors.

In Dog Springs quadrangle the Mesaverde group was divided into two formations on the basis of lithology and fossil content of the beds. The basal beds were called the La Cruz Peak formation (Tonking, 1957). The La Cruz Peak formation may be equivalent, at least in part, to the Gallup sandstone. The upper beds of the group were called the Crevasse Canyon formation, after the work of Allen and Balk (1954). This name was chosen because of the similarity of the beds in Dog Springs quadrangle,both in general lithology and stratigraphic position, to the type Crevasse Canyon formation.

The Mesaverde group is composed of sandstone and shale units of both continental and near-shore and shallow-water marine origin. The sandstone is present in greater amounts than the shale. Coal is found in thin lenticular beds in the upper part of the group.

Strikes taken on the Mesaverde strata are generally unreliable, owing to common crossbedding and slumping. The regional attitude of the beds can be obtained from aerial photos because typically the beds weather to a dip slope.

The Mesaverde is characteristically a ridge-forming series of strata. When dips of the sandstone beds are high, cuestas are formed and when the beds have a low angle of dip, the sandstones are likely to underlie mesas or form lowlands. The preservation of the mesas depends on the presence of a protective cap. This cap may be sandstone cemented by iron oxide, but is more typically basalt.

The intertonguing relationship within the Upper Cretaceous sediments has been discussed by many authors in great detail (Lee, 1915; Sears, 1941; Pike, 1946; and Spieker, 1947). There is no agreement, however, as to the exact cause of the intertonguing. The intertonguing has been ascribed to all three diastrophic conditions: (1) uplift, (2) subsidence, and (3) standstill, coupled with variations in the amount of sediment brought into the area. It is not within the scope of this report to discuss the cause of the intertonguing in detail.

It is well established that in the northwestern part of New Mexico there were three major southwesterly transgressions of the Mancos sea (Allen and Balk, 1954). In Dog Springs quadrangle the third transgression is probably not recorded in the geologic column. The sandy character of the Mancos shale in this quadrangle suggests that at no time was the shoreline very far to the southwest.

The two prominent sandstone units in the La Cruz Peak formation are interpreted as beach or offshore bar sandstone, because of their medium grain size and poor sorting. The sandstones of the Crevasse Canyon appear to be near-shore continental deposits, probably stream-channel sands. The interbedded mudstones of this formation probably represent swamp deposits.

The Mesaverde group in Dog Springs quadrangle probably was deposited between Carlisle and Montana time. Pike collected fossils of Carlisle age from the rock units above the base of the La Cruz Peak formation, and Winchester reported flora of Montana age in what is here called the Crevasse Canyon formation.

An understanding of age relationships within the Mesaverde requires some knowledge of the structural geology of the area. Early work in the quadrangle was of a reconnaissance nature, and the fault running to the west of D Cross Mesa was missed; hence there are discrepancies in the thickness reported as well as in the geologic age determinations.

The Satan tongue(?) of the Mancos, measured by Pike (1946), and the Bell Mountain sandstone, named by Winchester (1920) and measured by both Winchester and Pike, are merely repetitions, due to faulting, of part of the La Cruz Peak formation.

Because the fault was not recognized, Winchester remeasured a large part of his Miguel member and unknowingly included it in the basal part of his Chamiso member. The Montana flora which he found: in this series of strata is from rocks belonging to the Crevasse Canyon formation.

La Cruz Peak Formation

The name La Cruz Peak formation was given by Tonking (1957) to a sequence of ''olive-gray to bluish-gray marine shales, sandy shales, and gray to yellow quartzose sandstones and subgreywackes" conformably resting on the Tres Hermanos formation. The formation was named for La Cruz Peak in Puertecito quadrangle. The formation is very poorly exposed at the type locality, so that a reliable section could not be measured. However, on the slopes of D Cross Mesa, Dog Springs quadrangle, an excellent section of the La Cruz Peak formation is exposed. This exposure consists of a bed of marine quartzose sandstone, which varies in thickness from 40 to 100 feet, overlain by 190 feet of gray sandy shale. This shale is gypsiferous, calcareous, and fossiliferous. The shale is, in turn, overlain by a bed of quartzose sandstone, 70 feet thick, which contains marine fossils at its base.

The La Cruz Peak formation as mapped in Dog Springs quadrangle differs from the La Cruz Peak formation, as defined by Tonking, in that the shale, which he included at the base of the formation in Puertecito quadrangle, in Dog Springs quadrangle is included in the Mancos formation.

Because of their stratigraphic position, Pike (1947, p. 70) suggested that the strata here called the La Cruz Peak formation are probably equivalent to the Gallup sandstone.

Crevasse Canyon Formation

Crevasse Canyon is the name applied to a formation in the Mesaverde group by Allen and Balk (1954). At the type locality the formation consists of 240 feet of silty shale, laminated silt, thin beds of coal, and thin- to medium-bedded fine-grained sandstone. At the type locality Allen divided the formation into three members. These members were not recognized in Dog Springs quadrangle.

In Dog Springs quadrangle the Crevasse Canyon formation has the widest area of outcrop of any of the Cretaceous formations. Here it is made up largely of medium- to coarse-grained quartzose sandstones interbedded with mudstones, nonmarine shales, and coals. The lithologies of the Crevasse Canyon sandstones and the La Cruz Peak sandstones are very similiar. The sandstones of the Crevasse Canyon, however, are slightly coarser grained, more crossbedded, and more iron stained than those of the La Cruz Peak formation.

A section was measured on D Cross Mesa, where the formation is best exposed. However, owing to slump and lenticularity of intraformational units, this section may not completely represent the formation.

TERTIARY SYSTEM

Baca Formation

A bedded sequence of red arkoses and mudstones crops out at the base of the Gallinas Mountains and along the northeast front of Blue Mesa. This sequence was named the Baca formation by Wilpolt et al. (1946). The type locality is Baca Canyon in secs. 4, 5, 8, and 9, T. 1 N., R. 4 W., north Bear Mountains, Socorro County. The Baca formation is made up of the lower 684 feet of Winchester's (1920, p. 4) Datil formation.

