STRATIGRAPHY OF THE ESCARPMENT OF THE SACRAMENTO MOUNTAINS, OTERO COUNTY, NEW MEXICO

Thesis by

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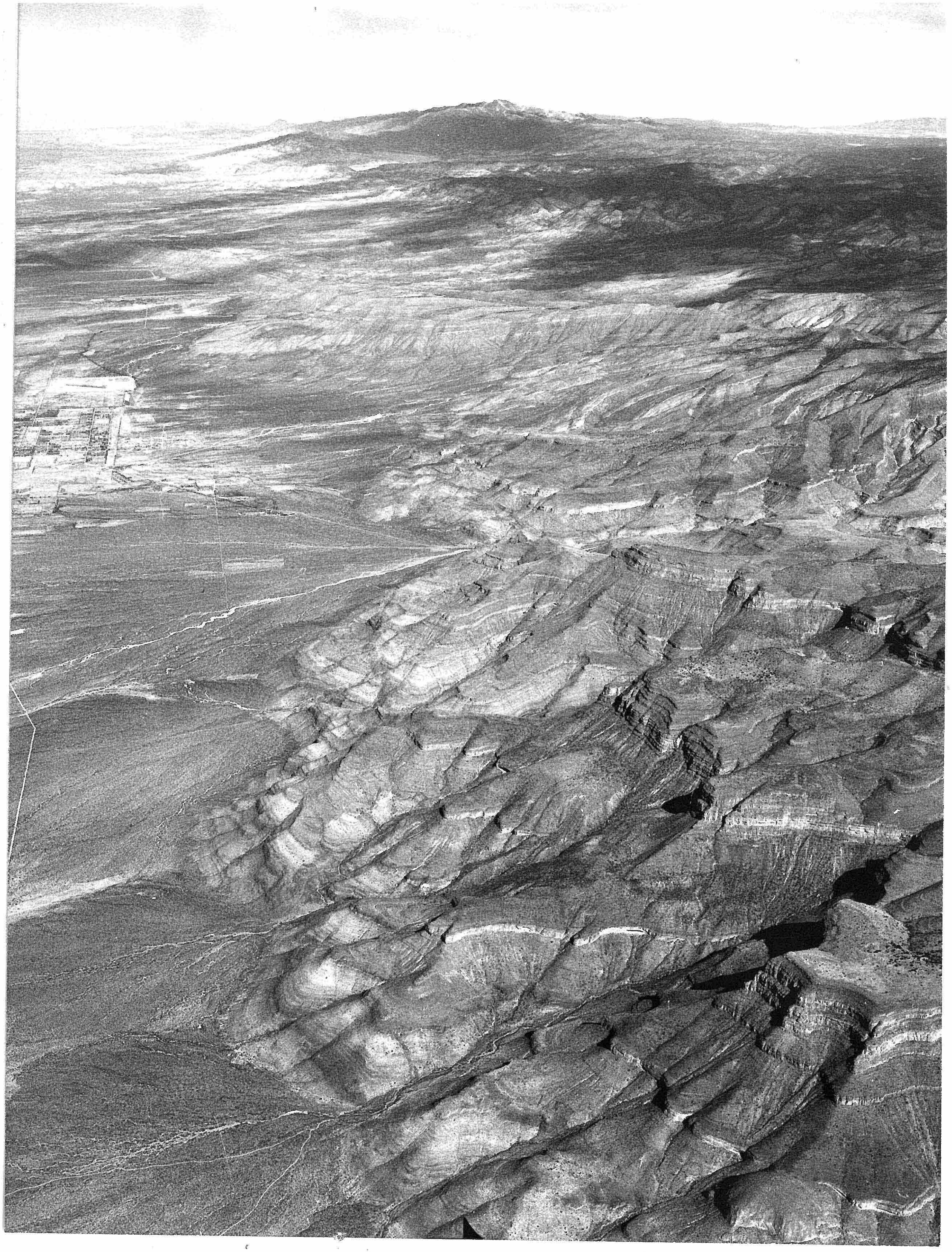

Frontispiece: View to the north along the west front of the Sacramento Mountains. The peak in the distance is Sierra Blanca (12,004'), the highest point in southern New Mexico. Photograph is supplied through the courtesy of Muldrow Aerial Surveys, Inc., Midland, Texas.

ABSTRACT

The Sacramento Mountains constitute a sharply asymmetrical cuesta at the eastern edge of the Basin and Range Province in south central New Mexico. The escarpment rises abruptly for more than a mile above the desert plains of the Tularosa Basin. From the crest, near 10,000 feet, the surface slopes gently to the Pecos River, 100 miles to the east and 6000 feet lower.

The rugged west-facing escarpment has been carved in section of sedimentary rocks about 7500 feet thick. This section is almost entirely of Paleozoic age. Geologic maps at a scale of two inches equals one mile of an area 28 miles long and 15 miles wide along the escarpment were prepared during 13 months of field investigations. This report deals with the stratigraphy of the mapped area, which is about 85 per cent of the area of the escarpment of the Sacramento Mountains.

The bedrock strata range in age from late pre-Cambrian (?) to middle Permian, and include representatives of all periods of the Paleozoic era. The strata are largely the product of marine deposition on a stable shelf area. Most formations are thin and laterally persistent across much of southern New Mexico and are separated by disconformities.

The oldest rocks exposed are late pre-Cambrian (?) and consist of about 100 feet of slightly metamorphosed quartz sandstone, siltstone, and shale, intruded by diabase sills. These rocks are separated from the Paleozoic strata by an unconformity with an angular discordance of about 10°.

The Upper Cambrian (?) Bliss sandstone forms the base of the Paleozoic sequence, and consists of 110 feet of glauconitic quartz sandstone

and minor clastic dolomite. The El Paso formation, 370 feet of sandy dolomite of Lower Ordovician age, is probably disconformable on the Bliss sandstone, and is separated from the overlying Montoya formation of Upper Ordovician age by a sharp disconformity representing all of middle Ordovician time. The Montoya formation is 140 to 250 feet thick. Dark massive dolomite forms the lower member, and lighter colored, cherty dolomite, the upper member. Lithologically distinctive strata composed of 150 to 200 feet of white weathering, thin bedded, sublithographic dolomite above the Montoya formation are termed the Valmont formation (new name) and are of Upper Ordovician (?) age. It appears to be gradational with the Montoya formation, but is separated from the overlying darker, cherty dolomite of the Fusselman (?) formation by a disconformity. The Fusselman (?) formation is about 70 feet thick along most of the escarpment, but thins and is locally absent toward the north. It contains a Silurian (?) fauna, somewhat older than is known from the Fusselman formation farther to the southwest in New Mexico and Texas.

Strata of Devonian age persist throughout the area, but are nowhere more than 100 feet thick. Lithologically, they represent a transition from the underlying dolomites of the lower Paleozoic section to the limestone and shale of the upper Paleozoic. Gray silty dolomite of the Onate formation (upper Middle Devonian) is overlain by yellow gray limestone and shale of the Sly Gap formation (Upper Devonian) in the northern half of the escarpment. Black shales of the Percha (?) formation (Upper Devonian) overlie the Onate in the southern escarpment, and lap northward onto the Sly Gap.

The base of the Mississippian strata throughout the area consists of gray nodular limestone and shale of the Caballero formation (Kinderhookian), which ranges from 15 to 60 feet thick. Abundant crinoidal limestone, and many bioherms, some as thick as 400 feet, form much of the Lake Valley formation (Osagian) and record a period of prolific marine invertebrate life. The Lake Valley formation is 200 to 450 feet thick in the northwestern part of the escarpment, and thins to the east and south. Dark siliceous limestone of the Las Cruces (?) and Rancheria formations (Meramecian) overlies a persistent unconformity of low angular discordance. These strata are about 300 feet thick to the southeast, where they overlie the Caballero formation, and thin by overlap to the northwest. The Helms formation (Chesterian), consists of about 60 feet of limestone and shale, and is restricted to the southern part of the escarpment.

The Pennsylvanian strata, 2000 to 3000 feet thick, record a period of structural unrest in New Mexico, as indicated by abundant coarsely clastic strata derived from nearby areas of uplift and erosion, and by considerable lateral variation of the strata. The Sacramento Mountain area received sediment during most of the Pennsylvanian time. The strata are subdivided into three formations and one member (all new names). The basal formation, the Gobbler, consists of 1200 to 1600 feet of coarse quartz sandstone, argillaceous limestone, and shale of Morrowan (?) to middle Missourian age. As much as 800 feet of gray cherty limestone, the Bug Scuffle limestone member, is prominent in the southwest and northeast part of the escarpment, and grades abruptly into shallow marine and deltaic clastic rocks that trend northwest through the area. The Beeman formation (upper Missourian) consists of 350 to 450 feet of feldspathic sandstone, limestone, and shale. Abundant sandstone in the Gobbler and Beeman formations indicate nearby highland areas of pre-Cambrian rocks, the Pedernal Mountains, were nearby to the east in pre-Virgilian Pennsylvanian time. The Holder formation, of Virgilian age, consists of as much as 900 feet of strata. Discontinuous limestone bioherms mark the base of the formation, and red marls, nodular limestone, and white massive limestone characterize much of the upper strata.

In the northwestern Sacramento Mountains, sedimentation apparently was nearly continuous from Pennsylvanian into Permian time. About 300 feet of alternating marine and non-marine gray and red shale, sandstone, and limestone conglomerate of the lower Wolfcampian Bursum formation directly overlies some of the youngest Pennsylvanian strata in North America. Elsewhere in the area, pronounced uplift and deformation by folding and high angle normal faulting occurred along northerly trends and is the major diastrophism of the Paleozoic Era in this area. It probably began in late Virgilian time, reached a climax before upper Wolfcampian time, and was of declining importance after Wolfcampian time.

The Abo formation of upper Wolfcampian age was deposited over a marked unconformity, and rests on truncated strata as old as the lower Lake Valley formation. The Abo formation ranges from 250 to 550 feet thick, and consists of continental red mudstone and coarse arkose in the northern part of the area. Toward the south, the middle part of the Abo formation grades into brackish to marine limestone and shale of the Culp tongue (new name) of the Hueco formation. Upper and lower tongues of

Abo red beds persist far to the south, and probably correlate with red strata in the Hueco formation of Texas.

The Yeso formation of Leonardian age is gradational with the Abo formation and consists of about 1300 feet of red beds, yellow and gray shale, limestone, silty quartz sandstone, and evaporites of gypsum and some halite. It records the fluctuating conditions of a shallow back-reef or lagoonal area. Carbonate rocks are more abundant toward the open seas to the southeast, and red beds and evaporites more prevalent toward the shore areas to the north.

The resistant crest and eastern slope of the Sacramento Mountains are formed by the limestone and dolomitic limestone of the Glorieta (?) and the San Andres formations of Guadalupian age. The Yeso, Glorieta (?), and San Andres formations appear to represent essentially continuous deposition. A total of about ten feet of several thin beds of clean, fine to medium grained quartz sandstone occur in the lower 120 feet of the carbonate strata. This section forms the Glorieta (?) formation. The sandstone beds thicken away from the crest of the mountains. Erosion has removed more than half of the 1400 feet of limestone of the San Andres formation from the crest of the Sacramento Mountains.

Quaternary deposits consist of at least three levels of terrace gravels, recent alluvium, spring deposits, and large amounts of slump material. The alluvium of the Tularosa Basin is a minimum of 1800 feet thick, and in part may be Tertiary age.

The Sacramento Mountains are a fault block range, tilted one to two degrees to the east, and bounded on the west by a gravity fault zone near the base of the present escarpment. Piedmont scarps and numerous sympathetic minor faults near the edge of the mountain block, the truncation of sculpture and internal structure of the range, the available stratigraphic evidence, and the regional tectonic pattern all are evidence in favor of faulting as the dominant mechanism for the uplift of the range. The estimated minimum displacement along the boundary fault is of the order of 7000 feet for a distance of 20 miles along the escarpment, and decreases to about half this amount at the northern and southern limits of the mapped area.

The internal structure of the mountain block was largely developed by folding and high-angle faulting during late Pennsylvanian and earliest Permian time. Most of these pre-Abo structures trend north-south. The intensity of the deformation appears to increase from west to east throughout the length of the escarpment, toward the area of maximum pre-Abo uplift and erosion. Anticlines are more sharply defined than synclines, and domes are common along the anticlinal crests. The deformation is believed to be controlled by both vertically acting forces and by lateral compression.

Gentle folds and some high-angle faults in the Permian strata indicate later mild deformation. If a dissected erosional surface in the highest part of the mountains represents the exhumed basal unconformity of former Cretaceous rocks, some of this later structural development is of Mesozoic age. Some of these later structural features may have developed during the intrusion of sills and dikes of trachyandesite of early Tertiary age, that are common in the lower Pennsylvanian and Permian shales.

The major uplift of the range is believed to be of late Cenozoic age, and may be continuing at the present time. A zone of monoclinal folding and gravity faulting along the Sacramento River in the southeast part of the area has formed in late Cenozoic time, and is en echelon with the boundary faults of the Sacramento and Guadalupe Mountains.

Some of the problems of major interest for further study in the Sacramento Mountain region include the bioherms of the Mississippian and Pennsylvanian formations, detailed studies of the lithofacies and biofacies of the Gobbler and Bursum formations, and detailed stratigraphic examination of the Paleozoic strata of adjacent mountain areas in order to permit proper regional analysis of the Paleozoic history of southern New Mexico. Careful collection and study of the invertebrate faunas of the rock units of the lower Paleozoic section of the Sacramento Mountains could result in a major contribution to the stratigraphy of New Mexico and other western areas.

INTRODUCTION

GENERAL STATEMENT

One of the largest mountain ranges in southern New Mexico trends northward for a distance of about 80 miles midway between the east and west border of the state. On the east lie the broad expanses of the Great Plains, and on the west is a region of other north-trending mountains, which rise abruptly above desert plains. The northern part of this range consists of several separate mountain masses, the most prominent of which is the Sierra Blanca with a maximum elevation of 12,003 feet above sea level. The Sierra Blanca and other mountains in the northern part of the range are composed largely of igneous rocks, intrusive into strata that range in age from Permian to Cretaceous.

The broader southern part of the range is known as the Sacramento Mountains*/. This high mountain mass trends southward for a distance of

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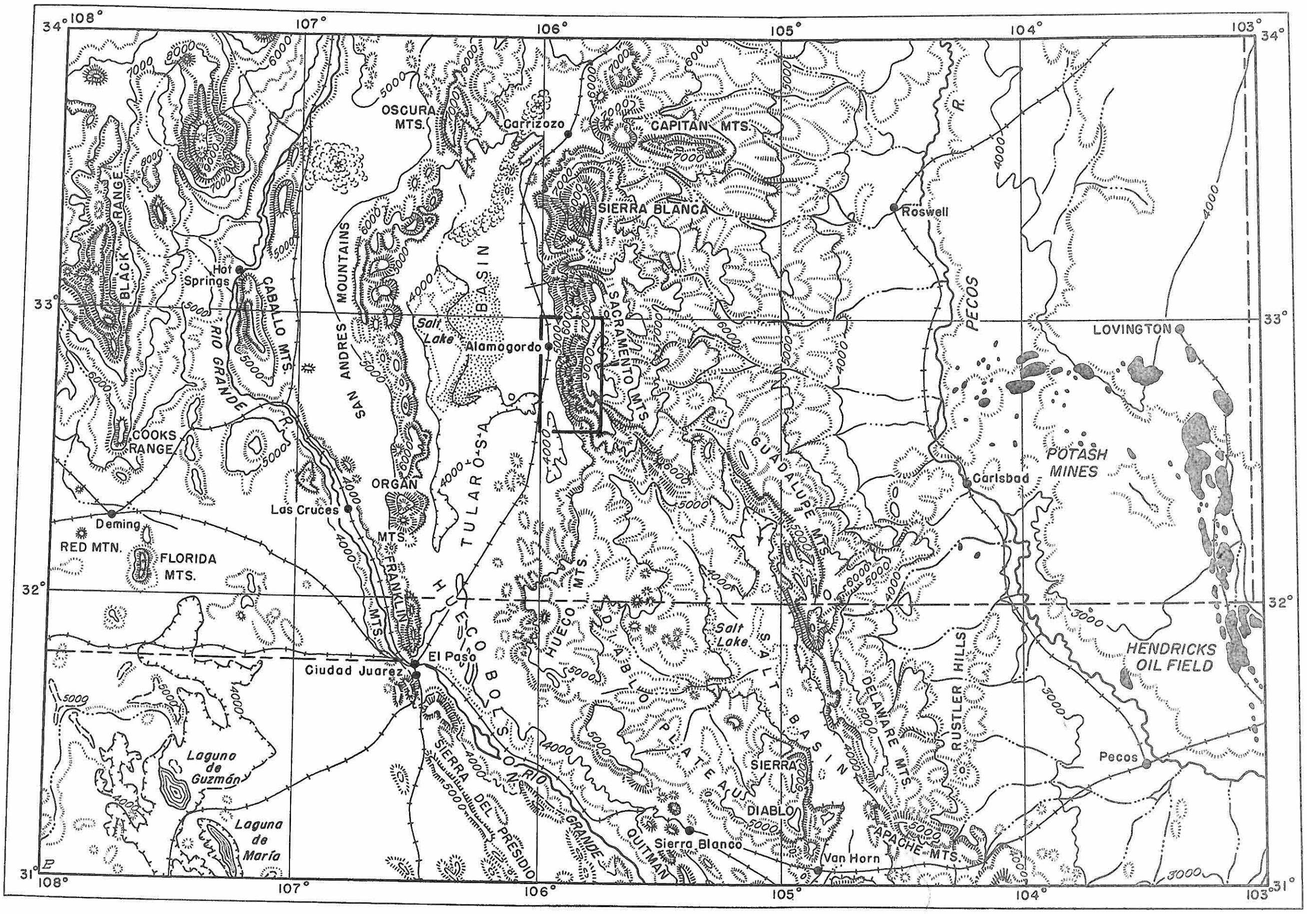
*/ Usages of the term "Sacramento Mountains" are somewhat conflicting. On some maps this name is applied to all of the mountain range between the latitude of Carrizozo (fig. 1) and the northwestern part of the Guadalupe Mountains, a distance of about 90 miles. By this usage the Sierra Blanca are a part of Sacramento Mountains. In this report the terms is applied only to the mountain areas south of Tularosa Canyon, thus excluding the Sierra Blanca area. The broader usage was adopted on the geologic map of the state of New Mexico, edited by N. H. Darton and published in 1928. This usage has been followed most recently by P. B. King (1948, fig. 1). A certain priority for this usage may be furnished by Disturnell's early map (in use in 1847), which was reproduced by Lang (1937, fig. 3) and which indicates a range "Sierra del Sacramento" extending southward from Santa Fe for a distance of about 150 miles. A map published in 1851 and reproduced by Meinzer and Hare (1915, pl. IV), shows more accurate delineation of features, and restricts the term "Sierra Sacramento" to the mountains south of the Sierra Blanca. The map of the Tularosa Basin and adjacent country of Meinzer and Hare (1915, pl. V) is an early accurate representation of the area. On this map the term "Sacramento Mountains" is restricted to that part of the range that lies south of the Sierra Blanca. Other more recent published maps using the term in this restricted sense are the following: General Land Office Map, State of New Mexico, 1927; Darton (1917, pl. XIII, and 1928, p. 198); DeFord (pl. 13 in Bates, R. L., 1942); Raisz (1939); Thompson (1942, p. 8); Lloyd (1949, p. 11); and maps of the U. S. Forest Service (e.g., Fire Map, Lincoln National Forest, 1945), which are the most detailed maps available for the region.

Figure 1



Oil and Gas Fields

Area covered by this report

Sources: East of 107° W. from P. B. King U.S.G.S. Prof. Paper 215; U.S.G.S. topographic maps, & U.S. Coast - Geodetic Survey Sectional Aeronautical Chart.

MAP OF SOUTHEASTERN NEW MEXICO AND ADJOINING PORTIONS OF WEST TEXAS AND NORTHERN CHIHUAHUA

SCALE IN MILES

10 0 10 20 30 40 50

about 35 miles, and thence merges southward and eastward into lower plateaus. The range is essentially a cuesta with a bold, west-facing escarpment, and a total relief of more than a mile. Its gentle east slope extends to the Pecos River, a distance of 80 miles from the crest. The steep western escarpment of the Sacramento Mountains exposes a thick section of sedimentary rocks, which range in age from pre-Cambrian to Permian. As many units of this sedimentary sequence are exposed in other mountain ranges of southern New Mexico, and are known to extend eastward in the subsurface section to the oil fields of southeastern New Mexico and western Texas, stratigraphic studies in the Sacramento Mountains have regional significance. A variety of structural features, minor igneous intrusives, and land forms add further interest to the geology of the escarpment.

The only comprehensive report on the geology of Sacramento Mountains was published in 1928 by Darton, as a part of the results of his regional reconnaissance in New Mexico. Later published reports have been largely concerned with specific portions of the geologic picture, such as the stratigraphic studies of the Devonian by Stevenson (1945), the Mississippian by Laudon and Bowsher (1941, 1949), or the Pennsylvanian by Thompson (1942). Data collected by many petroleum geologists are largely unpublished. The New Mexico Bureau of Mines and Mineral Resources has recognized the need for a more detailed investigation of the Sacramento Mountain escarpment, and as a part of a broad geological program for the state has sponsored the work that forms the basis for this report. It is hoped that the results of this investigation will prove helpful to other geologists interested in this part of southern

New Mexico, and be a stimulus toward further work in the area.

The present report deals principally with the stratigraphy of the Sacramento Mountains, and reviews some of the structural features. A more complete structural analysis of the area, the igneous intrusives, geomorphology, and economic features will be treated in later reports.

FIELD WORK

Most of the field work that is summarized and discussed in this report was done during the period September 1947 - May 1949, chiefly during the summer and fall seasons. A total of about 13 months was devoted to studies in the field. The area was revisited for a period of 5 weeks during the summer of 1950, when a group of students mapped an area of about 10 square miles near the center of the western escarpment, under the direction of Dr. Ian Campbell and the writer.

Topographic maps of the Sacramento Division of the Lincoln National Forest were used as a base map. These have a scale of 1:31,680, and a contour interval of 100 feet. Most positions were located by triangulation. Vertical aerial photographs*/, with an average scale of two inches to a mile, were used in conjunction with the topographic maps in both field and office work.

The Forest Service map, which was made by plane-table methods before aerial photographs were available, does not show the topographic features as accurately or in as much detail as maps of comparable scale

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*/ Aerial photographs of the Sacramento Division of Lincoln National Forest are of the CTF series of 1941-42, and may be obtained from the U. S. Department of Agriculture, Soil Conservation Service.

of other areas made by modern photogrammetric methods. This is especially true in the higher parts of the area, where forest cover severly handicaps surface triangulation. The accuracy of the base map is adequate, however, for plotting most details of the geology shown on the map. Major revision was necessary in only a few areas, and in these areas triangulation, pacing, and measurements from the aerial photographs were used to revise the base map. Where the field work suggested a need for only minor corrections of the base map, the geology was adjusted to the existing map as a matter of expediency. A prohibitive amount of time would be needed to correct all of these minor deviations on the somewhat generalized base map.

GEOGRAPHY

LOCATION

The area discussed in this report is in Otero County, New Mexico, nearly equidistant from the east and west borders of the state. The center of the area is about 50 miles north of the southern border of New Mexico. The mapped area is 28 miles long (north-south) and 15 miles wide (fig. 1). It includes all of the 15' Alamogordo quadrangle and the northern two-thirds of the Escondido Canyon quadrangle. Approximately two-thirds of its 420 square miles lies in the Sacramento Mountains and thus consists chiefly of bed-rock exposures. The remaining third of the area lies on the eastern fringe of the Tularosa Basin.

Alamogordo, the Otero County Seat, and only city in the area, lies in the Tularosa Basin near the base of the mountains. This city had a population of about 7,000 in 1950 and is the business center for a wide surrounding area. La Luz, High Rolls, and Mountain Park are small agricultural communities in the northern part of the area, each with a few hundred inhabitants. The resort village of Cloudcroft is on the crest of the range and lies at the northeast edge of the map area. Except for Alamogordo and these named smaller communities, the region is very sparsely inhabited. In 1950, less than a dozen families were year-round occupants of the southern 250 square miles of the mapped area.

PHYSICAL FEATURES

REGIONAL SETTING

The general relationship of the Sacramento Mountains to the

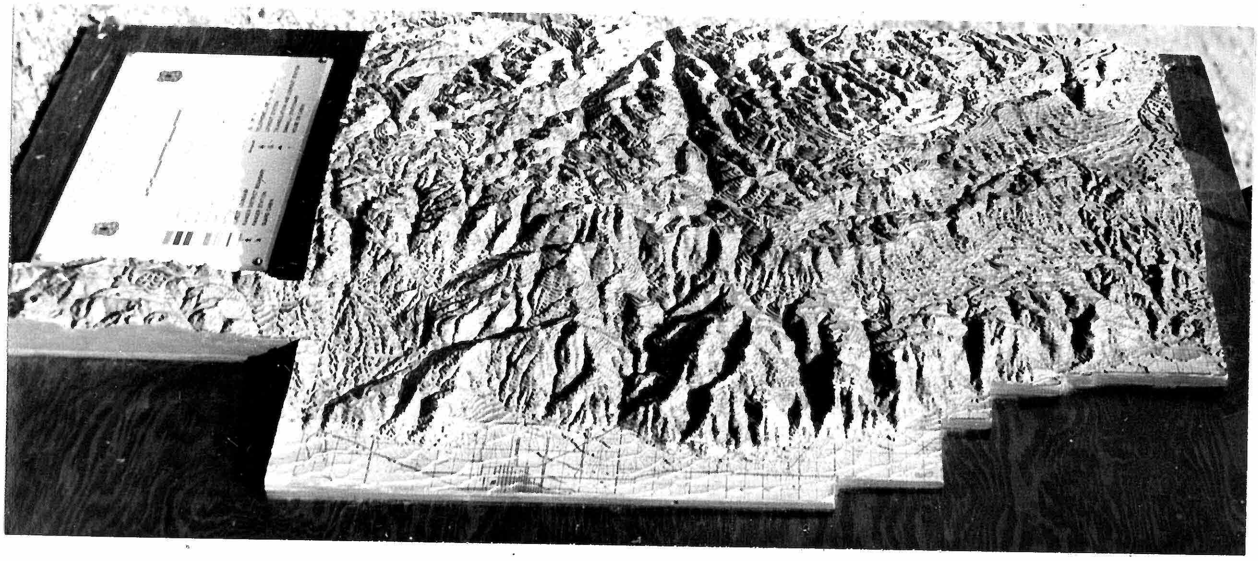


Figure 2. Relief model of the Sacramento Mountains portion of the Lincoln National Forest.

adjacent parts of southern New Mexico is shown in figure 1. These mountains form a part of the boundary between the Great Plains province to the east and the Basin and Range Province to the west (Fenneman, 1931). The north-south grain of the region west of the Sacramento escarpment is evident from inspection of the topographic map. The Rio Grande, largest river in the state, drains southward through New Mexico, and the elongation of the valleys and separate mountain masses is generally parallel to this course.

One of the most prominent of the valleys is the Tularosa Basin, which is 30 to 40 miles wide and extends northward from points near the Texas border through the center of the state for distances of more than 100 miles. For much of its length, this basin is fringed by escarpments of the bounding mountains, which are more than a mile high along parts of the eastern border, and rise 3000 to 4000 feet above the basin along the highest parts of the western border. The Tularosa Basin is an area of interior drainage and its lowest point, near its west side opposite the south end of the San Andres Mountains, lies at an elevation of 3900 feet above sea level. The monotony of the flat desert that forms the floor of the valley is interrupted in its center by a broad expanse of white dune sands, which are nearly pure gypsum. A part of this dune belt is the White Sands National Monument. In marked contrast to the white gypsum sands is a 40-mile tongue of dark, basaltic lava, the "Malpais", which extends southward into the northern end of the valley.

The Sacramento Mountains form a part of the abrupt eastern border of the central Tularosa Basin. South from these mountains, the edge of the basin is defined by the much lower escarpment of Otero Mesa. Farther south and somewhat to the west are the low-lying Hueco Mountains of New Mexico and Texas. The Sacramento Mountains merge northward into the Sierra Blanca, dominated by Sierra Blanca Peak, whose 12,004-foot summit is the highest point in southern New Mexico. In northward succession from the Sierra Blanca, and in order of decreasing size, are the Jicarilla Mountains, the Gallinas Mountains, and the Pedernal Hills. The Capitan Mountains, northeast of the Sierra Blanca, form one of the few east-trending ranges in the region.

The country slopes gently eastward from the crest of the Sacramento Mountains and the flanks of the Sierra Blanca, and extends toward the Pecos River 80 miles away. The broad Guadalupe Mountains rise from the southeastern part of the Sacramento cuesta and extend southward as a narrowing wedge to Guadalupe Peak, a few miles south of the Texas-New Mexico border. Like the Sacramento Mountains, the Guadalupe Mountains form a part of the boundary between the Basin and Range Province and the Great Plains to the east.

The west side of the Tularosa Basin is defined principally by the San Andres Mountains which lie directly across the valley from the Sacramento Mountains and the Sierra Blanca. This range is narrow but is about 80 miles long. The Organ Mountains, about 18 miles long, form a high and conspicuous mass south of the San Andres Mountains. The Franklin Mountains of New Mexico and Texas continue the San Andres-Organ Mountain trend, but are separated from the Organ Mountains by several miles of desert plain.

Most of the area discussed in this report lies on the steep west slope of the Sacramento Mountains. West of this is the marginal part of the Tularosa Basin, and east of the scarp the map includes the crest of the range, and part of the gentle east and southeast slopes. For convenience in description of the physical features, these areas are described separately in the following paragraphs.

TULAROSA BASIN

The part of the Tularosa Basin that lies within the map area consists of low, coalescing, alluvial fans (see the frontispiece) that form a fringe a few miles wide along the mountain base, and of wider, nearly flat areas beyond the lower edges of the fans. The altitude ranges from 4500 to 5000 feet at the heads of the fans. The low point of the area is about 4000 feet. The fans have rather low gradients, rarely more than three or four degrees, even near the mountains. The fans at the mouths of the larger canyons have maximum slopes of only two degrees.

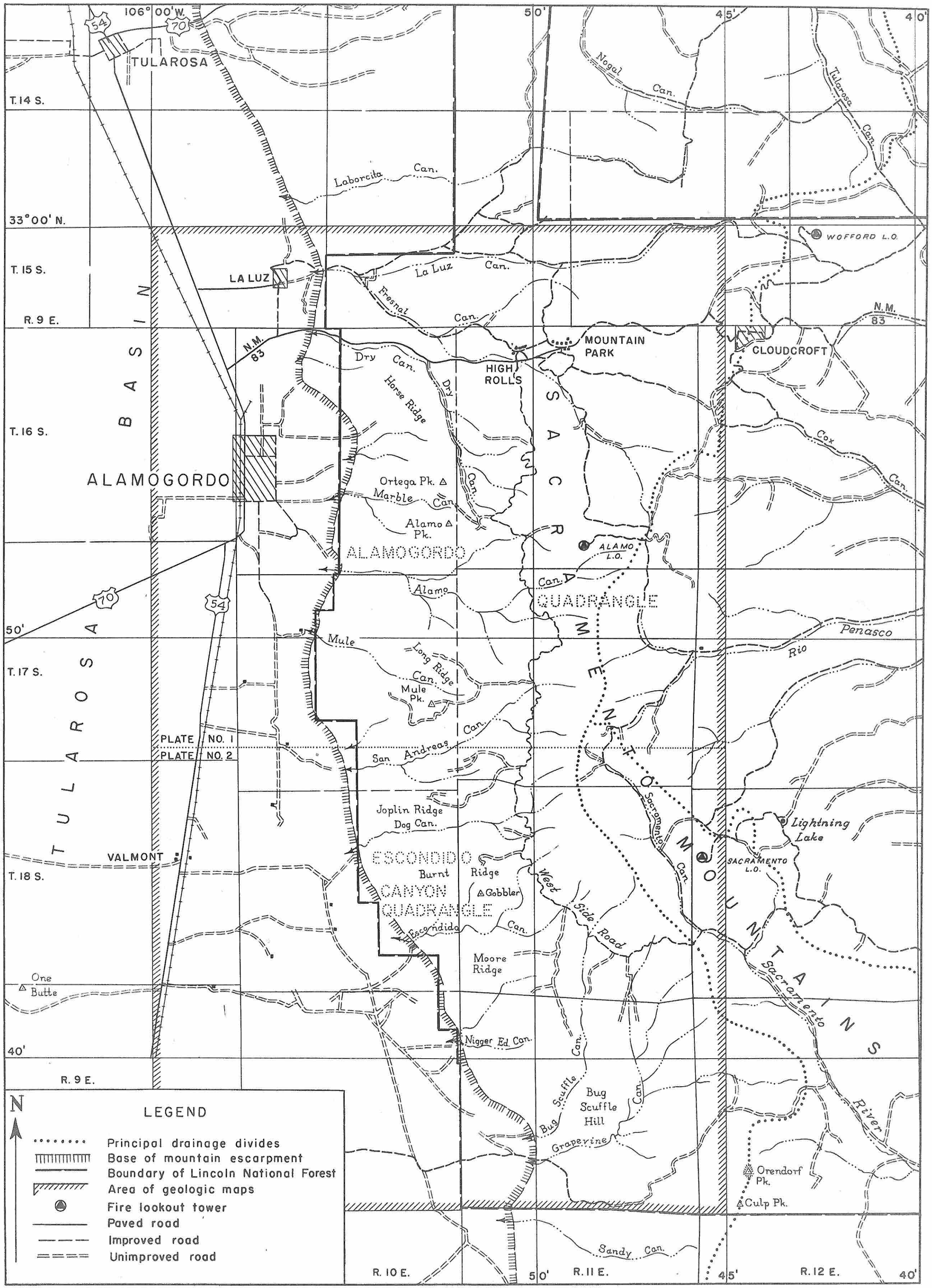
The relief between the heads and the lateral intercanyon fringes of the fans generally is only 100 to 200 feet over distances of a mile or more. Near the mountains some gullies are incised 10 to 20 feet into the coarse alluvial debris. The gullies and channels continue westward into the flatter areas as tortuous channels only a few feet in depth. In the western flatter areas, and especially toward the south, low dunes of reddish quartz sand cover much of the surface, and further complicate the drainage system.

WEST SLOPE OF THE SACRAMENTO MOUNTAIN ESCARPMENT

Almost all of the abrupt western escarpment of the Sacramento Mountains lies within the map area. The west slope has a pronounced two-step profile, especially in the central and southern parts of the area (fig. 2). The top or "tread" of the first step is a prominent structural bench that caps a cliff-making section of pre-Permian sedimentary rocks (frontispiece). This bench is highest in the southern and central part of the area, where it is about 7500 feet above sea level and more than 3000 feet above the level of the mountain base. Toward the north and south ends of the map area the bench becomes less clearly defined and its level decreases gradually. It merges with the Tularosa Basin near Tularosa to the north and El Paso Canyon to the south. The only cliffs facing the west beyond these points consist of Permian rocks that occur in the section above the bench in the central part of the escarpment.

The structural bench has been dissected to form a series of high, flat-topped ridges separated by steep-walled canyons spaced several miles apart (fig. 2). The major canyons listed from north to south in the map area are Fresnal and Dry Canyons, northeast of Alamogordo; Alamo Canyon, southeast of Alamogordo; and Mule, San Andreas, Dog, Escondido, and Grapevine canyons farther south. The vertical distance from canyon bottom to ridge top is 2000 to 3000 feet in many places. Most of the named high points in the Sacramento Mountains do not lie on the crest of the range, but are local prominences that rise above the general level of the bench in the central part of the area. The

Figure 3



INDEX MAP OF THE SACRAMENTO MOUNTAIN ESCARPMENT, OTERO COUNTY, NEW MEXICO

SCALE IN MILES

0 1 2 3 4 5 10

most conspicuous of these are two peaks east of Alamogordo. The northern peak, Ortega, rises to a height of 7675 feet above sea level, and Alamo Peak, a mile farther south, has an altitude of about 7850 feet. One of the most conspicuous and interesting of the local highs is Gobbler (pl. 2), a partially dissected dome, the summit of which is several hundred feet above the general level of the surrounding area. It lies near the center of sec. 19, T. 18 S., R. 11 E.

Above the level of the bench or first step, the slopesrise 1500 to 2500 feet to the crest of the range. These upper slopes contrast markedly with the more precipitous slopes below the bench level. Their profile is generally smooth, with a gradient that steepens gradually toward the crest. Cliffs are rare. A few ledges of limestone crop out near the top of the slope in the southern part of the area.

CREST OF THE SACRAMENTO MOUNTAINS

The crest of the range rises to more than 9600 feet in the center of the mapped area, but no single peak dominates this crest. In north-south, or longitudinal profile, the crest is very gently arched as its altitude is more than 9000 feet for a distance of 20 miles. In plan, it is convex toward the west. In the southern part of the area it lies about seven miles east of the base of the range, and the distance increases to about 13 miles at the northern end of the range.

Over much of its length, the crest is a simple divide between the gentle gradients of east-flowing streams and the steep profiles of the canyons to the west. The divide forks in the south, one arm trends southward, the other trends southeasterly. The Sacramento River system drains the rather narrow area between the arms along the southern part of the Sacramento Mountain crest. The divide to the east, between the Sacramento River system and the eastern slope of the range, is the higher of the two. Although it trends southeast in the map area, it swings farther to the east beyond the south edge of this area.

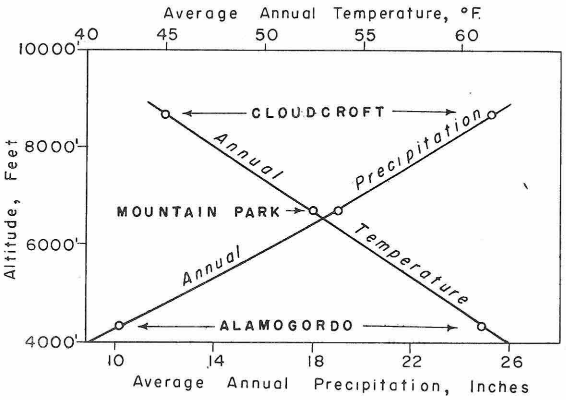
EASTERN SLOPE AND SACRAMENTO RIVER AREA

The eastern slope and Sacramento River area form a large part of the high timber country of the Sacramento Mountains, but lie east of most of the mapped area. The eastern slope of the Sacramento Mountains has been dissected to form many long, east-trending ridges and valleys. The entire drainage is tributary to the Penasco River, itself an east-flowing tributary of the Pecos River. The relief in the valleys is of the order of 500 to 1000 feet in their western, or headward parts, and diminishes toward the east. Both the valleys and ridges in the high part of the mountains slope eastward at a rate of about 100 to 200 feet per mile. The valley bottoms are rarely more than 1000 feet wide, and gullies 10 to 20 feet in depth are now rapidly eliminating the originally small areas suitable for agriculture in these valleys. The walls of the valleys are commonly steep, but cliffs are rare. The ridge tops are well rounded.

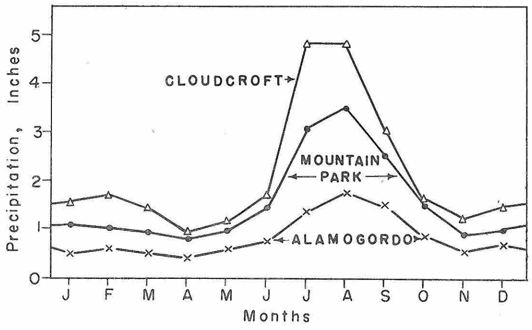
In the Sacramento River area, the relief and gradient along the main stream are similar to those of the east slope. However, the tributary valleys here are commonly perpendicular to the trunk valley, rather than nearly parallel to it, as on the eastern slope.

CLIMATE AND VEGETATION

Altitude is a major climatic control, and as the relief along the western escarpment is of the order of a mile, the climate changes markedly from the base to the crest of the range. The interrelations of altitude, precipitation and temperature are shown graphically in figure 4 for three stations within the map area: Alamogordo, at the base of the mountains; Cloudcroft, at the crest of the mountains; and Mountain Park, at an intermediate elevation.



EFFECT OF ALTITUDE ON TEMPERATURE AND PRECIPITATION



DISTRIBUTION OF PRECIPITATION BY MONTHS

Figure 4

The Tularosa Basin and the lower parts of the mountains are characterized by a hot desert climate with summer precipitation and dry winters according to Russell (1931, pl. 1), whereas the higher areas have a hot steppe climate with summer precipitation and dry winters.

It is possible to make geological surveys and to do other types of field work throughout the year without undue discomfort, particularly if one shifts from one general elevation to another at appropriate seasons. The least favorable time of the year for outdoor work is from mid-November to March as areas above 8000 feet are likely to have snow cover, and roads are often in poor condition or impassable. The spring months are characterized by warm weather, little precipitation, and occasional high winds. Summer temperatures along the base of the range are frequently near 100° F., but higher in the mountains cooler temperatures prevail, in part because of the altitude, and in part because of the increased frequency of partial cloud cover. Late morning and afternoon thundershowers during July and August supply much of the annual rainfall. Although often violent, they usually are of short duration, local in coverage, and do not seriously impede field work along the western escarpment. From September until mid-November the temperatures are moderate, the days sunny, and the precipitation very low. Conditions are then excellent for field work at all elevations.