The Baca formation in Dog Springs quadrangle consists almost wholly of two distinct lithologic types. The major portion of the section is composed of red sandy mudstone. Interbedded with mudstone is red medium-grained arkose. The arkose is made up largely of subangular grains that are poorly sorted and poorly consolidated. In the slump area on the front of Blue Mesa a bed of greenish arkose also was noted.

Most of the Tertiary sediments in the State have volcanic fragments included. This is not true of the Baca formation. A microscopic examination of the arkose revealed no volcanic fragments.

The contact between the Baca formation and the underlying Mesaverde is in general poorly exposed. In secs. 35 and 36, T. 3 N., R. 8 W., the base of the Baca is exposed and appears to be conformable with the Mesaverde. It was here that the Baca section was measured. There appears to be a discordance of dip between the Baca formation and the Mesaverde group. The contact, however, between the two formations is not visible, and the discordance may be due to slumping.

The contact between the Baca and the overlying Datil formation is angularly unconformable.

In general, the Mesaverde and Baca can be distinguished from each other by their respective colors, as well as by their differences in composition. The Mesaverde is a yellow quartzose sandstone, whereas the Baca is red arkose. The contact between the two formations is not distinct. Near the section that was measured, some of the yellow Mesaverde-type lithology interfingers with the red Baca-type lithology. However, a definite yellow quartzose sandstone horizon, whose exposed dip slope is pockmarked with iron concretions, crops out in sec. 35, T. 3 N., R. 8 W., and sediments above this quartzose sandstone are all arkosic. Therefore, the contact between the Baca and Mesaverde was drawn at the top of the quartzose sandstone.

Wilpolt et al. (1946) correlated the Baca with beds in a similar stratigraphic position in the Carthage coal field, mapped by Gardner in 1910. Gardner (1910, p. 454) reported finding a tooth identified as Paleosyops in these beds, which places their age possibly as Bridger (Eocene).

Wilpolt et al. (1946) also correlated the Baca with beds near Elephant Butte, which later were called the McRae formation by Kelley (1952, p. 115). Kelley (1952, p. 118) strongly argues against correlating the Baca and McRae formations. Wilpolt et al. (1946) also correlated the Baca formation with strata in the Organ Mountains and with the Galisteo sandstone.

These correlations must be considered tentative until more substantiating evidence becomes available.

The arkoses and mudstones of the Baca formation are finer grained in Dog Springs quadrangle than they are farther to the east. Within the quadrangle the arkoses also decrease in grain size toward the west along the strike of the formation. Therefore, the center of the basin in which the Baca was deposited probably lay near the western edge of the quadrangle or just to the west of it.

The Mesaverde group undoubtedly furnished some detritus to the Baca. Inasmuch, however, as the Baca sediments are composed largely of feldspar grains, and the Mesaverde group is poor in feldspathic sediments, it follows that the Baca sediments must have been derived largely from some other source. One clue to this source is the presence in the Baca sediments of well-rounded quartzite pebbles and peculiar petrified wood fragments. Similar quartzite and wood are known to be present in the Triassic Chinle formation. Hence, it may be that some of the Baca sediments were derived from the Chinle formation. Arkoses derived from sedimentary rocks are unusual; therefore, a large portion of the Baca may have been derived from granites exposed somewhere to the east, outside the area studied.

Datil Formation

The Datil formation was first named by Winchester (1920, p. 4). The following is taken from his description of the formation:

> . . . Unconformably overlying these Cretaceous sediments is a formation consisting of a series of tuffs, rhyolites, sandstones, and conglomerates, which is probably of late Tertiary age, although no fossils were found that lend evidence for this assumption. This formation is here named the Datil formation because it is the mountain-forming series of the Datil Mountains, . . .

Later, the basal 684 feet of Winchester's Datil formation, as already noted, was named the Baca formation by Wilpolt et al. (1946).

The Datil formation is a very thick sequence composed principally of pyroclastic rocks. The basal unit of the formation is a series of tuffs, agglomerates, and flow breccias which have the chemical composition of quartz latite (Tonking, 1957). Overlying the basal unit is a thick sequence of rhyolitic tuffs and welded tuffs. The unit also contains a basalt flow.

To the east, in Puertecito quadrangle, there is a thick sequence of volcanic rocks of basaltic and andesitic composition, which are exposed stratigraphically above the rhyolites. This member is not present in Dog Springs quadrangle, except perhaps for the basalt flow in the rhyolite member.

The Datil formation is the prominent mountain-forming unit in Dog Springs quadrangle. It overlies the Baca formation and the Mesaverde group with angular unconformity and underlies the Santa Fe formation. Later gravels in turn rest unconformably upon the Santa Fe.

Study of the Datil formation consisted of laboratory work, as well as field observations. Thirty-five thinsections were examined in conjunction with oil-immersion studies of crushed mineral grains. A great number of rock samples were crushed and fused, following the technique of Mathews (1951, p. 92-101), and the indices of refraction of the glasses were determined.

An attempt was made to determine how reproducible are the results obtained by the fusion technique. The experimental procedure outlined below was followed.

A rhyolite tuff was crushed in a diamond mortar. The material was thoroughly mixed in a container and divided into seven portions weighing 10 mg each. The seven samples were placed in a spectroscopically pure carbon electrode drilled to uniform depth. The electrodes then were individually arced in a spectrograph having time controls. The following times and sources were used: 90 sec a. c., 55 sec d. c., 4 *sec* d. c., 6 1/2 *sec* d. c., 75 *sec a. c., 10 sec* d. c., and 30 sec d. c. A photographic plate moved at 1-sec intervals was exposed on the first two runs to see if any element came off appreciably before the others. All lines of elements present in the tuffs showed on the plate taken during the first second.

The refractive index of the glasses was determined, using monochromatic sodium vapor light and oils whose refractive indices were checked as they were being used. The indices of all the glasses were 1.488.1 .001.

The same procedure was carried out for a basalt. The refractive indices of the basalt glasses did not vary more than .1 .001.

Over 100 samples of the Datil formation were fused, and the indices of refraction of the glass beads determined. It was found that the indices of all the rhyolite glasses were 1.488.1 .006, and the indices of the quartz latite glasses were 1.520 f .006.

Some of the rocks of the Datil formation have been analyzed chemically by H. Wiik, of Helsinki, Finland. The rocks which were analyzed were fused, following the technique of Mathews (1951, p. 92-101), and the indices of the glasses were plotted against the chemical composition of the rocks. The results of this work are reported more fully by Tonking (1957).

Spears Ranch Member

The name Spears Ranch member of the Datil formation was assigned by Tonking (1957) to the quartz latite tuff sequence lying above the arkoses of the Baca formation and below the rhyolite tuff sequence of the Datil formation. The member was named for its exposure at Guy Spears' ranch, in sec. 8, T. 1 N., R. 4 W., 1 mile south of the ranch headquarters.

The sequence is composed of purple, gray, blue, and red tuff breccias, agglomerates, tuffs, conglomerates, flow breccias, and volcanic sediments. These units, although distinct within themselves, could not be mapped satisfactorily as separate units. Their outcrop pattern suggests that the individual lithologic units are quite lenticular.

One striking feature of the Spears Ranch member is the presence of great blocks of limestone, shale, and sandstone. The blocks range in size from over 150 feet long and 50 feet thick to fragments less than a foot across. Field relations suggest that the blocks are of float origin and probably were brought up from the depths by the outpouring tuff. Fragments of corals and brachiopods were collected from the blocks. Although the fossil fragments were nondiagnostic, they have probable Permian affinity (Dr. R. H. Flower, personal communication). The lithology of the sandstone and shale blocks is similar to that of the Permian Abo and Yeso formations, and the limestone is similar to the Permian San Andres. Locally limestone blocks exhibit the yellow color characteristic of the San Andres limestone. The Abo, Yeso, and San Andres formations crop out a few miles to the east; they underlie the Chinle formation.

The tuffs of the Spears Ranch member are composed mainly of plagioclase feldspar and hornblende phenoclasts in a matrix of fragmented crystals and glass. Biotite, sanidine, quartz, magnetite, and glass are present in varying amounts.

The plagioclase occurs in large anhedral phenocrysts which in many cases are shattered. Some of the plagioclase shows oscillatory zoning, and a large percentage of it is twinned on the Albite law. Carlsbad and pericline twinning is also common. Optical properties referred to Wright's curves show the plagioclase to be mostly andesine in composition, but a small amount of oligoclase is present. Some of the feldspar is quite dusty with magnetite and apatite. Commonly the plagioclase is altered to sericite and/or kaolinite. Typically this alteration has taken place along a zonal boundary in the feldspar.

Hornblende is present in two varieties. Oxyhornblende, strongly pleochroic in the red browns, is most common. In the oxyhornblende, z'^c equals 0-6 degrees. A hornblende pleochroic in greens is also present. This is common hornblende, in which z'Ac equals 11-15 degrees.

Augite is also present in small amounts. In the augite z'^c equals about 42 degrees. Biotite is a common mineral; it is pleochroic in red browns. The hornblende, augite, and biotite are highly altered to hematite and/or magnetite in many instances.

The Spears Ranch member crops out in a continuous belt in Dog Springs quadrangle. This belt lies just north of the crest of the Gallinas Mountains. The weathering habit of the member is in direct contrast to that of the rhyolitic Hells Mesa member which lies above it. The rhyolite member weathers to steep vertical cliffs, whereas the Spears Ranch member weathers to rounded hills and ridges. Characteristically pinnaclelike blocks of rhyolite tuff surmount the gentle slopes of the Spears Ranch member. Negro Head, in sec. 28, T. 2 N., R. 7 W., is an outstanding example of one of these pinnacled hills.

Hells Mesa Member

The name Hells Mesa member has been assigned by Tonking (1957) to the rhyolite tuffs lying above the Spears Ranch member of the Datil formation. The member was named for its exposure in secs. 17 and 20, T. 1 N., R. 4 W. , at Hells Mesa. Although the most complete section of the rhyolite tuffs in the Datil-Gallinas Mountains is not exposed at Hells Mesa, Tonking felt that inasmuch as the tuffs were first mapped as a unit in Puertecito quadrangle they should be named for a locality there.

The Hells Mesa member of the Datil formation is composed of welded rhyolite tuffs, crystal rhyolite tuffs, volcanic conglomerates, and basalts. On the basis of color, degree of welding, and composition, the member can be divided into eight units in the field. These units are lenticular and gradational; hence it may not be possible to trace them into quadrangles to the west and south.

The tuffs mainly consist of phenocrysts of quartz and sanidine distributed at random through a matrix of glass shards and dust. Some of the tuff units have large percentages of plagioclase phenocrysts, with smaller amounts of biotite, hornblende, and augite. The welded tuffs contain collapsed pumice fragments and show triangular shards with concave edges (bogen structure), whereas the crystal tuffs do not display these features. The tuffs are white, gray, and pink.

Sorting of the phenocrysts within the tuff units is poor, and there appears to be no systematic change in the size of the phenocrysts from top to bottom of the tuff beds. Neither is there any systematic variation in the fabric displayed by the units. Gilbert (1938, p. 1835) reported marked gradational changes in the structure of the Bishop tuff from top to bottom. In the Bishop tuff, pumice fragments, which are unoriented and very porous at the top. are progressively collapsed, flattened, and alined in the horizontal plane toward the base of the unit. The matrix is soft at the top, becoming less porous and harder toward the bottom. The units of the Hells Mesa member do not show this gradational change. Some of the tuffs near the base of the unit have uncollapsed pumice fragments, whereas the uppermost tuff contains collapsed pumice fragments and vesicles.

The matrix of the Hells Mesa member does not change in hardness from top to bottom in a systematic way. Some of the tuff near the base of the unit is friable, whereas some of that near the top is hard and tough.

The welded tuffs show bogen structure, collapsed vesicles, collapsed pumice particles, and spherulitic growths. The collapsed vesicles and pumice are alined parallel to the plane of the bedding. Linings of quartz and zeolite are often present in the collapsed vesicles.

The units of the Hells Mesa member are not bedded in the sense of typically waterlaid sediments. The units, however, do display well-defined bedding planes that are easily discernible in the field. The individual tuff beds probably were deposited from the air.