The vegetation varies directly with altitude. At the base and lower levels, desert types of vegetation prevail. Cacti are numerous and include such types as the prickly pear, mesdal, cholla, hedgehog, and pin cushion. Cresote bush and mesquite are abundant in the

Tularosa Basin, the mesquite on the clayey soils and dune sands and the cresote bush on the higher parts of the alluvial fans. Ocotillo is common below 6000 feet. This shrub is useful for locating outcrops of bedrock in the few pediments of the area as it almost invariably roots in the bed rock rather than in alluvial debris.

Juniper and pinon pine characterize the growth at intermediate altitudes. Ponderosa pine, Engelmann spruce, and Douglas fir are the dominant evergreens of the highest part of the range. Quaking aspen is abundant above 8000 feet, especially in areas that have been logged over and burned.

ACCESSIBILITY

Many points within the Sacramento Mountain Escarpment are difficult to reach because of the rugged nature of the terrain. However, every point in the area is less than three miles from a road passable by automobile in dry weather (see fig. 3). Three major north-south routes are available for auto travel. Their locations are dependent upon the positions of the two steep rises of the Sacramento Mountain escarpment. U. S. Highway 54 parallels the railroad in the Tularosa Basin, and several unimproved roads connect this highway with the mouths of major canyons along the mountain front. The West Side Road, a secondary route that winds in and out of the canyon heads at the level of the main bench between the base and the crest of the range, gives access to ridges and the upper parts of the canyons in the central 20 miles of the escarpment. Another road trends southward along the crest for the length of the range, and serves to connect the western ends of roads that extend along the bottoms of many canyons east of the crest.

The only roads that cross the range from east to west are in the northern and southern ends of the map area (fig. 3). New Mexico Highway No. 83 is the only all weather east-west road across the map area. A nearby parallel, secondary road lies a few miles north of New Mexico No. 83 along the northern edge of the area. South of these two roads, the only other route that connects the base of the range with its crest is a steep and rough road up Grapevine Canyon, at the southern end of the area.

The main barriers to foot travel are the many ledges and vertical cliffs along the west face of the range below the West Side Road. Trails permit travel up most of the major canyons, but between these trails there are few places where the upper cliffs can be scaled without considerable difficulty. The slopes and ledges below an altitude of 5500 feet generally can be climbed without undue lateral traversing. Near and above the level of the West Side Road travel is difficult in some areas because of dense thickets, largely of scrub oak and bramble.

EXPOSURES

Exposures in the Sacramento Mountain Escarpment are generally excellent and locally spectacular. Below an altitude of 7500 feet all but the least resistant rock units are exposed. The largest covered areas are where rubble from some of the sheer cliffs of the Pennsylvanian units masks the underlying softer beds. This is particularly conspicuous in San Andreas, Dog, and Escondido Canyons, where floors are clogged by large accumulations of cliff rubble. The Devonian formations and the Caballero and Andrecito strata of the Mississippian form a continuous series of relatively non-resistant beds that are generally veneered with slope wash. However, nearly complete sections are exposed at intervals of a mile or less along much of the western escarpment.

Exposures are poor in the higher parts of the escarpment, especially on the steep western slope where there are large areas with few or no outcrops. This is particularly true of the slopes underlain by the soft Yeso formation and capped by the more resistant San Andres limestone. Rubble from this limestone forms a nearly continuous mantle on the upper Yeso slopes. As large landslides are also common on these slopes, the few rock outcrops are not entirely reliable.

Exposures east of the range crest, though neither abundant nor good, are nevertheless adequate guides to the general structural configuration.

STRATIGRAPHY

GENERAL STATEMENT

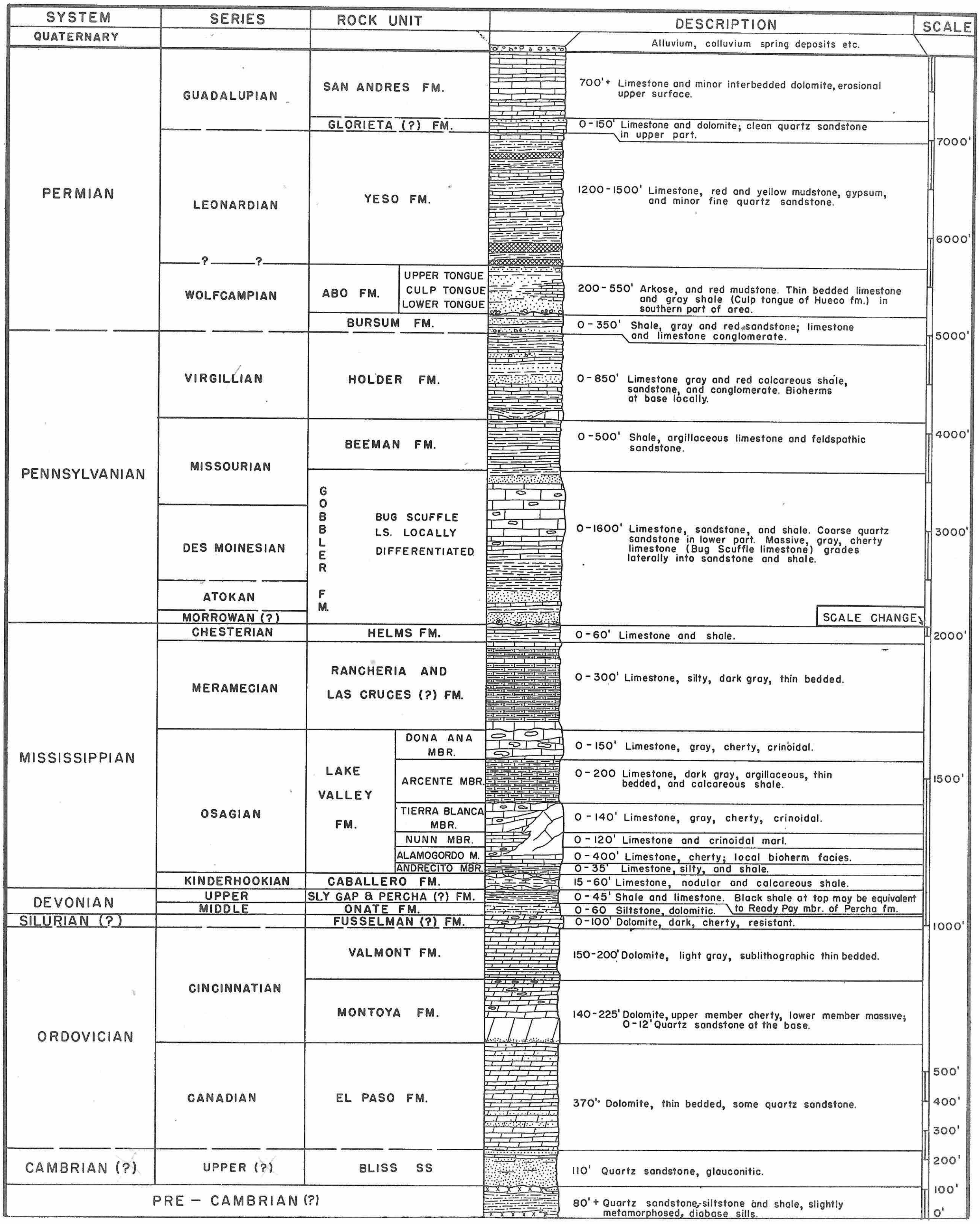
The geology of the Sacramento Mountains is largely the stratigraphy of the 7500 foot thickness of sedimentary rocks of the Paleozoic era. The excellent exposures of much of this section along the front of the escarpment for over 20 miles permits detailed study of the stratigraphic relationships. As the section contains representatives of many of the Paleozoic strata of southern New Mexico, these relationships are of regional significance.

Potential economic significance of the stratigraphy is seen in its relation to the oil fields of west Texas and southeastern New Mexico, one of the fastest growing and important petroleum producing areas in the nation. Early production was largely from Permian reservoirs, but in the past decade the emphasis has shifted to the older formations. The nearest outcrops of these older strata west of the producing areas are in the Sacramento Mountains, the Hueco Mountains of New Mexico and Texas, and at scattered localities in western Texas, such as the Sierra Blanca and Marathon regions.

Few detailed stratigraphic studies of the New Mexico mountain areas have been published to date. It is hoped that the data of this report will contribute toward a better understanding of the sedimentary record in south central New Mexico and serve to stimulate further investigations in this interesting region.

Thirty one sedimentary formations or members are discussed in this report. These are identified on the composite columnar section of figure 5. Of the 23 sedimentary units distinguished on the accompanying

Figure 5



SYSTEM	SERIES	ROCK UNIT		DESCRIPTION
QUATERNARY				Alluvium, colluvium spring deposits etc.
PERMIAN	GUADALUPIAN	SAN ANDRES FM.		700'+ Limestone and minor interbedded dolomite, erosional upper surface.
		GLORIETA (?) FM.		0-150' Limestone and dolomite; clean quartz sandstone in upper part.
	LEONARDIAN	YESO FM.		1200-1500' Limestone, red and yellow mudstone, gypsum, and minor fine quartz sandstone.
	?——? WOLFCAMPIAN	ABO FM.	UPPER TONGUE CULP TONGUE LOWER TONGUE	200-550' Arkose, and red mudstone. Thin bedded limestone and gray shale (Culp tongue of Hueco fm.) in southern part of area.
		BURSUM FM.		0-350' Shale, gray and red sandstone; limestone and limestone conglomerate.
PENNSYLVANIAN	VIRGILLIAN	HOLDER FM.		0-850' Limestone gray and red calcareous shale, sandstone, and conglomerate. Bioherms at base locally.
	MISSOURIAN	BEEMAN FM.		0-500' Shale, argillaceous limestone and feldspathic sandstone.
	DES MOINESIAN ATOKAN MORROWAN (?)	GOBBLER FM.	BUG SCUFFLE LS. LOCALLY DIFFERENTIATED	0-1600' Limestone, sandstone, and shale. Coarse quartz sandstone in lower part. Massive, gray, cherty limestone (Bug Scuffle limestone) grades laterally into sandstone and shale.
MISSISSIPPIAN	CHESTERIAN	HELMS FM.		0-60' Limestone and shale.
	MERAMECIAN	RANCHERIA AND LAS CRUCES (?) FM.		0-300' Limestone, silty, dark gray, thin bedded.
	OSAGIAN	LAKE VALLEY FM.	DONA ANA MBR.	0-150' Limestone, gray, cherty, crinoidal.
			ARCENTE MBR.	0-200 Limestone, dark gray, argillaceous, thin bedded, and calcareous shale.
			TIERRA BLANCA MBR.	0-140' Limestone, gray, cherty, crinoidal.
			NUNN MBR.	0-120' Limestone and crinoidal marl.
			ALAMOGORDO M.	0-400' Limestone, cherty; local bioherm facies.
			ANDRECITO MBR.	0-35' Limestone, silty, and shale.
	KINDERHOOKIAN	CABALLERO FM.		15-60' Limestone, nodular and calcareous shale.
DEVONIAN	UPPER	SLY GAP & PERCHA (?) FM.		0-45' Shale and limestone. Black shale at top may be equivalent to Ready Pay mbr. of Percha fm.
	MIDDLE	ONATE FM.		0-60 Siltstone, dolomitic.
SILURIAN (?)		FUSSELMAN (?) FM.		0-100' Dolomite, dark, cherty, resistant.
ORDOVICIAN	CINCINNATIAN	VALMONT FM.		150-200' Dolomite, light gray, sublithographic thin bedded.
		MONTOYA FM.		140-225' Dolomite, upper member cherty, lower member massive; 0-12' Quartz sandstone at the base.
	CANADIAN	EL PASO FM.		370'+ Dolomite, thin bedded, some quartz sandstone.
CAMBRIAN (?)	UPPER (?)	BLISS SS		110' Quartz sandstone, glauconitic.
PRE-CAMBRIAN (?)				80'+ Quartz sandstone, siltstone and shale, slightly metamorphosed, diabase sills.

COMPOSITE COLUMNAR SECTION, SACRAMENTO MOUNTAINS, OTERO CO., NEW MEXICO geologic maps (plates 1 and 2), 20 are of Paleozoic age. The general character of the stratigraphy and structure is illustrated by figure 6, a diagrammatic cross-section of the western escarpment. The typical appearance of most pre-Permian strata along the front of the range shows in figure 7.

SUMMARY OF THE STRATIGRAPHIC RELATIONS

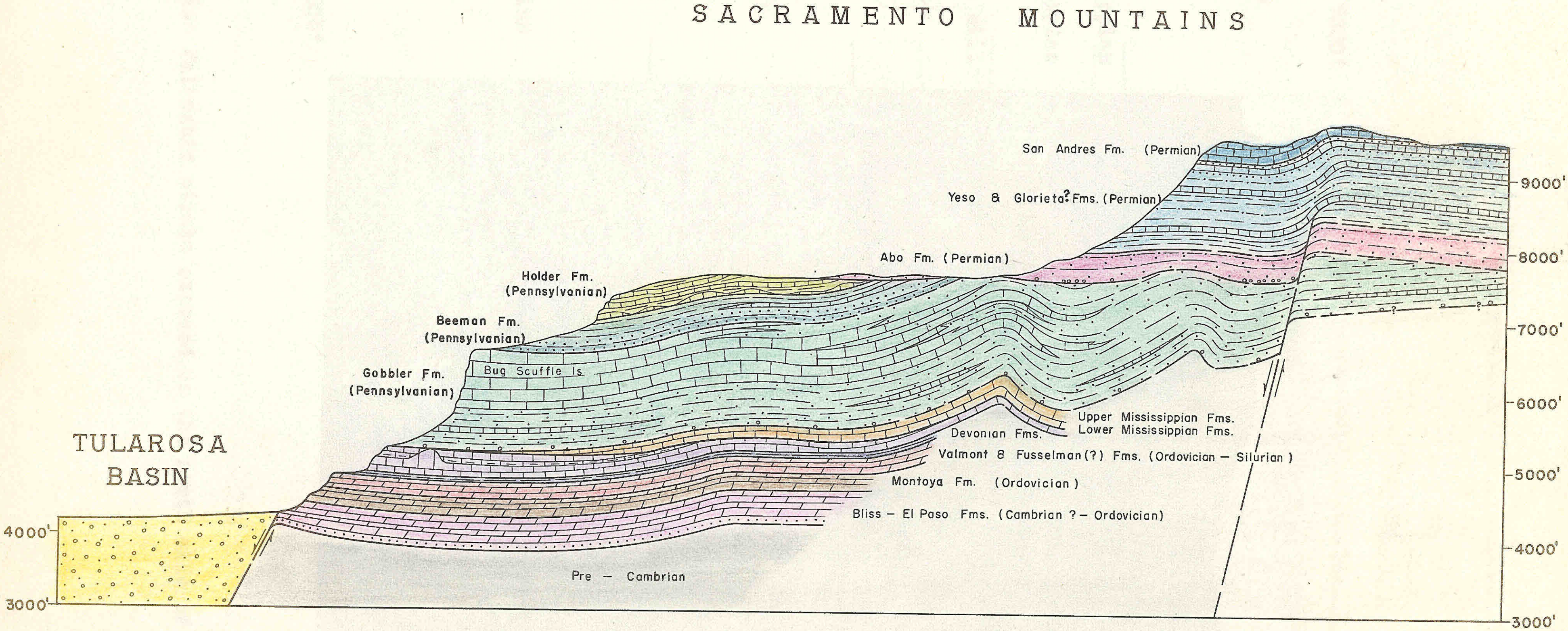
PRE-CAMBRIAN (?) ROCKS

The oldest rocks exposed in the Sacramento Mountains are about 100 feet of shales, siltstones, and quartzites in a small area near the southern end of the escarpment. These rocks, slightly metamorphosed and intruded by igneous sills, are provisionally considered as pre-Cambrian in age. An angular unconformity of about ten degrees separates these clastic strata and the associated intrusives from the overlying Paleozoic strata.

PALEOZOIC ROCKS

Viewed broadly, the Paleozoic strata of the Sacramento Mountains have many similarities to sedimentary units of the same era in much of the Rocky Mountain and Mid-Continent region. For example, nearly all the units are of marine origin; the older Paleozoic strata are dominantly carbonate rocks, in many places dolomitic; crinoidal limestones are a prominent part of the Mississippian strata; the Pennsylvanian section is thick and widely variable in lithology; and the Permian strata contain some red bed and evaporite units. For the purpose of generalized

Figure 6



DIAGRAMMATIC CROSS-SECTION OF CENTRAL PART OF SACRAMENTO MOUNTAIN ESCARPMENT

HORIZONTAL SCALE IN MILES

0 1 2 3 4 5

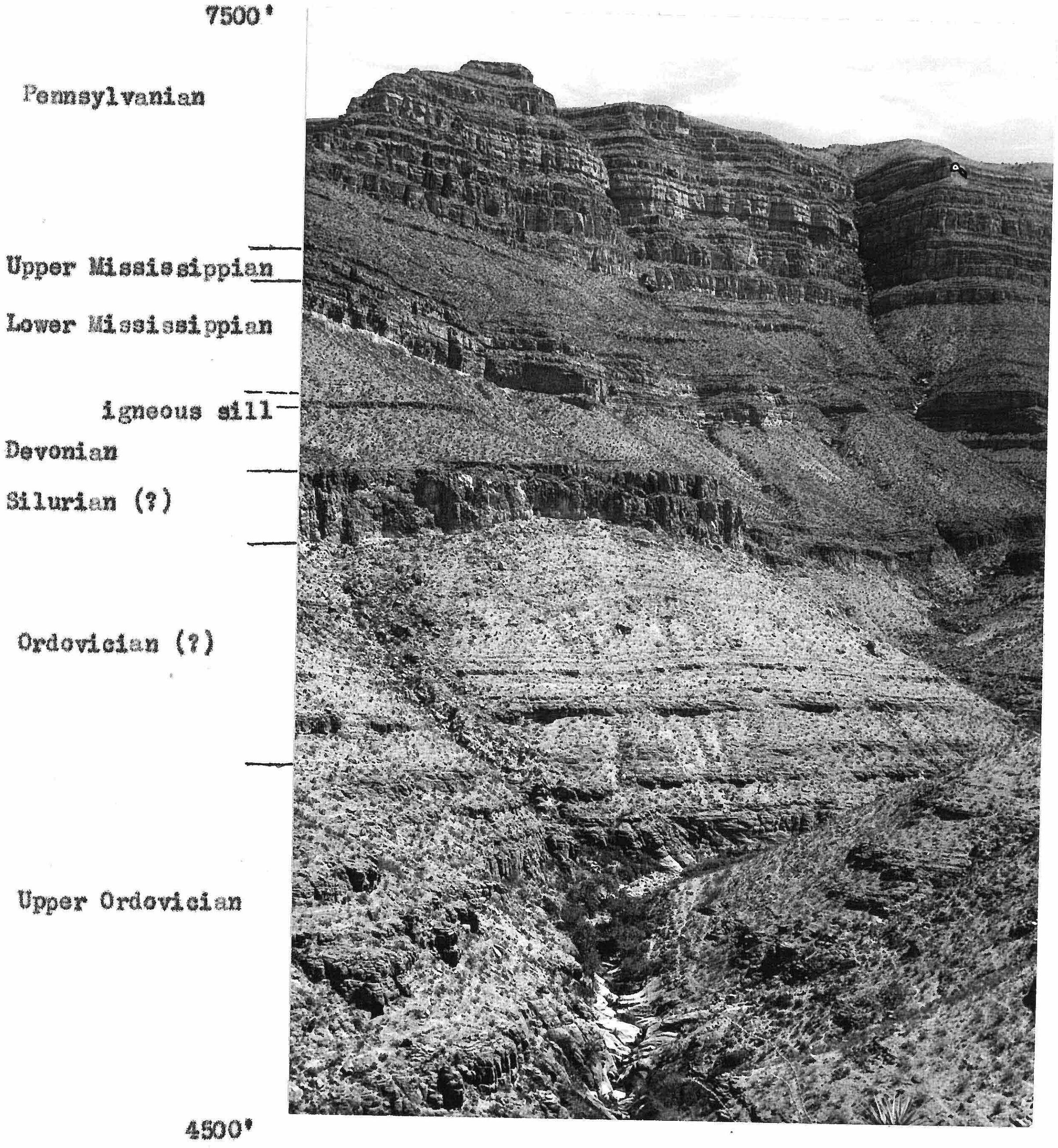


Figure 7. Paleozoic strata exposed on the north side of Dog Canyon.

description, the Paleozoic formations of the Sacramento Mountains can be divided into four main lithologic groups, or sequences, somewhat similar to the sequence of Sloss, et al, (1949, pp. 110 et. seq.):

1. Cambrian (?) through Silurian (?) strata
2. Devonian and Mississippian strata
3. Pennsylvanian strata
4. Permian strata

The lowest sequence, about 900 feet in aggregate thickness, consists largely of dolomite with thin quartz sandstone strata at the base. The formations are marine in origin, and are probably products of deposition on broad stable shelves in relatively shallow epicontinental seas. The units in the Sacramento Mountains are characterized by uniform thicknesses and lateral persistence of lithologic features. Cherts are common, and for some units are diagnostic. Fossils are not abundant, and most of the remains are silicified and poorly preserved. Most formations are separated by disconformities.

Strata of the Devonian and Mississippian systems form a convenient general unit. Although the composite thickness is about 1000 feet in the Sacramento Mountains, it is less than half this amount at any one point. The strata are dominantly limestones and shales of marine origin. Quartz sandstones or coarser non-carbonate clastics are absent except in the Onate (Devonian) formation, a unit that is transitional in lithologic character between the underlying pre-Devonian dolomites and overlying non-dolomitic strata. The coarse detrital rocks of this sequence are calcarenites and calcirudites, composed largely of crinoidal debris. Fossils are abundant in most of the formations, and commonly are well preserved. Bioherms, some 400 feet in thickness, and the associated facies are features of unusual interest that are well developed in the Lake Valley (Mississippian) formation. Units of the Devonian and Mississippian sequence show greater lateral variation in thickness and lithology than those of underlying sequence.

Strata of Pennsylvanian age, about 3000 feet in thickness, form nearly half of the total Paleozoic section and are lithologically distinctive from other parts of the section. The Pennsylvanian sequence is a composite of thin and laterally discontinuous beds of limestone, sandstone, and shale. These strata are dominantly marine in origin but locally appear to represent deposition in fresh or brackish waters. Although many diastems are present, the thick series probably represents almost continuous deposition. Interruptions in deposition do not appear to have been accompanied by significant widespread erosion. Field correlation of these strata is difficult because of the lateral variation or lack of persistence of individual beds, the pronounced facies variation of groups of beds, the absence of recognizable major unconformities in the sequence, and the truncation of much of the section by the pre-Abo (Permian) angular unconformity. A new subdivision of the Pennsylvanian strata is introduced in this report. Three formations that form mappable lithologic units along the Sacramento Mountain escarpment are named.

The Permian strata exposed along the Sacramento Mountains escarpment are about 2500 feet thick and are only the lowest part of a more complete Permian sequence that lies farther to the southeast. In the map area, the Permian deposits represent a wide variety of lithologic types, some of which are not present in older strata of the area. The lower parts, including the Bursum and the Abo formations, are dominantly clastic rocks of red color, and record periods of alternating marine and non-marine deposition. The Yeso formation contains abundant gypsum, in addition to other marine strata of shale, siltstone, limestone and dolomite. The youngest Permian strata exposed in the area are a resistant series of limestone and dolomite of the San Andres formation which is separated from the Yeso formation by a few feet of distinctive quartz sandstone correlated with the Glorieta sandstone.

MESOZOIC AND CENOZOIC ROCKS

No sedimentary rocks of Mesozoic age have been found within the map area, although strata of this age are known in the Sierra Blanca region to the north and near the state line to the south. Sediments of Cenozoic age in the area are largely alluvium, colluvium and spring deposits.

METHODS AND NOMENCLATURE

The author's approach to the stratigraphy of the area has been largely by the field mapping of lithologic units. Fossils were collected during the course of the work, but the faunal evidence has been used primarily in dating the lithologic units distinguished in the field, rather than as a basis for field correlation. Thorough investigations of the fauna of these lithologic units are needed, as few detailed paleontologic studies have been reported to date, except for the Devonian and Mississippian strata. The ages of many of the formations are in doubt, not only in the Sacramento Mountains but in adjacent mountain areas of southcentral New Mexico.

Most of the stratigraphic sections included in the report are described by a graphic log and key sections are accompanied by a word description of the lithology. The graphic log was plotted in the field. Although it is necessarily diagrammatic, attempts were made to plot bedding and other lithologic features to scale, in so far as possible. Where they are not to scale, the relative size is indicated by the size of the symbol. Except where otherwise stated, all sections were measured by hand leveling according to the Hewett technique (Hewett, 1920). Because many of the sections were measured up steep slopes or cliffs in areas of little structural disturbance, and because of good exposures the measured thickness of most sections is estimated as within 10 percent of true thickness.

The Rock Color Chart published by the National Research Council in 1948 was used for many of the color descriptions, either by direct comparison of the rock with the color chip, or by frequent enough direct comparison to keep estimates of color within reasonable limits. Except where the precise color number seems to be of diagnostic value, the colors are referred to only by the names on the chart. Although this is ambiguous for some colors, in general, the range of ambiguity does not seem large enough to justify a more precise but less readily visualized designation.

The detrital grain sizes are recorded in terms of the Wentworth grade scale (Wentworth, 1922).

Terminology for the crystal size of carbonate rocks is not well standardized[*/]. In the Sacramento Mountains area the size of the crysals of the dolomites is relatively uniform for a specific formation and therefore of diagnostic value. The range in crystal size of the dolomites is from about 0.01 to 0.2-0.3 mm. The terminology suggested by Payne (1942) adopts the familiar Wentworth grade scale limits to crystal sizes, and provides for closer distinctions within the above range of sizes rather than the other proposed scales. It also agrees well in general limits and terminology with most other classifications. For these reasons it was adopted for field description in the Sacramento Mountain area. The Payne grade scale is as follows:

mm.	
2-1	very coarsely crystalline
1-1/2	coarsely crystalline
1/2-1/4	medium crystalline
1/4-1/8	finely crystalline
1/8-1/16	very finely crystalline
1/16	sublithographic

Most of the limestones of the area are sublithographic with respect to the Payne terminology. Minor variations of the crystal size in these rocks do not appear to be of diagnostic value and are difficult to determine readily in the field. The more significant variation in the limestones of the Sacramento Mountain area is that between the sublithographic or very finely crystalline limestone and the megascopically granular, detrital limestone. The coarser-grained limestones are therefore noted in the lithologic descriptions, and the granularity or crystallinity are described according to the Wentworth terminology.

[*/] For example, see the following: Cloud and Barnes, 1948; Deford, 1946; Hills, 1942; Howell, 1922; Krynine, 1948; and Payne, 1942.

Where not otherwise indicated, the limestones are sublithographic or very finely crystalline.

Field descriptions of the crystal size of carbonate rocks were based on analogy with the more familiar sand sizes, and occasional comparison with carbonate rocks of measured texture. The accuracy of field description is nowhere near that implied by the limits of the Payne scale.

Terminology for thickness of beds is not well standardized in the literature. In most measured sections, the thickness of bedding is given in numerical terms, and is also shown on the graphic log where the scale permits. Where general terms are used for description, the following arbitrary classification serves to define those terms:

Separation of principal bedding planes

thick bedded	over 3 feet
medium bedded	1 to 3 feet
thin bedded	less than 1 foot

"Massive" is applied where the rock layer is devoid, or nearly so, of lithologic discontinuities except those at top and bottom, and is generally only applied to units several feet or more in thickness.

"Laminated" is applied where closely spaced ($<$ 1/4") layering is visible in the rock between the main bedding planes.

In the following discussion of the sedimentary formations, data pertaining to the contact between two formations are included in the section on contact relationships for the overlying formation, and only a summary statement is made of the relationships at the upper contact of a formation. As the time available for the study of any one formation was severely limited, discussion of many interesting features noted during the field work is necessarily confined largely to generalized description.

PRE-CAMBRIAN (?) ROCKS

GENERAL FEATURES

The oldest rocks known to be exposed along the Sacramento Mountain escarpment form a sedimentary sequence about 100 feet in thickness. They comprise slightly metamorphosed shales, siltstones, and fine-grained sandstones, and have been injected by basic igneous sills. The sediments and the associated later intrusives are believed to be late pre-Cambrian in age.

In their early reconnaissance studies, both Darton (1917, p. 33) and Baker (1920, p. 103) recognized the area of outcrop of the oldest rocks exposed along the Sacramento escarpment, but appear to have considered them to be "basement complex" rather than very mildly metamorphosed sediments intruded by igneous sills. Darton's views are best summarized by his statement (1928, p. 198):

> "A thin sandstone lies on a smooth surface of dark diorite or granite and is about eight feet thick."

He considered the sandstone to be either Bliss or basal El Paso, and the granite or dark diorite to be pre-Cambrian. Baker (1920, p. 103) refers to the

> "supposedly pre-Cambrian plutonics but with the upper contact not well exposed."

The locality believed to be the one described by Darton is at the northwest corner of sec. 18, T. 19 S., R. 11 E., where a few feet of quartz sandstone appears to overlie coarsely crystalline igneous rock, and to underlie dolomite. This anomalous sedimentary section is believed to be the result of faulting. The igneous rock consists of conspicuous large feldspar phenocrysts embedded in a fine-grained groundmass, and resembles a plutonic rock. The section given by Baker can be observed at the mouth of the canyon in the NW 1/4 sec. 1, T. 19 S., R. 10 E. Laterally from these two localities, slightly metamorphosed sediments appear to underlie the igneous rocks and to be intruded by them.

AREAL DISTRIBUTION

The pre-Cambrian (?) rocks crop out near the southern end of the Sacramento Mountain escarpment, in two areas flanking the broad alluvial fan at the mouth of Nigger Ed Canyon. The areal distribution of these rocks was indicated accurately on the reconnaissance map by Darton (1928, pl. 44). Appropriately enough, in view of the overall cuesta structure of the range, these exposures occupy the two lowest areas of bedrock outcrop along the Sacramento Mountain escarpment, areas that are lower than the head of the alluvial fan in Nigger Ed Canyon, but that are not covered by alluvium because of the lateral gradients of this and other flanking fans. The areal extent of these oldest rocks is small. The width of outcrop generally is less than 500 feet, and the total length is only about one and a half miles. In much of this area of pre-Cambrian (?) rocks, a veneer of alluvium and colluvium obscures the bedrock and prevents tracing of strata from one gullied exposure to the next.

The strata strike north, and dip gently east. Toward the western limit of outcrop the dip is locally reversed, presumably in response to drag along the faults bounding the west front of the range. Less than

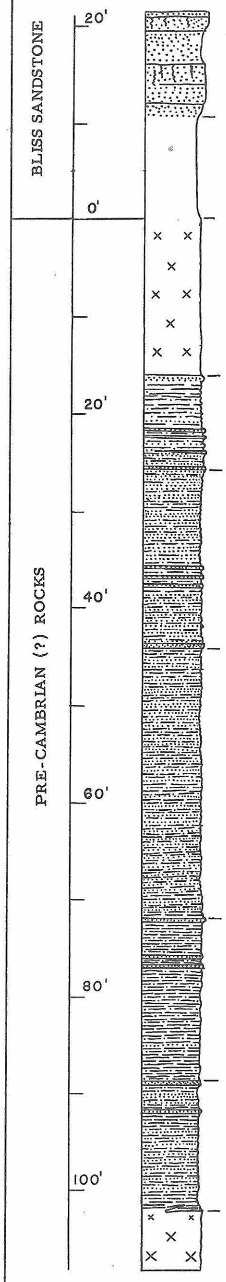
100 feet west of the zone of outcrops, low piedmont scarps are discernable in the alluvium. At two places a fault contact between pre-Cambrian (?) bedrock to the east and alluvium to the west was observed.

LITHOLOGY

The best exposures of the sedimentary beds lie north of Nigger Ed canyon, where the sequence measures about 80 feet in thickness. The total thickness is, of course, unknown. Details of the section measured near the middle of the west edge of sec. 1, T. 19 S., R. 10 E. are indicated on figure 8. All the rocks are clastic. Gray green shales and siltstones are dominant, and beds of quartz sandstone only a few inches thick form a conspicuous but minor part of the sequence. Many beds are delicately cross-laminated. The sandstones are generally fine-grained, clean, well-sorted rocks. Potash and plagioclase feldspars form only a small proportion of the clastic particles, and usually cannot be detected megascopically.

Some "fucoidal" markings on bedding planes are present, but no diagnostic fossils have been discovered. The lithologic character of the rocks suggests slow deposition of the original sediments in shallow water. The general lithology of the pre-Cambrian (?) strata south of Nigger Ed Canyon is similar to that at the measured section. The beds probably represent the same general interval, but no attempt was made to correlate units within the pre-Cambrian (?) sequence.

The pre-Cambrian (?) beds can be differentiated generally from the overlying Bliss sandstone by the abundance of siltstones and shales, the igneous sills, and the slightly metamorphosed character of the older



Base not exposed

Quartz sandstone, light brown, medium grained, some cross-laminated, worm (?) borings common

Covered. S. 30°E. 4000' at or near this interval an angular unconformity (10° discordance) separates the overlying sandstones from underlying finer grained quartzites, siltstones, and intrusive sills.

Diorite sill, dark, fine grained

Quartzite, fine to medium grained; interbedded siltstone; spotted shales near contact with sill.

Quartzite, mottled red and green, fine grained, 1-2" beds; siltstone; shaly partings, some "fucoids".

Siltstone, gray-green, thin bedded, micaceous; fine grained sandstone; shaly partings, slightly spotted by contact metamorphism.

Shales and siltstone, gray-green, thin bedded, micaceous; some fine grained quartzite beds less than 1" thick argillaceous layers distinctly spotted by contact metamorphism.

Quartzite, gray-green, fine grained; siltstones; shaly partings; thin bedded.

Diorite porphyry, intrusive into sedimentary beds and causing slight contact metamorphism. Base of sill (?) and underlying sediments not exposed.

Section measured eastward up slope from point on west line of sec. 1, 2000' south of NW corner sec. 1, T. 19 S. R. 10 E.

STRATIGRAPHIC SECTION OF EXPOSED PRE-CAMBRIAN (?) STRATA

Figure 8

strata. Conversely, these older strata lack the glauconite, the interbedded dolomites, and abundance of medium grained sandstone that are all characteristic of the Bliss sandstone.

CONTACT RELATIONSHIPS

The base of the pre-Cambrian (?) sedimentary strata is not exposed. Igneous rock at the base of the measured section is interpreted as intrusive, so the observed thickness of pre-Cambrian (?) must be only a minimum figure. The upper contact of the pre-Cambrian (?) rocks is at an erosional break which, at least locally, is an angular unconformity.

IGNEOUS ROCKS

Igneous rocks that are intrusive into the pre-Cambrian (?) sedimentary strata and appear to be restricted to strata below the unconformity at the base of the Bliss sandstone are considered to be pre-Cambrian in age. The igneous bodies are of dark colored hypabyssal rocks of intermediate composition, and are referred to in this report as diabase[*/].

Diabase forms about a third of the rocks that lie stratigraphically below the Bliss sandstone. That the sedimentary strata have been intruded by the diabase is shown by apophyses; by lenses, tongues and irregular inclusions of the sedimentary beds in the diabase; by minor discordance between the igneous contacts and bedding in the sedimentary

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[*/] The term diabase is used in this report as a field term for the igneous rocks in the pre-Cambrian (?) strata. In detail, many of the rocks differ from the strict definition of diabase as they generally are more silicic, and more generally have an intersertal, rather than ophitic texture.

rocks; and by the contact metamorphism above and below the igneous bodies. As most of the igneous contacts are parallel with the bedding of the intruded sediments, these bodies are classed as sills.

Some sills can be traced almost continuously for more than a quarter of a mile, and are as much as 30 feet thick. The largest sill is at the base of the exposed sedimentary rocks in the area north of Nigger Ed Canyon. The lower contact of this igneous mass is concealed so that its thickness may be much more than the exposed 30 to 40 feet.

The most abundant intrusive rock type is dark, fine crystalline, and non-porphyritic (table 1-A). It is composed of about equal quantities of dark and light minerals. Andesine is the predominant feldspar. Potash feldspar probably is not present, although some may be completely masked by alteration products. Chlorite, formed by alteration of augite and biotite, is the most abundant of the dark minerals. Augite and biotite are subordinate varietal minerals. Apatite and opaque minerals, largely magnetite and ilmenite (?) are abundant accessory minerals. The texture is intersertal; laths of plagioclase, as much as 2 to 3 mm. long, form a meshwork, the interstices of which are filled by the other more finely crystalline minerals. Rocks of this type are diorites (2-2-12) in Johannsen's classification.

The intrusives are locally porphyritic (table 1, B and C), especially in some of the larger masses. In most rocks, the phenocrysts, some as large as a centimeter, are andesine. In the exposures at the base of the measured pre-Cambrian (?) section the lowest igneous mass has both porphyritic and non-porphyritic phases. The top 2 to 3 feet is fine grained, with only a few small phenocrysts, and this chilled phase grades downward into rock with large and abundant phenocrysts of andesine. The markedly porphyritic zone, however, seems to be a border phase, as it grades downward into less porphyritic fine-grained rock, believed to represent the main mass of the sill. This part contains small quantities of potash feldspar.

In other porphyritic varieties of these igneous rocks, the phenocrysts are composed of potash feldspar. The most striking example of these rocks occurs just below the Bliss sandstone at the northwest corner of sec. 18, T. 19 S., R. 11 E. Here orthoclase (?) phenocrysts as much as 2 cm. across form more than half of the rock, and are embedded in a fine grained groundmass. Outcrops are not continuous at this locality, but a short distance below the outcrop of this strikingly "plutonic" rock is an exposure of dioritic rock that may represent the main part of a sill of which the porphyritic rock is a border phase. The general similarity of the modes of the groundmass (table I) of this rock to those without orthoclase phenocrysts supports this suggestion.

CONTACT METAMORPHISM

The intrusive rocks have caused some metamorphism of the enclosing strata. The more argillaceous layers have been converted to spotted slates, and the coarser quartzose clastic rocks have been cemented and partially recrystallized to quartzites. The metamorphic effects are visible in the argillaceous strata as much as 20 to 40 feet from the igneous contacts, and the entire pre-Cambrian section is believed to have been somewhat affected. Not all of the metamorphic changes are

TABLE I

Modal analyses of groundmass of specimens below

Specimen	A	B	C
Feldspars*	45.6	51.7	52.5
Quartz	***	2.6	4.3
Chlorite	26.2	21.7	26.5
Biotite	2.8	—	—
Augite	—	***	8.3
Opaque minerals	17.8	21.2	6.8
Other minerals	7.6**	2.8	1.6
	100.0	100.0	100.0
Johannsen Classification	2-2-12	2-2-12	2-2-11

*Almost all plagioclase. Potash feldspar definitely identified only in groundmass of Specimen C where it forms a small proportion of total feldspar. Alteration products of feldspar were included as feldspar.

**Largely apatite.

***Included in other minerals.

Specimen A. Microdiorite; non-porphyritic, fine-grained, intersertal texture; plagioclase composition $Ab_{52}An_{48}$; chlorite alteration product of pyroxene (?) and biotite.

Specimen B. Diorite porphyry; porphyritic, fine-grained, intersertal texture; plagioclase phenocrysts composition $Ab_{58}An_{42}$; groundmass similar to Spec. A, except composition of plagioclase is $Ab_{60}An_{40}$.

Specimen C. Syenodiorite porphyry; porphyritic, fine-grained, intersertal texture; phenocrysts largely highly altered potash feldspar, centers of some phenocrysts are intermediate plagioclase; groundmass similar to Spec. A, except some altered potash feldspar is discernible; plagioclase of groundmass $Ab_{64}An_{36}$.

to have been somewhat affected. Not all of the metamorphic changes are demonstrably of contact origin, however, and mild regional metamorphism may be partly responsible for some of them.

Examined microscopically, the spots in the argillaceous layers are dark in color, 1-2 mm. across, roughly ovoid in shape, and consist of finely crystalline muscovite and chlorite, with minor amounts of black iron oxides. Quartz clasts appear to have been but little affected and are in the spotted areas and matrix alike. The spots are distinguished from adjacent areas of the matrix by enrichment in sericite and chlorite, by the more coarsely crystalline development of these minerals, and by the absence of dusty clay particles and of limonitic iron stains. Metamorphism does not appear to have been sufficiently intense to form biotite.

Near the contacts, silicification along fractures in the strata has formed conspicuous salmon colored "dikes" several inches in thickness, and irregular in pattern.

AGE, CORRELATION, AND REGIONAL RELATIONSHIPS

In the Sacramento Mountains there is little evidence by which to date the oldest sedimentary rocks or the associated intrusives. The most significant field relationship is that these rocks are below strata referred to the Bliss sandstone, and are separated from that formation by an angular unconformity. The strata are necessarily older than the Bliss sandstone. Further evidence of the age is meagre. No fossils have been found in the pre-Bliss strata of the Sacramento Mountains, except for obscure "fucoids" of little value. This absence of fossils and the stratigraphic position suggest a pre-Cambrian age for the strata.

The slight degree of metamorphism indicates that these strata are not older than late pre-Cambrian (Proterozoic).