Several of the tuff units display well-developed columnar jointing. The columns are irregular in cross-section. Weathering, controlled by these joints, has resulted in many striking physiographic features.

The Hells Mesa member crops out as vertical cliffs across the entire front of the Gallinas Mountains. Some of the cliffs are 600 feet high.

Mineralogically the tuffs of the Hells Mesa member are quite simple. The most common mineral occurring as phenocrysts is quartz. Most of the quartz is anhedral, although some occurs as euhedral crystals with a six-sided outline. A few quartz crystals have been resorbed in part.

The next most common mineral which occurs as phenocrysts is sanidine. For the most part this is anhedral, but like the quartz, is present at places in euhedral crystals. The sanidine has a low negative 2V, which varies a little from grain to grain. The optic axis of the sanidine is parallel to X. A very small percentage of the sanidine is zoned. No zoned grains were found in which there was an appreciable .difference in 2V between zones.

Many of the sections examined contain small amounts of biotite, which commonly occurs in small, hexagonal books. In numerous instances the biotite is altered, not only at the edges but throughout the grain. The product of this alteration is hematite and magnetite. Well-defined, pleochroic grains of biotite grade into the altered material. The alteration appears to have occurred during the emplacement of the tuffs. Winchell (1947, p. 275) states that biotite, when heated, will alter to material of this type.

Hornblende is present in the rhyolite tuffs in two varieties. One of these, commonly called oxyhornblende, is recognized by the low angle of extinction, which ranges from 0 to 6 degrees. This hornblende is strongly pleochroic in shades of deep red brown. A common hornblende, which is pleochroic in shades of green, is also present.

A light-green mineral having a positive 2V of about 30 degrees and an extinction angle of approximately 45 degrees is present in limited amounts in many of the slides. This mineral most likely is augite. The grains are very small, and optical properties are difficult to obtain.

Oligoclase is common in a great number of the sections studied. The phenocrysts of this feldspar commonly are altered to sericite or kaolinite. The plagioclase characteristically displays an angular outline, and sometimes the phenocrysts are shattered. Albite, Carlsbad, and pericline twinning are common.

Collapsed vesicles are lined in some instances with material which has a very strong negative relief and rhombic crystal outline. This material was identified as zeolite. The zeolite characteristically occurs with secondary calcite. The biotite that is commonly associated with the zeolite usually is partly altered to chlorite. Apatite and magnetite are common accessories.

Rosiwal analyses of the rhyolite tuffs (in percent):

	Slide 1	Slide 2
quartz	3.9	1.8
sanidine	12.6	0.4
hornblende	0.4	
biotite	3.2	
plagioclase (oligoclase)	12.3	
groundmass	67.2	97.8

Description of Units. The Hells Mesa member has been divided into eight units on the basis of stratigraphic position, degree of welding, color, and composition. These units are not everywhere the same; often they can be recognized only after careful study of the units lying both above and below.

Unit 1 is the most persistent unit in the Hells Mesa member. This unit forms the basal beds of the member throughout the area and at places may be overlain by unit 2, unit 3,or unit 4. Unit 1 is made up of a white fine-grained crystal tuff which shows no collapsed vesicles, collapsed vesicles, collapsed pumice fragments, nor other criteria of welding. The tuff is fairly soft; the point of a geologic pick can be embedded in it without difficulty.

Unit 2 is a bed of water-laid volcanic conglomerate and contains a small percentage of other rock types, most of which are quartzite. Round iron oxide concretions are also common. The bed ranges in thickness from a few inches to 100 feet. The "clasts'' range in size from granules to pebbles. Crossbedding is common in the unit.

Unit 3 is made up of a coarse white crystal tuff which is very soft. The point of a geologic pick can be driven into it easily. West of North Lake Valley, where they could not be identified separately, units 4 and 5 were included in this unit. Locally the tuff is welded, and the welded portion of the unit is harder and finer grained than other parts of the unit. The welded portion is light pink.

Unit 4 is the most spectacular and easily recognized unit in the area. It is made up of a distinctive, deep-pink very coarsely crystalline welded biotite tuff. East of North Lake Valley this unit forms the bulk of the main Gallinas Mountains. Unit 4 is very hard and very difficult to break with a pick. At its thickest point, on Gallinas Peak, the unit is over 400 feet thick and grades imperceptibly into white crystal tuff at both its upper and lower contact. There is only a trace of the pink tuff on the west side of North Lake Canyon, where it appears to have pinched or graded out almost completely.

Unit 5 is a white unwelded coarsely crystalline tuff. It is similar in lithology to unit 3 and can be distinguished from that unit only by stratigraphic position.

Unit 6 is a nonporphyritic olivine basalt. In places the basalt is vesicular, and locally the vesicles are filled with zeolites. Augite, magnetite, and a plagioclase which was not identified, owing to the small grain size, are the other major components. The olivine commonly is altered to iddingsite.

The nonporphyritic character of this basalt (along with the index of its glass) serves to distinguish it from the Santa Fe basalts. The index of the glass of the fused basalt is 1.576.

Rosiwal analysis of unit 6 (in percent):

olivine	3.26
plagioclase	59.99
magnetite	8.28
augite	21.69
free space	6.77

Unit 7 consists of a white to light-pink welded tuff. The tuff is vesicular, brittle, and very finely crystalline to glassy. In many cases vesicles in the tuff are filled with calcite and/or quartz. This unit overlies all the other units of the Hells Mesa member and is overlain in turn by Santa Fe basalts.

Origin of the Tuffs. There is general agreement that the deposits of tuff were formed by ash falls and subsequently cemented. Some of the tuffs were water-worked during deposition, and others were not.

Many authors have attributed the origin of the welded tuffs to a cloud of gas and particles of "nuée ardente" type, which, upon settling, had enough internal heat to fuse the mass together (Mansfield, Fenner, Gilbert, Marshall, Westerveld, etc.). No welded tuffs have been formed, however, from "nuée ardente" flows which have actually been observed. It may be logical to postulate that the welded tuffs are simply a product of collapse of a very frothy tuff fall.

Santa Fe Formation

All young gravel deposits and their associated basalt flows, which are older than the recent gravels and have been tilted, have been called the Santa Fe formation. This usage is common among geologists in New Mexico to designate gravels of this type. Santa Fe beds in other parts of the State may or may not be age equivalents of the Santa Fe beds of Dog Springs quadrangle.

The Santa Fe gravels in Dog Springs quadrangle are, for the most part, typically white, in contrast to the red encountered elsewhere. There are, however, several small outcrops of red gravel under and in between the basalt of Tres Hermanos Mesa. The gravels consist mainly of rhyolite tuff and quartz latite tuff, with some basaltic fragments intermixed toward the top of the formation. Interbedded within the gravel are scattered beds of caliche.

The principal exposure of the Santa Fe gravels is on the high north-south trending ridge in secs. 2, 3, 9, 10, and 16, T. 2 N., R. 8 W., and sec. 35, T. 3 N., R. 8 W. This ridge warrants a careful description, because it helps establish a chapter in the geologic history of the region.

The ridge is made up wholly of gravel, well over 150 feet thick in places. The gravel occasionally is well bedded and dips 4°-6° S. In its lower portion the gravel is made up wholly of tuff fragments, and porphyritic basalt fragments occur toward the top. "Clast" size increases toward the south. The gravel extends many miles north of the quadrangle boundary. Where the gravel is in contact with the Mesaverde, it can be seen to fill what looks like a channel cut in the Mesaverde. The plane of the ridge top can be projected southward over the Gallinas Mountains and San Augustin Plains.

The gravel beds of the ridge may represent either (1) the remnant gravels of an old stream course, or (2) a sliver of the Santa Fe formation preserved because of its proximity to the Red Lake Valley fault.

Small outcrops of gravel made up wholly of tuff fragments can be found filling old channels under the basalt on Tres Hermanos Mesa and Table Mountain Mesa. On the west side of Tres Hermanos Mesa a lens of gravel can be observed lying between the basalt flows. This lens pinches out both to the south and to the north and does not crop out on the east side of the mesa.

Santa Fe Basalt

The summits of D Cross Mesa, Tres Hermanos Mesa, Table Mountain Mesa, and Blue Mesa are capped with a basalt which is considered to be part of the Santa Fe formation. The basalt truncates the Mesaverde group, the Baca formation, and the Spears Ranch member of the Datil formation. Old channels filled with Santa Fe gravel are present under the basalt on Tres Hermanos Mesa and on Table Mountain Mesa. There is also a lens of the Santa Fe gravel within the basalt of Tres Hermanos Mesa.

The Santa Fe basalt differs from the basalt which occurs in the Datil formation in two ways: (1) its texture is porphyritic, and (2) its glass has a different refractive index (1.595). Megascopically visible are large phenocrysts of green augite, olivine, and feldspar.

The Santa Fe basalt flows are believed not to be related genetically to the volcanic necks of D Cross Mountain, Tres Hermanos Mountain, and Table Mountain. The basalts occurring in these necks have the same textures as the basalts which cap the mesas, but the refractive indices of their glasses are different. Below is a Rosiwal analysis (in percent) of a sample of typical Santa Fe basalt:

andesine and magnetite	88.6
olivine	9.0
augite	1.8

The age of the Santa Fe formation and basalt is not definitely known. However, because it contains gravel from the Miocene(?) Datil formation it is believed to be Pliocene-Pleistocene in age.

QUATERNARY INTRUSIVES

In Dog Springs quadrangle there are several basaltic plugs and dikes which are apparently related to one another but not to other basalts in the area. These plugs form D Cross Mountain, Tres Hermanos Mountain, and Table Mountain.

The basalts of these intrusives appear similar to the basalts of the Santa Fe formation. However, the refractive indices of the fused basalts differ. For this reason they are considered to be of different ages.

No dikes are shown on the geologic map, but two crop out in the quadrangle. They are both located just south of D Cross Mountain and are so small (less than a foot wide and less than 6 feet long) that they could not be shown accurately on the map.

STRUCTURE

General Features

The structures of Dog Springs quadrangle are controlled by two distinct tectonic trends. The older, of probable late Cretaceous age, trends northeast-southwest, whereas structures affected by later movements (Pliocene?) exhibit a northwest-southeast trend. A third set of structures is present in the Triassic Chinle formation but is poorly exposed in Dog Springs quadrangle; it is well known in adjacent quadrangles to the northeast.

Folds

In the northern one-third of the area there are northwest-southeast trending folds. The dips on limbs of these folds never exceed 16 degrees and more commonly are close to 6 degrees. Red Lake anticline is the largest and most pronounced of the flexures.

The folding embraces all the Upper Cretaceous beds and hence is of probable late Cretaceous age. Wilpolt (1946) suggested that the Eocene(?) Baca beds are synorogenic. In Dog Springs quadrangle, however, the Baca is at places unconformable on the Mesaverde; hence this conclusion does not seem warranted.

The principal structure in the southern two-thirds of the quadrangle is a southward plunging syncline, a small anticline occurring on its east limb. The syncline is believed to be orogenic and to have been produced in Pliocene(?) time rather than to be a manifestation of original dip or a collapse structure associated with the withdrawal of magma. The following data support this conclusion, though none of the evidence is conclusive:

(1) Unit 7 of the Datil formation, which is undoubtedly a flow, does

not noticeably thicken toward the axis of the syncline.

(2) The trend of the syncline coincides with no known structure or topographic trends in the older rocks.

(3) An anticlinal flexure is present on one of the limbs of the syncline

(4) Definite Pliocene-Pleistocene tectonic structures have been reported by Wright (1946) in the Lucero Uplift, about 30 miles to the northwest.

(5) No vents for the Datil volcanics are known in the vicinity.

The syncline probably was folded in the Pliocene epoch, because the Miocene(?) beds are folded, and the overlying Santa Fe beds are angularly unconformable upon them.

Faults

The D Cross fault, the Red Lake fault, and the Alamo fault are located in the northern one-third of the quadrangle. The Red Lake fault is the best defined of the three and juxtaposes the Chinle formation against the Crevasse Canyon formation. On the accompanying map the Red Lake fault is shown passing under the Recent valley-fill gravels at the south and running out of the quadrangle at the north. It is possible, however, that the fault swings around the southern end of Blue Mesa and connects with the HH fault system. The Red Lake fault is not deflected by the topography and hence probably has a dip approaching 90 degrees. The displacement, as measured from the cross-section, is approximately 1,100 feet.