The associated intrusive rocks are younger than the intruded sedimentary rocks. Several lines of evidence suggest that these intrusives are also of pre-Bliss age. These intrusives are widely distributed throughout the oldest sedimentary unit, and at many places are within a few feet of the Bliss sandstone, but at no place have they been observed above the basal Bliss unconformity. The contact metamorphism associated with the intrusives appears to be restricted to rocks below the basal Bliss contact. This apparent restriction of the intrusives and their contact effects is significant as the strata above the unconformity are at least as susceptible to intrusion and contact metamorphism as are those below the unconformity. On the basis of composition, these intrusives are similar to the Tertiary (?) intrusives in other parts of the Sacramento Mountains. However, the later intrusives are most common farther north along the escarpment, and have not been observed in any of the lower Paleozoic strata in the area in which the pre-Bliss strata are exposed. Occurrence of pebbles of diabase in the basal conglomeratic layer of the Bliss sandstone would be excellent evidence for a pre-Bliss age of the intrusives, but none could be found.

The sedimentary rocks and the associated intrusives cannot be satisfactorily correlated with sections in other areas. The closest outcrops of pre-Bliss rocks are on the west side of the Tularosa Basin, in the Organ and San Andres Mountains, where they have been described by Dunham (1935, pp. 28-39) and Darton (1928, p. 184) as igneous and highly metamorphosed sedimentary and igneous rocks. There is no record of mildly metamorphosed sediments in the Organ or San Andres Mountains. Farther north, in the Los Pinos Mountains, Stark and Dapples (1946, p. 1127) report metamorphosed sedimentary strata, but the amount of deformation and metamorphism in this area appears to be much greater than that in the Sacramento Mountains. South of the Sacramento Mountains, in the Hueco Mountain area, the pre-Bliss rocks are granitic in character (King and Knight, 1945).

The nearest strata that might be correlated with the oldest rocks of the Sacramento Mountains are in the Franklin Mountains near El Paso, Texas. Richardson (1909, p. 3) described the Lanoria quartzite and some associated diabase intrusive rocks, which underlie the angular unconformity at the base of the Bliss sandstone. Near Van Horn, Texas, farther toward the southeast, clastic rocks termed the Van Horn sandstone lie below an angular unconformity at the base of the Bliss sandstone, and above an older sequence of much deformed pre-Cambrian strata. The Van Horn is considered as Cambrian or pre-Cambrian in age (King, P. B., 1940). No intrusives are known in the Van Horn sandstone.

A pre-Cambrian age for the intrusives in the oldest strata of the Sacramento Mountains seems more probable than Cambrian age. There is no record of igneous activity during early Paleozoic in southern New Mexico. On the other hand, at many places in New Mexico and the southwest, igneous activity during the late pre-Cambrian has been reported. Diabase intrusives, commonly sills, are common in many of the slightly metamorphosed sedimentary rocks dated as late pre-Cambrian. Some examples are in the Franklin Mountains (Richardson, 1909, p. 3), in central Arizona (Wilson, 1939, p. 1130), in the Grand Canyon in northern

Arizona (Noble, 1914, p. 55), and in the Death Valley area in California (Noble, 1941).

Although direct evidence is lacking, the oldest strata and the associated intrusives of the Sacramento Mountains are considered as pre-Cambrian (?) on the basis of the presence of igneous activity, the absence of Paleozoic fossils, the slightly metamorphosed character of the strata, and their stratigraphic position.

Lloyd (1949, p. 14) reports the presence of pre-Cambrian igneous rock on Pajarita Peak, on the eastern slope of the Sacramento Mountain cuesta northeast of the map area in T. 12 S., R. 15 E. However, Lloyd adds a footnote that some geologists who have studied the locality believe the igneous rock may be intrusive into the overlying Abo formation. The writer has not examined this occurrence.

CAMBRIAN (?) SYSTEM

BLISS SANDSTONE

Quartz sandstone forms the base of the Paleozoic sedimentary section in southern New Mexico and west Texas. Richardson (1904, p. 27) applied the name Bliss sandstone to this clastic unit which is well exposed in the Franklin Mountains of west Texas. The name has been since adopted over much of west Texas and New Mexico. In the Sacramento Mountains a clastic unit, about 110 feet thick, is lithologically similar to the type section in the Franklin Mountains, and is considered to be the Bliss sandstone.

Areal distribution:

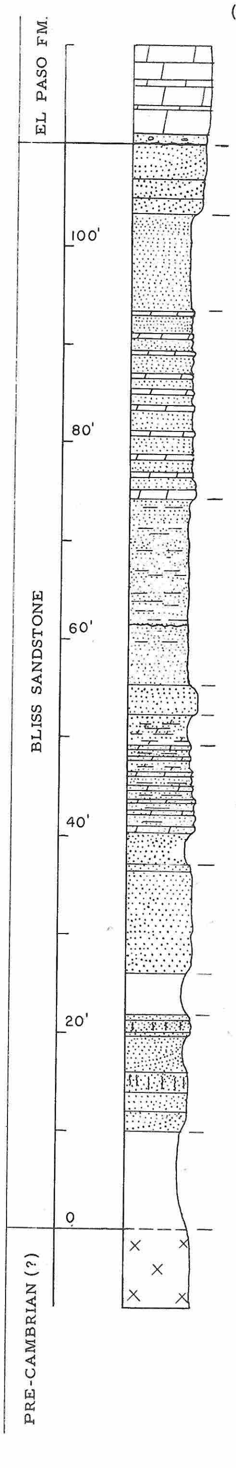
The major outcrops of the Bliss sandstone in the Sacramento Mountains are low in the southern part of the escarpment in small areas north and south of Nigger Ed Canyon. The unit overlies the pre-Cambrian (?) rocks and extends laterally somewhat beyond the exposed limits of the older rocks. The only other outcrop of Bliss sandstone is in a narrow faulted zone at the edge of the alluvium in the central part of the mountain front, in the NE 1/4 sec. 20, T. 17 S., R. 10 E. The scarcity of exposures of the Bliss sandstone, and of the underlying pre-Cambrian (?) as well, is remarkable considering the extensive outcrops of the overlying El Paso dolomite, a formation that is less than 400 feet in thickness, but is almost continuously exposed for a distance of about 15 miles along the base of the escarpment.

Lithology:

The Bliss sandstone of the Sacramento Mountain area consists mainly of quartz sandstone. Thin beds of clastic dolomite form about a quarter of the section, and siltstone and shale, though present, form only a minor proportion of the entire thickness. Details of the stratigraphic section are shown on fig. 10.

The detrital grains are largely of quartz, feldspar grains are uncommon. Glauconite forms a conspicuous part of many of the beds, and an abundance of this mineral is diagnostic of the Bliss in this area. Most of the glauconite is in the form of detrital pellets or

(See Figure 11 for details of overlying section)



		Dolomite, light to medium gray, finely crystalline; 6" to 2' beds; minor argillaceous dolomite and gray chert.
		Quartz sandstone, coarse grained, light brown; few quartz pebbles near base. Basal contact locally channeled a few inches.
12	7'	Quartz sandstone, light tan, medium to coarse grained; quartzitic, cross-laminated; abundant worm (?) borings; 2' of fine grained quartz sandstone 2' above base. Unit forms dark weathering low cliff.
11	10'	Quartz sandstone, light tan, fine grained.
10	19'	Quartz sandstone, tan, fine-grained; interbedded with minor sandy, medium crystalline dolomite; obscure small organic (?) nodules; beds average 1' thick; minor cross-lamination.
9	19'	Quartz sandstone, tan to greenish gray, fine grained; some interbedded siltstone. Minor fault 6' above base, few feet of section may be missing.
8	3'	Quartz sandstone, green, medium grained, massive, rich in glauconite.
7	3'	Quartz sandstone, fine grained, laminated, dolomitic. Weathered surfaces have distinctive "combed" texture
6	9'	Dolomite, tan, medium crystalline, sandy glauconitic; interbedded with minor glauconitic siltstone and shale. Dolomite beds 2 to 6" thick, form about half of unit, upper contact gradational.
5	3'	Quartz sandstone, green; richly glauconitic; poorly exposed.
4	11'	Quartz sandstone, deep purple to green, medium grained, glauconitic. This unit forms a distinctive marker of the lower Bliss.
3	4'	Covered.
2	12'	Quartz sandstone, light tan, medium grained; partly quartzitic; cross-laminated; worm (?) borings abundant in top and middle beds.
1	10'	Covered. S. 30° E. 4000' at or near this interval an angular unconformity (10° discordance) separates the overlying sandstone from underlying finer grained quartzites, silt stones, and intrusive sills of the Pre-Cambrian (?).
		Diorite porphyry sill

(See figure 8 for details of underlying section)

Bliss section measured in NW 1/4 sec. 1, T. 19 S., R. 10 E. Units nos. 1 - 6 measured directly above Pre-Cambrian (?) section at point 2000' south of NW corner sec. 1. Units nos. 6 - 12 measured in main channel of Agua Chiquita Canyon, beginning on west line of sec. 1, 1400' south of NW corner sec. 1.

STRATIGRAPHIC SECTION OF THE BLISS SANDSTONE

Figure 9

grains, but some finely crystalline green interstitial material also seems to be glauconite. Observed heavy minerals are the typical stable assemblage such as zircon, tourmaline, and garnet. Only the basal bed contains clastic grains larger than granule size, and pebbles were the largest particles noted in that bed.

Most of the sandstone is fine to coarse grained, clean, and rather well sorted. The grains are sub-round. Some of the strata are friable and porous, in marked distinction to the sandstones of the pre-Cambrian, but others are tightly cemented with silica. Worm (?) borings, generally nearly vertical in the beds, are common features. They are most prevalent at two distinctive horizons, one near the base and the other at the top of the formation. In general, these two marker units are cross-laminated, non-glauconitic, and tend to form low, resistant scarps.

Interbedded with glauconitic sandstones in the middle part of the Bliss section are glauconitic, dolomitic sandstones and sandy dolomites. Individual beds rarely are more than a foot in thickness. These laminae are generally parallel to the main bedding planes, but locally are slightly cross-laminated. A distinctive "combed" weathered surface consisting of alternate resistant and non-resistant laminae is caused by variations in composition from sandy dolomite to dolomitic sandstone. The dolomite is medium crystalline, yellow-brown in color. The association with abundant quartz particles, local gradation into sandy dolomites, and the cross-laminated structure indicate the clastic nature of the carbonate sediments.

Most of the major units of the measured section can be recognized over the entire northern area of outcrop, and can be correlated reasonably well with similar beds in the southern area of outcrop. The most easily traceable units are the massive, dark-red weathering, glauconitic sandstone and the wormy (?) sandstone near the base of the section; the laminated sandy dolomites in the middle of the section; and the upper wormy (?) cross-laminated sandstone. The dark red weathering unit is distinctly ferruginous. At many localities in the mountains farther west in New Mexico, some layers of the Bliss are highly ferruginous and are considered as low grade reserves of iron ore (Kelley, 1949).

The small exposure in a faulted slice at the base of the escarpment in the center of the NE 1/4 sec. 20, T. 17 S., R. 10 E. is considered to be Bliss because of the presence of glauconitic sandstone and some reddish quartzite. The area is too small to show at scale on the map, or to permit a comparison of beds with those exposed farther to the south.

<u>Conditions of deposition:</u>

The sum of the lithic characters of the Bliss sandstone seems to indicate that the environment of deposition corresponded to that of the stable shelf discussed by Dapples, Krumbein, and Sloss (1948, p. 1924 et seq.) In composition the strata are similar to the quartz-glauconite sandstones discussed by these authors, and their sedimentary structures seem compatible with the proposed environment.

Both the abundance of glauconite and the presence of brachiopod shells indicate deposition in a marine environment. The general similarity of the described sections of Bliss sandstone over much of southern New Mexico seems to imply uniform conditions of deposition over wide areas, which also is in keeping with the conditions postulated for the stable-shelf environment of deposition.

The relatively clean, well-sorted, cross-laminated sandstones, and the preponderance of coarse clastic detritus, suggest that many of the Bliss beds were deposited from rather turbulent waters that probably were shallow. The presence of much of the glauconite as detrital grains suggests that many of these sediments were reworked prior to their final deposition.

The strata richest in glauconite are generally those of relatively thin, even bedding, as contrasted to the conspicuously cross-laminated beds with abundant worm (?) borings and little glauconite. This deposition of the glauconite-rich beds under more quiescent conditions is most easily explained by deposition at greater depth.

Contact relationships:

The contact of the Bliss sandstone with the underlying pre-Cambrian (?) rocks is generally not well exposed. A fortunate exception is an excellent outcrop at the southern tip of the belt of Bliss and pre-Cambrian (?) rocks on the north side of Nigger Ed Canyon. More specifically, it is on the north line of sec. 12, T. 10 S., R. 10 E., about 2200 feet east of the west boundary of the section. Here an unconformity, with an angular discordance of about ten degrees, is continuously exposed for about 35 feet along the north bank of a washed channel that separates the alluvial fan from the bedrock to the

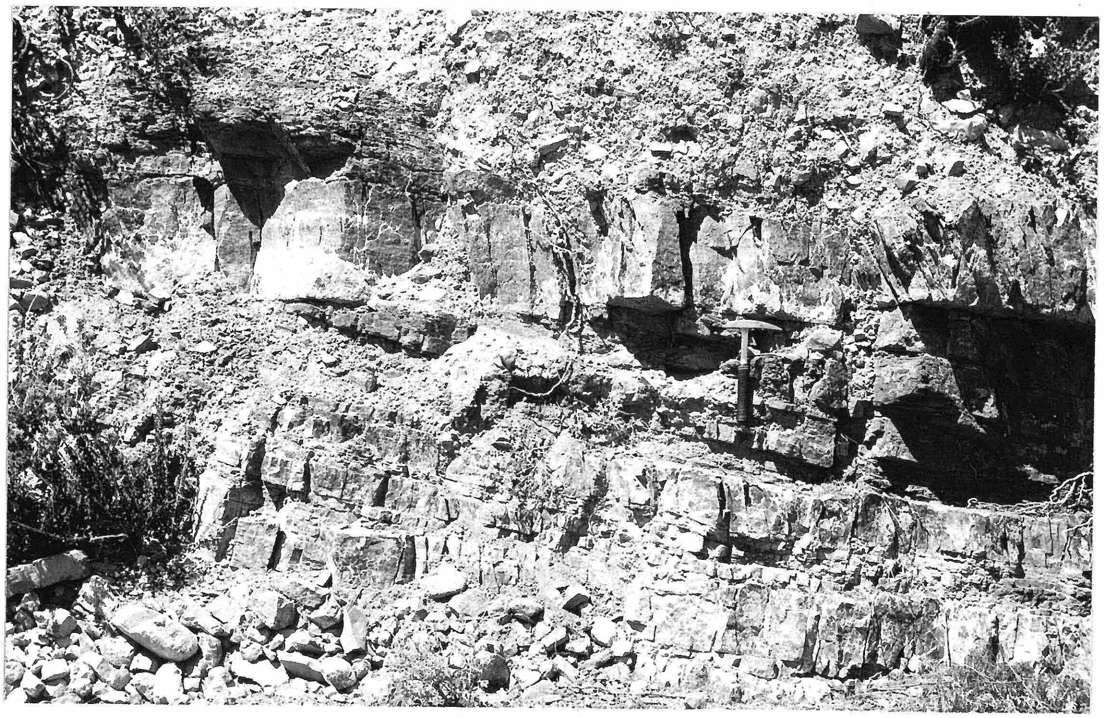


Figure 18. Angular unconformity between the Bliss sandstone and the underlying pre-Cambrian (?) strata at the south edge of the SE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 1, T. 19 S., R. 10 E.

north (fig. 10). About six feet of the underlying strata are truncated in the 35 foot distance. The overlying beds strike northwest and dip 8° northeast, and the underlying strata strike north and dip 18° east.

Although a local angular discordance of this magnitude in clastic strata is not necessarily a major unconformity, the available evidence strongly suggests that this structural break separates the overlying Bliss sandstone from the underlying pre-Cambrian (?) clastic rocks.

Directly overlying the break is a one to two foot bed of silicified pebble conglomerate and sandstone. The clastic grains are largely quartz; chert is a minor constituent. Many particles are granule size. Although the largest particle noted was only half an inch in diameter, this bed contains the coarsest interformational clastic particles observed in that part of the Sacramento Mountain section below the Pennsylvanian rocks, and is far coarser than any observed in the pre-Cambrian (?) sequence. It seems reasonable to interpret it as the basal deposit of transgressing Paleozoic seas.

Overlying the pebble bed are about three feet of greenish-yellow silty shale with minor thin layers of medium-grained sandstone, locally glauconitic (?). Unfortunately, exposures are not continuous from this bed to the overlying Bliss section. However, marker beds of the Bliss section, as traced from the north, indicate that the coarse basal bed and overlying few feet of less resistant beds is only a few feet stratigraphically below the lower wormy (?) sandstone layer at the base of the exposed measured section. At the measured section these basal beds, if present, must lie in the short covered interval between the diabase and the exposed Bliss sandstone. Scattered outcrops and float suggest that the coarse basal bed is continuous to the north.

The differences of the strata above and below this structural discordance are further evidence for interpreting the break as an unconformity. The strata below the unconformity at this exposure are thin beds of siltstone and fine-grained sandstone, similar to many in the pre-Cambrian (?) section exposed elsewhere in the area. These are intruded by diabase sills that range in thickness from less than a foot to at least 25 feet. All of the intrusives and the observed contact effects appear to be restricted to the beds below the break. The strata above the break are similar to other beds of the Bliss sandstone but differ from those strata below the break.

As judged from the surface of unconformity at the one good exposure, and from scattered observations to the north, the pre-Bliss surface appears to be one of very low relief. This is similar to that observed in many other parts of southern New Mexico and in the Franklin Mountains.

The upper contact of the Bliss cannot be fixed with the assurance possible at the basal contact. Somewhat arbitrarily several breaks in the lithologic sequence might be interpreted as a disconformity, although conclusive evidence that the Bliss sandstone is not gradational with the El Paso formation has not been observed. This contact is discussed in more detail in connection with the El Paso formation.

Fauna:

Fossils are scarce in the Bliss sandstone of the Sacramento Mountains, and those found to date are not very diagnostic. A few poorly preserved brachiopods were collected from beds of coarse quartz sandstone in the NE1/4 NE1/4 sec. 2, T. 19 S., R. 10 E., about 20 feet above a diabase sill and probably from the lower 10 feet of the Bliss. A. L. Bowsher has identified these as Lingulepsis sp. indet. and advised that age determination is not possible other than "probably Cambrian, possibly Ordovician". They are similar to the fossils from the type section of the Bliss at the Franklin Mountains.

The borings so abundant in some of the sandstone layers are not diagnostic as to age.

Age and Correlation:

The sandstone unit at the base of the Paleozoic rocks in the Sacramento Mountains is strikingly similar to the type section of the Bliss sandstone in the Franklin Mountains, 60 miles to the southwest. Although the Sacramento Mountain section is thinner, the lithologic similarity and the comparable stratigraphic positions of the two sections seem to justify use of the name Bliss sandstone in the Sacramento Mountain region. The Bliss of both areas overlies rocks of presumed pre-Cambrian age, and is separated from them by an angular unconformity of low relief. Both sections consist preponderately of quartz sandstones, some of them quartzitic. Glauconite is abundant, and is virtually restricted to this part of the Paleozoic section in both areas. Although a secure correlation on faunal evidence is not possible, there is a general similarity in the paucity of the fauna, and in the presence of the small brachiopod, Lingulepsis.

The age of the Bliss sandstone in the Sacramento Mountains, and over the entire outcrop area in southern New Mexico and west Texas has not been definitely established. It was considered to be Upper Cambrian by early workers in the region (Gordon and Graton, 1906, p. 392;

Lee, 1908, pp. 180-181; Richardson, 1910, p. 3; Darton, 1917, 1928). In 1940, P. B. King (p. 154) reported Ordovician gastropods, as well as a trilobite unknown in Cambrian rocks, from the Bliss (?) sandstone at Beach Mountain near Van Horn, Texas, and therefore considered both this unit and the type Bliss to be Ordovician in age. The most recent discussion of this evidence, and of new faunal evidence at the Beach Mountain section, is given by Cloud and Barnes (1948, pp. 68-70). They state that diagnostic Ordovician fossils are found only in the upper eight feet of the Bliss sandstone at Beach Mountain. The brachiopod, Lingulepsis, of the type Bliss section is also present in the Beach Mountain section, but the highest Lingulepsis is stratigraphically below the lowest diagnostic Ordovician fossil. Cloud and Barnes (1948, pp. 68-70) assign the entire Bliss (?) section to the Ordovician because of the absence of evidence for a stratigraphic break between the Lingulepsis-bearing strata and those with Ordovician fossils, and because of the abundance of gastropods (too poorly preserved to permit identification) in the beds below the diagnostic Ordovician fossils, but associated with and below Lingulepsis fossils. They conclude that the Bliss is Lower Ordovician in age, but state that this is by no means firmly established.

The assignment of Ordovician age to the Bliss sandstone is not universally accepted. Jones (1949, p. 2-3) discusses the Bliss sandstone as Cambrian, and points out the lithologic differences between the Beach Mountain section and the type section of the Franklin Mountains. However, he accepts as Ordovician at least the upper eight feet of the Beach Mountain section. Vanderpool (1950, pp. 61-63), on the basis of extensive study of insoluble residues, concludes that the El Paso formation of the

Franklin Mountains is equivalent at least in part to both the Ellenburger and Wilberns formations, as recognized in the subsurface section of west Texas. The Wilberns formation is considered to be Upper Cambrian by many geologists, including Cloud and Barnes (1948, p. 29). If the subsurface Wilberns is equivalent to the surface Wilberns formation, as many geologists believe, Vanderpool's correlations suggest the Upper Cambrian age for the Bliss formation.

The author is impressed by the lithologic similarity of the Bliss sandstone exposed in the Sacramento Mountains, the Hueco Mountains, and other mountains of southern New Mexico with the type Bliss sandstone in the Franklin Mountains. Glauconite is a prominent constituent in the formation at all of these localities. On the other hand, no glauconite is reported from the Bliss (?) sandstone of the Beach Mountain section. Furthermore, it is interesting and possibly significant that the Wilberns formation of Cambrian age of central Texas is highly glauconitic. The brachiopod Lingulepsis (cited as an Upper Cambrian index fossil by Cooper in Shimer and Shrock (1944, p. 285) has been found in many sections of the Bliss. Unfortunately, no recent work on the fossils of the New Mexico sections of the Bliss sandstone has been reported.

In summary it would seem that the burden of proof is on those who would date the Bliss in this wide area as Ordovician. The faunal evidence for Ordovician age is not conclusive for more than the upper eight feet of the one Beach Mountain section. This section is lithologically unlike all of the Bliss sections farther to the west, in the absence of glauconite. Until direct paleontologic evidence of Ordovician age can be presented for Bliss sandstone of the type section, or for lithologically similar sections in New Mexico, or until conclusive subsurface information to the same end is obtained, it seems best to consider the Bliss sandstone as Upper Cambrian (?).

Regional Relationships:

The lithology of the Bliss sandstone is similar over much of southern New Mexico and western Texas. Quartz sandstones, some of them quartzitic, are the dominant part of the section, glauconite is common, and siltstones, shales, and dolomite are minor but common constituents. Many of the strata are highly ferruginous (Kelley, 1950).

In the type area in the Franklin Mountains, Cloud and Barnes (1948, p. 369) indicate a thickness of about 250 feet of Bliss sandstone. The Bliss sandstone thins toward the north, as the formation is from 120 to 140 feet thick in the Organ Mountains (Dunham, 1935, p. 50), 30 to 40 feet in the central part of the San Andres Mountains, and about 6 feet thick in the northern part of the San Andres Mountains (Darton, 1918, p. 33). The formation is present in the southern part of the Oscura Mountains, but is missing in the northern Oscura Mountains (Darton, 1928, p. 194). King and Knight (1945) report 200 feet of Bliss sandstone from the Hueco Mountains, as compared to the 110 feet in the Sacramento Mountains, 50 miles farther north, and 125 feet at Beach Mountain, near Van Horn (Cloud and Barnes, 1948, p. 361-62). The formation is about 100 feet thick in the Caballo Mountains and is known in mountains west of the Rio Grande, as near Silver City, where 178 feet has been reported by Paige (1916).

ORDOVICIAN SYSTEM

EL PASO FORMATION

The El Paso formation in the Sacramento Mountains is a series of dolomites and minor dolomitic sandstones about 400 feet in aggregate thickness. It overlies the Bliss sandstone disconformably (?) and is separated from the overlying Montoya formation by a sharp disconformity. The formation is correlated with the El Paso limestone a formation named by Richardson (1909, p. 3) in the Franklin Mountains near El Paso, Texas. Cloud and Barnes, (1948, p. 61) proposed changing the name El Paso limestone to El Paso formation because of the abundance of dolomite and other rock types in many areas where this unit is exposed. The revised nomenclature is used in this report. The El Paso formation is lower Ordovician in age.

Areal distribution:

Outcrops of the El Paso formation are widespread in the Sacramento Mountain area. The complete section is exposed only in the area of Nigger Ed Canyon near the southern end of the escarpment. Northward from this vicinity to the mouth of Alamo Canyon, a distance of about 14 miles, the upper part of the El Paso crops out almost continuously along the base of the escarpment and in the mouths of the major canyons. The formation is partly exposed in several places east of the mountain front, where erosion has cut deeply into structurally high rocks. Six of these areas lie within a few miles of Alamo Peak, in the north-central part of the map area, and a seventh is in the middle reaches of Grapevine Canyon, near the southern border of the map area. Specific locations of individual areas are as follows:

1. Along the bottom of Arcente Canyon, in the NE1/4 NW1/4 sec. 20, T. 16 S., R. 11 E.; area extends along canyon for a distance of a few hundred feet.
2. Near the head of Marble Canyon, in the SW1/4 sec. 24, T. 16 S., R. 10 E.
3. On the steep southeast flank of Alamo Peak, along the east border of sec. 25 and 36, T. 16 S., R. 10 E.
4. Along the bottom of Caballero Canyon, in the NW1/4 NW1/4 sec. 1, T. 17 S., R. 10 E.; area extends only a few hundred feet.
5. Along the bottom and sides of Alamo Canyon, in Sec. 1 and 2, T. 17 S., R. 10 E.; the area extends for about half a mile.
6. In the bottom of Alamo Canyon, in the NE1/4 NW1/4 sec. 20, T. 16 S., R. 10 E.; the area extends for a quarter mile.
7. Along the east side of the Bug Souffle fault, in the NW1/4 sec. 27, T. 19 S., R. 11 E.; the area extends only a few hundred feet.

About half the El Paso section is exposed in the area on the southeast flank of Alamo Peak. At the other localities east of the mountain front, less than 100 feet of the formation is exposed.

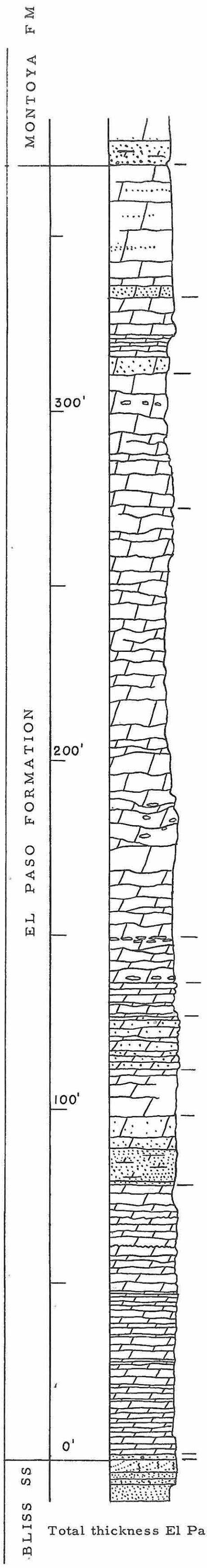
Lithology:

The El Paso formation in the Sacramento Mountains consists largely of thin-bedded, gray to brown dolomite and minor beds of dolomitic quartz sandstone and sandy dolomite. The El Paso forms a moderate slope broken only by a few low ledges at irregular intervals through the section. The prevailing light color of the weathered outcrops, the relatively thin beds, and the subdued weathered slope, are distinctive features of the El Paso formation. This unit is in marked contrast with the overlying lower part of the Montoya formation, which characteristically forms a dark, massive cliff a hundred or more feet high (Fig. 13).

The lithologic details of two measured sections of the El Paso formation are reproduced in Figures 11 and 12. Dolomite is the major rock type. The color ranges from light or medium gray to pale brown. Color is not completely diagnostic, but the general occurrence of subtle light yellow-brown colors is helpful in identifying the rock. Weathered surfaces are darker than the fresh dolomite, and range from grayish brown to moderate yellowish brown. Much of the dolomite weathers to rounded surfaces. In detail these rounded surfaces are formed by spalling of scaly flakes of dolomite. This type of weathered surface is more common in the El Paso rocks than in other dolomites in the area.

Individual beds are rarely more than 3 or 4 feet thick, and generally are 6 inches to 2 feet thick. Many of the bedding planes are regular, even, and clearly defined, but some are undulatory and obscure. The field appearance of weathered surfaces suggests that little argillaceous material is present in most of the dolomite. Most of the bedding appears to represent an interruption in sedimentation, rather than an alteration in the type of sediment being deposited. The texture ranges from very fine to medium crystalline.

Chert is not abundant, but occurs as scattered nodules and minor seams in many of the dolomitic layers. Locally it forms as much as a fifth of a 10-foot sequence of strata. Its surface has a chalcedonic luster, and ordinarily this color is light to medium gray. Discrete nodules and the seams of chert are rarely more than 2 to 3 inches thick.

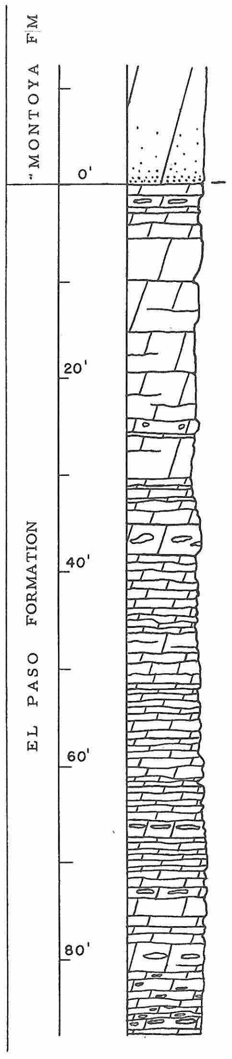


Unit	Thickness	Description
		Quartz sandstone, fine to coarse grained, subrounded, frosted; few granules of quartz. Base is channeled few inches. Top gradational into dolomite.
11	38'	Dolomite, light to medium gray, finely crystalline; fine to medium grained quartz sand forms a third of basal ledge, minor sandy streaks throughout unit.
10	21'	Dolomite, light to medium gray, finely crystalline; Quartz sand abundant at base, minor near top.
9	39'	Dolomite, medium gray, finely crystalline; minor chert.
8	123'	Dolomite, light gray to light tan, finely crystalline, irregular beds; few chert nodules. Many fractures and shears, some beds may be duplicated or eliminated by small scale faulting.
7	13'	Dolomite, light tan, finely crystalline, irregular bedding; argillaceous dolomite interbeds; gray chert nodules.
6	9'	Dolomite, medium light gray, finely crystalline, 1 - 2' beds, thin irregular interbedded dolomite
5	16'	Dolomite, medium dark to light gray, finely crystalline, sandy (quartz)
4	13'	Dolomite, poorly exposed
3	20'	Quartz sandstone, fine grained, white, dolomitic, massive; grades up into light olive gray sandy dolomite, few worm (?) borings.
		Fracturing and minor faulting
2	77'	Dolomite, light to medium gray, finely crystalline; 6" - 2' beds; minor argillaceous dolomite and gray chert. Top part cross-laminated. Endoceras? baylorense near top.
1	1'	Quartz sandstone, coarse grained, light brown; few quartz pebbles near base. Basal contact locally channeled few inches.
		Quartz sandstone, medium to coarse grained, quartzitic, cross-laminated; abundant worm (?) borings.
Total thickness El Paso	370'	

Section measured up Agua Chiquita Canyon, base of section at 4500', 200' E and 1400' S of NW corner sec. 1, T. 19 S., R. 10 E.

Figure 11. STRATIGRAPHIC SECTION OF THE EL PASO FORMATION

(See plate 5 for details of overlying section)



Dolomite, dark gray, fine to medium crystalline, massive; basal 10" about half subangular quartz grains up to 2mm., scattered sand grains up to 6' above basal contact.

Disconformity. Contact very smooth, and parallel to underlying beds. Less than 1" of channeling observed over 100' of contact. Few small clusters of limonite pseudomorphous after pyrite.

5	30'	Dolomite, light gray, finely crystalline, 1-5' beds, irregular near base; minor gray chert nodules.
4	5'	Dolomite, light gray, finely crystalline, 1"-2' obscure beds.
3	4'	Dolomite, medium gray, finely crystalline, massive; irregular gray chert nodules.
2	34'	Dolomite, medium gray, finely crystalline, obscure slightly nodular beds 1" - 1' thick, Very minor gray chert nodules.
1	15'	Dolomite, light gray, finely crystalline; irregular nodules of gray chert 6"-1' apart form 10-20% of unit.

Base not exposed

Section measured toward northeast from the bottom of Alamo Canyon, in the SW 1/4 SW 1/4 sec. 6, T. 17 S. R. 11 E.

STRATIGRAPHIC SECTION OF THE EL PASO FORMATION

Figure 12

Quartz sandstones and sandy dolomites are common, but form a minor part of the entire section. The distribution of sand shown in Figures 12 and 13 is believed to be representative throughout the area. Sandstone occurs as a thin basal bed and forms a thicker clastic zone about 250 to 300 feet below the top. Some sandstone and the more prevalent sandy dolomite occurs at irregular intervals in the upper two thirds of the section. The sandstones of this thick clastic zone weather to low, dark ledges. Sandstone of the El Paso formation is composed of quartz, generally with dolomite cement. Most of the detrital particles are fine grained, and the only coarse particles appear to lie in the basal one foot of sandstone, which contains scattered quartz pebbles as much as half an inch in diameter. The sandstones are clean, and relatively free of clastic particles finer than sand sizes. Many of the sandstones and sandy dolomites show small-scale cross-lamination, in which individual laminae are a foot or less in length.

The El Paso formation is 370 feet thick where the complete section is exposed at Agua Chiquita Canyon in the southern part of the escarpment. The base of the formation is not exposed north of this locality, although almost 400 feet of El Paso appears along the mountain front between the mouth of Alamo Canyon and a point a mile to the south. At the southern end of this area, in the SW1/4 SW1/4 sec. 4, T. 17 S., R. 10 E., a zone of quartz sandstone about 40 feet thick overlies finely crystalline dolomite, 85 feet of which is exposed above the alluvium of the Tularosa Basin.

Correlation of this section with the complete section farther south suggests that the base of the formation lies close to the surface in the northern area. Thus the total thickness of the El Paso formation in the Sacramento Mountain area is generally constant, and of the order of 400 feet. If the thickness is not so uniform, the formation must thicken northward, and the thickening caused by the additional beds in the basal part of the section. Such thickening is not compatible with regional relations as the formation thins toward the north.

Conditions of deposition:

The fauna of the El Paso formation consists of marine forms. The lithologic consistency of the formation in the Sacramento Mountain area, both laterally and from the base to the top, suggests deposition under the rather uniform conditions similar to those of the stable shelf environment. The roundness of the sand grains, the dominance of quartz, and the clean, well-sorted nature of the beds, are compatible with the stable shelf environment. The clastic units, sandstones and sandy dolomites, suggest periods of deposition under moderate current activity, probably reflecting a shallower environment of deposition than most of the beds in the formation.

The source of the quartz grains is unknown, but on the basis of the known distribution and composition of the El Paso formation, a land area toward the north is suggested (Lloyd, 1949, pp. 56-61). The El Paso formation is largely dolomitic in the mountains of south-central New Mexico. In the Franklin Mountains and adjacent areas of west Texas, limestone forms part of the section. Many geologists (for example, see Cloud & Barnes, 1948, p. 94) consider that a regional lateral transition which a formation from limestone to dolomite indicates a warmer sea temperatures in the area of the dolomite than in the area of mixed lithology or all limestone. The warmer temperatures are generally considered to be nearer shore. This reasoning points toward a land area in the north.

Contact relations:

The general lithology of the El Paso formation contrasts with that of the Bliss sandstone, but the selection of a specific contact between them is somewhat arbitrary as several interruptions in the sequence of strata may represent disconformities, and in the absence of diagnostic fossils from beds near these possible breaks, lithologic and structural features provide the only possible bases for differentiation. Moreover, the beds are essentially parallel on both sides of the contacts, and hence structural features are of little use.

The basal contact of the El Paso formation is placed at the bottom of a one-foot bed of coarse, locally pebbly quartz sandstone (Figure 12) that underlies the lowest thick unit of dolomite, and that overlies "wormy" quartz sandstone, glauconitic sandstone, and clastic dolomites considered to be parts of the Bliss sandstone. In support of the interpretation of this horizon as the boundary between the two formations are the following features:

1. The horizon effectively separates the major lithologic types. Above the contact are all the dolomites except the relatively thin, clastic dolomite beds that are intimately associated with glauconitic quartz sandstone. Only the sandstones below this contact contain glauconite or abundant "worm" borings, both features present in most sections of the Bliss sandstone.
2. The thin sandstone above the contact is distinctly coarser than the sandstones below the contact, except for the basal bed of the Bliss sandstone, which is interpreted as a basal deposit of a transgressive sea. The coarse thin bed considered

as the basal sandstone of the El Paso formation is subject to the same interpretation. It is true that many disconformities are not marked by overlying coarse clastics, and certainly most clastic beds are not subject to this interpretation. In the lower Paleozoic section of the Sacramento Mountains, however, many of the known disconformities are directly overlain by a basal clastic zone.

3. Alternative horizons at which to separate the Bliss and the El Paso appear less favorable. Possible separations might be just above the highest glauconite or below the lowest dolomite, as these are essential characteristics of the Bliss and El Paso formations respectively. However, both of these lithic features appear to be gradational. Moreover, these features overlap. Probably the best alternate choice would be at the top of the one foot layer of quartz sandstone herein considered the basal bed of the El Paso. Except that this contact is not as sharp as that at the base of the sandstone, there is little reason to prefer the basal contact.

Until conclusive faunal evidence is found, or very detailed field studies reveal a structural discordance, the horizon that separates the Bliss and the El Paso formations will remain somewhat arbitrary, and the more pertinent question of the existence of a disconformity between these two units will remain unanswered.

The upper boundary of the El Paso formation is one of the sharpest and best exposed disconformities in the lower Paleozoic section. The overlying Montoya dolomite contrasts sharply in lithology with the El Paso, and most places a basal deposit of coarse quartz sandstone and quartz granule conglomerate lies directly on a smooth, clean surface of El Paso dolomite. The beds above and below the contact are essentially parallel.

Fauna:

Fossils are widely scattered through the El Paso formation of the Sacramento Mountains, but in general are silicified and poorly preserved. The few fossils collected, however, confirm the correlation of the El Paso formation in the Sacramento Mountain area with the type section at El Paso, Texas. Most fossils have been noted in the upper part of the section, although careful collecting probably would yield a variety of fossils from points throughout the section.

The following identifications, kindly supplied by A. L. Bowsher, refer to fossils collected from the El Paso formation during the course of the present work:

Loc. 26: Near top of unit No. 2 of El Paso section on Figure 12.
NW1/4 NW1/2 sec. 1, T. 19 S. R. 10 E.

1-*Endoceras* ? *baylorense* Ulrich, Foerste, Miller and Unklesbay

Loc. 202b: Five feet below base of Montoya dolomite in SE1/4 SE1/4
sec. 23, T. 16 S., R. 10 E.

2-*Orospira* ? sp. and genus indet.

Loc. 223: Twenty feet below the Montoya dolomite in the NE1/4
SE1/4 NE1/4 sec. 33, T. 16 S., R. 10 E.

2-*Archaeoscyphia* sp.

Loc. 250: 55 feet below the Montoya dolomite in the NE1/4 NE1/4
SE1/4 sec. 4, T. 17 S., R. 10 E.

1-*Orospira* sp.
1-*Raphistoma* sp.
3-*McQueenoceras franklinense* Ulrich, Foerste, Miller and Unklesbay

Age and Correlation:

In the early report of Gordon and Graton (1906), Ordovician fossils were listed from beds now considered to lie within the El Paso formation. Richardson (1909) and Darton (1917, 1928) subsequently reported the El Paso formation to be Lower Ordovician in age. Kirk (1934) considered the El Paso section in the Franklin Mountains to be Lower and Middle Ordovician. Recent detailed investigations by Cloud and Barnes (1948, Pl. 15) results in correlation of the El Paso formation of West Texas with the units of the Ozark uplift that range from the Roubidoux formation through the Black Rock formation, all of Lower Ordovician (Canadian) age.

A. L. Bowsher*/ makes the following comment concerning the fauna from the El Paso formation of the Sacramento Mountains:

> "Specimens of *McQueenoceras franklinense* Ulrich, Foerste, Miller, and Unklesbay *Endoceras* ? *baylorense* Ulrich, Foerste, Miller, and Unklesbay are known only from the Jefferson City group of Missouri and sub-unit B_1 of the El Paso formation of Texas (Cloud and Barnes). *Orospira* is known only from the Jefferson City group of Missouri and correlative strata. *Archeoschyphia* sp. is known from the Jefferson City group in Missouri, and from sub-unit B_1 of the El Paso formation and from the Gorman formation of the Ellenburger group in Texas. All identifiable fossils from the El Paso formation of the Sacramento Mountains are known from sub-unit B_1 of the El Paso formation . . . (of west Texas) . . . which suggests that the dolomites of the Sacramento Mountains may represent only a part of the El Paso formation, i.e., the sub-unit B_1".