The D Cross fault extends along the west side of D Cross Mesa. Its trace, like that of the Red Lake fault, is not deflected by the topography and therefore must dip steeply. The trace of the fault is well defined by both fault gouge and discordance in dip between beds on opposite sides of the fault plane. The fossiliferous nonmarine Crevasse Canyon formation is in contact with the marine shale of the La Cruz Peak formation along part of the surface trace of this fault. The stratigraphic displacement as measured from the cross-section is approximately 500 feet.

The Alamo fault is a minor feature located in the northeastern part of the quadrangle. The trace of this fault is well defined by both gouge and sharply discordant dips in the beds which lie near the fault. No measurement of stratigraphic displacement could be made. The displacement, however, is estimated to be about 200 feet. Springs occur along its trace and furnish water for the immediate area.

The HH faults and the Gallinas faults are local features which are evidenced only by discordance between the members and units of the Datil formation. The Gallinas faults lie wholly within the Hells Mesa member. The block weathering of the member and the similarity of units within the member make the tracing of these faults difficult. The two faults which make up this system are located on the extreme ends of a downdropped block within the member. This block is a warped portion of the limb of the large syncline mentioned earlier.

The HH faults are a system of fractures which bring the Spears Ranch member of the Datil formation into contact with the Hells Mesa member. The difference in rock types on both sides of the fault makes the trace easy to locate. The faults extend out of the quadrangle both to the north and south.

Evidence for the North Lake fault is the well-defined ridge to the south of North Lake. The presence of the lake without the fault would be a vexing problem. The lake lies in the structural trough formed along the axis of the North Lake syncline. Since, however, the syncline plunges to the south, the lake could hardly exist unless there were. some sort of dam to hold it back. Immediately to the south of the lake there is a well-defined gravel ridge which, though slightly rounded, looks very much like a Recent fault scarp. The edge of this ridge was taken to be the trace of the North Lake fault.

The Martin Ranch fault is not well defined, and its existence is problematical. Sole evidence for the fault is the outcrop pattern of the Baca formation. On the east side of the canyon the apparent contact of the Crevasse Canyon formation with the Baca is much farther south than is the corresponding contact on the west side.

The faults of Dog Springs quadrangle appear to be of relatively recent inception. The Red Lake Valley fault disappears under the gravel on the east side of Blue Mesa. There the latest basalt dips to the east and is apparently cut off by the fault. D Cross fault, on the other hand, cuts the Baca and Datil formations, but apparently does not cut the basalt. These faults probably are of Miocene(?) or later age.

The HH and Gallinas faults do not cut formations higher than the Datil; thus, the earliest age that can be assigned to them is Miocene(?). The Gallinas fault is probably Pliocene and is related to the postulated Pliocene folding of the Datil formation, whereas the HH faults are probably Miocene(?) or later and may be related to the Red Lake Valley fault.

The postulated North Lake fault must cut Recent bolson deposits; therefore, if present, it is of Recent inception.

GEOMORPHOLOGY

The southern two-thirds of the quadrangle slopes gently southward from the crest of the Gallinas Mountains. This slope is roughly a dip slope; it is cut by youthful streams. The north-south trending North Lake Canyon breaches the entire Gallinas range. The north face of the Gallinas Mountains drops off sharply into a series of high, round-topped hills, which are dissected by valleys having very steep walls. North of the zone of hills is the valley of the Rio Salado with its associated mesas.

In the quadrangle the results of gravity slumping are spectacular. Slumping is common in the Upper Cretaceous sedimentary rocks, as well as in the rocks of the volcanic Datil formation. In the Hells Mesa member of the Datil formation this process is particulary spectacular. Every steep cliff has a great pile of talus at its base, and piles of talus are found on small benches near the tops of mountains. The Hells

Mesa is particularly susceptible to this type of wasting, because it is massive and well jointed. The Mesaverde group, on the other hand, slumps for another reason; it is composed of alternating soft and hard strata.

Both mechanical and chemical weathering processes are active within the quadrangle. The Hells Mesa member commonly is jointed, and both frost heave and chemical decomposition take place along the joints.

Although the Rio Salado and its tributaries now are degrading the area at a rapid rate, in the 1800's the Salado was an aggrading stream. It had a year-round flow which promoted grassy banks and cottonwood trees. The Rio Salado now flows sporadically and has cut into its former bed, leaving stream terraces along its banks. During dry periods the bed of the stream supplies great quantities of windblown sand, which forms dunes along the banks.

RECENT GEOLOGIC HISTORY

Evidence of the Recent geologic history of the area is conspicuously present, owing to the location and character of the Santa Fe gravel and basalt.

The following assumptions are consistent with available data:

(1) The area now occupied by the San Augustin Plains was a physiographic high and drained to the north.

(2) The main drainage of the area ran north-south, rather than east-west as it does today.

(3) Red Lake Valley was cut by a master stream.

(4) The present-day Gallinas were a series of low-lying hills during the Pleistocene.

(5) The summit of the present-day foothills of the Gallinas was the base level of erosion during the Pleistocene.

The main key to these suppositions is the Santa Fe gravels which form the ridge lying to the west of the Fred Martin ranch. As was discussed earlier, this ridge may represent deposits in the channel of an old stream which had its source somewhere to the south, or else it is the remnant of an extensive gravel mantle which likewise has its source to the south. The surface on which the Santa Fe gravel rests in the Gallinas Mountains can be correlated with the surface on which the gravels of the Martin ranch ridge were deposited. The pediment surface reconstructed on the basis of this correlation slopes upward from the south to the north. The projection of this surface to the south does not clear the top of the Gallinas Mountains. It appears, therefore, that the Gallinas were probably foothills when the gravel was laid down.

Subsequent to the formation of the Santa Fe pediment surface, the San Augustin Plains were formed, thus lowering a previous physiographic high. Only a small portion of the Plains lies within the area studied; therefore, the mechanism of this lowering was not determined.