The fact that three or four collections were obtained from beds less than 60 feet beneath the base of the Montoya dolomite, seems to furnish additional evidence that the strata of the El Paso formation are correlative with only a part of the type section. The upper 735 feet of the Franklin Mountain section (Cloud and Barnes, 1948, p. 361), which

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*/ Personal communication, 1949.

are post-Honeycut (post-Jefferson City group) strata, appear to be missing from the Sacramento Mountains.

Regional Relationships:

According to published information, the El Paso formation of the Sacramento Mountains is similar in lithology to the El Paso beds that are exposed in most of the other mountain ranges of south-central New Mexico. Variation within the section appears to be more pronounced in a north-south direction than in an east-west direction. The El Paso formation in the southern Sacramento Mountains is more similar in general lithology and thickness to that in the southern San Andres Mountains than to that in the mountains of west Texas. The west Texas sections contain both dolomite and limestone, whereas the New Mexico sections are largely of dolomite. Cloud and Barnes (1948, pp. 66, 72) report a thickness of 1590 feet in the Franklin Mountains, and 1125 feet in Beach Mountain in the Sierra Diablo. This can be compared with less than 400 feet in the Sacramento Mountains. The sequence in the Hueco Mountains is similar to that in the Franklin and Beach Mountain sections, but published details are somewhat conflicting. Cloud and Barnes (1948, p. 72) note a 1300-foot section that contains all the faunal units of the Franklin Mountain section, whereas Vanderpool (1950) shows a section from the southern Hueco Mountains that is only about 900 feet thick, and, on the basis of correlations by insoluble resudies, indicates the absence of the younger beds of the Franklin Mountain sequence.

Lloyd (1949, p. 58) reports a maximum subsurface thickness of 845 feet of El Paso beds in Otero County, at the Turner Everett well in sec. 22, T. 24 S., R. 12 E. This figure appears to indicate a gradual northward decrease in thickness from the Texas-New Mexico border toward the Sacramento Mountains. Northward thinning of the El Paso formation is best displayed in the surface sections along the chain of the Franklin, Organ, San Andres, and Oscura Mountains. The thinning is progressive, and the vanishing point is reached in the Oscura Mountains. Details of this are given by Darton (1917, p. 45), and results of some later work by Nelson (1940, p. 161) and Dunham (1935, p. 42) corroborate Darton's earlier findings.

Paleontologic work in the area north of the Franklin Mountains has not been recorded since the early identifications by Darton, and hence the detailed northward progression of faunal units within the El Paso is not known.

MONTOYA FORMATION

Overlying the El Paso formation in the Sacramento Mountains is a series of dolomites that is 190 to 225 feet thick. These beds are correlated with the Montoya limestone, a formation named by Richardson (1909, p. 4) from the Franklin Mountains of west Texas. As the limestone lithology does not persist over much of the area in which the name Montoya is used, it seems advisable to refer to the unit as the Montoya formation. The basal contact is a sharp disconformity, as already noted, but the upper contact with the Valmont formation (new name) is not so clearly marked, and may not represent an erosional interval. The Montoya is Upper Ordovician (Cincinnattian) in age.

Areal distribution:

Outcrops of the Montoya formation follow much the same pattern as those of the El Paso formation (p. 47), but as the Montoya is higher in the stratigraphic section the lateral extent of the outcrops is greater. The major differences in surface distribution of this unit, as compared with the underlying El Paso, are as follows:

1. The Montoya formation extends about three miles farther north than the El Paso formation, and parts of it are exposed in the bottoms of canyons between Alamo Canyon and Indian Wells Canyon, northeast of Alamogordo.
2. The Montoya outcrops are continuous from the west front eastward for distances of three to four miles in Alamo Canyon and its major tributaries. In this eastern area, complete sections of the Montoya can be measured at localities where the El Paso formation crops out (see p. 47).

3. The upper part of the Montoya formation is exposed at the crest of the anticline in Pig Canyon, in the NW1/4 SW1/4 sec. 7, T. 16 S., R. 11 E.

Lithology:

The Montoya formation consists almost entirely of dolomite where exposed in the Sacramento Mountains. Its base, however, is marked by a thin but rather persistent basal unit of dolomitic quartz sandstone. The total thickness of the formation is 190 to 225 feet. The Montoya rocks can be separated into two members, each with distinctive lithologic characteristics. These were described in this area by Darton (1918, 1928). The lower member consists of dark, massive dolomite that contains little or no chert. It is commonly about 100 feet thick. This unit grades upward into about 100 feet of thinner bedded, lighter colored dolomites. These are characterized by an abundance of chert nodules. The lower member forms a conspicuous dark cliff between the underlying lighter colored, slope-forming dolomites of the El Paso formation and the overlying upper member of the Montoya formation (Figure 13). The thickness of the major units of the Montoya formation is relatively constant in the Sacramento Mountains, as is indicated by the data of Table I.

Table I. Variation in thickness of units of Montoya formation.

Locality	Sec. 34, T. 16 S., R. 10 E.	Sec. 7, T. 17 S., R.10 E.	Sec. 21 T. 17 S., R.10 E.	Sec. 9, T. 18 S., R.10 E.	Sec. 1 T. 19 S., R.10
Upper member	128	104	127	98	86
Lower member					
Dolomite	87	97	90	87	103
Sandstone	2	1	10	5	7
Total thickness in feet	217	202	227	190	196

Figure 13. Typical cliff profile and appearance of the Montoya formation, and of the underlying upper El Paso formation. The base of the Montoya formation is at the level of the distant sky line. The lower member of the Montoya formation forms the dark, massive cliff, and the upper member the overlying lighter slope. (NE$\frac{1}{4}$ sec. 20, T. 17 S., R. 10 E.)

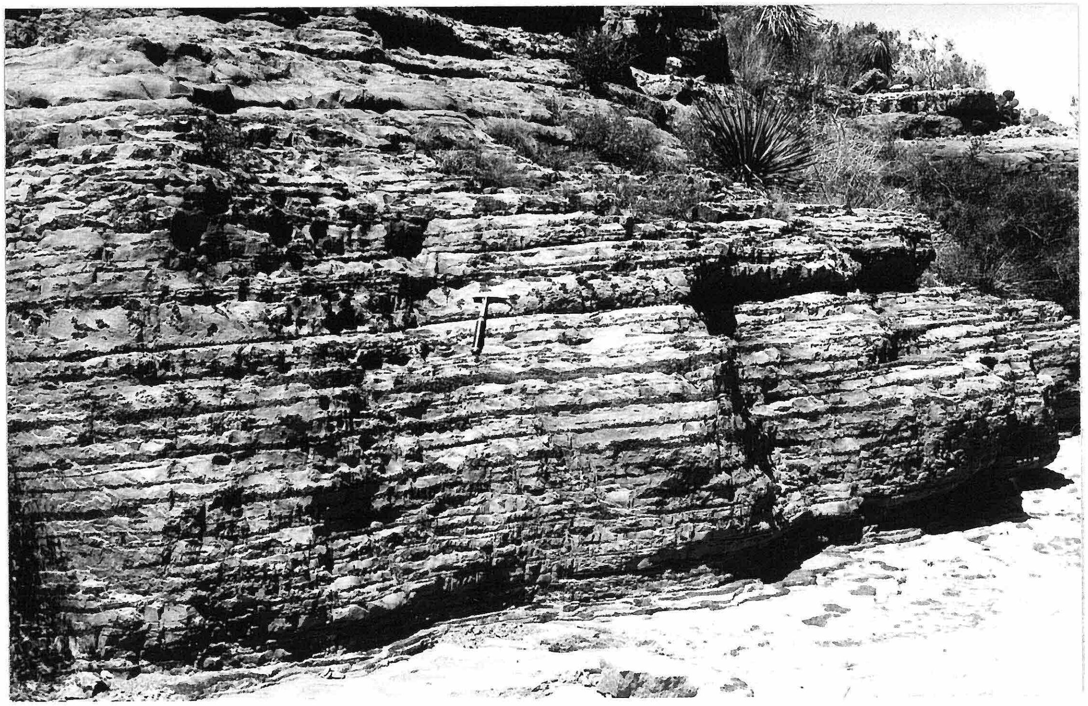
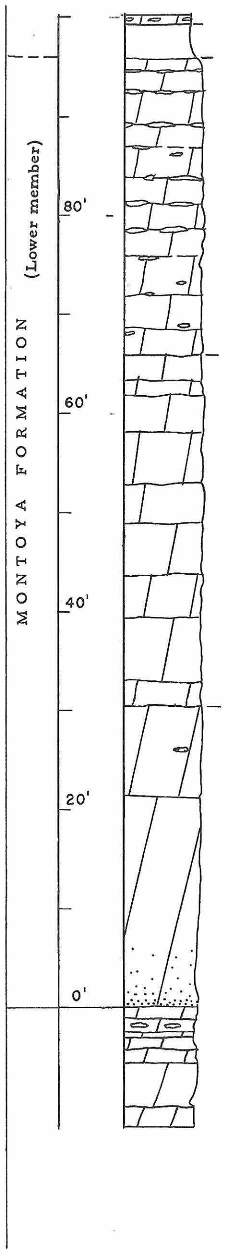


Figure 14. Exposure of cherty dolomite of the upper member of the Montoya formation. (SE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 9, T. 17 S., R. 10 E.)

The two measured sections of the Montoya formation reproduced on Plate 5 show some of the details of typical Montoya sequences. Well-exposed sections of the formation could be measured almost anywhere along the western escarpment, but the lithology varies so little within the Sacramento Mountain area that additional sections do not seem necessary for adequate stratigraphic description and analysis.

Lower Member: A thin layer of coarse quartz sandstone forms the base of the lower member at almost all localities. In exposures near the head of Marble Canyon, in the SE1/4 SE1/4 sec. 23, T. 16 S., R. 10 E., as well as south of Alamo Peak, this basal sandstone is only a few inches to a foot thick, but elsewhere it is commonly three to six feet thick. The maximum thickness observed was in the NE1/4 NE1/4 sec. 8, T. 17 S., R. 10 E. where the sandstone is 12 feet thick. The base of this sandstone is sharply defined, but at most places its upper contact is gradational through sandy dolomite into pure dolomite.

Most of the clastic particles in the basal sandstone are in the medium sand to granule size range. Almost all of the detrital particles are composed of quartz. Although most of the coarser fragments are distinctly subangular, many of the smaller grains are sub-rounded to well rounded. As the reverse would be expected if the quartz particles were derived from a primary source, it seems probable that the smaller rounded particles were derived from pre-existing sediments, and possibly the coarser, angular fragments from a primary source of detrital quartz. The dolomite that forms the bulk of the lower member is remarkably constant in lithology throughout the area. It ranges in color from dark and medium gray to olive gray, a distinctive color in the lower Paleozoic

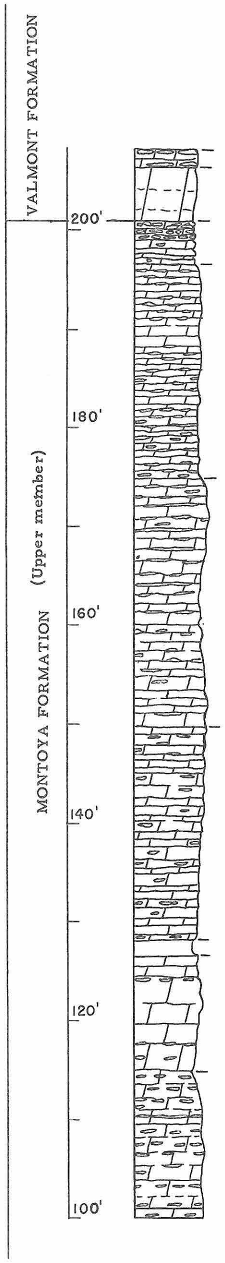


4	3'	Covered.
3	30'	Dolomite, dark gray, fine to medium crystalline, massive to thick bedded. Dark gray chert nodules and layers more abundant toward the top (5-to 10%). Forms the top unit of resistant dark lower Montoya cliff.
2	45	Dolomite, dark gray, fine to medium crystalline; some dark gray chert nodules 1 to 2" thick; corals.
1	21'	Dolomite, dark gray, fine to medium crystalline, massive, chert free; basal 10" dolomitic quartz sandstone, subangular grains up to 2 mm; grades upward into quartz free dolomite 6' above basal contact.

El Paso-Montoya formation contact: Clean, knife-edged contact, parallel to the underlying El Paso beds, less than 1" of channeling noted over 100' of exposed contact; scattered pseudomorphs of limonite after pyrite up to 1/2" size.

Dolomite, light gray, finely crtstalline, 1 to 5' beds; minor chert.

(See Fig. 12 for details of underlying El Paso formation.)



(See Fig. 6 for continuation of this section)

	2'	Dolomite, medium light gray, sublithographic, thin bedded; irregular chert layer at base, top 1' irregular nodules form discontinuous band of light gray chert. Top contact of chert with overlying dolomite is smooth, mammillary surface.
	6'	Dolomite, medium light gray, very finely crystalline, massive.
10	5'	Dolomite, mottled medium gray and white, finely crystalline. White bands resemble chert nodules and layers but are finely crystalline dolomite, locally with centers of white chert. Chert nodules form 30% of top 3', no evidence of erosional break at top.
9	22'	Dolomite, medium gray to medium light gray, finely crystalline, obscure thin (6") beds; 10-15% white weathering chert in smooth nodules 1-2" thick, and in unnumerable thin shreds and irregular bodies 1 to 2 mm. and larger.
8	46'	Dolomite, light gray, finely crystalline, beds average 6" thick, grades upward into medium light gray dolomite in obscure beds 1-2' thick which forms resistant dark gray weathering cliff; minor chert, top 15' contains about 10% light gray crinkly and nodular chert.
7	2'	Covered.
6	12'	Dolomite, medium gray, finely crystalline; minor chert; weathers to medium gray resistant ledge.
5	16'	Dolomite, medium light gray, finely crystalline, weathers light gray; smooth surfaced light gray chert nodules, 1 to 3" thick form 10-20% of unit; unit forms slope.

Section continued from the top of the column to the left.

Section measured toward northeast from the bottom of Alamo Canyon, in the SW 1/4 sec. 6, T. 17 S. R. 11 E.

STRATIGRAPHIC SECTION OF THE MONTOYA FORMATION section of the Sacramento Mountains. It is somewhat coarser in texture than most of the dolomites in the area. Most of the constituent crystals are about 0.2 mm. in diameter, but a few as large as a millimeter tend to give the rock a more coarsely crystalline appearance. Weathered surfaces of the lower member are characteristically dark in color, about a brownish black, and are irregularly pitted and granular in detail. The pitted nature of the weathered surfaces is shown in the foreground on the right of Figure 13.

The most distinctive feature of the lower member is the massive bedding of the dolomite. Sharply defined bedding planes within the unit are widely spaced, especially in the lower part of the member. Some obscure bedding planes several feet apart can be detected locally within the essentially massive beds. The characteristic vertical cliff of the lower member probably is a result of the massive bedding.

Chert, which is almost absent from the lower half of the lower member, increases in amount within the upper part of the member, and is very abundant in the upper member of the Montoya. The chert is commonly grayish in color, forms nodules a few inches thick, and occurs along and hence partially defines obscure bedding planes in the dolomite.

The lower member is one of the most fossiliferous units in the entire section of lower Paleozoic dolomites. Most of the fossils have been found within 20 to 30 feet of the base.

Upper member: The upper member of the Montoya formation is a lithologically distinctive unit throughout the Sacramento Mountain area, and consists largely of cherty dolomite. Most of the dolomite is lighter in color than that of the underlying member, and ranges from light gray to medium dark gray. Most is a slightly olive gray, rather than a neutral gray. The texture ranges from fine to medium crystalline, but the average grain size is smaller than that of the underlying lower member. The color and texture seem related, as the more coarsely crystalline beds are darker.

The dolomite is thin to medium bedded, and in many places bedding planes are obscure and best defined by an alignment of chert masses. The abundance of chert nodules and layers is a diagnostic feature of the member, and the chert locally forms 10 to 20 percent of the beds in which it occurs. The top few feet of the upper member of the Montoya in much of the area is very rich in chert. In parts of Alamo Canyon, along the west front of the mountains in T. 17 S., and in several other scattered localities, one to three feet of solid chert marks the top of the Montoya formation as recognized in this report. The characteristic appearance of one of the cherty zones in the upper member of the Montoya formation is shown in Figure 14. The chert is gray to black in color. The irregular nodules and layers rarely exceed two to three inches in thickness. The distribution of the chert through the member is not uniform, but is concentrated largely into chert-rich zones that alternate with chert-free dolomite, or dolomite in which only sporadic nodules occur.

Conditions of deposition:

The fauna and lithology of the Montoya formation indicate deposition in a marine environment. The strikingly persistent lithology of this formation over much of southern New Mexico suggests deposition under the widespread and uniform conditions of a stable shelf. The virtual absence of siliceous clastic sediments either in individual layers or as constituents of the dolomite is notable. Either siliceous clastic sediments were not introduded into the shelf areas, or such sediments were cut off from the area of Montoya deposition by an intervening channel, or some other current action process that effectively barred the transport of clastic debris from the site of deposition of the Montoya.

Contact relationships:

The contact of the Montoya formation with the underlying El Paso formation is the best exposed and sharpest disconformity in the lower Paleozoic sequence. The surface of disconformity is remarkably even and smooth. At an exposure in Alamo Canyon, in the SW1/4 sec. 6 T. 17 S., R. 10 E. the relief of the surface is less than an inch over a distance of 100 feet. In many places the dolomitic quartz sandstone rests directly on the clean, smooth surface of the El Paso formation. At other places, a few inches at the contact is poorly exposed, which suggests that a thin layer of clayey material locally separates the major units. Fossils within a few feet of the contact confirm the interpretation of this sharp lithologic break as a disconformity.

The upper and lower members are not sharply separated, and at many places the change in lithology is transitional over thicknesses of 20 or 30 feet. The lowest finely crystalline dolomite of color distinctly lighter than that of the average dolomite of the lower member is considered as the contact of these two members, as it gives a more consistent thickness of the Montoya units obtained than if the contact were picked on the basis of the chert. Because of the transitional contact and the problems of scale, the two members are not differentiated on the geologic map, although the members were of considerable use in making structural interpretations.

The Montoya formation is overlain by the Valmont formation everywhere in the Sacramento area. The contact does not appear to represent a widespread erosional break, but does mark a rather persistent change in lithologic character. The change is from cherty, fine to medium crystalline dolomite to very finely crystalline to sublithographic dolomite that contains little chert. Too, the chert of the Valmont formation is generally in smooth, rounded, pillow-shaped nodules, six inches or more in thickness and several feet in length, whereas the nodules of chert in the upper Montoya are smaller and more irregular in form.

Fauna:

With systematic collecting, a large fauna could be obtained from the Montoya formation. Only enough forms were collected in this investigation, however, to permit a certain identification of the unit as Montoya.

The lower member contains many fossils. Corals and sponges are abundant in the lower 20-30 feet. The following fossils, collected from the lower member of the Montoya formation during this investigation, have been kindly identified by A. L. Bowsher.

Loc. 228: NW1/4 NW1/4 SW1/4 sec. 34, T. 16 S., R. 10 E. This locality is easily accessible, and a relatively large fauna could be obtained. Fossils are from west edge of outcrop of lower member of the Montoya formation, about 100 feet west of National Forest fence and 20 feet north of the first small gully north of the canyon mouth.

3 Palaeophyllum thomi (Hall)
2 Calapoecia cf. C. cribiforme (Nicholson)
2 Streplelasma sp. indet.
4 Pachyodicta ? sp. indet.

Loc. 249: Center of sec. 4, T. 17 S., R. 10 E., float of lower member.

2 Palaeophyllum thomi (Hall)

Loc. 273: SW1/4 NE1/4 sec. 20, T. 17 S., R. 10 E. From 8-20 feet above the base of the Montoya

4 Halysites gracilis (Hall)

Loc. 318: NW1/4 SW1/4 sec. 15, T. 18 S., R. 10 E. From 30 feet above the base of the Montoya.

1 Nyctopora goldfussi (Billings)
2 Zaphrentis sp.
2 Halysites gracilis (Hall)

Fossils are common at some horizons in the upper member of the Montoya formation, although in general the shells are silicified and fragmental. The following forms have been identified by A. L. Bowsher:

Loc. 281c: NE1/4 SE1/4 sec. 20, T. 17 S., R. 10 E. 70 feet below the top of the upper member.

1 *Bythopora?* sp. indet.
Numerous bifoliate bryozoans, poorly preserved.

Loc. 295: SW1/4 NW1/4 sec. 28, T. 18 S., R. 10 E. 5 feet below the top of the upper member.

1 *Rynchotrema perlamellosa* Whitfield
2 *Rynchotrema* aff. *R. increbescens* (Hall)
2 *Streptelasma* sp. indet.

Age and Correlation:

The Montoya limestone, described by Richardson (1909, p. 4) from the Franklin Mountains, was considered to contain a Richmond fauna. Darton (1928, p. 200) reported the same for the Montoya formation of the Sacramento Mountains. A. L. Bowsher's report on the age of the fossils identified from the Montoya formation in the Sacramento Mountains is as follows:

> "Fossils identified from the lower member of the Montoya could be Black River, Trenton, or Richmond in age. As *Paleophyllum thomi* occurs elsewhere only in Richmond strata, the lower member . . . is most likely Richmond in age. Fossils from the upper member . . . appear to be Richmond in age. They are at least Upper Ordovician. The presence of *Rhynccotrema perlamellosa* and *Resserella* aff. *R. tersa* indicates Richmond age for the strata."

Regional relationships:

Very little information concerning the Montoya formation stratigraphy of the mountains in southern New Mexico has been added to the literature since the early work of Darton (1917, 1928), and most of his findings have been since verified where checked. The two members of the formation can be recognized in nearly all the surface outcrops. The thickness of the formation decreases toward the north. In the Franklin

Mountains, values of 200 to 400 feet are indicated by Nelson (1940, p. 160) The two-fold character of the Montoya persists throughout the Organ-San Andres mountain chain, but the total thickness decreases from about 300 feet at the southern end to 70 feet at the Northern end, and the formation is missing from the north end of the Oscura Mountains, where Pennsylvanian strata overlie pre-Cambrian granite (Darton, 1928, pp. 185, 194).

King (1945) reports a 320 foot section of Montoya in the Hueco Mountains; this thickness is a third more than is present in the Sacramento Mountains to the north. The uniform thickness and lithology in the area of present study suggest that the northern limit of deposition of the formation was well beyond the present limit of outcrops.

Information recently published by Lloyd (1949, p. 54) and Jones (1949, p. 7), indicates that the Montoya formation has about the same lithologic characteristics and thickness in the subsurface of southeastern New Mexico as in the surface sections farther west. They report a general decrease in thickness and a change from limestone to dolomite toward the north.

ORDOVICIAN (?) SYSTEM

VALMONT FORMATION

The standard stratigraphic section of the lower Paleozoic in much of west Texas and southern New Mexico is based on the terminology established by Richardson (1904, 1909) for the strata of the Franklin Mountains. From the base upward, this section consists of the Bliss sandstone, the El Paso limestone, the Montoya limestone and the Fusselman limestone. Darton (1917) used this terminology for the rock units that he found during regional reconnaissance studies in southern New Mexico. Overlying the Montoya in the Sacramento Mountains and some of the other mountains are a series of lithologically distinctive strata considered by Darton to be a lower member of the Fusselman formation. Darton (1917, p. 43) discussed these strata as follows:

> "Compact fine-grained white weathering limestone[a] which yielded no fossils but is arbitrarily included in the ... Fusselman formation ... because of its unlikeness to the underlying distinctively cherty beds at the top of the Montoya limestone."

On the basis of the information resulting from the present investigation, it appears desirable to establish this distinctive series of strata as an independent formation. In this report the name Valmont formation is given to the strata consisting predominantly of light gray weathering, thin to medium bedded, sublithographic dolomite that lie between the underlying cherty member of the Montoya formation and the generally darker, more coarsely crystalline, and more massive, overlying dolomite considered to be the Fusselman (?) formation. Thus the Valmont formation is equivalent to the lower member of the Fusselman formation as described by Darton. The name is derived from the station of Valmont, which is on

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[a] The term limestone is used throughout Darton's reports for rocks either calictic or dolomitic in composition.

the Southern Pacific railroad in Sec. 14, T. 18 S., R. 9 E., 10 miles south of Alamogordo. The type section is located on the northeast side of Alamo Canyon, in the SE1/4 SW1/4 sec. 6, T. 17 S., R. 11 E.

It seems desirable to rename the lower Fusselman member as an independent rock unit of formational rank for the following reasons:

1. The strata form a distinctive, mappable unit, which is lithologically unlike other recognized formations and members of the Paleozoic section exposed in southern New Mexico.
2. These strata are laterally persistent over a wide enough area to justify formational rank. This area includes not only the Sacramento Mountains, but most of the Organ-San Andres Mountain range, and some of the mountains with exposed Paleozoic strata in the area west of the Rio Grande. [See Darton (1917, 1928); Dunham (1935)].
3. In the Sacramento Mountains, the sharpest and most persistent lithologic break in the strata between the base of the Montoya and the base of the Onate (Devonian) formation is at the top of the strata for which the name Valmont formation is proposed. This break is considered to be a disconformity, and is the only one recognized within the Montoya-Fusselman sequence. It therefore seems reasonable to emphasize this discontinuity by applying different names to the rock units above and below the break, rather than to mask it by using the same formational name, Fusselman, for strata separated by this break.
4. In the Sacramento Mountain area, diagnostic Ordovician fossils have been obtained from the lower part of the strata "lower Fusselman". The Fusselman formation of the Franklin Mountains has

been considered of Silurian age (Richardson, 1909).

5. The best alternative to naming a new formation is to consider these strata a part of the Montoya formation. The apparent absence of a disconformity between the Montoya and these strata supports this alternative suggestion. However, the Montoya formation of the type area is similar lithologically to the strata below the "Valmont" over much of southern New Mexico in the surface sections and the subsurface (Jones, 1949, p. 7; Lloyd, 1949, p. 54), but is not similar to the strata in question. To expand the application of the term Montoya formation to include a lithologic unit not recognized in the type area seems inadvisable, and is more likely to lead to additional stratigraphic confusion than is the introduction of a new formation name for this widespread and distinctive lithologic unit.

Areal distribution:

The Valmont formation is exposed almost continuously along the west front of the Sacramento Mountains Marble Canyon east of Alamogordo to a point a mile south of Nigger Ed Canyon. In the area between Marble Canyon and Indian Wells Canyon to the north, the Valmont formation is locally exposed along canyon walls where erosion has cut down below the dip slopes of the resistant Fusselman (?) formation. The Valmont formation crops out on both sides of Alamo Canyon and its major tributaries from the front of the range eastward to the area of Alamo Peak. South of Alamo and Mule Canyons, the formation is exposed only in the canyons within half a mile of the west front. Small and isolated outcrops are on the structurally high areas in Pig Canyon and Arcente Canyon in T. 16 N., R. 11 E., and along the Bug Scuffle fault in Grapevine Canyon in T. 19 S., R. 11 E.

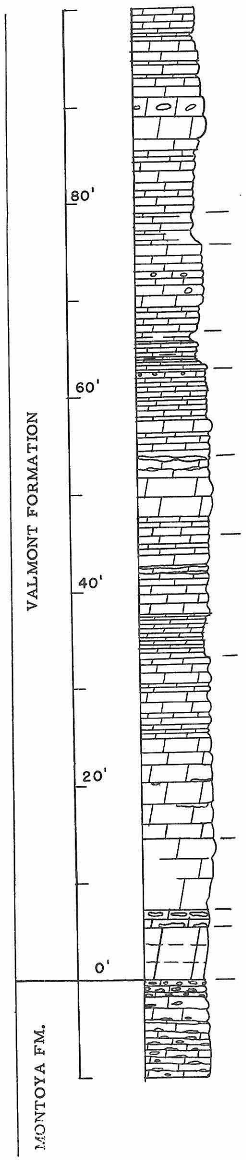
Lithology:

The Valmont formation consists largely of medium to very light gray, thin to medium-bedded sublithographic dolomites. The rock weathers white. Chert is not abundant in the formation, and where developed is commonly in large, smooth nodules or layers. In the upper part of the section, partially silicified nodules and layers weather to a distinctive light brown color. The measured thicknesses range from 148 to 215 feet. From 40 to 70 feet above the base of the formation, a zone of non-resistant argillaceous dolomite, several feet in thickness, forms a distinctive marker horizon, and serves to separate the formation into an upper and lower member.

The formation weathers to a distinctive white slope in marked contrast to the generally dark cliff of the overlying Fusselman formation. A distinctive feature of the Valmont dolomite is the fracture surfaces of the Valmont dolomite. They are commonly distinctly conchoidal as shown in Figure 15.

The Valmont formation is remarkably similar in lithologic characteristics throughout the area of exposures in the Sacramento Mountains. Details of the type section of the Valmont formation, measured in the SE1/4, SW1/4, sec. 6, T. 17 S., R. 11 E., are shown in Plate 6. Table II indicates some of the variations in thickness of the Valmont formation within the area of the Sacramento escarpment.

Figure 15. Strata of the Valmont formation exposed in Alamo Canyon. The sharply defined bedding and the conchoidal fracture surfaces are characteristic of the Valmont formation.

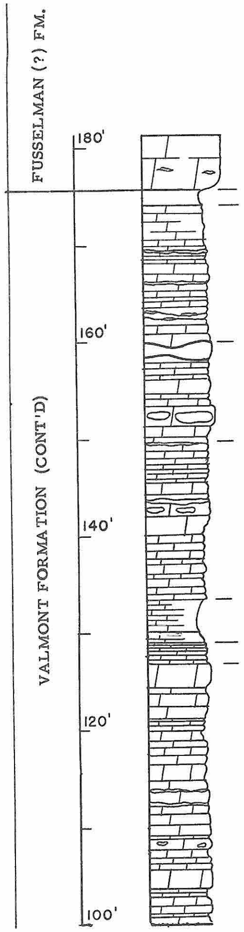


10	3'	Poorly exposed; probably argillaceous, thin bedded dolomite.
9	8'	Dolomite, medium gray, sublithographic; basal 3' argillaceous; beds 3" to 1' thick; minor dark gray, round chert nodules 1 to 4" across.
8	4'	Dolomite, medium gray, argillaceous, 1 to 4" laminated beds; appears gradational with underlying strata. This unit forms persistent non-resistant white weathering zone in Valmont formation.
7	10'	Dolomite, medium gray to medium light gray, sublithographic beds 2" to 1'; upper part argillaceous; minor gray-brown chert nodules 1" in upper 3'.
6	8'	Dolomite, light olive gray, sublithographic; even beds 6" to 2' thick; conspicuous conchoidal fracture. Brown weathering 2 to 4" thick at top contains local small chert nodules.
5	12'	Dolomite, light olive gray, sublithographic; obscure bedding planes 1 to 6" apart; uppper beds more massive.
4	18'	Dolomite, very light gray, sublithographic; obscure beds 2" to 1' thick; some medium gray, smooth chert nodules along bedding, 2" thick, 2 to 3' long.
3	7'	Dolomite, very light gray, sublithographic.
2	2'	Dolomite, Medium light gray, sublithographic, thin bedded; irregular chert layer at base, top 1' irregular nodules form discontinuous band of light gray chert. Top contact of chert with overlying dolomite is smooth, mammilary surface.
1	6'	Dolomite, medium light gray, very finely crystalline, massive.
		Dolomite, mottled medium gray and white, finely crystalline White bands resemble chert nodules and layers but are finely crystalline dolomite, locally with centers of white chert. Chert nodules form 30% of top 3'. No evidence of erosional break at top.

(See Plate 5 for details of underlying Montoya formation.)

Section measured in gully that trends N. 55° E. from base of Alamo Canyon, 1000' east and 500' north of the SW corner sec. 6, T. 17 S., R. 11 E. Top of section is S 72° E. of conspicuous 6100' peak in west part of sec. 1, T. 17 S., R. 10 E.

(See Plate 7 for details of overlying Fusselman (?) formation)



		Dolomite, light brown gray to brown gray, finely crystalline, massive; weathers dark brown gray; very irregular gray chert masses.
17	2'	Covered.
16	14'	Dolomite, very light gray, sublithographic; most beds less than 1' thick. Minor nodules and seams of gray chert.
15	10'	Dolomite, very light gray, sublithographic; even beds; conspicuous brown weathering nodules and layers up to 1' thick of siliceous dolomite containing some small masses of pure chert. Most nodules are within dolomite beds.
14	16'	Dolomite, very light gray, sublithographic; even beds 6" to 1' thick, some slightly nodular bedding; 9' above base brown weathering nodules of siliceous dolomite; 1 to 2" seam gray chert at top.
13	4'	Covered, probably similar to underlying unit.
12	2'	Dolomite, medium light gray, sublithographic; beds less than 2" thick.
11	48'	Dolomite, medium to light gray, sublithographic; even to slightly undulating bedding planes 6" to 2' apart; minor partings of argillaceous dolomite near base. Minor chert nodules 11' and 31' above the base.

Section continued from the top of the column to the left.

STRATIGRAPHIC SECTION (TYPE SECTION) OF THE VALMONT FORMATION

Table II.

Thickness of Valmont Formation*

Location	Thickness in feet		Total thickness in feet
	Upper member	Lower member	
Sec. 7 T. 16 S. R. 11 E.	83	65	148
Sec. 6 T. 17 S. R. 11 E.	113	64	177
Sec. 1 T. 17 S. R. 10 E.	117-	55 +	172
Sec. 7 T. 17 S. R. 10 E.	123	52	175
Sec. 3 T. 17 S. R. 10 E.	89	69	158
Sec. 21 T. 17 S. R. 10 E.	111 ± 10	40 ± 10	151
Sec. 9 T. 18 S. R. 10 E.	107	40	147
Sec. 26 T. 18 S. R. 10 E.	160	55	215
Sec. 1 T. 18 S. R. 10 E.	114	48	162

*Overlying formation is the Fusselman (?), except at location in Sec. 7, T. 16 S., R. 11 E., which is overlain by the Onate formation. Underlying formation is the Montoya formation.

Lower member: The lower member of the Valmont formation consists of 40 to 70 feet of dolomite and minor chert. The strata are transitional in lithology between that of the cherty upper member of the Montoya formation, and the overlying upper member of the Valmont formation. Most of the dolomite is sublithographic in texture and light to very light gray in color and is similar to the dolomite of the upper member. However, beds of medium gray, finely crystalline dolomite near the base of the lower member, closely resemble some of the upper Montoya dolomite. Most of the beds are sharply defined, and spaced a few inches to 1 to 2 feet apart. Near the base a series of obscurely defined beds of dolomite forms a relatively resistant ledge 10 to 20 feet in thickness. Small (1-2") vugs lined with dolomite crystals are common in this lower ledge, which is a useful stratigraphic marker in many places. Conchoidal fractures, characteristic of most of the Valmont formation, are particularly conspicuous in the lower member, as illustrated by Figure 15.

Chert forms a minor part of the lower member. Most of the chert is light gray in color, and forms large, smooth nodules, as much as 6 inches thick and 4 feet across, that resemble pillows in shape. They are distinctly different from the smaller, highly irregular chert nodules so abundant of the upper member of the Montoya formation. Some small irregular nodules of chert (commonly ½ to 1" across) occur along some bedding planes in the lower member of the Valmont formation.

Lateral variation and lenticularity of the dolomites in the lower member of the Valmont formation is more common in the Alamo and Marble Canyon areas than elsewhere in the mountains. For example, in the NW1/4 NW1/4 sec. 1, T. 17 S., R. 10 E., a zone of dolomite, about 10 feet above the top cherty zone of the upper Montoya, is 12 feet thick but thins to 5 feet in less than 300 feet. This particular zone contains several lenticular beds with abundant silicified gastropods (loc. 239a). Similar fossils, also in lenticular streaks, were observed at about the same horizon in the Alamo and Marble Canyon areas.

The upper contact of the lower member of the Valmont formation is arbitrarily placed at the base of the persistent zone of argillaceous dolomite. The contact is believed to be gradational.

Upper member: It cannot be established with certainty that Darton included the strata of the lower member of the Valmont formation, as defined in this report, in the lower Fusselman formation. There can be little doubt that all of the upper member of the Valmont formation was included by him in the lower member of the Fusselman formation as the lithology corresponds to his description and is very uniform in composition, texture, color, and bedding throughout the area. The member consists largely of light to very light gray dolomite, which weathers white. The texture is uniformly sublithographic. Examination of thin sections shows the rock to consist of an even granular aggregate of dolomite crystals with an average size of about 0.02 mm. Most of the bedding planes are sharply defined, regular, and very persistent laterally. Individual beds range from less than half a foot to more than two feet in thickness, but most are slightly less than a foot thick. This spacing and the sharply defined character of the beds results in a staircase-like appearance of the outcrops where well exposed in small drainage courses.

The base of the member is considered to be at the base of an interval of very argillaceous dolomite, 40 to 70 feet above the base of the Valmont formation. This argillaceous unit ranges in thickness from a few feet to about 15 feet within the area. The beds are soft and non-resistant. Few are more than 2 inches thick, and most are shaly and not clearly defined.

The writer has found a zone of colonial corals in the upper member of the Valmont formation. These are the only fossils known from this member. The coral masses, some as large as 6 inches in diameter, are scattered intermittently along a horizon about 50 feet above the base of the member. Locally, the fossils occur at several horizons, but all within a stratigraphic interval of about 10 feet. In the measured sections in which the corals were observed, the interval between the base of the Valmont formation and the coral zone ranges from 110 to 120 feet in the northern part of the area and from 80 to 90 feet near the south end. Both the corals, and the surrounding few inches of rock generally are silicified, so that on casual inspection, the coral horizon resembles the other layers containing siliceous nodules in the Valmont formation. Unfortunately, the silicification has not preserved the details of the corals, and a precise age determination has not been possible from the collected specimens. Pure chert nodules or seams are only minor constituents of the upper member of the Valmont formation. However, nodules of partially silicified dolomite that weather to a light brown color are abundant and conspicuous in the upper member, especially in the upper 50 feet. These layers and nodules are generally 2 to 6 inches thick, and tend to occur within single otherwise homogeneous beds of dolomite, rather than along the bedding planes. The shape and abundance of these siliceous masses seems to be rather constant in certain beds of the dolomite, which is locally useful in detecting the truncation or channeling at the top contact of the Valmont formation. Thus, for example, in exposures along the south bank of the canyon in the SW1/4 sec. 14, T. 16 S., R. 10 E., certain dolomite beds that contain these silicified layers and nodules of distinctive shapes can be viewed for more than a quarter mile. Here the variation in thickness of the interval between the top of the Valmont formation and the key beds of siliceous nodules indicates a truncation of about six feet of Valmont strata over the quarter mile exposure.

Although these nodules and layers superficially resemble solid chert masses, they are only partially silicified dolomite. Silica is the minor constituent. Small concentrations of pure chert occur, commonly near the base of the partially silicified nodule, as in Figure 16a. Beyond the limit of the pure chert masses, the distribution of the silica is not uniform, but seems to occur along discontinuous arcuate segments and bands, convex toward the outside of the mass. These structures must have formed subsequent to the deposition of the carbonate. However, the stratigraphic control, and the position of these nodules within the beds* seems strong support for the concept of a local redistribution of primary silica, rather than epigenetic introduction of silica from outside the bed. Some well formed rhombs of dolomite within the small arcuate bands of silica suggest the dolomitization took place after the silica formed.

Conditions of deposition:

The Valmont sediments were probably deposited in a marine environment, in a depositional area of a stable shelf that was free from clastic debris.

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* These arguments are commonly used in support of the syngenetic theory of chert formation as outlined by Tarr, 1926, which the writer views as most satisfactory origin for much of the chert of the Sacramento Mountains.

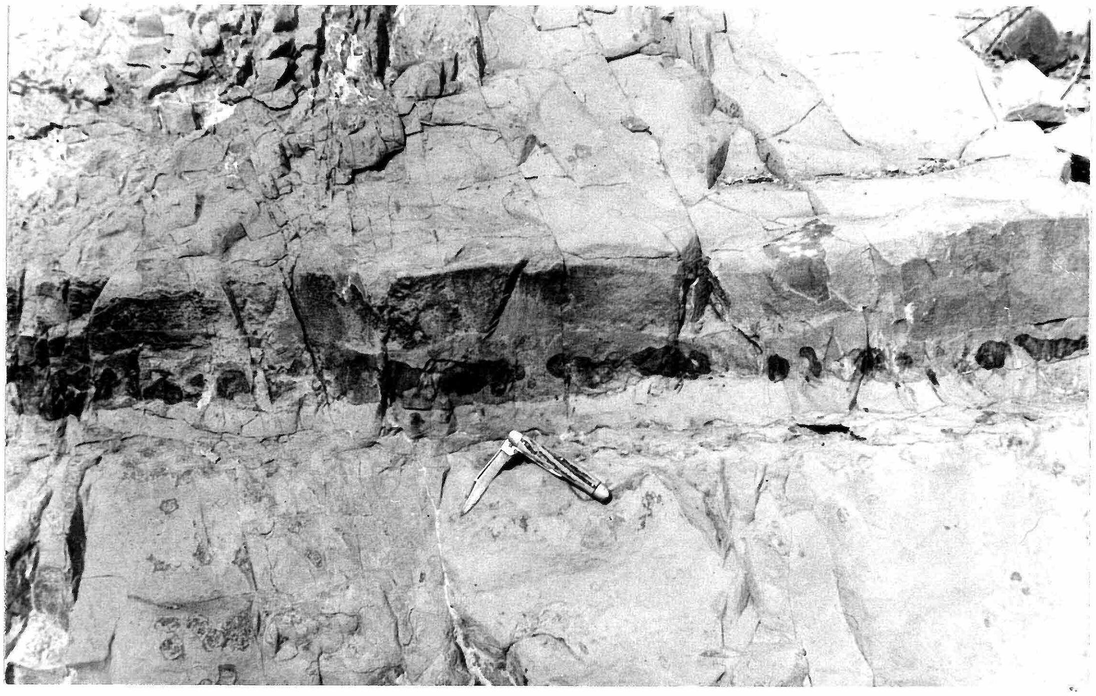


Figure 16A. Layer of partially silicified dolomite in the upper member of the Valmont formation at the type section. The black nodules near the base of the dark silicified layer are pure chert.

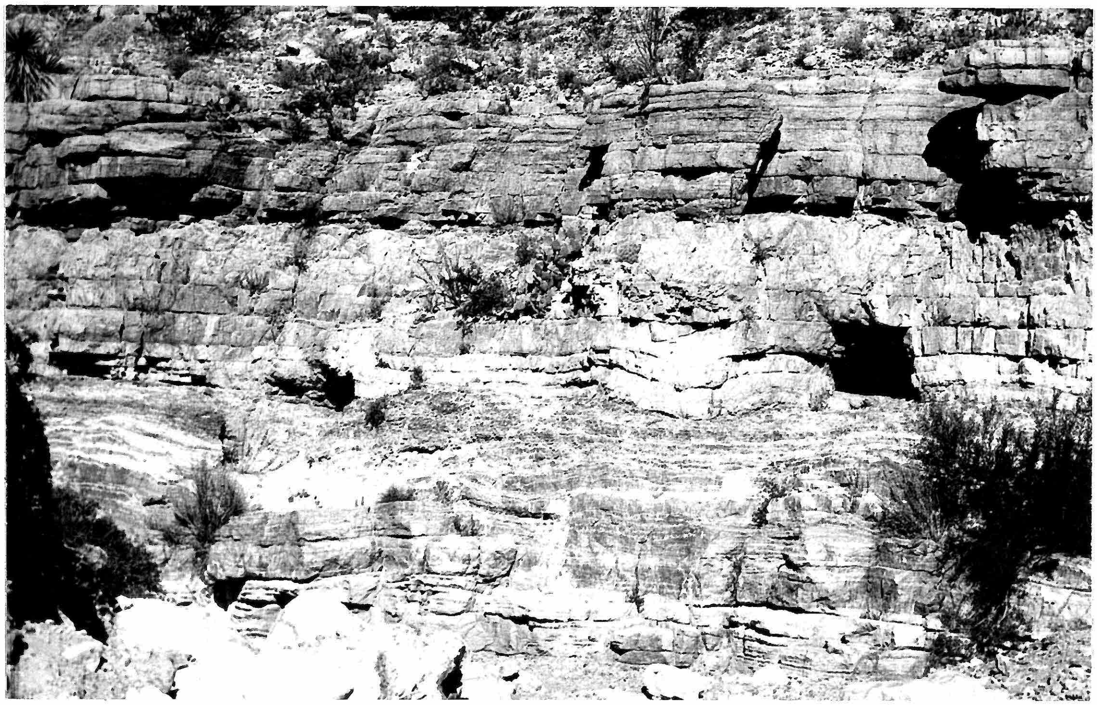


Figure 16B. Contact of the Valmont formation with the upper cherty member of the Montoya formation at the mouth of the Deadman Canyon branch of Alamo Canyon, sec. 3, T. 17 S., R. 10 E. The upper 2 to 3 feet of the Montoya formation are almost solid chert.

The remarkable uniformity in lithologic character, the lateral persistence of the thin and sharply defined beds, and the scarcity of lenticular beds or cross bedding, suggest deposition of this unit in undisturbed water, probably below the zone of wave influence. A relatively uniform depth of the sea floor area would probably minimize the influence of bottom currents. The sharply defined bedding must have been caused by temporary cessation of deposition, possibly in response to changes in temperature of the water, or to some other factor that would affect broad areas of the sea floor at the same time and would be repeated. The absence of fossils in most of the formation, the homogeneity and extreme fine grain of the texture, are suggestive of origin dominantly as a chemical precipitate.

Contact relationships:

The contact between the Valmont and Montoya formations does not appear to represent a disconformity. Locally a sharp discontinuity has been observed, but no continuous break could be traced throughout the area. The contact zone appears to represent a changing condition of sedimentation rather than an erosional hiatus of regional extent. The lower contact of the Valmont formation is selected at the top of the highest zone that is rich in chert nodules of the type characteristic of the Montoya formation (Figure 14). The uppermost chert-rich zone of the Montoya contains a third or more chert -- a greater concentration than is found lower in the formation. In the mouth of Alamo Canyon and at many places southward along the escarpment, the top 1 to 3 feet of this zone consists of solid chert, as shown in Figure 16b. This cherty zone forms an excellent stratigraphic marker in much of the area, and satisfactorily separates the dominant lithologies of the Montoya and Valmont formations. The contact appears to agree with the boundary between the Fusselman and Montoya formations selected by Darton (1917, 1928) in this area, although the published data are too generalized to establish this point with assurance. In the area of the type section, and at many other places along the western escarpment, the chert-rich zone is gradational into lighter colored, more finely crystalline dolomite characteristic of the Valmont formation. Until a disconformity is discovered by more detailed field work, the top of the chert, although gradational in detail, appears to be the most satisfactory horizon at which to separate these strata for purposes of mapping and general description.

The upper contact of the Valmont formation is a sharp, persistent disconformity in the Sacramento Mountain area.

Fauna:

The lower member of the Valmont formation is locally fossiliferous. Those forms collected in the course of this investigation have been identified by A. L. Bowsher, and are listed below:

Loc. 471: Center of the west edge of NW1/4 NW1/4 sec. 3, T. 17 S., R. 10 E., in bottom of small gully on south side of Alamo Canyon, about 80 feet above the base of the Alamo Canyon. Fossils are from top 20 feet to the lower member of the Valmont formation.

3 *Cornellites* ? sp.
2 *Labechia* ? sp.
11 *Modiolopsis* sp. (Similar to an undescribed species from the Cincinnatian strata of Ohio)
1 *Hebertella* aff. *H. sinuata* (Hall)
3 *Orbiculoidea* sp.
2 *Zygospira* aff *Z. modesta* (Say)
2 *Zygospira* sp.

Loc. 239a: Near center of west edge of NW 1/4 NW1/4 sec. 1, T. 17 S., R. 10 E., 10-20 feet above the top chert-rich zone of the upper member of the Montoya formation, and in lenticular zones in the NE1/4 SW1/4 sec. 14, T. 16 S., R. 10 E. Abundant highly silicified fossils of a few types.

1 *Bucania nashvillense* (Ulrich)

The only fossils noted from the upper member of the Valmont formation in the Sacramento Mountain area are the silicified and poorly preserved colonial corals from the thin zone near the middle of the formation. As the corals can be found at about the same horizon in the section almost everywhere in the Sacramento Mountains, the separate localities are not listed. All of the corals have been identified by A. L. Bowsher as Foerstephyllum sp. indet.

Age and Correlation:

The age of the Valmont strata, heretofore termed "lower Fusselman" has been considered as Silurian. It appears now that at least the lower part of these strata are Upper Ordovician. The report by A. L. Bowsher on the fossils from the lower member of the Valmont formation states:

> "Fossils from this zone are not well preserved and could not be properly identified. Most of the species seem to be similar to forms found in rocks of Richmond age. The species of Hebertella, Modiolopsis, and Zygospira suggest upper Ordovician, probably Cincinnatian, age for these rocks. The occurrence of Bucania nashvillense (Ulrich), which is common in the Cannon limestone of Tennessee (Trenton) is somewhat disconcerting."

More collecting and careful identification are needed to establish the age of the lower member of the Valmont formation. The forms collected, however, are clearly of Ordovician affinities, and seem to confirm the interpretation of a transition from the strata of the upper Montoya into the lower member of the Valmont formation.

The report by A. L. Bowsher on the age of the corals found in the upper member of the Valmont formation states:

> "Intense silicification of the specimens makes it impossible to make accurate identifications of these fossils. If the specimens are truly Foerstephyllum, there is a good possibility that the age of the strata from which they were collected is upper Ordovician."

As the faunal evidence for the lower member indicates Upper Ordovician age, and the age of the upper member is not determinate, the age of the Valmont formation as a whole is considered to be Upper Ordovician (?). The apparent absence of a persistent erosional break in the strata between the base of the Montoya formation and the top of the Valmont formation, is compatible with an Ordovician age for all of these strata. The discovery of a disconformity separating the Valmont formation from the overlying Fusselman (?) formation of Silurian (?) age adds some support to an Ordovician age for the Valmont.

Regional relationships:

Strata lithologically similar to the Valmont formation and in the same stratigraphic position, have been described in surface sections west of the Sacramento Mountains in southern New Mexico. Thus in the San Andres Mountains, Darton (1928, p. 186) states:

> "The Fusselman formation has two members - an upper one of hard dark-colored massive limestone, marked by a cliff in most places, and a lower one of fine-grained limestone, most of which weathers nearly white. The upper member contains distinctive fossils, but the lower one has yielded no fossils and is arbitrarily placed in the formation because of its distinctness from the underlying cherty beds which are everywhere characteristic of the upper part of the Montoya . . . The lower limestone is 140 feet thick at the south end of the range but it thins somewhat north of San Andres Peak. It is nearly 100 feet thick in Sulphur Gap but thins out and disappears in the slopes north of the gap. In places some of its beds are soft and earthy, as in Lostman canyon, but most of it is a fine-grained compact, dark gray rock that weathers to very light gray or nearly white, so that it is conspicuous in all outcrops."

This is strikingly similar to Darton's description of the strata now termed the Valmont in the Sacramento Mountains, and the general equivalence of the units seems certain. Strata considered by Darton as the lower member of the Fusselman formation have been described also from outcrops west of the San Andres Mountains. Thus Darton (1928, p. 320) shows a section from the Sierra Caballo with about 100 feet of white weathering beds labeled "Fusselman cliff", and at Lake Valley he describes (1917, p. 42)

> "an 80 foot bed of massive limestone which weathers to a light tint, and which yielded no fossils, but is tentatively regarded as the Fusselman, as in other regions."

It may be possible to recognize the Valmont lithology in other districts south and west of Lake Valley, but the published descriptions are too inadequate and the writer has not examined these areas.

In the Sacramento Mountains, the separation between the Montoya and the Valmont formations is not sharply defined. Evidence suggests a transition of lithologic characteristics rather than a major erosional hiatus. This same situation may obtain in the other areas where the lithologic equivalents of the Valmont are best developed. In the introductory general description of formations in New Mexico, Darton states (1928, p. 14)

> "the Fusselman everywhere lies on a plane of erosional unconformity, in places marked by conglomerate of the underlying formation."

Elsewhere in his writing, however, one searches in vain for specific descriptions of this reported relationship. The only other mention is his earlier statement (1917, p. 41)

> "the Fusselman limestone lies on the Montoya limestone without conspicuous unconformity; at one locality two miles north of El Paso its lower layers carry small pebbles of black limestone similar to some that occur in certain beds of the Montoya."

This is the same relationship reported by Richardson (1909, p. 4). Dunham (1935, p. 43) states that the Montoya formation in the Organ

Mountains passes upward without apparent break into the beds of the Fusselman formation. The published record for southern New Mexico at present does not establish to the author's satisfaction the existence of an unconformity between the Montoya and the lithologic unit termed the lower member of the Fusselman by Darton, the Valmont formation in the Sacramento Mountains. Critical examination of field relationships and of faunas of the Upper Ordovician-Silurian sequence is needed over all of the area of surface outcrops in southern New Mexico.

Published information concerning subsurface relationships east and southeast of the Sacramento Mountains, and in the Franklin and Hueco Mountains to the south, does not indicate the presence of strata clearly equivalent to the Valmont formation. Detailed work is necessary to show either a correlation or to explain the absence of the Valmont from these areas. As the Fusselman formation is much thicker in these areas and amounts to 630 feet in the Hueco Mountains (Lloyd, 1949, p. 52) and 960 feet in the Franklin Mountains (Nelson, 1940, p. 140), this suggests that some equivalent of the Valmont may be present in these thicker southern sections.

The field relations in the Sacramento Mountains and their analogy to the relations in the San Andres Mountains suggest that the Valmont formation was initially deposited considerably further to the north than is now indicated by surface outcrops. (See Lloyd, 1949, Fig. 7).

SILURIAN (?) SYSTEM

FUSSELMAN (?) FORMATION

In the stratigraphic sequence established by Richardson (1909) in the Franklin Mountains, the thousand feet of dolomite and limestone overlying the Montoya formation was termed the Fusselman limestone, and considered to be of Niagaran age. Darton (1917, 1928) correlated with the Fusselman limestone a widespread series of carbonate strata in southern New Mexico, and in most of the mountains of south-central New Mexico he recognized two members of the Fusselman formation. The strata referred to by Darton as the lower member of the Fusselman have been termed the Valmont formation in this report, and in the Sacramento Mountains are, at least in part, of upper Ordovician age. The upper member of the Fusselman formation described by Darton (1928, p. 201) in the Sacramento Mountains is referred to in this report as the Fusselman (?) formation.

The Fusselman (?) formation consists of dolomite that is generally dark, resistant, and cherty, and it ranges in thickness from 0 to 100 feet. These strata probably are correlative with a part of the type section of the Fusselman limestone in the Franklin Mountains. However, the fauna of the Fusselman (?) in the Sacramento Mountains appears somewhat different and older than that known from the type section. For this reason, and because of the lack of detailed information at the type section and in the intervening areas, the correlation is uncertain.

Areal distribution:

The Fusselman (?) formation crops out along the west front of the Sacramento Mountains from Indian Wells Canyon northeast of Alamogordo, southward for 18 miles to a point a mile south of Nigger Ed Canyon, where the pre-Pennsylvanian formations plunge south below the surface. Because of the resistance of the formation to erosion, as compared with the overlying strata, some of the outcrops are relatively wide with respect to the total thickness of the unit, as is well shown in the western 3 miles of the Alamo Canyon area. South of Alamo Canyon the formation is exposed continuously along the front of the mountains, commonly from 300 to 600 feet above the base of the range. It extends eastward into the major canyons but in a few places is more than a mile east of the mountain front. One of the two isolated areas of outcrop east of the mountain front is along the Bug Scuffle Fault in Grapevine Canyon, in T. 19 S., R. 11 E. near the south end of the mountains, and the other is in the structurally high area of upper Arcente Canyon in T. 16 S., R. 11 E. The only place in the Sacramento Mountains where the Fusselman (?) formation is absent from the exposed stratigraphic sequence is in Pig Canyon, where the Devonian rocks directly overlie the Valmont formation in the NW1/4 SW1/4 sec. 7, T. 16 S., R. 11 E. Pre-Devonian erosion probably removed the Fusselman (?) from this area.

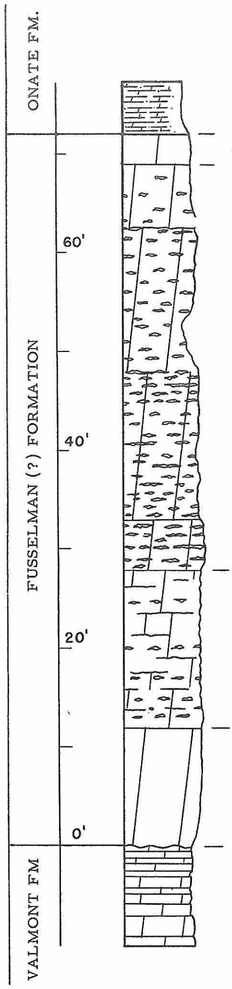
Lithology:

The Fusselman (?) formation of the Sacramento Mountains consists of dark weathering, cherty dolomite that forms a distinctive lithologic unit which in most places is about 75 feet thick. The basal contact is sharply defined and easy to trace because of the juxtaposition of the white slope-forming dolomite of the Valmont formation and the darker cliff-forming Fusselman (?) dolomite. The upper contact with the soft Devonian formations is rarely exposed.

Although the Fusselman (?) formation is lithologically distinctive from other strata, many minor variations in the dolomite exist within the formation. In many places, the variation is abrupt, both laterally and vertically. With the exception of a few streaks of quartz sand, the composition is entirely dolomitic. Details of the formation at three points in the area are indicated on Plate 7.

The color of the dolomite ranges from very light gray, for a unit near the base in the Alamo Canyon area, to the more common, darker shades of gray or of hues of olive or brown gray. The weathered surface is darker in color than the fresh rock. The texture of the dolomite ranges from very finely crystalline to medium crystalline, and most is finely crystalline, somewhat sugary in texture. Although predominant in the underlying strata, sublithographic textured dolomite has not been observed in the Fusselman (?) formation. The nature of the bedding varies widely, and in many places abruptly. In some sections many of the component units of the formation are essentially massive, or separated by widely spaced bedding planes. In other beds are closely spaced. The bedding is commonly obscure.

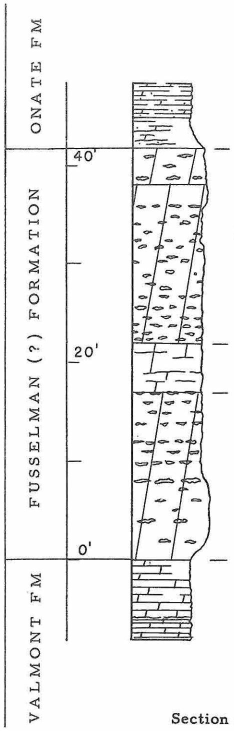
Chert is abundant in the formation, but the distribution is erratic. Most of the chert ranges from gray to gray brown in color, and tends to weather to a yellow brown. Porcelaneous textures are common. The chert masses rarely form in smooth, even layers or nodules as in the Montoya or Valmont formations, but are extremely irregular in form, as is shown in Figure 17. Most chert masses are oriented parallel with the bedding. Where abundant, the irregular masses and nodules seem to be concentrated along horizons in the dolomite that are spaced at intervals of 6 inches to a foot apart, a spacing that may persist throughout 20-30 feet of strata.



		Covered, non-resistant strata, gray-brown silty shale float.
		Top surface of exposed dolomite locally dark red brown, silicified.
4	3'	Dolomite, medium light gray, finely crystalline, chert free.
3	41'	Dolomite, medium light gray, finely crystalline; abundant irregular nodules, layers, and masses of gray to yellow chert, locally forms half of rock.
2	16'	Dolomite, medium gray to brownish gray, finely crystalline, massive; very irregular nodules and masses of brown weathering chert parallel to obscure bedding.
1	12'	Dolomite, very light gray, very fine to finely crystalline, massive; weathers dark gray brown.
Total thickness	72'	Contact relief 1 to 2', locally slight reddish stain.
		Dolomite, medium light gray, sublithographic, beds 6" to 3' average 1' thick.

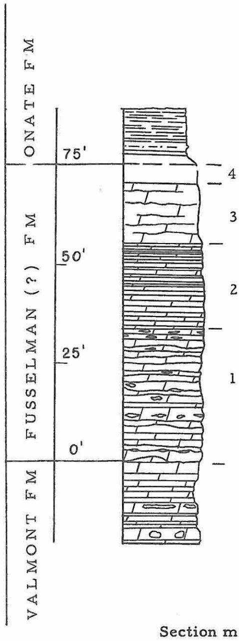
(See plate 6 for details of the underlying Valmont formation)

Section measured above type section of Valmont formation; base of Fusselman (?) section about 1200' W. and 400' N. of SW corner sec. 6, T. 17 S. R. 11 E.



		Dolomite, olive gray, silty, thin bedded; shaly near base
		Covered, probably dolomitic shale
		Top surface of Fusselman (?) formation locally dark red brown, silicified.
3	25'	Dolomite, medium gray, finely crystalline, massive; irregular gray chert forms third of lower 5'.
2	5'	Dolomite, medium gray, finely crystalline
1	17'	Dolomite, light brown gray to brown gray, finely crystalline, massive, weathers dark brown gray; very irregular gray chert masses up to 3" thick.
		Dolomite, very light gray, sublithographic, thin even beds; minor light gray chert.

Section measured on south side of Alamo Canyon in center of the north line of sec. 3 T. 17 S. R. 10 E.



		Siltstone, dolomitic, gray, minor shale.
4	5'	Top of Fusselman (?) fm. faulted out. Total thickness measured 100 feet south of canyon bottom.
3	14'	Dolomite, light olive gray to medium gray, finely crystalline, obscure bedding.
2	22'	Dolomite, dark gray, finely crystalline; even but indistinct beds 2" to 1' thick.
1	33'	Dolomite, dark gray, finely crystalline; minor thin layers and scattered nodules of gray chert. Few scattered fossils, mostly gastropods, 10 to 20' above the base.
		Contact sharp, locally several inches of relief
		Dolomite, light gray, sublithographic; minor brown weathering silicified nodules.

Section measured in Agua Chiquita Canyon, 1800' W. and 1000' S. of NW corner T. 19 S. R. 11 E.

STRATIGRAPHIC SECTIONS OF THE FUSSELMAN (?) FORMATION IN THE SACRAMENTO MOUNTAINS

Figure 17. Cherty dolomite of the Fusselman (?) formation.

The distribution of chert gives these units a thinly bedded appearance, although the dolomite may be massive or obscurely bedded. Within the irregular outlines of the siliceous material are many smaller, irregular dolomite areas, which range in size from megascopically visible patches to single microscopic rhombs of a dolomite crystal. The weathering of these irregularly silicified masses selectively leaches the dolomite, and produces a punctate or reticulate pattern.

Although almost entirely of dolomite, locally at the base of the formation are minor amounts of clastic material, both quartz particles and detrital dolomitic fragments. The most clearly marked detrital zone observed is on the north side of Escondido Canyon in the NW1/4 NW1/4 sec. 26, T. 18 S., R. 10 E. At this point, a two-foot thick section of detrital material in a dolomitic matrix directly overlies the Valmont formation. This clastic unit is sharply separated from both the underlying Valmont, and from the overlying part of the Fusselman formation, but its matrix resembles the overlying Fusselman (?) dolomite. The abundant clastic particles are rounded, somewhat elongate granules and small pebbles of dolomite and minor chert. The texture of the dolomite in the particles is sublithographic, and although darker in color, they closely resemble the Valmont lithology and are believed to be derived from it. The chert fragments are not diagnostic.

Elsewhere, quartz grains are locally present in the basal part of the Fusselman (?) formation. They have been detected in the basal 1 foot of the Fusselman (?) formation in the SE1/4 SW1/4 sec. 34, T. 16 S., R. 10 E., on the north side of Alamo Canyon. The basal foot of a section in the formation measured in the NE1/4 SW1/4 sec. 10, T. 18 S., R. 10 E.

near Dog Canyon likewise contains quartz particles. In upper Alamo Canyon, in the NW1/4 SW1/4 sec. 6, T. 17 S., R. 11 E., a relatively smooth surface separates typical Valmont lithology from five feet of fine to medium crystalline, massive dolomite considered to be the basal unit of the Fusselman (?) formation. At this locality a zone as much as three inches thick directly above the Valmont dolomite contains numerous granules of dolomite and minor chert. A few grains resemble glauconite.

Massive, light gray to nearly white non-cherty dolomite occurs as a basal unit of the formation in many parts of the area. It is absent along the southern part of the escarpment, and in the northeastern part of the Fusselman (?) outcrops. This unit is prominent near the mouth of Alamo Canyon, and forms the lower 12 feet of the section measured in that area (sect. 1, plate 7). The color of the fresh rock is similar to that of the underlying Valmont formation, but the two are easy to distinguish. The basal unit of the Fusselman (?) weathers to a darker color, is more coarsely crystalline, contains no chert or silicified nodules, and is massive. The very finely crystalline to finely crystalline texture of the basal unit of section 1, plate 7, is atypical, as at most places, this basal unit is fine to medium crystalline. The variation in thickness of the unit is extreme. For example, within half a mile of section 2, the observed range in thickness of this lower unit is from 0 to 60 feet.

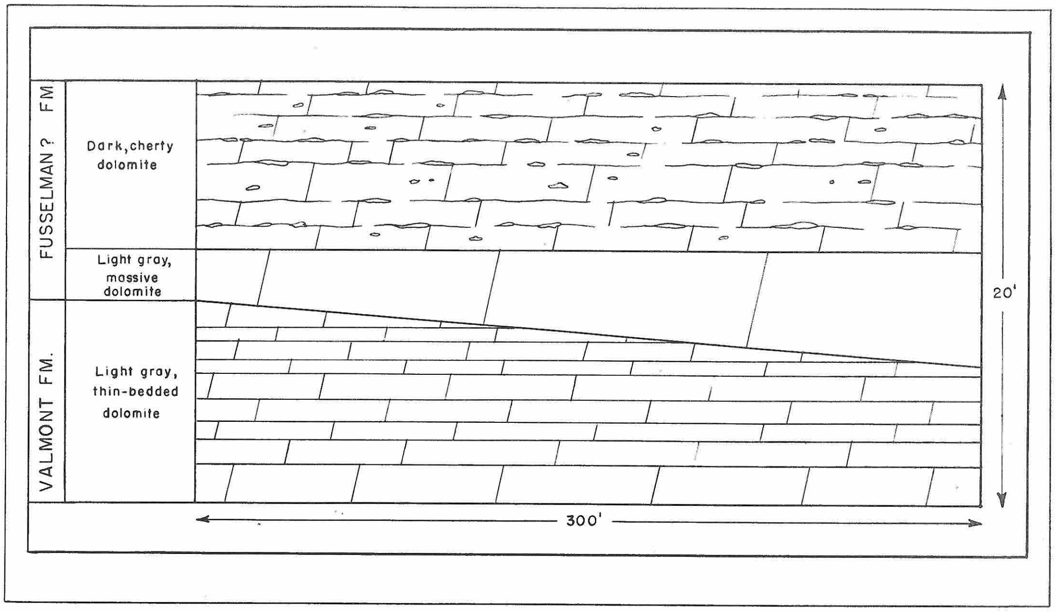


Fig. 18. Sketch of Valmont-Fusselman (?) formation contact in NE1/4 SW1/4 sec. 36, T. 16 S., R. 10 E. Valmont strata truncated by pre-Fusselman (?) erosion.

Locally the thickness of the lower massive unit of the Fusselman (?) formation appears to be in response to the pre-Fusselman (?) formation erosion surface, as is shown in Figure 18. The contact at the base of the massive unit of the Fusselman (?) formation truncates the even beds of the Valmont formation. The massive dolomite unit forms a wedge, the top surface of which is parallel to the bedding of the overlying cherty dolomite and is essentially parallel to beds of the Valmont formation. The similar relationship, on a smaller scale, was observed at the westernmost tip of the Valmont formation outcrop in the SE1/4 NW1/4 sec. 14, T. 16 S., R. 10 E. where the basal contact of the lower massive unit is irregular and has a local relief of about one foot. The massive unit is 3 to 4 feet in thickness, and the variation of thickness compensates for the relief of the lower surface so that the thickness between a horizon within the Valmont and a horizon in the darker cherty dolomite above the massive unit is nearly constant. Relationships in these two areas suggest that at least a part of the variation of thickness of this massive unit may be related to irregularities of the surface of deposition, and that the first phase of Fusselman deposition largely eliminated the irregularities of the sea floor.

Non-cherty phases of the Fusselman (?) formation are not restricted to a basal unit. However, the higher non-cherty zones are commonly thinner, not as persistent laterally, somewhat darker in color, and less massive than the basal unit. Some of these massive zones are distinctly wedge-shaped in cross section, and relationships similar to the basal wedge shown in Figure 18 have been observed.

Thicknesses and lithologic notes on the Fusselman (?) formation at points along the Sacramento Mountains escarpment are indicated in Table IV. The thicknesses are more representative than the notes on lithology, as this table is used to conveniently summarize both the abnormal and the more representative lithologic features. The localities listed are in a general north to south order.

Table IV. Thickness and Notes on Lithology of the Fusselman (?) Formation.

Locality	Thickness	Remarks
NW1/4 SW1/4 sec. 7 T. 16 S., R. 11 E.	0	Devonian in depositional contact with Valmont formation.
SW1/4 NW1/4 sec. 14 T. 16 S., R. 10 E.	17'	3-4' massive dolomite at base.
NW1/4 sec. 20 T. 16 S., R. 11 E.	2-20'	Cherty throughout.
SE1/4 NE1/4 sec. 28 T. 16 S., R. 10 E.	60'	14' massive dolomite at base grades upward into darker cherty dolomite.
NE1/4 NW1/4 NE1/4 sec.25 T. 16 S., R. 10 E.	30-40'	Top few feet completely silicified. Abundant corals. Minor quartz sandstone near top.
SW1/4 SW1/4 sec. 6 T. 17 S., R. 11 E.	43'	Cherty throughout.
NE1/4 NE1/4 sec. 3 T. 17 S., R. 10 E.	72'	12' massive dolomite at base.
SE1/4 NE1/4 sec. 20 T. 17 S., R. 10 E.	73'	Minor chert.
NW1/4 NW1/4 sec. 21 T. 17 S., R. 10 E.	78'	28' massive dolomite at base, upper part cherty.
SE1/4 sec. 28 T. 17 S., R. 10E.	60' ?	Irregular richly fossiliferous zones, highly silicified.
NE1/4 SW1/4 sec. 10 T. 18 S., R. 10 E.	85'	30' massive dolomite at base, upper part cherty.
NW1/4 NW1/4 sec. 26 T. 18 S., R. 10 E.	77'	2' of dolomite with chert ? granules and pebbles at base,
NE1/4 NW1/4 sec. 1 T. 19 S., R. 10 E.	74'	Minor chert.
NE1/4 SE1/4 sec. 22 T. 19 S., R. 11 E.	65' plus	Minor chert.

Along much of the escarpment the formation ranges in thickness from 70 to 80 feet. The maximum measured section is 85 feet, but probably the maximum thickness in the area is nearly 100 feet. The thickness diminishes in the eastern part of Alamo Canyon and farther north. It is about 15 feet at the northwestern limit of outcrop, and the formation is absent from the Pig Canyon structure in the NW1/4 SW1/4 sec. 7, T. 16 S., R. 11 E.

The thinning of the basal massive unit in the northwestern outcrops, and the absence of the formation from the northeastern part of the area may indicate that the original thickness of the formation was less in these areas. However, the Devonian section is in depositional contact with a horizon lower in the Valmont formation in the Pig Canyon area than elsewhere, which suggests the importance of pre-Devonian erosion. The variation in thickness from 2 to 20 feet in the small area of upper Arcente Canyon also suggests that erosion is a significant factor.

Conditions of deposition:

The fauna of the Fusselman (?) formation indicates deposition in a marine environment. As with most of the lower Paleozoic formations in this area, the Fusselman (?) formation is believed to be the product of deposition on a stable shelf. The depositional area of the Fusselman (?) formation is similar to that of the Valmont and Montoya formations in the virtual absence of terriginous clastics. The deposition conditions contrast with those of the Valmont however, as that formation is characterized by uniformity and lateral persistence of lithologic character to a much greater degree than is the Fusselman (?) formation, in which lateral and vertical variation are common. These variations in the color texture, and bedding of the dolomite, and in the relative abundance and distribution of the chert, can be most easily interpreted as the result of deposition in relatively shallow water, where more fluctuation of temperature, wave action, and currents is to be expected than in deeper water. Reworking of previously deposited sediment is likely to occur in shallower areas, and the lenticularity of some of the units of the Fusselman (?) formation may be the result of this process.

Contact relationships:

The Fusselman (?) formation is separated from the underlying Valmont formation and the overlying Devonian formations in the Sacramento Mountains by sharp surfaces of discontinuity interpreted as disconformities. The break between the Silurian and Devonian formations has long been recognized. The disconformity at the base of the Fusselman (?) formation is an interpretation based on field observations during the current investigation.

Darton (1928, p. 201) recognized a sharp break between the upper and lower members of the Fusselman formation in the Alamo Canyon area, but this is the only mention made of this contact in the Sacramento Mountain area. In reconnaissance at the south end of the Sacramento Mountains, Baker (1920, p. 100) reported the Niagaran strata to be dark to light gray limestones 50 feet thick. This Niagaran unit best describes the Fusselman (?) of this report. From this it is probable that Baker considered the lower boundary of the present Fusselman (?) formation as the separation of Ordovician and Silurian strata at this locality, but he makes no specific reference to the contact.

The separation between the Valmont and Fusselman (?) formations is the most persistent lithologic and structural discontinuity observed in that part of the section that lies between the base of the Montoya formation and the top of the Fusselman (?) formation. The interpretation of this discontinuity as a disconformity is based largely on the following evidence:

1. Evidence of erosion of the Valmont formation prior to the deposition of the Fusselman (?) formation.
2. Clastic material locally in the base of the Fusselman (?) formation.
3. Abrupt change of lithology from the Valmont to the Fusselman (?) formation.
4. Association of nearly all features suggestive of a disconformity in the Valmont or Fusselman (?) formations at the same stratigraphic horizon throughout the Sacramento Mountain area.

The evidence of erosion of the Valmont formation prior to the deposition of the Fusselman (?) dolomite appears strong. The amount of relief of the contact surface, and the amount of local truncation of the underlying beds, are more than are present along the disconformity at the base of the Montoya formation, but are small compared to the deeply channeled surface of moderate relief on which the Pennsylvanian strata were deposited in the Sacramento Mountain area. At many places, the contact relief observable in 10 feet of strata is several inches to a foot. At several localities, as for example in the NE1/4 SW1/4 sec. 36, T. 16 S., R. 10 E. shown on Figure 18, a relatively smooth surface of discontinuity truncates several of the upper beds of the Valmont over a distance of about 300 feet. These relationships are most easily explained by erosion prior to deposition of the Fusselman (?) strata, and could be interpreted as an angular unconformity except for the wedging influence of the basal massive unit of the Fusselman (?) at this point which is wedge-shaped and the upper strata of the Fusselman (?) appear to parallel the Valmont strata.

It appears unlikely that the observed truncation and the more localized minor relief of the surface of discontinuity would be developed if the break represented only a brief cessation of deposition. Intraformational truncation can be widespread (Rich, 1951). It is perhaps significant that in the Valmont formation the major and almost the only truncation observed is at the top, and that this has been observed at this horizon throughout the area. In strata as fine in texture as the Valmont, and with as uniform bedding, the truncation and relief along a clean, sharply defined surface probably could be developed more readily by erosion of consolidated strata than by local submarine erosion of unconsolidated sediments.

On a larger scale, not directly observable at any one point in the field, it appears that the Valmont formation was initially thicker toward the north, and that the present top of the formation in that area is at a lower stratigraphic horizon in the northern part of the area than to the south (Table III). The major variation in thickness is in the upper part of the Valmont formation, which suggests an erosional break. This apparent beveling and relief at the top of the Valmont strata supports the interpretation of erosion, and thus of an unconformity at the base of the Fusselman (?) formation.

Most of the known disconformities in the Sacramento Mountain escarpment are marked at least locally by a zone of clastic material above the discontinuity. It is significant that nearly all of the detrital material in the Fusselman (?) formation occurs at the base of the formation. The occurrences appear to represent only local accumulations as they are not laterally continuous. Three specific examples were described in the discussion of the lithology. Undoubtedly many more examples could be found by detailed study.

A sharp change of lithology is a condition in many places associated with an unconformity. The Valmont-Fusselman (?) formation contact represents a sharp change. Nowhere in the uppermost 100 feet of the Valmont formation has dolomite with the lithologic characteristics of the Fusselman (?) been observed. None of the dolomite observed within the Fusselman (?) formation is similar to that of the underlying Valmont, except for the minor particles considered as clastics derived from the Valmont formation. This appears to be true over the entire Sacramento Mountain escarpment. The persistence of this break, the uniformity of the underlying lithology, and the more variable lithology of the overlying strata, seems suggestive of disconformity.

As pointed out by Krumbein (1942, p. 58), the occurrence of a single criterion of a disconformity is rarely diagnostic. However, the mutual association of a number of criteria at the same horizon, greatly increases the probability of a disconformity. In the Sacramento Mountain escarpment, the evidence of a disconformity in the Valmont-Fusselman (?) strata is largely restricted to a single horizon. It seems logical to consider that this break is a disconformity. It must be pointed out, however, that the evidence of subaerial erosion of consolidated strata of the Valmont is not conclusive. It is possible, although not probable, that the break described could have formed by submarine erosion. Regardless of the ultimate interpretation of the nature of this break in the

Sacramento Mountains, it forms an excellent surface for the subdivision of the lower Paleozoic strata.

Fauna:

The following fossils collected during the present investigation have been tentatively identified from the Fusselman (?) formation of the Sacramento Mountains:

Loc. 336b

1 Raphistoma sp.
3 Donaldiella sp.
1 Loxaplocus, probably n. sp. A
3 Loxaplocus, probably n. sp. B
3 Streptelasma, sp.
1 Zygospira sp.

Loc. U.S.N.M. 3067

1 Raphistoma sp.
1 Streptelasma sp.
6 Heliolites sp. indet.
5 Stromatocerium ? sp. indet.

Loc. 625 NE1/4 NW1/4 NE1/4 sec. 25, T. 16 S., R. 10 E.
Abundant silicified corals in upper 10 feet of Fusselman (?) formation.

Calapoecia sp.
Halysites sp.
Streptelasma ? sp.

Loc. 288

1 Foerstephyllum sp. indet.
1 Lichenaria sp.

Loc. 293b

3 Lichenaria sp. indet.

Loc. 472b

1 Stromatocerium rugosum (Hall)

Age and Correlation:

Detailed paleontologic work is needed before the age of the Fusselman (?) formation is known. The poor preservation of some of the fossils collected, the absence of some of the better known index fossils from the meagre collections available for study, and the incomplete study of the fossils already collected, all contribute to the unsatisfactory status of knowledge of the age of the Fusselman (?) formation in the Sacramento Mountains.

A. L. Bowsher and some associates of the U. S. National Museum, who have made the tentative identifications cited in this report, are not certain whether the fauna is Ordovician or Silurian. It is perhaps significant that the pentamerid brachiopods of undoubted Silurian age that are known* from the Silver City area and the Florida Mountains of New Mexico and the Franklin Mountains of western Texas, have not been identified in the Sacramento Mountains fauna.

Until more evidence is available, it seems best to consider the age of the Fusselman (?) formation of the Sacramento Mountains as Silurian (?).

Regional relationships:

As the exact correlatives of the Fusselman (?) formation of the Sacramento Mountains are not known, the regional relationships of this formation are speculative. In the mountains of south-central New Mexico, it is again necessary to use mainly the work of Darton (1917, 1928). On the assumption that his correlation of the upper member of the Fusselman formation throughout the area of southern New Mexico is valid, some data are available for comparison.

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* A. L. Bowsher - personal communication.

In the San Andres Mountains, the upper member of the Fusselman formation is described by Darton (1928, p. 186) as

> "hard dark colored massive limestone, marked by a cliff.....
> Its thickness is 80 feet in the southern part of the range,
> but it gradually thins northward to 40 feet in Lostman Canyon,
> 30 feet in Membrillo Canyon, and 25 feet in Sulpher Gap."

It is not found farther north. The northern end is in T. 15 S., only a few miles north of the northern limit of the formation in the Sacramento Mountains. Darton (1928, p. 320) reported about 50 feet of the "characteristic dark-colored massive limestone" present in the Caballo Mountains. At Lake Valley (1917, p. 42), fragments of Silurian fossils were collected from the 120 feet or more of limestone, in part cherty, that overlies the lower member of the Fusselman. The upper member of the Fusselman formation of Darton may be recognizable west of Lake Valley, but the published descriptions are too meagre for satisfactory correlation.

Dunham (1935, p. 40) recognized the two-fold division in the Fusselman formation, and indicates about 80 feet for the thickness of the upper member at two localities. Published sections of the Fusselman strata in the Franklin Mountains are not sufficiently detailed to determine limits or even the existence of two members at the type section. However, the correlation by Darton of the two members of the Fusselman in New Mexico with the type Fusselman section of the Franklin Mountains has not been questioned by either Nelson (1940) or Dunham (1935), the two workers who have published correlation charts of the Organ and Franklin Mountains region.

Only the upper part of the Fusselman formation of the Hueco Mountains is indicated in a detailed section by Laudon and Bowsher (1949) but they apparently did not question the identity of the strata considered by them as Fusselman. They noted, however, a 30-foot thick sequence of coarsely crystalline limestone between the Fusselman formation and below the Devonian strata, and mention the resemblance of these strata to the Lower Silurian Chimney Hill formation of Arkansas. Lloyd (1949, p. 38) questions the significance of the lithologic similarity, as he considers the Fusselman to be of Niagaran age.

DEVONIAN SYSTEM

Although Devonian strata form but a small part of the Paleozoic section of New Mexico, they have been more thoroughly studied than many other parts of the sedimentary sequence. Devonian strata were first recognized in southwestern New Mexico by Gordon and Graton (1906, pp. 394-395), and were named the Percha shale by Gordon (1907, pp. 60, 62). Girty (in Gordon and Graton, 1906, pp. 394-395) and Kindle (1909, pp. 6-14) considered the fauna of the Percha as equivalent to that of the Ouray limestone of Colorado. Keyes (1906, pp. 197-98) was the first to report an older fauna (Lime Creek). Darton (1917, p. 46) correlated Devonian strata in the San Andres, Caballo, and Sacramento Mountains with the Percha shale, and suggested that the fauna of the strata in the San Andres Mountains was older than that in the type Percha areas farther west.