There is a pediment surface younger than the surface on which the Santa Fe gravel rests. This surface slopes gently to the northwest, and is overlain by what are called Quaternary pediment gravels. It represents a drainage surface tributary to the ancestral Rio Salado.

Economic Geology

A detailed discussion of the petroleum possibilities of the area surrounding Dog Springs quadrangle is outside the scope of this report. It should be noted, however, that there is a pronounced anticlinal trend in the northwestern part of the quadrangle. This anticline has been drilled north of the quadrangle, and "basement" was encountered at 4,012 *feet.* It is likely that the "basement" was actually one or more sills. To the east, in Puertecito quadrangle, there are sills exposed in the outcrop area of the Yeso formation. The sills are basaltic and probably related to the Quaternary dikes and intrusions in the area. The depth at which the sills would be expected on the anticlinal trend in Dog Springs quadrangle is the same as the depth at which "basement" was encountered. These sills have had very slight contact-metamorphic effect on the formations they intrude, and it is possible that the intrusion of the sills did not affect any oil that may have been present.

According to McKee's isopachous maps (1951, pl. 2), there are approximately 2,000 feet of Permian section and 2,000 feet of Pennsylvanian section present under the Triassic. Detailed stratigraphic study is needed to ascertain whether or not these rocks could be considered as possible sources of petroleum.

When the quadrangle was in the process of being mapped, a Geiger counter was not available. According to several reports, however, a high count was obtained on the western side of D Cross Mesa, in the vicinity of D Cross fault.

The area is arid. Water in sufficient quantities for watering stock can be obtained from wells in the Mesaverde group. To the south, where the Mesaverde strata do not crop out, the problem of getting water is more difficult. The principal source of water within the Datil formation appears to be the zone of contact between the rhyolite tuffs and the quartz latite tuffs. At the contact, in many places, there is a zone of volcanic conglomerate which acts as an aquifer between the two impervious tuff units. All the springs of the southern part of the area originate in this zone of conglomerate, and many of the water wells of the area are drilled into it.

It may be possible to obtain fairly large quantities of water on the east side of the D Cross fault, for the whole Upper Cretaceous section dips against the upthrown west side of this fault. It is known that the Mancos is an aquifer, at least to a limited extent, because the I. N. M. spring originates in this formation The area of recharge is fairly large, and the fault may have acted as a barrier to the circulation of subsurface water. A well drilled to the Mancos on the east side of the D Cross fault might supply sufficient water for irrigation.

Measured Sections

DAKOTA(?) SANDSTONE

(Sec. 16, T. 3 N., R. 8 W.)

Description	Thickness (in feet)
Quartzose sandstone, medium-grained, well-consolidated, cream-colored (yellow on weathered surface), well-sorted, silica-cemented, bench-forming; frosted grains	10
Quartzose sandstone, conglomeratic, medium-grained, silica-cemented, cream-colored (yellow on weathered surface), slightly channeled, ridge-forming; iron oxide concretions; conglomeratic lenses of pebble- and granule-size subrounded quartzite fragments	10
Total Dakota(?) sandstone	20

MANCOS SHALE

(Sec. 16, T. 3N., R. 8 W.)

Description	Thickness (in feet)
Lower shale member:	
Sandy shale, gray, gypsiferous, carbonaceous, calcareous, fossiliferous	104
Tres Hermanos member:	
Quartzose sandstone, cream-colored (brown-yellow on weathered surface), fine-grained in some layers, medium-grained in other layers, well-sorted, iron-stained in places, massive, ridge-forming; frosted grains	25
Upper shale member:	
Sandy shale, gray, gypsiferous, carbonaceous, calcareous, fossiliferous, containing interbedded very flaggy finely crystalline arenaceous unfossiliferous limestone	47
Quartzose sandstone, fissile, gray, fine-grained, silica-cemented, nonresistant	4
Quartzose sandstone, cream-colored (yellow on weathered surface), even-bedded, fine- to coarse-grained, well-sorted, silica-cemented	15
(The two preceding units may be slumped)	
Sandy shale, gray, gypsiferous, carbonaceous, calcareous, fossiliferous	96
Total Mancos shale	291

MESAVERDE GROUP

(Secs. 17 and 18, T. 3N., R. 8 W.)

Description	Thickness (in feet)
La Cruz Peak formation:	
Quartzose sandstone, cream-colored (yellow on weathered surface), fine-grained, well-sorted, poorly consolidated, silica-cemented, interbedded with thin shale beds; frosted grains	5. 5
Quartzose sandstone, medium- to fine-grained, silica-cemented, well-consolidated, cream-colored (yellow on weathered surface), well-sorted, even-bedded, ridge-forming; frosted grains	12
Quartzose sandstone, cream-colored, fine-grained, poorly consolidated, fossiliferous, slope-forming	1
Quartzose sandstone, medium- to fine-grained, well-sorted, silica-cemented, partially crossbedded, cream-colored (yellow on weathered surface), massive, ridge-forming	30
Three beds of medium- to fine-grained fairly well-sorted unfossiliferous poorly consolidated yellow quartzose sandstone interbedded with gray gypsiferous carbonaceous calcareous fossiliferous sandy shale; poor exposure; contains coal beds	82.5
Quartzose sandstone, medium- to coarse-grained, cream-colored (yellow on weathered surface), partly flaggy, fairly well-sorted, slope-forming	83
Quartzose sandstone, fine- to medium-grained, well-sorted, for the most part massive, cream-colored (yellow on weathered surface), silica-cemented, cliff-forming; parallel bedding	72
Shelf, covered; top 3 feet is a medium-grained fairly well-consolidated quartzose sandstone	8.5
Quartzose sandstone, yellow (cream on fresh surface), medium- grained, fairly well- sorted, silica- cemented, massive, cliff-forming	62
Total La Cruz Peak formation	356. 5