The first detailed work on the Devonian strata in the Sacramento Mountains was by Stainbrook (1935), who described a 40-foot section of Devonian strata from upper Alamo Canyon, stated that the fauna is definitely older than that of the Percha shale, and correlated it closely with that from the Independence shale of Iowa. Stevenson has done much of the recent work on the Devonian of southern New Mexico (1941, 1943, 1944), and published in 1945 a summary and general review of the Devonian of southern New Mexico. Laudon and Bowsher (1949) describe the Devonian strata at many localities in the Sacramento Mountains and other parts of southwestern New Mexico.

The classification of rock units established by Stevenson is followed in this report and summarized on Figure 19.

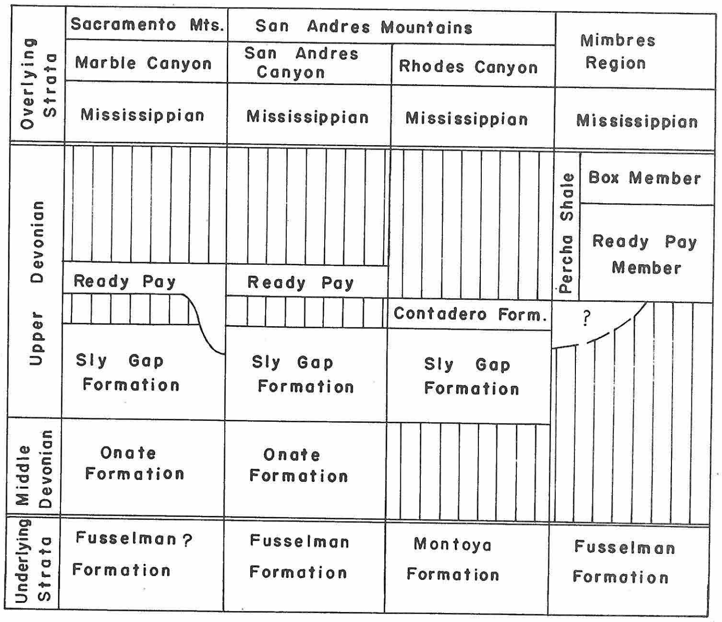

Figure 19. Devonian formations of southwestern New Mexico. (After Stevenson, 1945)

ONATE FORMATION

Stevenson (1945, p. 222) proposed the name Onate formation for the "variable and intergradational series of shale, siltstone, fine sandstone, and limestone" below the Sly Gap formation in the San Andres and Sacramento Mountains. The type section is located in Sec. 18, T. 18 S., R. 4 E., on the north slope of San Andres Canyon in the San Andres Mountains. The formation is 86 feet in thickness at the type section, and thinner elsewhere.

In the northern Sacramento Mountain area two major lithologic units are readily distinguishable. The lower unit is composed predominately of dark colored, silty dolomite and dolomitic siltstone, and the overlying unit is composed of non-resistant, yellow, gray, and black shale with interbedded, thin and somewhat nodular limestone. As the principal characteristics of the units thus distinguished correspond generally to the definition of the Onate and Sly Gap formations, these names are used in this report. However, on the basis of lithologic similarity, it appears that this contact in the Sacramento Mountains is not strictly equivalent with the contact at the type sections in the San Andres Mountains. The writer believes the boundary between the two mappable units of the Sacramento Mountains is equivalent to a horizon 10 feet above the base of the Sly Gap type section.

Areal Distribution:

The Onate formation is the most widespread of Devonian units recognized in the Sacramento Mountains, and is present throughout the area of the escarpment. The formation extends along the western escarpment of the mountains from Indian Wells Canyon on the north to a mile beyond Nigger Ed Canyon on the south, a distance of about 18 miles. The

Onate extends eastward from the western front to a depth of about four miles in the broad Alamo Canyon area, but south of this, the eastern limits of outcrop are much closer to the front of the range. The Onate formation is exposed in the isolated, structurally high areas of Pig Canyon and Arcente Canyon, both northeast of Alamo Peak, and thin Onate (?) strata crop out on both sides of Grapevine Canyon along the Bug Souffle fault in the southernmost part of the area.

Lithology:

In the Sacramento Mountains the Onate formation consists largely of silty dolomite and dolomitic siltstone, dark gray or brown-gray in color. Coarse clastics are absent except for pebbly sandstone locally occurring at the base of the formation. The beds are commonly thin. In the central part of the escarpment 1 to 3 foot beds of silty dolomite and dolomitic siltstone form resistant ledges that weather red-brown. In the southern 2 miles of Devonian outcrop, a few feet of silty dolomite is tentatively correlated with the Onate formation.

The Onate formation ranges in thickness from less than 10 feet to about 70 feet. It lies disconformably above the Fusselman (?) and the Valmont formations, and is overlain by strata ranging in age from Upper Devonian to Lower Mississippian. The formation is much less resistant to erosion than the underlying dolomite of the earlier Paleozoic periods and is somewhat more resistant than the overlying Sly Gap and lower Mississippian strata. Thus it generally forms a low step well behind the outer steep cliff of the Fusselman (?) formation, and lies near the base of the slope of younger Devonian and Mississippian formations. The exposures of the Onate formation are locally excellent, but over wide areas only the most resistant strata are exposed.

Details of the Devonian strata at five well exposed sections are shown on plate 8, together with a correlation diagram which indicates the general lithology and thickness of these sections and of five supplementary sections in the Sacramento Mountain area.

In the western part of Alamo and Marble Canyons, the lower 2 to 6 feet of the Onate consists of quartz sandstone with minor pebble zones. This was first reported by Stevenson (1945, p. 226). At other places in the Sacramento Mountains, however, the basal part of the Onate formation is generally dolomitic siltstone, thinly bedded, dark gray to gray-brown in color, and more argillaceous than the upper part of the formation. In the SE1/4 NW1/4 sec. 14, T. 16 S., R. 10 E., the basal foot contains some dark carbonaceous streaks interpreted as plant fossils.

Most of the Onate formation is composed of silty dolomite. The dolomite generally is very finely crystalline. Almost all the silt particles are quartz. They are well sorted, sub-angular, and in general are of coarse silt size, although in some rocks, the quartz particles are as coarse as fine sand. The size of the quartz particles is generally somewhat smaller than the crystals of the dolomite, but the similarity in the size of the detrital quartz particles and the dolomite crystals is striking. This may be coincidental, but possibly indicates that the carbonate part of the rock also is detrital in origin, and that subsequent recrystallization to the present well formed rhombs of dolomite has occurred without much redistribution of the carbonate part of the rock. No beds, lenses, or concentrations of pure dolomite or quartz silt or sand have been observed. If both siliceous and carbonate parts of the sediment were detrital, it would satisfactorily explain the complete mixing of these different constituents. Most of the Onate formation is thin bedded, but some relatively massive beds are as much as 1 to 3 feet in thickness. The typical color of the fresh surface is dominantly a medium gray to brownish-gray (5YR 5/1) or olive gray (5Y 5/1), but the color range is from dark to light gray in the neutral hue, and spans the middle range of lightness values in the yellow red and yellow hues.

In the northern part of the area, the Onate-Sly Gap formation boundary indicated on Plate 8 seems to correspond to that described by Laudon and Bowsher (1949, p. 23-27), but the present author's interpretation differs somewhat from that of Stevenson (1945, fig. 10) in this area, and to the south differs from that of Laudon and Bowsher and Stevenson. In discussion of the Onate formation, Stevenson (1945, p. 222) states the following:

> "the top of the Onate is not marked by any disconformity readily detectable in the field. An outstanding difference between the Onate and the overlying Sly Gap formation, however, is the gray-brown color of the former and the tan to light yellow color of the latter. Thin, shaly limestone beds, containing Sulcoretopora anomalotruncata, occur within 3 to 4 feet of the top of the Onate. These bryozoa are found in most sections and form an excellent horizon marker for the near top of the formation."

In the northern part of the Sacramento Mountain escarpment, this difference in color appears to be a valid general criterion for distinguishing the two major parts of the Devonian section. Locally in Alamo Canyon the zone with abundant bryozoans of Sulcoretopora anomalotruncata lies within a few feet of the top of the dolomitic siltstones. However, at other places in the Alamo Canyon area, 10 to 15 feet of dolomitic siltstone overlie the most abundant bryozoan horizon, and are similar to the strata below the Sulcoretopora zone. These higher beds contain numerous small, irregular nodules, some of which are all chert, but most are only partially silicified carbonate rock. The nodules are siliceous and distinct from the larger nodules of limestone that form a characteristic part of the Sly Gap formation.

As the writer's correlations of the Devonian strata differ from earlier interpretations in the area south of Alamo Canyon, the following paragraphs outline the reasons for the Onate correlations of plate 8. In addition to the persistence of the dominant silty dolomite lithology in all of the Onate, two minor lithologic features are valuable in tracing the lateral changes in the formation. These are the siliceous nodules in the area of Alamo to San Andreas Canyon, and the relatively massive silty dolomite layers 1 to 3 feet thick that form a minor but conspicuous part of the Onate. These silty dolomites weather to a distinctive pale red to brown color. Although discernible in almost all of the area, they are best developed between Mule Canyon and Escondido Canyon along the western escarpment. As indicated in section No. 3 on plate 8, there appears to be no break in the Devonian sequence below the horizon of either the lowest siliceous nodules or the red-brown massive strata. Instead, the entire sequence indicated as Onate appears to the writer to be completely gradational. The occurrence of Sulcoretopora anomalotruncata in sections 3, 5,and 6, interbedded with the red brown markers and with the siliceous nodules of sections Nos. 3 and 5 corroborates the interpretation based directly on the lithology, as these bryozoa are Onate forms.

Stevenson (1945, p. 231) indicates 10 feet of calcareous siltstone and limestone as the lowest one of the Sly Gap at the type section, and comments about the basal ten feet

> "everywhere represented in the Sly Gap formation and makes a red brown marker for the Paleozoic section of the region where the Sly Gap is exposed. Crinoid columnals are commonly found in this horizon, although this characteristic is not so marked in the Sacramento Mountains as in the San Andres."

At least in the Sacramento Mountains, the red brown marker units of the Paleozoic section are better placed within the Onate formation. Stevenson (1945, p. 234) describes the strata in the Dog Canyon area under the Sly Gap formation, but states that a meagre fauna from the "puzzling strata" of the Dog Canyon area resemble the Onate more than the Sly Gap formation. Correlation of the Dog Canyon section as Onate is only puzzling if the "dark brown siltstones" are considered as Sly Gap rather than Onate. Traced southward toward Escondido Canyon, some of the red-brown marker units grade into fine-grained dolomitic quartz sandstone, and some interbedded units of the sequence are calcitic rather than dolomitic. In the area of Dog and Escondido Canyons the Caballero lies directly over the strata considered by the writer to be the Onate formation.

South of Escondido Canyon, at Agua Chiquita Canyon and beyond, the Devonian lithology changes rapidly and correlations indicated on plate 8 are uncertain. In the Agua Chiquita Canyon the lowest 32 feet of the Devonian sequence is shaly. However, some beds of dolomitic siltstone are suggestive of the red-brown marker units farther north, and thus this part of the section is believed to be Onate. In Grapevine and Nigger Ed Canyons, the lower 8 to 15 feet of the Devonian strata is a light gray-brown silty dolomite. This is overlain by dark gray, non-calcareous, fissile shale. The dolomite is considered to be Onate. The dark shale may be Onate, but probably is younger. It may represent a Sly Gap facies (Laudon and Bowsher, 1949, p. 30) or the Ready Pay member of the Percha shale.

Conditions of deposition:

The deposition of the Onate formation appears to have been in a marine environment under relatively stable conditions prevailing during deposition of the earlier dolomitic strata of the area. For the first time since the deposition of the Bliss sandstone, clastic material is of significance in the section. Although the strata are largely silty dolomites, the silt content of many of the specimens is nearly half of the rock, and in some examined in the laboratory, more silt than dolomite is present. Argillaceous material is scarce in the Onate sediments, as are coarse clastic materials. Almost all of the siliceous clastic debris ranges from the size of coarse silt to very fine sand. The constant crystal size of the dolomite and the complete mixing of the dolomite and sand has already been discussed. The deposition was probably in a relatively shallow area in which the finest clastic sediments were winnowed out from the supply and transported beyond the area of the Sacramento exposures. The increase in the shale toward the southern part of the Sacramento Mountains may indicate increased distance from a shore line, but available data are inadequate.

Contact relationships:

The Onate formation is separated by a disconformity from the underlying Fusselman (?) formation over most of the Sacramento Mountain escarpment. The exception is at the structurally high area of Pig Canyon, the northernmost limit of the Devonian formations, where the Onate is in depositional contact with the Valmont formation. The disconformity is sharply marked by an abrupt change of lithology and fauna, but the exact contact is almost everywhere concealed. Because of the extreme relative resistance to erosion of the Fusselman (?) formation, the upper surface of this formation is exposed in many places. Siliceous iron-rich masses are scattered sporadically on the upper surface of the pre-Devonian dolomite. Locally, as in the upper Marble Canyon in the NE 1/4 NW 1/4 NE 1/4 sec. 25, T. 16 S., R. 10 E., the upper few few of the Fusselman(?) formation is completely silicified. The silicification may have been developed during erosion of the formation, similar to that described by Leith (1925) at other erosion surfaces. Where observed, the surface of erosion is essentially smooth.

Although the upper contact of the Onate with the Sly Gap may not represent an erosional break (Stevenson, 1945, p. 222), the writer considers a disconformity is probable between the Onate and Sly Gap formations of this report.

In much of the southern part of the Sacramento Mountains the Onate (?) is directly overlain by the shales tentatively considered to be the Ready Pay member of the Percha shale. In the area between Dog and Escondido Canyons, the Onate formation is directly overlain by the Caballero formation.

Fauna:

Much of the Onate formation is unfossiliferous, although locally abundant fossils of a few genera are present. The following fossils collected from the Onate formation have been identified by A. L. Bowsher:

Loc. 39

5 *Leiorhynchus* aff. *L. kellogi* Hall

Loc. 243a

8 *Sulcoretopora anomalotruncata* Fritz
2 *Cranaena lata* Stainbrook
1 *Leiorhynchus* aff. *L. kellogi* Hall

Loc. 287a

5 Sulcoretopora anomalotruncata Fritz
1 Productella cf. P. lachrymosa var. stigmata Hall
9 Atrypa devoniana Webster

Loc. 320b

1 Sulcoretopora anomalotruncata Fritz
7 Atrypa devoniana Webster
2 Schizophoria lata Stainbrook
2 Aulopora ? sp. indet.
1 Meristella sp. indet.

The locality descriptions are as follows:

Loc. 39: On the south side of Alamo Canyon, in the center of the SW1/4 NW1/4 sec. 3, T. 17 S., R. 10 E. Abundant poorly preserved Leiorhynchus along some bedding planes of the upper part of the Onate formation.

Loc. 243a: At the northwestern side of the conical hill of Devonian and Mississippian strata in the east center line of the SE1/4 NE1/4 sec. 2, T. 17 S., R. 10 E. Fossils from upper 3 feet of the Onate formation 22 to 25 feet above the base of the formation.

Loc. 287a: On the south side of Escondido Canyon, in the center of the SE1/4 SE1/4 sec. 26, T. 18 S., R. 10 E. The fossils occur about 40 feet above the base of the Onate formation, between two red-brown calcareous siltstone beds. Similar fossils observed at the same horizon in section 7, pl. 8, a mile to the north in the NE1/4 NW1/4 sec. 26.

Loc. 320b: On the north side of Deadman Canyon, in the NW1/4 SE1/4 sec. 15, T. 18 S., R. 10 E. The fossils were collected 45 feet above the base of the Devonian strata, along the line of section 6, pl. 8.

Stevenson cites as fossils of the Onate formation (1945, p. 227) "two species of Atrypa, a thin shelled Stropheodonta, Leiorhynchus sp. Melocrinites, sp., and a bryozoan described as S. anomalotruncata."

Age and correlation:

Stevenson (1945, p. 227) suggests that the Onate formation is late Middle Devonian or early late (Upper) Devonian. A. L. Bowsher reports as follows on the fossils from the Onate formation collected by the writer and on some additional fossils that he has collected:

> "Fossils submitted for identification from the Onate formation are not adequate to permit more accurate age determination than Middle or Upper Devonian . . . Fossils from the Onate formation collected recently appear from cursory examination to be late Middle Devonian. Some of the museum collections contain poorly preserved brachiopods which seem to be *Protoleptostrophia*. They resemble forms found in the Tully limestone. A single poorly preserved specimen of *Nervostrophia* is represented. *Protoleptostrophia* and *Nervostrophia* occur together only in the Tully and Cedar Valley levels of the Middle Devonian. In conclusion, I believe that the Onate formation of the Sacramento Mountains is late Middle Devonian in age and probably correlative to the Tully formation."

The Onate formation probably correlates with the fossiliferous middle part of the Canutillo formation of the Franklin Mountains. Nelson (1937, p. 89) named the Devonian strata of the Franklin Mountains the Canutillo formation. The formation there consists of three parts, a basal cherty limestone, a medial portion of fossiliferous gray limestone, and an upper portion of dark shale. The fossiliferous limestone unit is considered Middle Devonian. Stevenson (1942, pp. 22-23) termed the beds below the Sly Gap in New Mexico the Canutillo, but later applied the term Onate formation to these strata. He considered (1945, pp. 221-222) the Canutillo as a possible time equivalent but not a stratigraphic equivalent of the Onate formation. Laudon and Bowsher (1949, pp. 36, 37) indicate as Canutillo in the Franklin Mountains only the middle fossiliferous portion of Nelson's type section, and consider it to be the direct equivalent of the Onate formation of New Mexico. They believe the overlying shale unit of the type Canutillo section of the Franklin Mountains is probably Percha shale.

Regional relationships:

Compared to the older Paleozoic formations, the Onate is relatively restricted in distribution. Stevenson (1945, p. 222) recognized the Onate formation in the San Andres and Sacramento Mountains. It is probable that the lower unit of the Percha formation in the Organ Mountains indicated by Dunham (1935, p. 46) corresponds with the Onate formation. The only other outcrop area of the formation is reported by Laudon and Bowsher (1949, p. 71), who show ten feet of siltstones considered as Onate in the section on north Percha Creek in the Mimbres Mountains. The Onate formation is not recognized in the Hueco Mountains, or in the subsurface sections east of the Sacramento Mountains (Lloyd, 1949, p. 50). Thus if the Canutillo-Onate correlation is correct, and these other reports be accepted, the present known extent of the Onate formation is from the Mimbres region on the west to the Sacramento Mountains on the east, and from the Franklin Mountains on the south to the northern end of the San Andres Mountains on the north. The maximum reported thickness of the Onate formation is 86 feet at the type section in the southern San Andres Mountains, and over much of the area the formation is less than half this thickness.

SLY GAP FORMATION

Sly Gap is the name applied by Stevenson (1941, p. 65) to Upper Devonian strata in the San Andres and Sacramento Mountain areas that are older than the Percha shale. The type section is in Sly Gap on the south side of Sheep Mountain, sec. 25, T. 11 S., R. 5 E. in the northern San Andres Mountains. Stevenson correlated with the Sly Gap formation the strata described earlier by Stainbrook (1935) from near the head of Alamo Canyon, as well as similar strata from elsewhere along the Sacramento Mountain escarpment. The Sly Gap formation forms the upper unit of the Devonian strata in much of the Sacramento Mountain area, and consists largely of calcareous shales, minor nodular limestone, and black shale.

Areal Distribution:

The Sly Gap formation is widespread and rather well exposed in the area from Alamo Canyon northward. The typical Sly Gap lithology was found at all observed complete Devonian sections north of San Andres Canyon. The formation is missing in the vicinity of Dog and Escondido Canyons, where the Onate formation is overlain directly by the Caballero formation. Dark shales of uncertain affinities crop out above a basal silty dolomite in and south of Agua Chiquita Canyon along the western escarpment, and also in the structurally high area along the Bug Scuffle fault in Grapevine Canyon, several miles east of the front of the mountains. These may represent atypical lithofacies of the Onate or Sly Gap formation, or be equivalent to the Percha shale.

Lithology:

In this report the name Sly Gap formation is applied to the apparently conformable and intergradational sequence of gray calcareous shale, interbedded thin somewhat nodular gray limestone and minor black shale that overlies the dolomitic strata of the Onate formation. The unit is soft, non-resistant, and weathers to a light yellow color that conspicuously marks the larger outcrops and subtly colors the Sly Gap slopes. Good exposures are uncommon because of the non-resistant nature of the formation. Fossils are common. The thickness ranges from 0 to about 45 feet, and averages from 30 to 40 feet in most of the Mule, Alamo, and Marble Canyon areas.

Details of selected stratigraphic sections of the Devonian strata, including the Sly Gap formation, are shown on plate 8, together with correlations of these and other Devonian sections in the Sacramento Mountains.

The lower half or more of the formation at most localities consists of calcareous light gray or olive gray shale, commonly with thinner interbedded dark gray shales. Limestone nodules are conspicuous but form a small part of most sections. In the upper part of the formation, gray to pale yellow brown beds of limestone, rarely more than 6 inches in thickness are interbedded with gray and yellowish calcareous shales. Most of the fossils are in this part of the section. The light yellowish color of the weathered strata is helpful in locating good exposures of this formation in the field. Some of the limestones are nodular and resemble the overlying Caballero formation, but the Sly Gap strata can be distinguished by the interbedded black and gray shales, and by reference to the thin zone of "phosphatic" concretions, bone fragments, fish teeth, and other resistant materials at the base of the Caballero formation.

The "black" shale of the Sly Gap formation is non-calcareous, and the precise color is grayish black or brownish black rather than true black. Mica flakes are the only megascopically visible mineral. Although called shale by all workers, these rocks are rarely fissile. Rounded iron sulphide concretions are common.

Black shales are common in the upper part of the Devonian strata in many parts of New Mexico (Lloyd, 1949, p. 50), including the Sacramento Mountains. Stevenson reports dark, non-calcareous shale in the Sly Gap, Contadero, and Percha formations. Because of the general lithologic similarity, it is difficult to correlate with certainty the thin, non-fossiliferous dark shale units in many isolated areas of outcrop. In the Sacramento Mountains black shales are of at least two distinct ages; those of the Sly Gap formation, and later Devonian (?) shales.

The Caballero formation in the northern Sacramento Mountains locally directly overlies the thickest bed of black shale of the pre-Caballero sequence, as shown in figure 22. At least in one place in Marble Canyon in the NE 1/4 NW 1/4 sec. 28, T. 16 S., R. 10 E. the black shale is clearly later than the Sly Gap and is correlated with the Ready Pay member of the Percha shale. At other places, the black shale could be either Sly Gap or a later unit. At many of the places where the Caballero appears to overlie the dark shale, a few feet of nodular limestone and gray shale separate the dark shale from the distinctive detrital zone at the base of the Caballero formation. This was observed by Stainbrook (1935) at the section that he measured, and more recent observations by the writer and A. L. Bowsher indicate this to be common.

In the Devonian strata measured on the north side of the San Andres Canyon (see section 5, pl. 8), 20 feet above the top of the Onate formation, about 10 feet of thin, dark argillaceous limestones is interbedded with minor gray shale. One of the limestone beds is about three feet thick, and is locally replaced by dolomite. This part of the section has more limestone and thicker, more massive beds than those observed in the Sly Gap formation farther to the north. This may be only minor lateral variation within the Sly Gap section. These strata may be equivalent to the silty limestone of the *Spirifer* zone at the top of the Sly Gap type section, or possibly to the Contadero formation of the San Andres Mountains described by Stevenson (1945, p. 239). Detailed examination of all Devonian sections in the Mule and San Andres Canyon area is needed to determine the relationship of these limestone beds to the Sly Gap formation. Unfortunately, well exposed sections are uncommon in the area.

Grayish black shales separate the Onate formation and the Caballero formation in the area between Dog and San Andres Canyons. Strata typical of the Sly Gap are missing, and it seems probable that the dark shale is a later formation.

Neither the Sly Gap formation nor any black shales have been observed in the area from Dog Canyon southward to Escondido Canyon. Where well-exposed sections were examined (see sections 6 and 7, plate 8), the Caballero formation directly overlies silty dolomite of the Onate formation.

Southward from the vicinity of Agua Chiquita Canyon in the northern part of T. 18 S., R. 10 E. the Devonian rocks differ from sections farther north. The upper 20 feet in Aqua Chiquita Canyon (section 8, pl. 8) consists of dark gray, fissile, non-calcareous shale, which differs from the underlying shaly and dolomitic strata, but is similar to the dark shale north of Dog Canyon. On the south side of Nigger Ed Canyon (section 9, pl. 8), the lower strata resemble the Onate and are so correlated by the writer. The entire Devonian section at this point has previously been correlated with the Sly Gap (Stevenson, 1945, p. 226; Laudon and Bowsher, 1949, p. 30). The shaly part resembles that at the top of the Devonian in Agua Chiquita Canyon. Five feet of olive-gray, slightly nodular, silty limestone caps the shale, and is tentatively considered as Caballero, but this is an uncertain correlation. The writer does not recognize in the southern Sacramento Mountains, strata lithologically similar to Sly Gap strata in the northern part of the area. The correlations of plate 8 in this southern area are based on lithology. It is possible that some of these strata are equivalent to the Sly Gap, but until this is proved by faunal studies, the writer favors restricting the Sly Gap to the northern area where it forms a distinctive mappable lithologic unit. The only fossils found in a re-examination of this section with A. L. Bowsher during the spring of 1949, were a few fragments of the bryozoan, possibly Sulcoretopora.

Conditions of deposition:

The Sly Gap formation represents a change in both the type of sediment available for deposition and in the conditions prevailing during deposition of the Onate and older formations. Non-carbonate clastic material coarser than clay particles or the finer silt sizes is rare in the Sly Gap formation, but abundant in the underlying Onate. The carbonate mineral of the Sly Gap formation is generally calcite, as contrasted with dolomite in the Onate formation. The Sly Gap probably accumulated in a shallow marine basin that occupied much of south-central New Mexico. The rapidly alternating but recurring types of shale and limestone suggest considerable fluctuation of sea level. At times the bottom conditions were foul, permitting deposition and burial of the black shales which contain abundant organic matter and iron sulfides (Pettijohn, 1949, p. 457). This condition appears to have been increasingly prevalent during the deposition of the Sly Gap strata.

Contact relationships:

The basal contact of the formation is placed at the change from strata consisting largely of silty dolomite or dolomitic siltstone to less resistant beds of shale and limestone. It is possible that this contact is a disconformity. The contact and lower few feet of the Sly Gap are almost everywhere concealed by surficial debris. The lithologic change is abrupt. There is local evidence suggesting that parts of the underlying Onate formation are missing as a result of erosion prior to the deposition of the Sly Gap formation (see p.102). At one of the few places where the upper surface of the Onate formation is well exposed, in the SE1/4 NW1/4 sec. 14, T. 16 S., R. 10 E. red iron stains and small red-brown siliceous masses are scattered over the top surface of the Onate formation. These resemble others along the top surface of the Fusselman formation, a known disconformity. The relief of the basal Sly Gap contact appears to be very low.

The upper contact is with the Ready Pay member of the Percha shale, and the Caballero formation in the Sacramento Mountain area. The contact is probably disconformable. The only angular discordance is at a local channel structure in the Marble Canyon area as discussed on p.120.

Fauna:

The Sly Gap formation is one of the few units in the area that has received much attention from paleontologists. The large and varied fauna of the formation at the type locality has been summarized by Stevenson (1945, p. 239), but faunal lists of his collections from the Sly Gap of the Sacramento Mountains have not been published. Stainbrook (1948, pp. 765-790) recently has summarized his earlier work (1935; 1945), and described additional fossils from the Sly Gap strata, all collected in the Sacramento Mountains and north of Alamo Canyon. The strata from which his fossils were collected are believed to be equivalent to the Sly Gap formation recognized in this report.

No attempt was made to collect a large fauna from the Sly Gap formation. The few fossils collected have been identified by A. L. Bowsher:

Loc. 180a: From two feet of gray shale at base of nodular Caballero formation at the east end of Devonian and Mississippian strata NE1/4 SW1/4 sec. 14, T. 16 S., R. 10 W.

1 Barroisella sp.
6 Chonetes sp. indet.
1 Stenoschisma ? sp. indet.
1 Ambocoelia sp. indet.

Loc. 187c: From yellow weathering shales 10 feet above the top of the Onate formation in the SE1/4 NW1/4 sec. 14, T. 16 S., R. 10 W.

1 *Hypothyridina* aff. *H. emmonsi* (Hall and Whitfield)
4 *Thomasaria altumbona* Stainbrook

Loc. 243b: From the thin limestone beds 30 feet above the top of the Onate formation on the northwest side of the conical hill of Devonian and Mississippian strata in the east center line of the SE1/4 NE1/4 sec. 2, T. 17 S., R. 10 E.

1 *Ambocoelia* sp. indet.
1 Coral-genus ans sp. indet. (Macgeea?)

A. L. Bowsher is currently studying the detailed lithologic sequence and the associated fauna from many zones within the Devonian rocks of the northern Sacramento Mountains.

Age and Correlation:

The age of the Sly Gap formation is known from the abundant fauna to be Upper Devonian, but the precise faunal equivalent in the Devonian sequence of the Mississippi Valley area has been debated by Stevenson and Stainbrook. Stevenson (1945, p. 239) believes the Sly Gap fauna is

> "slightly older than the Hackberry and younger than the Independence fauna, . . . slightly older than that from the Martin limestone of Arizona, . . . and tentatively suggests a correlation with the Devils Gate formation of Nevada."

Stainbrook (1948, pp. 784) sums up his extensive studies of the Sly Gap fauna as follows:

> "comparison of the Sly Gap fauna of Alamogordo, New Mexico, with that of the Independence shale of Iowa, demonstrates that they are practically identical and therefore, probably of the same age."

Stainbrook considers the Independence shale to be basal Upper Devonian, somewhat lower than its position indicated by Cooper, et al (1942, p. 1737).

Regional relationships:

The Sly Gap formation is widespread in the mountains of south-central New Mexico, but is somewhat more restricted in distribution than the Onate formation. Stevenson (1945) and Laudon and Bowsher (1949, p. 35) recognize the Sly Gap throughout the San Andres Mountains. The upper Percha, recognized as a lithologic unit in the Organ Mountains by Dunham (1935, p. 46), probably is the Sly Gap formation. To the south the formation is not recognized in the Franklin Mountains, nor is it known to the north in the Oscura Mountains. Stevenson (1945, p. 237) states the western limit of outcrop of the Sly Gap is in the Mud Springs Mountains, two miles northwest of Hot Springs, in the Rio Grande Valley. Sections similar to those in the Mud Springs Mountains are reported from the Sierra Caballo Mountains in the same region. The eastern limit of outcrop of the formation is in the Sacramento Mountains, where it is largely restricted to the central and northern part of the mountains. No Sly Gap strata or faunal equivalents have been reported in the Hueco Mountains or in the subsurface sections east of the Sacramento and Hueco Mountains (Lloyd, 1949, p. 49).

PERCHA SHALE

The Percha shale was named by Gordon (1907, p. 60, 62) from the Hillsboro area, and the name was applied to the entire Devonian section in the mountains of southern New Mexico by Darton (1917, 1928). Stevenson (1942, pp. 23-24) divided the Percha shale into the "lower Percha shale" and the "upper Percha shale", and in 1945 (p. 241) proposed the names, "Ready Pay member" and the "Box member" for the lower and upper Percha shale, respectively. Keyes (1908) had proposed the names, Silver and Bella shale for the Devonian in New Mexico, and his subdivisions were used by Stainbrook (1947, p. 298). Other workers in the stratigraphy of the Devonian of New Mexico have not adopted the Keyes nomenclature. Laudon and Bowsher (1949, p. 57) sum up the arguments as follows:

> "Keyes . . . units were poorly defined, type localities were vaguely referred to and Keyes himself subsequently so misused the names that they are best discarded."

Stevenson correlates with the Ready Pay member the black, fissile non-fossiliferous shale found above the Sly Gap and below the Mississippian formations in the San Andres, Franklin, and Sacramento Mountains.

The dark shales in the southern end of the mountains may be Onate, Sly Gap, or the Ready Pay member of the Percha shale. The writer favors assigning these to the Percha, but has no conclusive evidence. Lloyd (1949, pp. 49-50) considers the dark shales of the Devonian in the subsurface areas southeast of the Sacramento Mountains to be the Ready Pay member of the Percha. The southeasternmost exposure of the Devonian strata in the Sacramento Mountains (section 10, pl. 8) appears to be transitional in lithology between the Devonian sections exposed at the surface to the northwest and the subsurface sections reported by Lloyd

(1949, p. 49), as in those areas 40 to 80 feet of black shale directly overlie the Fusselman formation.

In the northern Sacramento Mountains, (Stevenson (1945, pp. 234-237) discovered and reported in some detail a local angular unconformity between black shale overlying the Sly Gap formation and underlying the Mississippian strata. It is the only known angular unconformity in the Devonian of the region. The location of this interesting feature is in the east edge of the NE1/4 NW1/4 sec. 26, T. 16 S., R. 10 E., on the south side of Marble Canyon. At this locality, the Silurian and most Devonian and Mississippian strata exposed strike N. to N 20° W. and dip 15 to 20° to the west. The Sly Gap and Mississippian formations are exposed in this area around the base of two V-shaped promentories that project eastward on the dip slope of Fusselman (?) formation (Fig. 20). The two promentories are about 600 feet apart, and are separated by a small draw; the best exposures are on their sharp eastern ends. On the southeast side of the northern promentory, as reported by Stevenson, black shales lie with angular discordance upon the Sly Gap formation, and are unconformably overlain by younger Devonian or Mississippian strata. The Fusselman (?), Onate, Sly Gap, and Mississippian formations are essentially parallel. The black shales, with minor siltstone beds less than 1 inch thick, appear to form a channel filling in the Sly Gap formation. At the northern promentory, as described by Stevenson, the black shales clearly lie with angular unconformity of about 20 degrees with the Sly Gap formation. Over a distance of less than 100 feet, most of the Sly Gap formation is cut out. Exposures where the black shale is in depositional contact with the Onate or Fusselman (?) formation were not observed. Exposures on the southern promontory about 500 feet southwest of the northern one, are not as good, but dark shale and siltstone beds here are also discordant to the Caballero formation, and significantly dip toward the north. Thus the shale body is lenticular and the beds dip toward the center. Meagre data suggest that the shale thins to the east as well as to the north and south. The discovery of the angular unconformity on the southern promontory, not observed by Stevenson, seems to rule out his explanation of faulting and to explain the angular discordance.

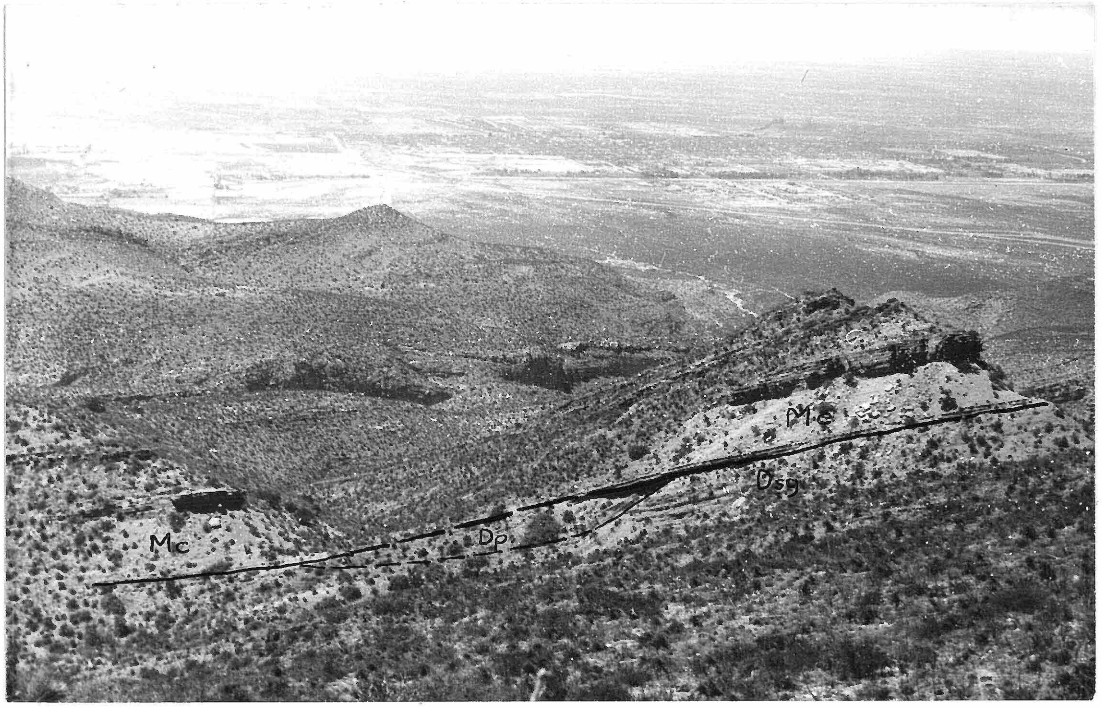

Figure 20. View from the east of locality where black shales of the Ready Pay member of the Percha shale occupy a channel cut into the Slay Gap formation. M_c = Caballero formation, D_p = Percha shale, D_{sg} = Sly Gap formation. NE¼ NW¼ sec. 26, T. 16 S., R. 10 E.

The main body of black shale is interpreted as a channel filling deposit, and is clearly younger than the Sly Gap formation and older than the Caballero formation. Stevenson (1945, p. 220) has indicated the probable correlation of the black shales with the Ready Pay member of the Percha shale, and this is adopted in this report. The black shales presumably were once more extensive, and were largely removed by pre-Caballero erosion. The shales of the channel deposit are overlain by 6 inches to a foot of dark gray-black shale separating the angular unconformity from the lowest nodular beds of the Caballero formation. This layer of black shales may be either later Devonian, or a basal deposit of the Caballero formation.

MISSISSIPPIAN SYSTEM

The stratigraphy of the Mississippian formations constitutes a notable exception to the general lack of recent research in the Paleozoic formations of southern New Mexico. Laudon and Bowsher first reported the results of their studies on the Mississippian formations of the Sacramento Mountains in 1941. Since this early publication, they have extended their studies to the Mississippian formations in all parts of southwestern New Mexico. Their comprehensive report on Mississippian formations of southwestern New Mexico (1949, p. 1-68) includes ten pages (pp. 22-31) of excellent discussion of relations in the Sacramento Mountains.

Laudon and Bowsher kindly made the manuscript and stratigraphic sections of the 1949 paper available to the writer in the fall of 1947, before the start of detailed mapping in the present project. The time available to the writer for study of this small but interesting part of the Paleozoic stratigraphic section precluded any attempt to study all phases of the Mississippian stratigraphy in more detail than the previous work. In the amount of time available, it seemed best to concentrate on the features of the Mississippian strata that could be best studied during the mapping of the Sacramento Mountain escarpment, rather than to duplicate stratigraphic detail already recorded by Laudon and Bowsher. The writer concentrated largely on mapping the major formations and some of the members of the Mississippian established by Lauden and Bowsher. Details of the stratigraphic section have been studied only where the observed relationships appeared to vary significantly from those previously reported, and where this detail was necessary to adequately map the major units of the Mississippian formations. The interesting problems of stratigraphy and sedimentary petrology of the bioherms and their associated facies have been left largely untouched. These are the subject of continuing investigations by A. L. Bowsher (1948).

Laudon and Bowsher (1941, pp. 2109-10; 1949, pp. 6-8) have presented an historical review of the Mississippian stratigraphy of southern New Mexico. The following statement concerns only the principal literature of the Mississippian formations of the Sacramento Mountain area, and is summarized on Figure 21.

<table>
<tr><th colspan="8">SACRAMENTO MOUNTAINS</th><th colspan="4">STANDARD SECTION</th></tr>
<tr><th rowspan="2">HERRICK 1900</th><th rowspan="2">DARTON 1917–1928</th><th colspan="4">LAUDON AND BOWSHER</th><th colspan="2" rowspan="2">THIS REPORT</th><th colspan="2" rowspan="2">ROCK UNITS SOUTHERN NEW MEXICO</th><th rowspan="2">SERIES</th><th rowspan="2">SYSTEM</th></tr>
<tr><th colspan="2">1941</th><th colspan="2">1949</th></tr>
<tr><td rowspan="10">LAKE VALLEY FM.</td><td rowspan="10">LAKE VALLEY FM.</td><td colspan="2" rowspan="2"></td><td colspan="2"></td><td colspan="2">HELMS FM.</td><td colspan="2">HELMS FM.</td><td>CHESTERIAN</td><td rowspan="10">MISSISSIPPIAN</td></tr>
<tr><td colspan="2">RANCHERIA FM.</td><td colspan="2">RANCHERIA FM.
LAS CRUCES (?) FM.</td><td colspan="2">RANCHERIA FM.
LAS CRUCES FM.</td><td>MERAMECIAN</td></tr>
<tr><td rowspan="7">LAKE VALLEY FM.</td><td rowspan="2">Dona Ana Mbr</td><td rowspan="7">LAKE VALLEY FM.</td><td rowspan="2">Dona Ana Mbr.</td><td rowspan="7">LAKE VALLEY FM.</td><td rowspan="2">Dona Ana Mbr.</td><td colspan="2">KELLY FM.</td><td rowspan="7">OSAGIAN</td></tr>
<tr><td rowspan="6">LAKE VALLEY FM.</td><td>Dona Ana Mbr.</td></tr>
<tr><td>Arcente Mbr.</td><td>Arcente Mbr.</td><td>Arcente Mbr.</td><td>Arcente Mbr.</td></tr>
<tr><td rowspan="4">Alamogordo Mbr.</td><td>Tierra Blanca Mbr.</td><td>Tierra Blanca Mbr.</td><td>Tierra Blanca Mbr.</td></tr>
<tr><td>Nunn Mbr.</td><td>Nunn Mbr.</td><td>Nunn Mbr.</td></tr>
<tr><td>Alamogordo Mbr.</td><td>Alamogordo Mbr.</td><td>Alamogordo Mbr.</td></tr>
<tr><td>Andrecito Mbr.</td><td>Andrecito Mbr.</td><td>Andrecito Mbr.</td></tr>
<tr><td colspan="2">CABALLERO FM.</td><td colspan="2">CABALLERO FM.</td><td colspan="2">CABALLERO FM.</td><td colspan="2">CABALLERO FM.</td><td>KINDERHOOKIAN</td></tr>
</table>

CLASSIFICATION OF MISSISSIPPIAN STRATA OF SACRAMENTO MOUNTAINS

Figure 21

Mississippian strata were first identified in the Sacramento Mountains by Herrick (1900 pp. 6-8), although the prolific Mississippian crinoid faunas of Lake Valley, New Mexico, had been known for nearly twenty years (White, 1881, p. 671; Cope 1882, pp. 158-159, and later workers). Meinzer and Hare (1915, p. 57) state that G. E. Girty found lower Mississippian fossils in several hundred feet of limestone east of Alamogordo in 1908. Darton (1917, pp. 48-50) presents a stratigraphic section measured by Girty northeast of Alamogordo, and states that the Mississippian limestones are continuous from east of Alamogordo nearly to Grapevine Canyon. Darton (1928, pp. 104-05) correlated all of the Sacramento Mountain Mississippian strata with the Lake Valley formation established by Cope (1882, pp. 158-59).

Baker (1920, pp. 104-05) reported a 285 foot section of Mississippian strata in Agua Chiquita Canyon, in the southern Sacramento Mountains, and stated that he recognized similar strata only in the southern Sacramento and San Andres Mountains. Although Baker considered the strata of Kinderhookian or possibly of Burlington age (probably on the basis of the fauna of the more fossiliferous lower units), his recognition that similar strata are confined to the southern parts of the Sacramento and San Andres Mountains indicates his awareness of mappable units in the Mississippian that were not defined until recently (Laudon and Bowsher, 1949, pp. 17-19, 30).

Laudon and Bowsher (1941, pp. 2107-53) divided the lower Mississippian strata into two formations, the Caballero formation of Kinderhookian age, and the Lake Valley formation (restricted) of Osagian age. The Lake Valley formation was subdivided into three members, which, in order of decreasing age, are the Alamogordo, the Arcente, and the Dona Ana members.

The type section for these three members and for the underlying Caballero formation is located in the Deadman Canyon branch of Alamo Canyon, in NW/14 SE1/4 sec. 3, T. 17 S., R. 10 E.

On the basis of further studies in southwestern New Mexico, Laudon and Bowsher (1949, p. 1-88) subdivided the Alamogordo member of the Lake Valley formation into the Andrecito, the Alamogordo (restricted), the Nunn, and the Tierra Blanca members, in order of decreasing age. They also recognized Upper Mississippian strata in the southern Sacramento Mountains and correlated these strata with the Rancheria formation, a unit named by them from the Franklin Mountains of western Texas.

During the present investigation, the Mississippian strata were found to be essentially as outlined by Laudon and Bowsher in 1949. The differences are mostly those that would normally be expected when stratigraphic units are traced continuously over a wide area, and concern largely the distribution of the Upper Mississippian strata. The major changes are the recognition of the Rancheria formation as far north as Alamo Canyon; recognition of the Helms formation in the southern part of the Sacramento escarpment; discovery of strata that appear to correlate with the Las Cruces formation, and identification of Mississippian strata in the Grapevine Canyon area, 4 miles southeast of previously known Mississippian outcrops.

Mississippian strata are exposed in the major canyons and along the west front of the Sacramento Mountains from Indian Wells Canyon northeast of Alamogordo to a mile south of Nigger Ed Canyon. They also crop out in the isolated structural highs of Pig and Arcente Canyons northeast of Alamo Peak, and on both sides of the Bug Scuffle fault in Grapevine Canyon, near the southern end of the mountains.

In a general way, the areal extent of the Mississippian formations decreases with decreasing age. The Caballero formation is present at the base of the section throughout the area of outcrop of Mississippian rocks. The overlying Lake Valley formation is known in the Mississippian section throughout the area, except at the southeasternmost area of outcrops in the Grapevine Canyon area. The Rancheria formation is thick in the southern area, and overlaps far to the north on the Lake Valley formation, but is absent from the northwestern part of the mountains. The youngest, the Helms formation, is only known in the southern part of the mountains.

The Lake Valley formation and the Upper Mississippian strata form mutually compensating wedges that taper toward the southeast and the northwest respectively. Thus the stratigraphic interval from the Caballero formation to the base of the Pennsylvanian is almost everywhere 200 feet thick, whether the interval be examined in the northern part where only the Lower Mississippian formations are present, in the southeasternmost area where Upper Mississippian strata are predominant, or at intermediate points where strata of both Lower and Upper Mississippian are well represented.

CABALLERO FORMATION

Laudon and Bowsher (1941, p. 2115) proposed the name Caballero formation for the gray, nodular, shaly limestone beds that form the basal part of the Mississippian strata in the Sacramento Mountains and that are separated from the overlying Lake Valley formation by a disconformity. The type section is located in the NW1/4 SE1/4 sec. 3, T. 17 S., R. 10 E. in a small tributary near the head of the Deadman Canyon* branch of Alamo Canyon.

The nature and relationships of the Caballero formation have been found to be essentially as described by Laudon and Bowsher (1941, 1949). The essential lithologic features of the Caballero formation at the type section are indicated on Figure 22, reproduced from Laudon and Bowsher (1949, Fig. 18). Although the maximum thickness of the Caballero formation is not more than 70 feet, the formation has been found at the base of every well exposed section of Mississippian strata examined by the writer in the Sacramento Mountains. Because of this, and for cartographic convenience, the Caballero formation is combined with the four lower members of the Lake Valley formation on the geologic maps. Variations in lithology and thickness have been indicated by Laudon and Bowsher (1941, p. 2154), and additional data are shown on plate 9, a generalized correlation diagram of the Mississippian strata of the Sacramento Mountains based on sections measured during the present investigation.

The Caballero formation is one of the more distinctive lithologic units of the Sacramento Mountains. It is composed of interbedded gray, argillaceous limestone nodules and gray, calcareous shales, in about

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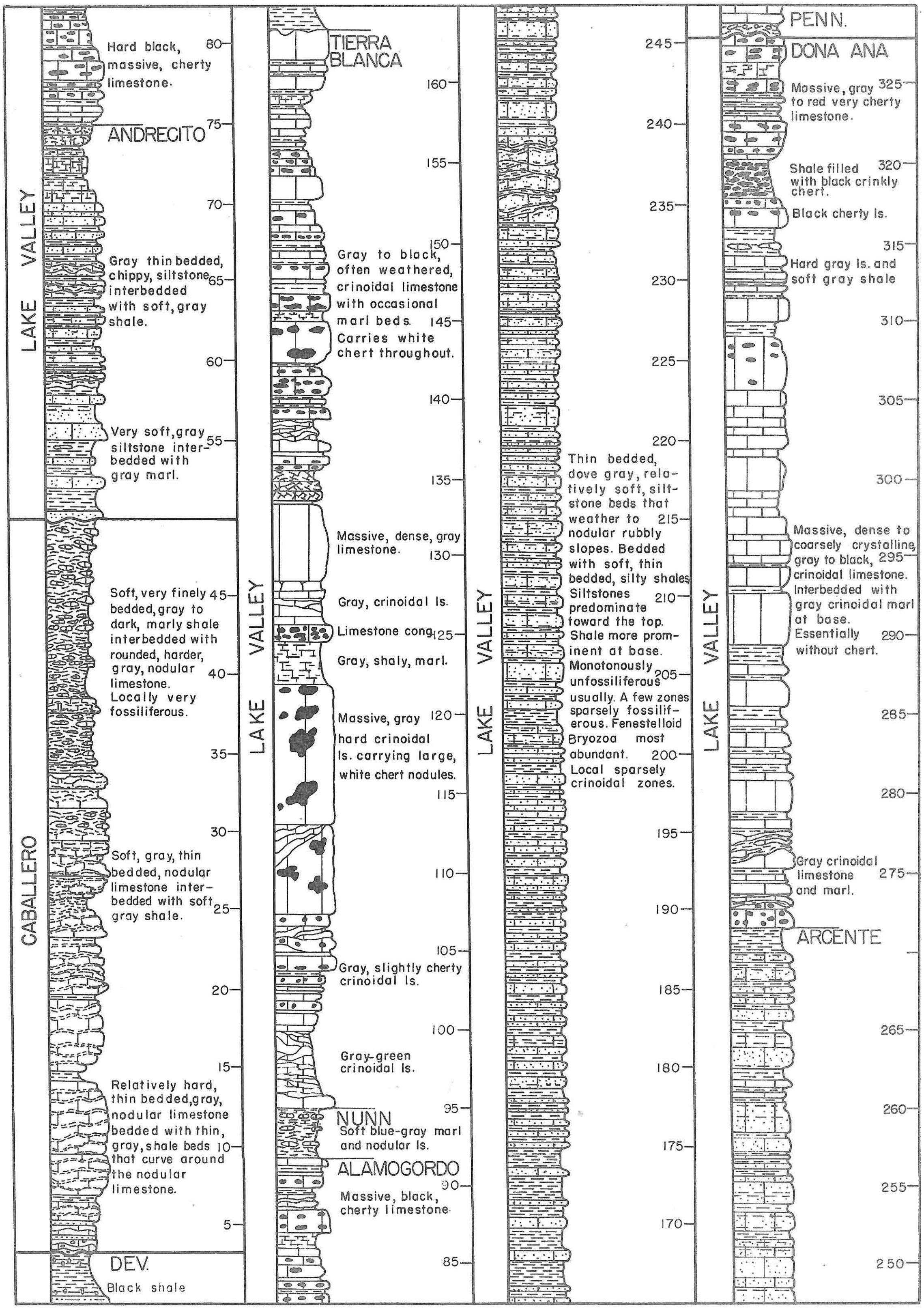
* Not to be confused with Deadman Canyon in the center of T.19S., R. 10 E.

DEADMAN CANYON
SACRAMENTO MOUNTAINS
SEC. 3, T. 17 S., R. 10 E.



LAUDON & BOWSHER (1949)

Figure 22. Stratigraphic section of Mississippian strata at the Deadman Canyon branch of Alamo Canyon, reproduced from Laudon and Bowsher (1949)

equal proportions. The only other strata of the area that might be confused with the Caballero are some of the nodular limestones of upper Sly Gap. However, the latter are generally interbedded with yellow, gray, and black shale, and can be differentiated in most places by their stratigraphic position with respect to the sharply defined base of the Caballero formation.

The Caballero formation has relatively low resistance to erosion, and at most places is covered by a thin veneer of slope wash. The basal and upper parts of the formation commonly are somewhat more resistant than the strata above and below, and form low scarps in some better exposed sections.

The nodules are ellipsoidal in shape, commonly one to two inches in diameter, and two to four inches long. Both the nodules and the enclosing shaly matrix contain abundant small fossil fragments, which locally form more than half of the rock. The nodules are resistant and litter the Caballero slopes. The shaly beds tend to wrap around the nodules, as pointed out by Laudon and Bowsher (1941, p. 2122), but few of the shale laminae appear to terminate abruptly against the nodules. Boundaries between the nodules and the shaly matrix commonly are sharp, but they appear to reflect more a discontinuity of cementation than a major change in composition.

The nodules are believed to be essentially syngenetic in origin. They are distributed along stratigraphic horizons in the Caballero formation. The strata containing only a few nodules can locally be traced laterally into more continuous beds of limestone, which are considered syngenetic. The shale wraps around the nodule, which strongly suggests the nodule existed prior to compaction of the strata. This relationship has been used as a criterion for syngenetic formation of concretions by

Tarr (1921, p. 384). See also Tarr and Twenhofel, in Twenhofel (1932, p. 713). Detailed field and laboratory studies are needed to understand the origin of these nodules.

Above the basal ledge of the formation, the Caballero is less nodular, and calcareous shale and marl are more abundant than limestone. In the upper part of the formation, particularly in the northern area, some of the limestones are calcarenites, composed largely of comminuted fossil debris, and form even, resistant beds a foot or less in thickness. In the southern part of the area, the Caballero formation contains more calcareous shale and marl than in areas to the north. Nodular limestone is less abundant and is largely restricted to the lower part of the formation. In the vicinity of Dog and Escondido Canyons, strata of calcareous green-gray shale and minor reddish calcareous shale are in the upper Caballero formation.

The thickness of the formation ranges from about 15 feet in the south to about 60 feet. In much of the northern and central areas it averages about 45 feet. The thinnest Caballero sections are in the Grapevine Canyon area, where the formation is overlain by the Upper Mississippian formations. Whether the thinness of the section is caused by pre-Upper Mississippian erosion, or by less initial deposition is not known. Probably both causes have been important.

The basal contact of the Caballero formation is sharply defined and is interpreted as a disconformity. The lower inch of the formation at almost all well exposed sections contains small, rounded, siliceous nodules ("phosphatic" nodules), bone fragments, fish teeth, and other resistant objects. These are known to occur at disconformities (Krumbein, 1942). The siliceous nodules commonly are an inch or less across, and dark gray in color, except for irregular white to pinkish mottling. These resistant nodules and fragments do not form a continuous layer, but it is rare to not find one or more in an exposure more than two or three feet long. As these materials have not been observed elsewhere, the zone makes an excellent horizon marker for the base of the Caballero formation.

The Caballero formation was deposited on a smooth surface of low relief where the surface has been observed. The systematic variations in the thickness of the Devonian strata also indicate the absence of much relief of the pre-Caballero erosion surface.

The Caballero formation underlies the Lake Valley formation in all but the small southeastern exposure in Grapevine Canyon, where Upper Mississippian strata overlies a thin section of Caballero beds. The contact is a disconformity in most of the area, but is probably an unconformity of low angular discordance where Upper Mississippian strata overlie the Caballero.

The Caballero formation contains a large invertebrate fauna, a detailed description of which was published by Laudon and Bowsher (1941, pp. 2123-25). They consider the fauna to be closely correlative with that of the Chouteau formation of the Upper Mississippi Valley, and hence of Kinderhookian age. In a recent paper, Miller and Youngquist (1947, pp. 113-117) describe a cephaloped fauna from the Caballero formation of the Sacramento Mountains, and consider this to confirm the Kinderhookian age of the formation. In comparison with the fauna of the Lake Valley formation, most of the Caballero forms are small in size. Two of the most abundant fossils of the Caballero are the coral, _Zaphrentis cliffordiana_ and the small brachiopod, _Spirifer louisianensis_. Laudon and Bowsher (1949) indicate the Caballero formation to be widespread in southwestern New Mexico. Lloyd (1949, p. 45) reports discovery of fossils equivalent to the Caballero formation in well cores from the subsurface of eastern New Mexico.

LAKE VALLEY FORMATION

The Lake Valley formation, as defined by Laudon and Bowsher (1941, p. 2115), is well developed in the Sacramento Mountains and consists largely of coarse crinoidal limestones and minor calcareous siltstones, shales, and marls. In 1941 Laudon and Bowsher divided the Lake Valley formation into three members, the Alamogordo, Arcente, and Dona Ana. The lowest of these was subdivided in 1949 into the Andrecito, Alamogordo (restricted), Nunn, and Tierra Blanca members (Figure 21).

The 1949 classification is well suited to detailed description and tracing of the highly variable lithologic units of the Lake Valley formation in many parts of the Sacramento Mountain area. However, the threefold division of the 1941 terminology was better adapted to the scale of mapping during this investigation, particularly in view of the thinness and the local rapid lateral transitions of the Alamogordo, Nunn, and Tierra Blanca members. On the geologic maps (Plates I and II) accompanying this report, the Arcente and Dona Ana members of the Lake Valley formation are differentiated as separate units. The Andrecito, Alamogordo (restricted), Nunn, and Tierra Blanca members of the Lake Valley formation are combined with the Caballero formation as a single map unit. The thinness of the Caballero formation, the scarcity of exposures of the contact at the top of the Caballero formation, and the fact that this formation occurs throughout the map area justify the inclusion of the Caballero formation with the basal strata of the Lake Valley formation as a single map unit.

The Andrecito, Alamogordo, Nunn, and Tierra Blanca members are the only units of the Lake Valley formation present in the northernmost parts of the area, where they comprise 150 to 350 feet of strata. The interesting biohermal structures are present largely in the northern and central part of the area. These introduce many complexities into the stratigraphy of the entire Lake Valley formation, and especially into that of the lower four members. The Lake Valley formation thins southward and eastward in the Sacramento Mountains, in part because of less original sedimentation in these directions, and in part because of erosion prior to the deposition of the Upper Mississippian strata. Along the southern part of the western escarpment, the lower four members are thin, and of these, only the Alamogordo member can be recognized with assurance. No Lake Valley strata have been identified in the Grapevine Canyon area, the southeastern limit of Mississippian outcrops of the Sacramento Mountains.

The Lake Valley formation is unconformably overlain by upper Mississippian formations in the central and southern part of the Sacramento Mountain escarpment, and by the Pennsylvanian strata in the northern part of the area.

Bioherms:

Bioherms which locally are conspicuously developed in the Lake Valley formation are one of the most interesting stratigraphic features of the Sacramento Mountains. Bioherms were first recognized and described by Laudon and Bowsher (1941) and in 1948 were the subject of a short paper by Bowsher. As the bioherms are currently under investigation by Bowsher, and because of the time limitations in the present project, the writer has not attempted detailed studies of these interesting features. However, in the course of mapping even the major units of the Mississippian strata it was necessary to recognize and interpret the larger features of the bioherms. The observations and interpretations are summarized in the following paragraphs.

Definitions: The term bioherm was first proposed by Cumings and Shrock (1928, p. 599), and the definition was later rephrased by Cumings (1930, p. 207) as follows:

> "The term bioherm . . . is defined as consisting of any dome-like, mound-like, lense-like or otherwise circumscribed mass, built exclusively or mainly by sedentary organisms such as corals, stromatoporoids, algae, brachiopods, molluscs, crinoids, etc., and enclosed in normal rock of different lithologic character."

In 1932, (Cumings (1932, pp. 331-52) further discussed the definition of bioherms and reefs. It is significant that he included under the term, bioherm, organically formed structures in which the top of the growing mass was not necessarily higher than the top of the contemporaneous sediments. For example, he cites as bioherms the Lucina shell banks that form the Tepee Buttes of Colorado, and describes these masses as probably never higher than the level of adjacent contemporaneous sediments during the time of formation. Stockdale (1931, p. 711) demonstrated that the crinoidal mounds of the Borden formation of Indiana accumulated at the same rate and level as the contemporaneous sediments, and comments that the term bioherm is particularly suitable for these structures. Shrock (1939, pp. 529-62) described the Silurian bioherms of Wisconsin and indicated that these structures were probably above the level of adjacent contemporaneous sediments at the time of formation, but does not restrict the definition of bioherm of this type of structure.

The recent petroleum production from reefs and bioherms has stimulated much discussion and redefinition of terms. Link (1950, p. 263) redefines bioherm as

> "An accumulation of the secreted hard parts of sessile types of primative invertebrates and plants such as corals, bryozoans, crinoids, sponges, algae, et cetera, which accumulation is greater than the surrounding contemporaneously deposited sediments, thus giving rise to mounds, ridges, and reefs."

This restriction of the term to organic accumulations that were above the level of contemporaneous adjacent sediments, does not seem justified to the writer. However, many bioherms have formed at and above wave base, higher than the level of contemporaneous adjacent sediments, and the distinction is important where it can be made. Most modern definitions of the term reef, for example (Ladd, 1944, and Lowenstam, 1950, pp. 432-33), require that the growing organic accumulations be a wave resistant feature formed above the level of contemporaneous lateral sediments. Current usage also seems to restrict the term reef to large-scale features. Those only a few feet or tens of feet in size are generally referred to as bioherms, and not reefs, regardless of the relationship of the growing mass to contemporaneous sediments.

The lenticular limestone masses in the Mississippian strata of the Sacramento Mountains have been termed bioherms by Laudon and Bowsher (1941, 1949) and by Bowsher (1948). Not all of these features appear to conform to even the broad definition of bioherm as stated by Cumings. Some appear to have formed by the aggregation of organic material essentially in place, and can be classed as true bioherms. Of these, some appear to have formed above the probable level of contemporaneous sediments, in part were subject to marine erosion, are large masses, and hence can be considered true reefs. Others may be only aggregations of crinoidal detrital material into mound-like or ridge-like forms. The crinoidal debris may have been shifted considerably from the point of growth so that the resulting accumulations are neither bioherms nor reefs, but simply clastic accumulations or buildups. Unfortunately, it is difficult to determine whether crinoidal debris is essentially an autochthonous or allochthonous accumulation. The structures of the clastic buildups can be similar to some true bioherms. Detailed petrologic studies are necessary to properly differentiate the bioherms, reefs, and clastic buildups of this area.

In this report, the berm bioherm is used for all of the thickly lenticular limestone masses that have a massive, resistant core, although it is recognized that detailed examination of these features may indicate some of them to be allochthonous accumulations of crinoidal detritus and therefore, not within the strict definition of the term.

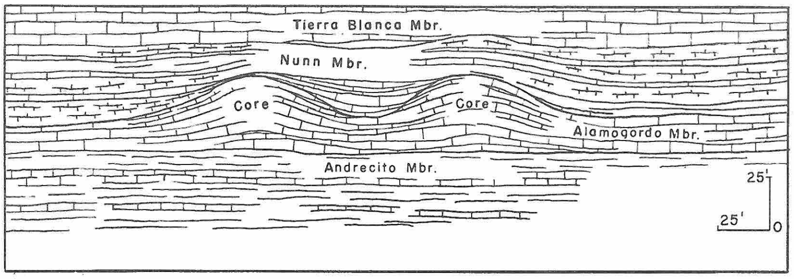
Distribution: Bioherms are present in nearly all of the members of the Lake Valley formation, but are most abundant in, and rising from, the Alamogordo member. Some extend from near the base of the Alamogordo member upward through the entire Mississippian sequence. Many are local features of the Tierra Blanca member, and a few small bioherms have been noted in the Dona Ana member. Laudon and Bowsher (1949, p. 31) cite one in the Rancheria formation in the southern part of the area.

Within the Lake Valley formation, the bioherms are most abundant in the northern part of the area. Bowsher (1948, p. 27) indicates more than 30 on a small scale geologic map in the area of Mississippian outcrops north of Long Ridge. Most of the bioherms are near the mountain front in the area between Marble and Indian Wells Canyon, and near the mouth of Alamo Canyon. In this area the bioherms are elongate along a north-south trend. The size and abundance of the bioherms and the total thickness of the pre-Arcente members of the Lake Valley formation diminishes toward the east. Only widely scattered small bioherms have been noted in the centermost Mississippian outcrops.

A second concentration of bioherms is in the vicinity of San Andreas Canyon, where the largest of these features in the area are developed. Two of these form conspicuous klints on the west front of the mountains, and are large enough to be visible from the main highway, four miles to the west. One of these, on the north side of Muleshoe Canyon near the center of sec. 28, T. 17 S., R. 10 E., was described by Laudon and Bowsher (1941, p. 2148), and is the mass shown on figure 24, and shows in the foreground of the aerial photographs used as the frontispiece. The second prominent mass, a mile south of San Andreas Canyon, in the SE1/4 sec. 4 and the NE1/4 sec. 9, T. 18 S., R. 10 E., is shown in Figure 25. A third large but poorly exposed bioherm is at the junction between the north and south fork of San Andreas Canyon, in sec. 35, T. 17 S., R. 10 E. Numerous smaller bioherms occur in the triangular area outlined by these three major bioherms. The Lake Valley formation, and especially its pre-Arcente members, thin markedly south of this area and no significant bioherms have been noted south of Dog Canyon.

Description and Interpretation: Bowsher (1948, p. 24) has classified the bioherms of the Sacramento Mountains into simple and compound types, as indicated in the diagram of figure 23. All gradations exist between the simple type with but a single core facies, and the compound type composed of multiple core facies.

SIMPLE TYPE BIOHERM



COMPOUND TYPE BIOHERM

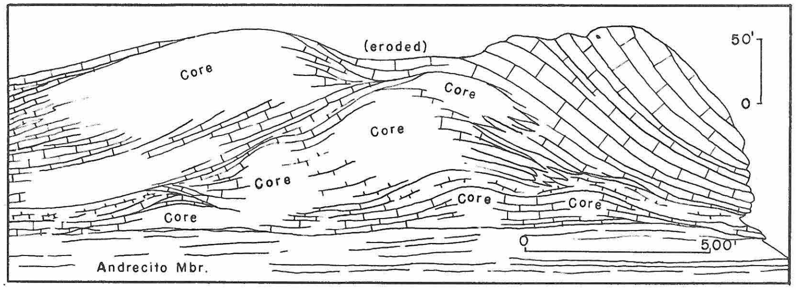


Figure 25. Simple and compound types of bioherms. (After Bowsher, 1948)

The simple bioherms are generally domical, and flanking strata dip outward from the core. This type of bioherm ranges in size from those only a few feet thick to the impressive features shown in figures 24 and 25, in which the core facies is more than 300 feet thick. The compound type, with multiple core facies, are commonly elongate, and may extend half a mile or more in the north-south direction, although it seems probable that single core facies are not continuous over this distance.

The core facies is composed largely of gray, finely crystalline to sublithographic limestone. Fossiliferous materials, mostly crinoid columnals are abundant, but in the true core facies, the amount of this material that is much less than in the flanking, bedded criquinas.

Some of the massive core facies appears to be partially recrystallized, as outlines of fossil fragments are indistinct. The massive cores appear to grade laterally into coarse crinoidal material.

Detailed study is needed to establish the extent of the recrystallization of the core facies. The nature of crinoidal material is such that it is not likely to form an actively growing bioherm that rises appreciably above the level of adjacent contemporaneous sedimentation. Some binding mechanism is needed to build the rigid mass that can remain above the adjacent sea floor. In other known bioherms and reefs, the most important organism is considered to be colonial algae. These have not been observed as yet in the bioherms of the Sacramento Mountains.

One of the largest and best exposed bioherms is north of San Andreas Canyon in sec. 28, T. 17 S., R. 10 E. The relationship of the core facies to the adjacent strata is best shown by reference to figure 24 and to plate 9, which includes a section at the bioherm core and a section less than half a mile to the south. The massive core rises from the Alamogordo member, and grades laterally into bedded strata composed dominantly of coarse crinoidal detritus, and of soft calcareous marl, which form the Nunn and Tierra Blanca members. The Andrecito and the basal part of the Alamogordo member appear to persist unchanged throughout the area, and are believed to have been deposited before the growth of the bioherm.

The growth of the bioherm appears to have begun during the deposition of the Alamogordo member and continued throughout the deposition of the Nunn and Tierra Blanca members, as all these members grade laterally into the core facies. The core facies of this bioherm stood

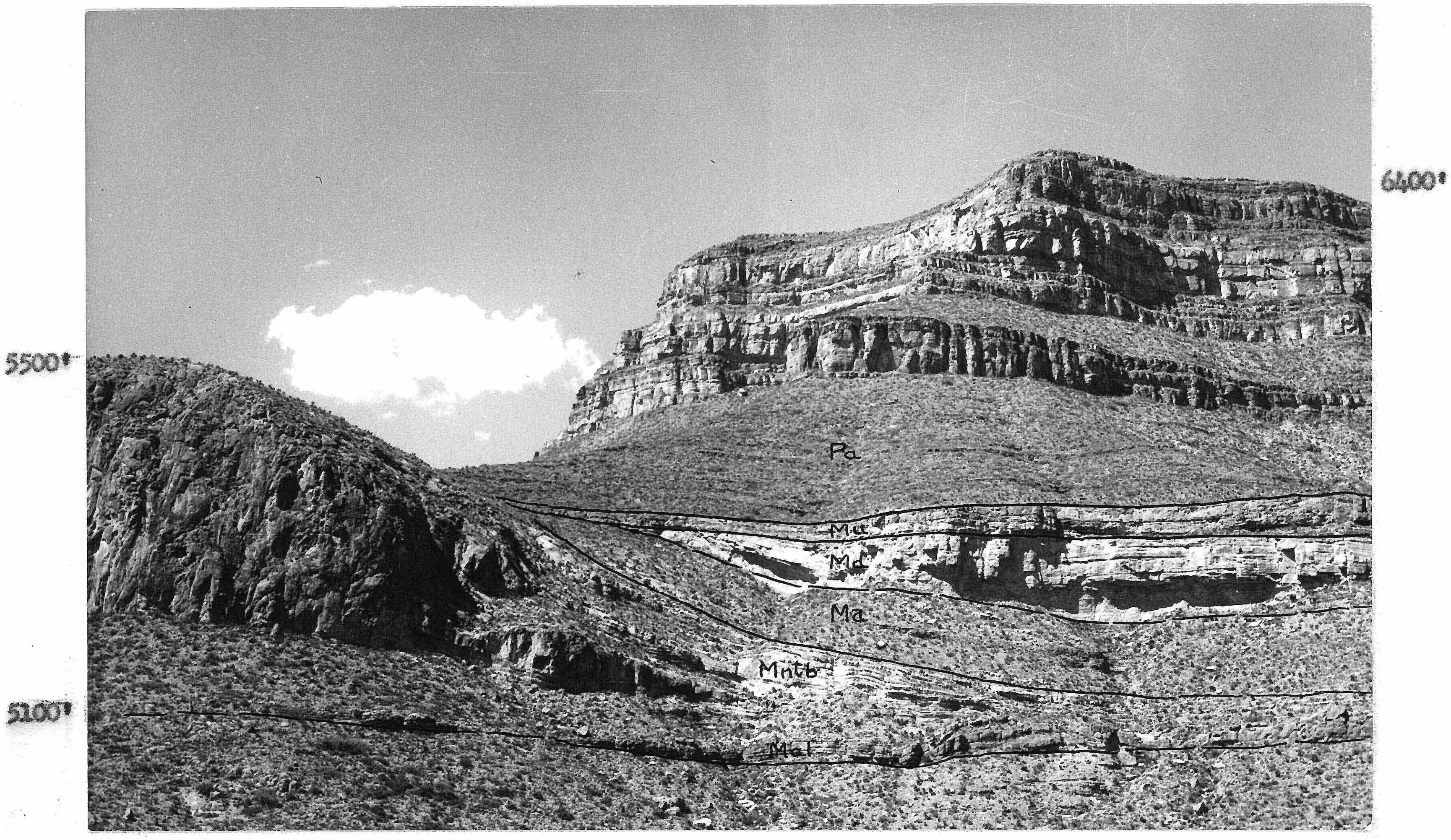


Figure 24. Bioherm and associated facies of the Lake Valley formation. Mal = Alamogordo member, Mntb = Nunn and Tierra Blanca member, Mar = Arcente member, Md = Dona Ana member of the Lake Valley formation; Mu = Upper Mississippian (Rancheria) formation; Pa = Pennsylvanian. North side of Muleshoe canyon, center of secs 28, T. 17 S., R. 10 E.

above the level of adjacent contemporaneous sedimentation. Part of the outward dip of the flanking strata is undoubtedly caused by the differential compaction of the soft strata adjacent to the bioherm as compared to the rigid core facies, but some of the outward dip is primary in origin. The best reason for this is the thinness of the strata of the adjacent areas that could have been subject to compaction. Less than 85 feet of strata are equivalent to the core facies that is nearly 400 feet in thickness. Of these 85 feet, probably less than half consist of marls that would undergo appreciable compaction. The coarse crinoidal limestone that forms the remainder of the section could not be expected to thin appreciably by compaction. At the section measured by Laundon and Bowsher (1941, p. 2147) about half a mile to the east of this bioherm only 70 feet of strata from the Andrecito to the Arcente are present. The possible compaction of these strata is much less than would be required for these strata to have accumulated at the level of the growing bioherm.

The growth of the bioherm must have ceased before the deposition of the Arcente strata. Possibly the introduction of large amounts of fine clastic material such as are in the Arcente member was a factor in killing of the bioherm, although if the Arcente is unconformable on the older members of the Lake Valley, the growth necessarily stopped prior to deposition of the Arcente. The Arcente laps onto, and sometimes over bioherms, but evidence of significant erosion prior to the deposition of this member in the area of the bioherms of the Sacramento Mountains, has not been observed by the writer. Laudon and Bowsher (1941, p. 2135) report evidence of disconformity where the Arcente overlies a bioherm in the San Andres Mountains.

The influence of the largest bioherms on later sedimentation and their resistance to erosion in Paleozoic time as well as at present, is striking. The Arcente and Dona Ana members are thickest in the interbiohermal areas, and thin over the bioherms. At some of the larger bioherms, they lap onto the flanks of the core facies, as in figures 24 and 25, indicating that the massive core facies was a prominence of the sea floor which influenced the deposition of these strata, as well as the older members of the Lake Valley formation. The resistance of these massive cores is further indicated by the fact that they were not removed by the erosion that preceded the deposition of the Upper Mississippian formations. This is shown on figure 24 by the thickening away from the biohermal core of the Upper Mississippian strata. The figure also shows truncation of the Dona Ana strata by the unconformity at the base of the Upper Mississippian strata. Even the erosion preceding deposition of the Pennsylvanian strata did not completely obliterate the knob made by the core of the bioherms of figures 24 and 25, as the lowest Pennsylvanian strata appear to lap onto the core.

There are almost all gradations from the striking large bioherms of essentially the simple type with a single core facies to bioherms only a few feet in thickness and to the larger compound types of bioherms. Many anomalies from the relatively simple picture here presented exist, but could not be studied in any detail. An example is indicated, however, by figure 26, in which the core facies of the Alamogordo member rises to a sharp point, a feature not observed elsewhere. The steep beds indicated on figure 26 in the Tierra Blanca cliff, seem further proof of primary dip of the beds flanking biohermal cores, as compaction cannot explain the structures shown on figure 26.

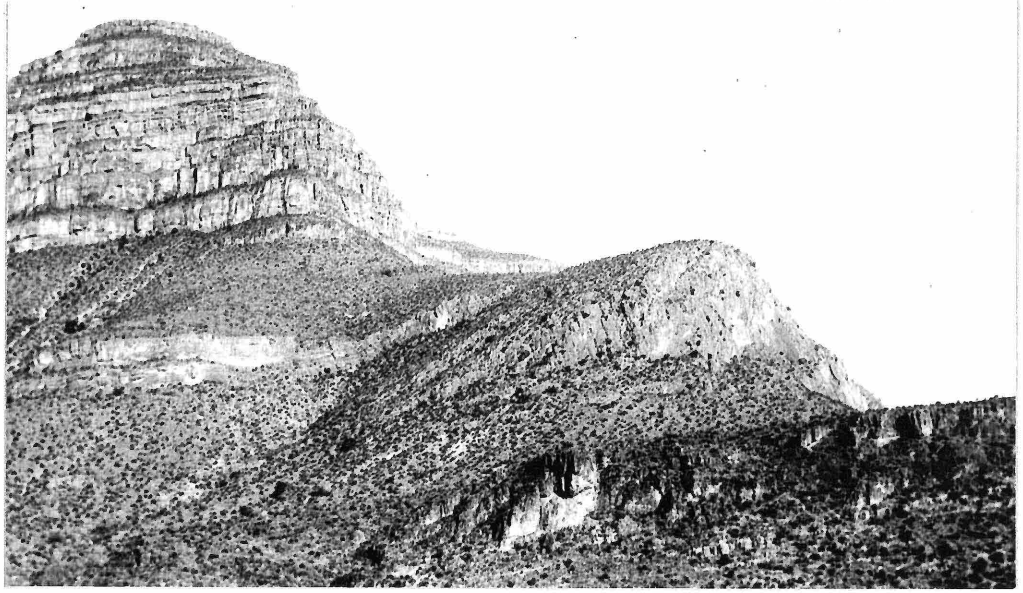


Figure 25. Bioherm of the Lake Valley formation. The core facies forms the conspicuous cliff in the center of the photograph. Dona Ana member of the Lake Valley formation and Upper Mississippian strata lap onto biohermal core. (SE¼ sec. 4, NE¼ sec. 9, T. 18 S., R. 10 E.)

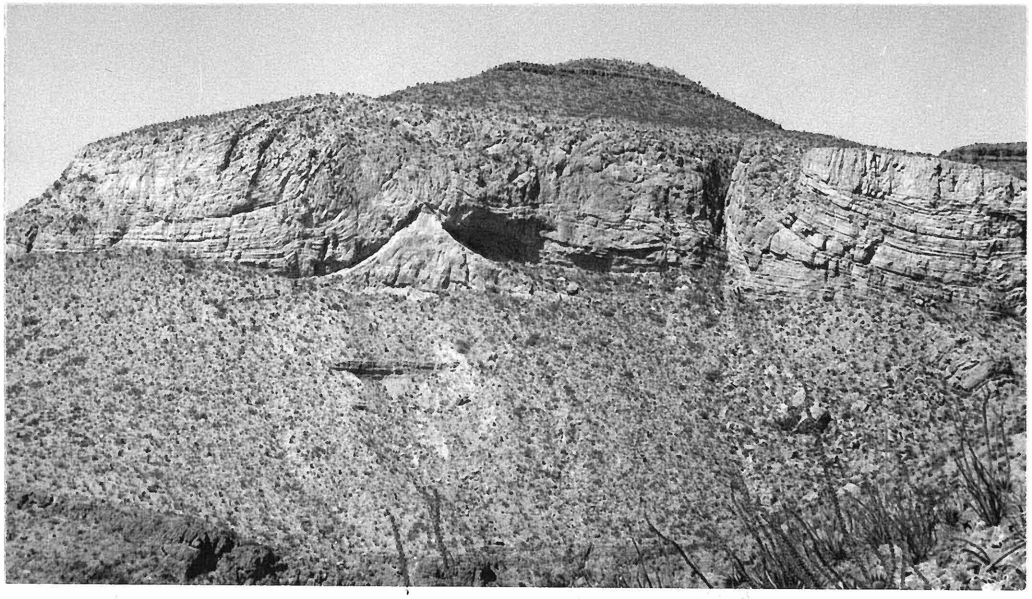


Figure 26. Bioherm (?) with anomalous concave profile, overlain by crinoidal limestone of the Tierra Blanca member of the Lake Valley formation. Unconformity at base of Pennsylvanian strata truncates structures of the Tierra Blanca member. (SE¼ NW¼ sec. 34, T. 16 S. R. 10 E.)

Andrecito Member:

The basal member of the Lake Valley formation was named the Andrecito by Laudon and Bowsher (1949, pp. 12-13), who designated the type section as the exposures along the south wall of Andrecito Canyon in the San Andres Mountains in the NW1/4 sec. 8, T. 18 S., R. 4 E. The member was referred to as the Taonurus siltstone by these authors in 1942 (p. 2126) because of the abundance of imprints of the fossil *Taonurus caudigalli*.

In the northern part of the Sacramento Mountains the Andrecito member forms a distinctive lithologic unit. The strata have little resistance to erosion, and form a short slope interval between the minor ledges at the top of the Caballero formation and the overlying cliff-forming Alamogordo member. The light yellow brown to greenish gray color of the weathered outcrops, the even bedded, argillaceous limestone, and the abundance of the *Taonorus* imprints all serve to distinguish this member.

The member is composed largely of calcareous shale, marl, and thin-bedded argillaceous limestone. Fossils are abundant. Figure 22 shows the details at the type section. Some of the beds are silty, especially at the base of the member. The coarsest siliceous particles noted in the Andrecito member are in the basal one-foot ledge that is present in much of the northern outcrop area. Insoluble residues from this stratum show few particles coarser than silt.

The thickness ranges from about 25 to 35 feet in the northern part of the Sacramento Mountains and thins toward the south. In the southern part of the mountains (fig. 27) about five feet of soft, buff-colored marl and a thin bed of argillaceous, silty limestone are probably correlate with the Andrecito, but the distinctive lithologic features of the northern sections are not present, and these thin strata may be a part of the Caballero formation.

The basal contact of the Andrecito member has been interpreted as an unconformity by Laudon and Bowsher (1941, p. 2122). These writers state (1949, p. 26) that relief due to erosion of the upper part of the Caballero formation can be demonstrated in the northern part of the Sacramento Mountains. The writer agrees with this interpretation. At several localities an angular discordance of a few degrees occurs between the Andrecito member and the Caballero formation. For example, on the east slope of Alamo Peak, in the NE 1/4 SE 1/4 sec. 25, T. 18 S., R. 10 E., erosion prior to the deposition of the Andrecito strata truncated the beds of the upper Caballero. About 5 feet of beds are cut out across a lateral distance of 50 feet. A similar relationship was observed in the SW 1/4 NE 1/4 sec. 14, T. 16 S., R. 10 E. The angular discordance must represent local conditions only as the thin Caballero formation is nowhere absent in this area. The local angular discordance adds support to Laudon and Bowsher's suggestion that reworked Caballero sediments form a part of the Andrecito member. The contact of the Andrecito member with the overlying Alamogordo member is defined by a change of lithology, but does not appear to represent an erosional break.