Description	Thickness (in feet)
Crevasse Canyon formation:	
Quartzose sandstone, white, fine-grained, slightly iron-stained, nonresistant; mudstone, gray and yellow-brown; covered by slumped material	33
Quartzose sandstone, coarse- to very coarse-grained, silica-cemented, white, massive, bench-forming; parallel bedding	36
Sandy shale, gray and yellow, capped by a bed of cream-colored (bright-yellow on weathered surface) medium-grained sandstone	22
Quartzose sandstone, cream-colored (light-yellow on weathered surface), coarse-grained	1
Shale, gray and black	5.5
Coal	0.5
Mudstone and sandstone	1.5
Sandy shale, gray; interbedded coal	12
Quartzose sandstone, cream-colored, coarse-grained, fairly well-consolidated	1
Sandy shale, gray	7.5
Mudstone, gray	2
Shale, gray; partly covered	55
Quartzose sandstone, cream-colored (yellow on weathered surface), loosely consolidated, coarse-grained, slope-forming	27.5
Shale, gray; partly covered	61
Quartzose sandstone, coarse-grained, cream-colored (yellow on weathered surface), poorly consolidated	22
Shale and mudstone, gray	36
Quartzose sandstone, coarse-grained, cream-colored (yellow on weathered surface), poorly consolidated	25
Shale, gray; partly covered	88
Cover	165
Total Crevasse Canyon formation	601.5

MANCOS SHALE

(Secs. 19 and 20, T. 3 N., R. 8 W .)

Description	Thickness (in feet)
Lower shale member:	
Sandy shale, gray, gypsiferous, calcareous, carbonaceous, fossiliferous	95.8
Middle sandstone member:	
Quartzose sandstone, cream-colored (brown-yellow on weathered surface), fine-grained in some layers, medium-grained in other layers, well-sorted, iron-stained in places, massive, ridge-forming; frosted grains	28
Upper shale member:	
Sandy shale, gray, gypsiferous, calcareous, carbonaceous, fossiliferous	196
Total Mancos shale	319.8

LA CRUZ PEAK FORMATION

(Secs. 19 and 20, T. 3 N., R. 8 W.)

Description	Thickness (in feet)
Quartzose sandstone, medium- to fine-grained, silica-cemented, well-consolidated, cream-colored (yellow on weathered surface), well-sorted, partially crossbedded, ridge-forming; frosted grains	105
Sandy shale, gray, gypsiferous, calcareous, carbonaceous, fossiliferous	190
Quartzose sandstone, fine- to medium-grained, well-sorted, for the most part massive, parallel- and crossbedded, cream-colored on fresh surface (yellow on weathered surface), cliff-forming	80 +
Total La Cruz Peak formation	375 +

MANCOS SHALE

(Sec. 19, T. 3 N., R. 6 W.)

Description	Thickness (in feet)
Upper shale member:	
Sandy shale, gray, gypsiferous, calcareous, carbonaceous, fossiliferous	138 +

LA CRUZ PEAK FORMATION

(Secs. 19, 30, and 31, T. 3 N., R. 6 W.)

Description	Thickness (in feet)
Quartzose sandstone, cream-colored (yellow on weathered surface), slightly fissile, fairly well-sorted, silica-cemented, fine- to medium-grained, slightly fossiliferous; subangular to subrounded grains	14
Same unit, with no fossils	1
Mudstone, gray	0.5
Quartzose sandstone, cream-colored, slightly fissile, fairly well-sorted, silica-cemented, fine- to medium-grained, moderately consolidated, unfossiliferous; subangular to subrounded grains	10
Same, but very fissile; top 2 feet very fossiliferous	28
Same, but slightly fissile and only slightly fossiliferous	16
Shale, gray; partly covered	11
Quartzose sandkone, medium-grained, fairly well-sorted, moderately consolidated, massive	6
Sandstone, greenish and reddish, fine-grained, very compact, hard	7
Quartzose sandstone, medium-grained, fairly well-sorted, silica-cemented, moderately consolidated, fissile; contains petrified wood fragments	6
Mudstone, black; a few lenses of coal	50
Quartzose sandstone, medium-grained, massive, fairly well-sorted, silica-cemented (yellow on weathered surface); several iron-stained layers	106
Total La Cruz Peak formation	255 . 5

BACA FORMATION

(Secs. 35 and 36, T. 3 N., R, 8 W.)

Description	Thickness (in feet)
Unless stated otherwise, the arkoses are red, fairly well consolidated, and poorly sorted, with medium grains that are angular and subangular	
Arkose, cream-colored	2
Sandy mudstone, red	4
Arkose, red	0.5
Sandy mudstone, red	6
Arkose, red	1
Sandy mudstone, red	4
Arkose, cream-colored, crossbedded	4
Sandy mudstone, red	8.5
Arkose, red	2.5
Cover	30
Sandy mudstone, red	9.5
Arkose, red, with interbedded red sandy mudstone	16.5
Arkose, cream-colored, well-consolidated, poorly sorted, medium-grained, partially crossbedded, bench-forming; angular and subangular grains	23
Arkose, red, poorly consolidated, with interbedded red sandy mudstone	5.5
Sandy mudstone, color-banded red and yellow brown, fairly well-consolidated	15.5
Arkose, cream-colored (red on weathered surface), crossbedded, medium-grained, poorly sorted, fairly well-consolidated	6
Sandy mudstone, red	13
Arkose, brown	1

Sandy mudstone, red	13
Arkose, cream-colored, poorly consolidated	2
Sandy mudstone, red	6. 5
Arkose, cream-colored	15
Arkose, red and cream-colored, poorly consolidated	3.5
Sandy mudstone, red	32.5
Arkose, cream-colored	25.5
Arkose, red and cream-colored	15
Sandy mudstone, red	14
Arkose, cream-colored	4
Cover	38
Sandy mudstone, red	5
Arkose, cream-colored	4
Sandy mudstone, red	6
Arkose, cream-colored	12
Mudstone, red, partially covered	8
Arkose, cream-colored	7
Cover	11
Arkose, cream-colored	3
Cover	15
Arkose, cream-colored	3
Cover	27
Arkose, red	1
Sandy mudstone, red	20
Arkose, red, poorly consolidated	4
Sandy shale, olive-green	4

Sandy mudstone, red and gray	17
Arkose, cream-colored	8
Sandy mudstone, red	11
Arkose, cream- colored, well- consolidated	15
Sandy mudstone, red	40
Total Baca formation	542.5

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