The age of the Andrecito member is considered by Laudon and Bowsher (1949, p. 26) as early Osagian on the basis of a large fauna.

Alamogordo member:

The Alamogordo member was initially defined by Laudon and Bowsher (1941, p. 2114), but in 1949 this name was restricted to only the "black chert limestone facies" of the original Alamogordo member. The type section is in a tributary of Deadman Canyon branch of Alamo Canyon, in the NW1/4 SE1/4 sec. 3, T. 17 S., R. 10 E. Most of the bioherms of the Lake Valley formation are developed in the Alamogordo member.

The Alamogordo beds form a resistant cliff in much of the area, and in many places this is the first conspicuous cliff above the Fusselman (?) formation. Where the bioherms are developed, their resistant cores stand out conspicuously as bold, nearly vertical cliffs (figures 24 and 25). Where the formation is uncomplicated by the bioherms, its thickness generally ranges from about 15 to 40 feet. Along the southern part of the escarpment, however, it thins to less than 5 feet (figure 27). The cliff weathers to a dark color, relative to the adjacent and overlying crinoidal limestones, but is rarely darker than a medium gray. The bedding planes, though sharply defined, are somewhat undulatory in detail, and generally are spaced from 6 inches to 2 feet apart. The limestone of the normal Alamogordo member is resistant, massive, calcilutite. The color of the rock is characteristically medium gray. Crinoid fragments and other fossiliferous material are sparsely distributed through the rock. Chert nodules and layers, medium to dark gray or brownish gray, are locally conspicuous, but generally form less than 10 per cent of the member. In the northern part of the area layers and nodules of chert are more abundant. Figures 22 and 27 give lithologic details of the Alamogordo member at two places in the area, thicknesses and general lithology are also indicated on plate 9.

The contact of the Alamogordo member with the Andrecito member is probably not a disconformity, although the change in the lithology is generally sharply defined. However, a possible detrital zone at the contact is exposed in the NE1/4 SE1/4 sec. 25, T. 16 S., R. 10 E., on the east side of Alamo Peak, where a one inch layer of dark limestone, fragmental in appearance, separates the fossiliferous and argillaceous limestone of the Andrecito member from the characteristic calcilutite of the Alamogordo member. The contact of the Alamogordo member with the overlying Nunn member is at a change in lithology, but probably is not a disconformity.

The age of the Alamogordo member is early Osagian (Laudon and Bowsher, 1941, p. 2133). The age is based in part on the fauna from the Alamogordo member, and in part on the age of the larger faunas collected from the Andrecito and the Nunn members.

Nunn Member:

The Nunn member was defined by Laudon and Bowsher in 1949 (p. 13), and consists of soft blue-gray marls and crinoidal limestone that lie above the Alamogordo member and below the more massive, gray, cherty, crinoidal limestone of the Tierra Blanca member. The type section is at Apache Hill, in the NE1/4 NW1/4 sec. 21 T. 18 S., R. 7 W. The unit is recognized by Laudon and Bowsher from the type section west of the Rio Grande to the Sacramento Mountains. It is equivalent to the "blue-gray shaly marl facies" noted by these men in the Sacramento Mountain area (1941, p. 2130).

The Nunn member is well developed in the Sacramento Mountains, but is much less resistent than the underlying and overlying members of the Lake Valley formation, and hence is poorly exposed. The interbedded soft marls and thin crinoidal limestones apparently were formed in a much less turbulent environment than that of the Alamogordo or Tierra Blanca members, as evidenced by the abundance of marl and the excellent preservation of crinoid calyxes and many segmented portions of crinoid stems.

Where large bioherms are developed, the Nunn member is thickest in the interbiohermal areas and commonly feathers out laterally against the bioherm, or continues over the mass as a unit only a few feet in thickness. In the southern part of the Sacramento Mountains, the Nunn member can be recognized as a thinning lithologic unit in the area of San Andres and Dog Canyons. Farther south the Arcente formation rests directly on the Alamogordo member, and the Nunn is missing. Pre-Arcente erosion may have removed the Nunn from this area. However, the Nunn member thins toward the south in the area in which it is overlain by the Tierra Blanca member, so it is probable that the original thickness of the Nunn member was less toward the south.

The abundant crinoidal fauna of the Nunn member is considered to be early Osagian by Laudon and Bowsher (1949, p. 28), and the crinoids midway in evolution between the Kinderhook and the Burlington forms.

Both upper and lower contacts of the member are believed to be conformable, and represent changes in sedimentation rather than erosion surfaces.

Tierra Blanca Member:

The name Tierra Blanca was proposed by Laudon and Bowsher (1949, p. 13-14) for the section of medium-bedded, gray to brown, crinoidal limestone beds containing light-colored chert that caps the Mississippian section at Lake Valley, New Mexico. This member grades imperceptibly down into the soft blue-gray marls of the Nunn member. The type section is near Lake Valley at Apache Hill, in the NE1/4 NW1/4 sec. 21, T. 18 S., R. 7 W., and the name is derived from Tierra Blanca Creek about six miles to the north. The member has been recognized in the area between Lake Valley and the Sacramento Mountains.

In the Sacramento Mountains the Tierra Blanca member forms a light colored, resistant cliff. It is very conspicuous east of Alamogordo, where it is nearly 200 feet in thickness (figure 26). The member consists almost entirely of coarse, well cemented, crinoidal detritus. Beds range in thickness from less than a foot to many feet, and in many places are very irregular and poorly defined. The member is a coarse clastic aggregate, and clastic structures such as cross-lamination, scouring, and channeling are common. Bioherms occur locally in the member.

In the Sacramento Mountains the member is thickest near the mountain front in the vicinity of Marble and Alamo Canyon, where it is almost everywhere more than 100 feet, and locally nearly 200 feet thick. Toward the east the unit decreases in thickness and is 50 to 100 feet thick in Arcente Canyon and the headwaters of Alamo Canyon. The member can be recognized adjacent to the large bioherms in the San Andreas-Dog Canyon area, but elsewhere south of Mule Canyon the distinction between the Nunn and Tierra Blanca is difficult. The Tierra Blanca is absent south of Dog Canyon, probably because of pre-Arcente erosion of an originally thin section of Tierra Blanca beds.

Large nodules of light gray and white chert are abundant. In many places, as on the north side of Alamo Canyon in sec. 7, T. 17 S., R. 10 E., the chert forms a matrix enclosing abundant crinoidal detritus, none of which is silicified. The delicate surface markings of the crinoids are preserved in detail against the embedding chert. This preservation of detail is used by Tarr (1926, pp. 39-40) as an indication of syngenetic origin of the chert.

The lower contact of the Tierra Blanca member with the Nunn member is gradational at most places in the Sacramento Mountains, and is not believed to represent an erosional break. The upper contact of the Tierra Blanca formation, in contrast, is an erosional break. The overlying unit is the Arcente member of the Lake Valley in most areas, Pennsylvanian rocks in the area north of Marble Canyon, and the Abo formation of Permian age locally in Arcente Canyon.

The age of the Tierra Blanca member is considered by Laudon and Bowsher (1941, p. 2132; 1949, p. 291) as early Osagian and pre-Burlington.

Arcente Member:

The term Arcente member was assigned by Laudon and Bowsher (1941, p. 2116) to the "soft, gray, shaly siltstone part of the section lying above the Alamogordo member" (Tierra Blanca member as defined in 1949) in the NW1/4 SE1/4 sec. 3, T. 17 S., R. 10 E., in a tributary of the Deadman Canyon branch of Alamo Canyon. The name was derived from Arcente Canyon, in T. 16 N., R. 11 E., five miles northeast of the type section. The Arcente member is exposed in most areas of Mississippian outcrops along the Sacramento Mountain escarpment. In the area north of Marble Canyon and Alamo Peak (including Arcente Canyon), the member has not been recognized and Pennsylvanian rocks lie directly upon the Tierra Blanca and older members of the Lake Valley formation. The Arcente member is well developed from Alamo Canyon southward throughout the length of the escarpment (plate 9), but is absent in the isolated southeasternmost exposures of Mississippian rocks in the Grapevine Canyon area.

The member is lithologically unlike the other members of the Lake Valley formation. In areas where the Upper Mississippian strata directly overlie the Arcente, the contact between these rock units is difficult to locate because of their general lithologic similarity. Where the upper Lake Valley sequence is complete, the Arcente member forms a light gray slope separating the cliffs of the Tierra Blanca and the Dona Ana members.

The Arcente consists of about equal quantities of dark gray, very argillaceous limestone and calcareous shale. The beds rarely exceed one foot in thickness, most are about 6 inches thick. The limestone and shale beds alternate monotonously throughout much of the section. Insoluble residues of the few samples tested show that the content of clay and fine silt of the limestone comprise nearly half of the rock, and that the actual variation in composition between the shale and the limestone is slight. The light gray color of the weathered surface, and the dark gray, sublithographic surface of the fresh rock are diagnostic features of the Arcente member of the Lake Valley formation.

Although the alteration of dark, argillaceous limestone and shale characterizes most of the Arcente member, several variants form local lithologic markers within the member. Two to three feet of crinoidal limestone, best developed in the Alamo Canyon area, form a resistant ledge near the middle of the member. Freshly broken, this limestone has a distinct petroliferous odor, and is the only consistently petroliferous zone noted in the Lake Valley formation of the Sacramento Mountains. The enclosing dark limestones and shales of the Arcente member are probably rich in organic matter, and the crinoidal limestone forms as a local reservoir rock. This occurrence, although of small scale, suggests the possibility that the Arcente member elsewhere may form source beds for oil which has migrated into reservoirs of commercial significance.

A conspicuous and persistent feature of the Arcente member is a zone 10 to 30 feet thick in the upper half of the member that is composed almost entirely of argillaceous limestone. This forms a low scarp on the Arcente slopes. Dark gray chert nodules, 1 to 2 inches thick, are common in this zone. Elsewhere in the member, chert is almost entirely lacking.

The lateral variation in thickness and lithology of the Arcente member is indicated on plate 9. The maximum thickness observed is about 200 feet, in the area of Mule and Dog Canyons, along the west front. In the north, the member thins to the east as a result of less initial deposition in that area. Farther south, the formation thins to the east and south. Most of this thinning is caused by truncation of the Arcente by pre-Upper Mississippian erosion. The member is lighter in color and more shaly toward the south than at the type section in the north. Where bioherms are present, the Arcente member is thickest in the area between the bioherms. The member laps onto some of the largest bioherms (figure 24), which apparently remained as positive elements during deposition of the Arcente member in surrounding areas.

The lower contact of the Arcente member with the underlying formations is considered a disconformity by Laudon and Bowsher (1949, p. 29). This interpretation best explains the field relationships noted by the writer. Evidence of disconformity is best in the southern area, where the Arcente lies directly on the Alamogordo member, and the Nunn and Tierra Blanca are not present. In the north, the Arcente rests on the Tierra Blanca and appears to be essentially conformable. The thinning of all pre-Arcente members of the Lake Valley formation toward the south indicates less initial deposition in that direction. It seems probable that the area received little or no sediment during the time the Nunn and Tierra Blanca were being deposited toward the north. The disconformity at the base of the Arcente in this area therefore, probably represents a longer hiatus of deposition and probably more erosion of the pre-Arcente strata than is represented to the north.

The upper contact of the Arcente member with the Dona Ana member appears to be conformable, as stated by Laudon and Bowsher (1941, p. 2136), and represents a transition in the lithology. In much of the southern area, the Arcente member is directly overlain by upper Mississippian formations. The contact is a distinct angular unconformity. The discordance, locally as much as 10°, is generally much less.

The Arcente member contains relatively few fossils compared to the other members of the Lake Valley formation. The fauna is considered by Laudon and Bowsher (1949, p. 31) to be early Osagian and older than upper Burlington.

The areal extent of the member is small compared to other underlying members of the Lake Valley formation, as it is known only in the Sacramento Mountains and in the central part of the San Andres Mountains (Laudon and Bowsher, 1949, p. 15). It has not been recognized in the subsurface sections to the east and south (Lloyd, 1949).

Dona Ana member:

The Dona Ana, the youngest member of the Lake Valley formation was defined by Laudon and Bowsher (1941, p. 2116), and consists dominantly of gray, cherty, crinoidal limestone. The type section is in NW 1/4 SE 1/4 sec. 3, T. 17 S., R. 10 E., in a tributary of the Deadman Canyon branch of Alamo Canyon.

The member is a thick and conspicuous part of the Lake Valley section in the area between Dog and Alamo Canyons, but extends less than a mile north and south of this area. The member characteristically forms a resistant, light colored cliff above the gray slopes of the Arcente member.

The Dona Ana member consists almost entirely of coarse crinoidal limestone, and is similar to the Tierra Blanca member of the Lake Valley formation. Small amounts of calcareous shale are interbedded with the crinoidal limestone, especially near the base. Chert is abundant, and forms large light gray nodules. The member locally contains small bioherms. The lithology of the Dona Ana member is rather uniform throughout the exposed area.

The thickest sections observed are along the west front in the vicinity of Mule Canyon where the member locally forms sections about 150 feet thick. The Dona Ana member thins toward the east in most of the area. This, in part, is due to original differences in thickness of the member, but in much of the area south of Alamo Canyon, is due primarily to erosion prior to the deposition of the Upper Mississippian strata. The exposures along San Andreas Canyon and

Dog Canyon show clearly the truncation of the Dona Ana and part of the Arcente member by pre-Rancheria erosion.

The Dona Ana member overlies the Arcente member almost everywhere except where the Arcente is locally displaced over a bioherm, and the Dona Ana rests directly on the core facies. The Dona Ana member appears to be transitional with the underlying Arcente member, as reported by Laudon and Bowsher (1941). The upper contact of the Dona Ana is with the Pennsylvanian strata in most of Alamo Canyon. Locally in Alamo Canyon, and almost everywhere farther south, the Dona Ana lies below the unconformity at the base of the Meramecian strata, which locally are part of the Las Cruces (?) formation, but in most of the area, are part of the Rancheria formation.

The Dona Ana member laps onto the resistant biohermal core of the two large masses near San Andreas Canyon, and is lower than the top of the bioherm. The member appears to have been deposited at the level of the top of the bioherm, and later compaction on the Arcente and underlying strata brought the Dona Ana to its present position. It is probable that the cores were topographic prominences at least at the start of the deposition of the Dona Ana member. The writer has seen no evidence that the cores of the bioherms continued to grow during the deposition of the Dona Ana member.

The Dona Ana member is fossiliferous; crinoids and brachiopods and corals are all abundant types represented. Laudon and Bowsher (1941, p. 2137) list a large fauna from the member and consider it to be Osagian. They correlate the fauna with that of the upper part of the lower Burlington formation in the Upper Mississippi Valley.

The member is the most areally restricted unit of the Lake Valley formation, not only in the Sacramento Mountains, but in New Mexico as well. Beyond the Sacramento Mountains, the member is known only in the central part of the San Andres Mountains (Laudon and Bowsher, 1949, p. 15).

LAS CRUCES (?) AND RANCHERIA FORMATIONS

The Las Cruces and Rancheria formations were defined by Laudon and Bowsher (1949, p. 17) in the Franklin Mountains as follows:

> "The name Las Cruces is proposed for the hard, dense, black, sublithographic, even-bedded, gray-weathering, sparsely fossiliferous limestone beds that rest unconformably on the black "Percha" (Nelson, 1940, Canutillo fm.) and are unconformably overlain by the Rancheria formation. The name Rancheria formation is proposed for the sequence of cherty, black bituminous, argillaceous limestone beds that rest unconformably on the Las Cruces formation and are unconformably overlain by the green shales of the Helms formation (restricted)".

The type sections are on the west slope of the Franklin Mountains almost directly east of Vinton, Texas (SW 1/4, sec. 67, S. Blk. 82, El Paso Co., Texas). The formations are both Meramecian in age.

The first recognition of Upper Mississippian strata in the Sacramento Mountains was by Laudon and Bowsher (1949, p. 19) who identified the Upper Mississippian strata in the area of Escondido and Nigger Ed Canyons as the Rancheria formation.

Locally within the strata termed the Rancheria (Laudon and Bowsher, 1949, p. 31) in the southern Sacramento Mountains, the writer has observed unconformities of low angular discordance. At some of these places the strata below the unconformity are similar to the descriptions of the Las Cruces formation. It is probable that some of the Meramecian strata of the Sacramento Mountains correlate with the Las Cruces formation, and tentative boundaries between the Las Cruces (?) and the Rancheria formation have been indicated for several sections on plate 9. Differentiation of the Meramecian strata in much of the area of the Sacramento Mountains into the Las Cruces (?) and Rancheria formation is impractical or impossible. Most of the Meramecian section is believed to correlated with the Rancheria formation.

Areal distribution:

Strata of Meramecian age are present throughout southern and central part of the Sacramento escarpment. Although previously recognized only as far northward as Escondido Canyon, a thin wedge of strata can be traced between the Pennsylvanian formations and the Dona Ana member of the Lake Valley formation continuously along the escarpment to Mule Canyon. Even farther north, in the bottom of Alamo Canyon in the SW 1/4 NW 1/4 NE 1/4 Sec. 7, T. 17 S., R. 11 E., about ten feet of strata lithologically similar to the Rancheria formation, and containing Meramecian fossils has been identified, and indicated on the geologic map. Detailed field work will probably indicate that this unit can be recognized at other points in this northern area.

It is probable that the strata believed correlative with the Las Cruces formation are restricted to the area south of Dog Canyon, and that only strata of the Rancheria formation overlap far to the north.

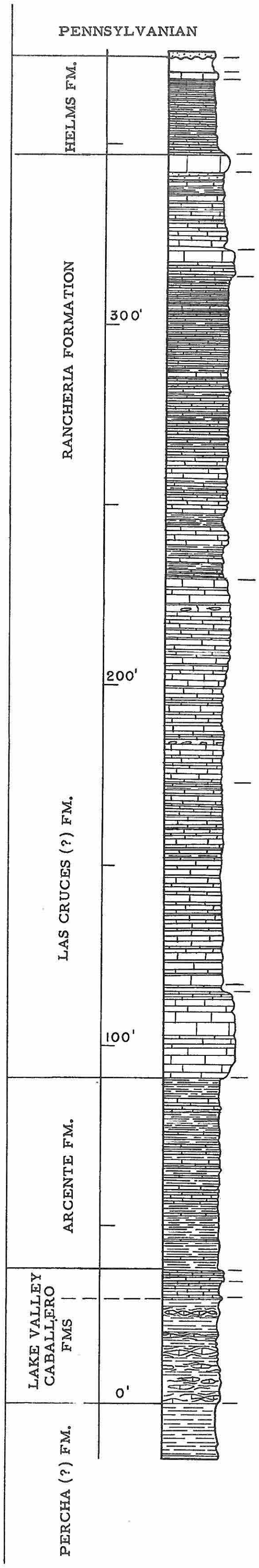
Lithology:

The Meramecian strata in the southern Sacramento Mountains consist largely of dark gray, thin-bedded, silty limestone or dark calcareous siltstone. Interbedded granular, massive limestones form local ledges from 5 to 25 feet high on the gray to brown slopes. The Meramecian strata are from 30 to 70 feet thick in much of the area of exposures north of Deadman Canyon, and thicken to a maximum of about 300 feet in the southern end of the mountains (pl. 9).

The Meramecian strata appear to represent progressive overlap toward the northwest, as the strata thin toward the west in all major canyons and also thin toward the north. The thinner sections appear to consist of the upper strata of the thicker sections, overlap toward the northwest which explains the absence of the Rancheria formation at the mouth of Alamo Canyon, although it has been found farther east.

The Meramecian strata of the southern Sacramento Mountains are best exposed in Escondido and Agua Chiquita Canyons. Details of the complete Mississippian section at Agua Chiquita Canyon are indicated on figure 27, and generalized diagrams of this and other stratigraphic sections are indicated on plate 9.

The strata below the Helms formation vary in detail at the different measured sections, but all sections observed contain a recurrence of a few rock types, which in spite of observed erosional breaks, including at least two angular unconformities, indicates a certain homogeneity of these Meramecian strata. The major rock types recognized are as follows:



16	2'	Quartz sandstone, greenish gray, fine grained,
15	4'	Covered, non-resistant
14	2'	Limestone, brown gray, oolitic; massive; weathers yellow brown
13	21'	Limestone, medium gray, argillaceous, thin beds less than 1', weathers light gray; interbedded with gray shale.
12	5'	Limestone, medium gray, granular, massive; much lateral variation in thickness; silicified brachiopods, fish teeth.
11	22'	Limestone, medium gray, silty; conspicuous brown weathering silicified nodules , bands, and laminae; 2' of gray calcareous shale at base. This unit is nearly 40 feet thick locally in the southern Sacramento Mountains.
10	7'	Limestone, medium gray, granular, fossiliferous; upper part is massive and grades downward into laminated medium dark gray silty limestone
9	83'	Limestone, medium gray, silty and argillaceous; beds less than 1' thick; interbedded with dark gray argillaceous limestone and calcareous shale. Unit weathers light gray except for brown siliceous layers in upper part.
8	57'	Limestone, medium dark gray to olive gray, sublithographic silty; beds 3" to 2' thick; minor shale partings. Gray chert nodules 11' above base, 1' dark gray chert layer at top. Basal 50' weathers very light gray and is capped by thin dark colored zone.
7	56'	Limestone, medium dark gray, sublithographic, silty. Even laminated beds 2" to 1' thick are interbedded with minor dark calcareous shale. Siliceous laminae of limestone weather brown; forms distinctive brown weathering slope.
6	2'	Shale, brown gray, calcareous.
5	25'	Limestone, gray, granular, petroliferous; basal 4' argillaceous. Forms first resistant cliff above Fusselman (?) fm.
4	53'	Shale, light gray, calcareous (60%) interbedded with 1-3" beds sublithographic, medium light gray limestone; more argillaceous toward top. "2" bed crinoidal limestone 28' above base.
3	3'	Limestone, medium light gray, sublithographic, thin-bedded, resistant. Alamogordo member.
2	5'	Limestone, yellow gray, very argillaceous; 1' resistant reddish argillaceous limestone at base.
1	29'	Shale, yellow gray, calcareous; minor somewhat nodular limestone.
		Shale, light gray-green, calcareous.
		Limestone, light gray, argillaceous, nodular; and calcareous shale.
		Shale, olive gray to dark gray; top 10' poorly exposed.

Section of Mississippian strata measured in Agua Chiquita Canyon. Base of section is 2300' W. and 1600' S. of NE corner of T. 19 S., R. 10 E.

Figure 27

STRATIGRAPHIC SECTION OF MISSISSIPPIAN FORMATIONS IN SOUTHERN SACRAMENTO MOUNTAINS

1. Dark gray, thin bedded, argillaceous and silty limestone and/or calcareous siltstone, that contain abundant streaks, nodules, and laminae of porous chert. This siliceous rock weathers a distinctive yellow brown color. Where the thickness of these strata is sufficient, the yellow brown bands can be recognized and visually traced along the mountain front. The alternation of siliceous laminae and carbonate laminae produces a corrugated surface when weathered. Beede (1920, p. 8) named this rock the "Woodyard chert" because the surfaces resembled the grain of wood, and slopes littered with the rock resembled a woodyard. This distinctive rock type is apparently restricted to Meramecian strata in the region of western Texas and southern New Mexico. This rock type forms units 7, 11, and the upper part of 9 in the Agua Chiquita section (fig. 27).

2. Dark gray, thin bedded argillaceous and silty limestone and/or calcareous siltstone similar to type 1 except that these are not cherty or siliceous. These strata weather to a light gray color, in contrast to the brown siliceous layers. This rock type forms most of units 8 and 9 of the Agua Chiquita section (fig. 27) and locally occurs at the base of the Meramecian rocks in the central part of the escarpment.

3. Medium gray, granular, silty, crinoidal limestone. Rock of this type occurs as relatively massive strata that form minor ledges on the slopes of the Meramecian strata. This limestone is clearly detrital in origin, and contains abundant crinoid fragments, poorly preserved brachiopods, shark teeth, and other fossils. Much of the rock is silty or sandy. Freshly broken, these limestones have a distinct petroliferous odor. This rock forms most or all rock units 5, 10, and 12. These beds are persistent throughout the southern Sacramento Mountains, and form excellent markers.

4. Calcareous gray and brown shale. This rock type forms only a small part of the Meramecian strata, but is interbedded as thin layers, rarely more than one foot thick, with the predominant limestone.

The section of figure 27 is representative of most Meramecian sections in the southern part of the Sacramento Mountains, and many of the units can be recognized in the other sections. The uppermost part of the section, units 10, 11, and 12, are persistent and easy to recognize throughout the southern area.

Numerous erosional discontinuities, some of which are unconformities with local angular discordance as high as 10°, are interesting features within the sequence of Meramecian strata. On the south side of Escondido Canyon, the break indicated on plate 9 can be traced for more than a quarter mile. It is probably the same as the discontinuity in the sequence exposed half a mile farther north. In Deadman Canyon, farther north, three angular unconformities have been observed. The lowest truncates the Dona Ana and part of the Arcente member of the Lake Valley in this area. A second unconformity, shown in figure 28,

Figure 28. Angular unconformity within strata of Meramecian age. The unconformity may mark the boundary between the Las Cruces (?) and Rancheria formation in this area. Exposed on north side of Deadman Canyon, NW 1/4 SW 1/4 sec. 14, T. 18 S., R. 10 E.

separates strata similar to the Las Cruces formation from overlying siliceous limestones. About 30 feet higher in the section, another sharp erosional break and a mild angular discordance occurs in the sequence.

The multiplicity of these angular discordance within the Meramecian strata, and the prevailing uniformity of the lithology above and below the breaks, suggests to the writer that these may be of intraformational origin, and are not to be interpreted as representing regional uplift and subaerial erosion. Instead they may indicate only local warping and possibly submarine erosion. Clearly marked erosional breaks are found at the base of most of the granular limestones (type 3) in the area.

Detailed field work in the area of the southern Sacramento Mountains is needed to properly evaluate the significance of the strata of the Las Cruces (?) and Rancheria formations, and of the numerous discordances within these strata.

In the northern Sacramento Mountains, the thin wedge of the Rancheria formation has a distinctive lithology that consists largely of silty, medium gray, finely granular limestone which is commonly massive. Locally this is distinctly crinoidal. The strata in most of this area directly overlie the Dona Ana, and unless examined critically, can be easily confused with the Dona Ana member. Large chert masses and nodules are common; some of these show a relict cross-lamination which must indicate deposition of the strata prior to the localization of the silica that forms the present chert masses.

Conditions of deposition:

The fauna of the Las Cruces (?) and Rancheria formations indicates deposition in a marine environment. The lithologic sequence consists largely of finely laminated argillaceous, silty limestone or calcareous siltstone that alternate in the section with subordinate coarsely granular limestone. These different types must involve two contrasting depositional environments. It seems probable that the fine grained limestone accumulated well below wave base, thus accounting for the delicate lamination of many of the beds, and that at recurring intervals, the depositional zone was brought into the area of a shallow zone characterized by intermittent wave or current erosion, which beveled some of the earlier deposited strata. The granular fossiliferous, locally cross-laminated limestones that commonly overlie these breaks are the type to be expected as the depositional product of this turbulent environment. This area appears to provide an example of the undaform and clioform environments recently proposed by Rich (1951).

Contact relationships:

The strata of Meramecian age, the Las Cruces (?) and the Rancheria formation overlie a distinct angular unconformity throughout the area. The angular discordance has been observed as much as 10°, although in most of the area, the discordance is only a degree or two. The pre-Meramecian section was apparently tilted slightly to the northwest and eroded, as successively older strata occur below the unconformity as it is traced eastward in the major canyons, and southward along the mountain front. Siliceous clastic debris is lacking along much of this unconformity, but the change in lithology, the structural discordance, and presence of oxidized zones all clearly mark this unconformity. The photograph of figure 28 could be duplicated at this lower unconformity. The contact with the overlying Helms formation is somewhat arbitrary. In the sections shown on plate 9, and on figures 27 and 29, the writer has selected as the contact the base of the section composed dominantly of shale as the overlying strata contrast with the underlying sequence composed predominately of limestone. This contact appears to correspond to the contact selected by Laudon and Bowsher in the Franklin and Hueco Mountains.

Fauna:

Fossils collected during the field work have been kindly identified by A. L. Bowsher as the following:

Spirifer cf. *S. arkansanus* (Girty)
Spirifer aff. *S. littoni* (Swallow)
Composita cf. *C. trinuclea* (Hall)
Buxtonia cf. *B. semicircularis* (Sutton and Wagner)
Camarotoechia sp.
Moorefieldella eurekensis (Walcott)
Orbiculoidea batesvillense (Weller)
Linoproductus cherokeensis (Snider)
Chonetes cr. *C. oklahomensis* (Snider)
Dielasma cf. *D. bisinuatus* (Weller)
Geffinina sp.
Sansabella sp.
Zaphrentis sp.

These were collected from strata throughout the area from Mule Canyon on the north to Grapevine Canyon on the south.

Age and correlation:

The fauna collected by Laudon and Bowsher from the Rancheria formation throughout the southern New Mexico and west Texas area is termed the "*Leiorhynchus carboniferum* fauna", and believed to correlate with that from the Moorefield formation of the Ozark area, and is considered to be early Meramecian (Laudon and Bowsher, 1949, p. 19). Bowsher considers the fauna listed above to be equivalent to the Rancheria fauna.

Regional relationships:

The strata in the Sacramento Mountains termed the Rancheria formation are correlated with similar sections exposed in the Hueco Mountains to the south, the Franklin Mountains to the southwest, and the southern San Andres Mountains to the west (Laudon and Bowsher, 1949). In these areas, the Rancheria formation is about 200 feet thick. Strata correlated with the Rancheria (Lloyd, 1949, pp. 43-44) are widespread in the subsurface of southern New Mexico where they vary up to 850 feet in thickness.

The Las Cruces (?) formation is only recognized in the surface sections in the Franklin, San Andres, and Sacramento Mountains.

HELMS FORMATION

The Helms formation was named initially by Beede (1920, p. 8) in the Hueco Mountains, and included strata between the Fusselman and the Magdalena formations. King and Knight (1945, sheet 2) restricted the name to the Mississippian rocks, and published six measured sections of the Helms formation in the Franklin and Hueco Mountain area. Laudon and Bowsher (1949, p. 8) restricted the term to the part of the Mississippian section containing Chesterian fossils, and named the Rancheria and Las Cruces as underlying formations of Meramecian age.

Strata similar in lithology and fauna to the Helms from the Hueco and Franklin Mountains were found by the writer in the southern Sacramento Mountains, and are termed the Helms formation in this report.

Areal extent:

The Helms formation has only been identified in the southern Sacramento Mountains. It was first recognized and is best exposed in the area of Mississippian outcrops along Grapevine Canyon in sec. 27, T. 19 S., R. 11 E. The formation has been identified along the west front of the mountains from the south end of the Mississippian outcrops northward to Escondido Canyon. The Helms formation may extend farther north, but was not observed in the Mississippian section measured in Deadman Canyon.

Lithology:

The Helms formation of the Sacramento Mountains consists largely of soft, calcareous, olive gray and brown gray shale, interbedded with thin, argillaceous limestone, especially common in the upper part of the section. The maximum thickness observed is 58 feet in Grapevine Canyon.

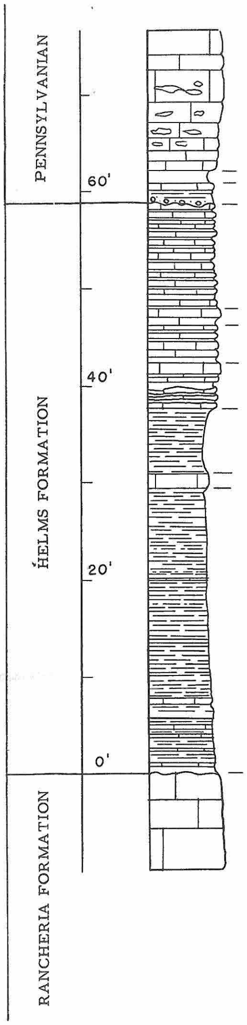
The upper part of the formation contains oolitic limestone. At most places oolitic limestone forms a single bed, 1 to 2 feet thick that occurs as streaks within a single bed. In the Escondido Canyon area about seven feet of oolitic limestone occurs as a resistant ledge. The oolites are 1-2 mm. across and form an estimated 80% of the yellow brown rock. As no other oolitic limestone is known in the Mississippian and lower part of the Pennsylvanian section, this forms an excellent stratigraphic marker. If laterally persistent, it should be recognizable and useful in the subsurface.

In Escondido Canyon, a two-foot bed containing abundant *Linoproductids* overlies eight feet of brown gray shale at the base of the Helms formation. The *Linoproductid* bed forms a distinctive marker in much of the southern mountain area.

The best exposure of the Helms formation is along the north edge of Grapevine Canyon, in the NW 1/4 NW 1/4 sec. 27, T. 19 S., R. 11 E. The section measured at this point is shown in figure 29. The Helms formation is part of the Mississippian section measured in Agua Chiquita Canyon (fig. 27). These sections and others in the southern Sacramento Mountain area are indicated on plate 9.

Contact relationships:

The lower contact of the Helms formation with the Rancheria formation is somewhat arbitrarily selected at the horizon that separates the part of the Upper Mississippian section in which shale is predominant, from the underlying section composed largely of silty and argillaceous limestone (figs. 27, 29, pl. 9). The contact is placed just above the highest dark, granular limestone of the type common throughout the Rancheria formation. The strata above and below the contact



		Limestone, dark gray, argillaceous, large irregular dark gray chert nodules, corals
		Shale, red-brown and minor quartz sandstone; Basal contact truncates upper limestone bed, and is overlain 2" chert pebble conglomerate.
6	11'	Limestone, medium gray, sublithographic argillaceous; even beds 2" - 1' thick; interbedded with olive gray calcareous shale.
5	2'	Limestone, gray, oolitic.
4	8'	Limestone, medium gray, sublithographic, argillaceous; interbedded with light olive gray calcareous shale. 2' of dark gray granular limestone 2' above the base, fossiliferous.
3	7'	Shale, light olive gray, calcareous.
2	1 1/2'	Limestone, medium gray, medium granular; top is fossiliferous (*Archimedes* sp.).
1	29'	Shale, light olive gray, calcareous; interbedded with thin argillaceous limestone; minor siltstone.
		Limestone, dark gray, medium granular, silty, fossiliferous (Brachiopods, crinoids). Upper surface locally iron stained.

Above section measured at stream level along north side of Grapevine Canyon in the SW 1/4, NE 1/4, NW 1/4 sec. 27, T. 19, S., R. 11 E.

STRATIGRAPHIC SECTION OF THE HELMS FORMATION

Figure 29

appear to be parallel. The contact is probably a disconformity.

This contact appears to be equivalent to the contact selected in the Hueco and Franklin Mountains by Laudon and Bowsher (1949) and lies at the top of bed 9 of the Vinton (Franklin Mountains) section of King and Knight (1945, sheet 2).

The upper contact is with the Pennsylvanian strata, and is marked by quartz sandstone, dark, hard, fissile shale, or dark silty limestone with abundant black chert. The contact is a pronounced disconformity.

Fauna:

Although the Helms formation was recognized in the southern Sacramento Mountains on the basis of the lithology, the fauna is diagnostic, and fossils abundant in certain beds. After the completion of the mapping, the Helms outcrops at Escondido Canyon and Grapevine Canyon were visited with A. L. Bowsher, who made the following report on the fossils collected for the U. S. National Museum from the Helms strata:

Loc. 3061 (U. S. N. M.) Zone "J", NW 1/4 SW 1/4 sec. 25, T. 18 S., R. 10 E.

2 *Sandalotus* sp.
1 *Buxtonia* sp.
1 *Michelinia* sp.

Loc. 3061 (U. S. N. M.) Zone "K", SE 1/4 NE 1/4 SE 1/4 sec. 26, T. 18 S., R. 10 E.

72 *Linoproductus* sp.
3 *Spirifer* aff. *S.* *arkansanus* (Girty)
1 *Schizophoria* sp.

Loc. 3067 (U. S. N. M.) Zone "K", SE 1/4 SE 1/4 SW 1/4 sec. 7, T. 19 S., R. 11 E.

1 Lovenechinus (?) sp.
1 Decadorcrinus (?) sp.
4 Schizophoria sp.
2 Dictyoclostus sp.
1 Spirifer aff. S. arkansanus (Girty)

Loc. 348, Unit No. 2, figure 27. NW 1/4 NW 1/4 sec. 27, T. 19 S., R. 11 E.

2 Dictyoclostus sp.
1 Sulcoretopora cf. S. lineata (Ulrich)
2 Fenestellid bryozoans

Age and correlation:

The age of the fossils collected from the Helms formation of the Sacramento Mountains is considered to be Chesterian by A. L. Bowsher. On the basis of lithology and fauna the Helms formation correlates closely with the Helms formation as defined by Laudon and Bowsher (1949). The Helms fauna possibly correlates with that of the Fayetteville formation of northwestern Arkansas (Laudon and Bowsher, 1949, p. 8).

Regional relationships:

Data on the surface sections of the Helms formation are provided in the Hueco and Franklin Mountain areas by the sections of King and Knight (1945, sheet 2), and by the sections of Laudon and Bowsher (1949, pp. 33, 37). This information and data from the subsurface of southeastern New Mexico is summarized by Lloyd (1949, pp. 42-44).

The Helms formation, as currently defined (Laudon and Bowsher, 1949, p. 8) is recognized in surface sections in the Franklin, Hueco, and Sacramento Mountain areas. It is traced throughout southeastern New

Mexico as dark shale containing minor limestone that overlies the limestone of the Rancheria formation. The Helms formation is 265 feet in thickness in southern Lea County. The formation ranges in thickness from about 35 to 150 feet in the Franklin and Hueco Mountains, where it consists largely of shale, with minor limestone, and sandstone. The Helms of the Sacramento Mountain differs from these surface sections farther south in the absence of sandstone, but is otherwise similar.

PENNSYLVANIAN SYSTEM

CLASSIFICATION

The Pennsylvanian is considered in this report to be a geologic system and a period, a usage of the term favored by most American geologists (for example, see Cheney, et. al., 1945; Moore, 1949). The subdivision of the Pennsylvanian into time and time-rock units (Moore, 1947) varies in different parts of the United States. The time and time-rock terms of most significance in New Mexico are indicated in Table V.

Table V.

Terminology of Pennsylvanian series in New Mexico

Thompson 1942	Lloyd 1949	Name in common usage in Texas	This report
Virgil	Virgil	Cisco	Virgilian
Missouri	Missouri	Canyon	Missourian
Des Moines	Des Moines	Strawn	Desmoinesian
Derry	Atoka	Bend	Atokan
	Morrow (?)		Morrowan (?)

The series names used by the New Mexico Bureau of Mines and Mineral Resources (Lloyd, 1949, p. 34) will be used in this report, except that the "an" or "ian" suffixes are added. A classification by Moore and

Thompson (1949) which reduces the above series to stages and names three new Pennsylvanian series is not used in this report.

The terminology for time-rock units is much better established than that for the rock units in the New Mexico area. The confusion of terminology of the Pennsylvanian strata reflects primarily the nature of the rock succession. The Pennsylvanian system in many parts of New Mexico is several thousand feet thick, and is characterized by a lack of persistent and clearly marked lithologic units or unconformities. Read and Wood (1947, pp. 220-223) discuss the classification and the nature of sedimentation of the Pennsylvanian system in northern New Mexico. Much of their discussion is pertinent to the system in southern New Mexico and the Sacramento Mountains, and hence their summary statement is reproduced as follows:

> "We have accepted lithologic features as a principal basis in dividing the Pennsylvanian series in northern New Mexico. Paleontology is considered a guide for recognition of formations and not a method of establishing them. The procedure has been followed of limiting units by changes in sedimentation rather than by unconformities, which in the area in question, have not been demonstrated to be regionally continuous or to represent important hiatuses. There has resulted from this procedure, which we believe to be in accord with important principles of sedimentation, the establishment of several contacts of stratigraphic units which are not "line-thin". Instead the boundaries in many instances have been drawn in terms of transition zones."

A haphazard initial definition of many of the rock units within the system contributes to the present confusion in terminology. Thompson (1942, pp. 21-24) reviews the history of nomenclature of the Pennsylvanian system in detail. The term, Magdalena group or formation requires comment. Since initially proposed by Gordon (1907) for the strata of central New Mexico between the Kelly limestone (Mississippian) and the Abo formation (Permian), the name has had many different connotations. As used by Read and his co-workers of the U. S. Geological Survey, it includes the Wolfcampian formation termed the Bursum, as well as all of the underlying Pennsylvanian strata recognized in New Mexico. Thompson (1942, p. 22) considered the term essentially synonymous with Pennsylvanian, a usage recommended by DeFord and Lloyd (in King, 1942, p. 534). Bates et al (1947, p. 17) reject the term Magdalena on the basis of redundancy of stratigraphic nomenclature. Lloyd (1949) does not refer to the Magdalena in his discussion of the Pennsylvanian system. Because of the stratigraphic confusion surrounding the term, and as its adoption would be of little value for this report, the term Magdalena is not used.

Pre-existing terminology of rock units has not proven to be applicable to the strata of the Sacramento Mountains. The various lithologic subdivisions recognized in northern New Mexico (Read and Wood, 1947) can be recognized in a general manner in the Sacramento Mountains, but these units do not appear to form the best lithologic subdivision of the Sacramento Mountain section. Thompson's elaborate subdivision (1942), which consists of eight groups, 15 formations, and 1 member, is based in large part on fusulinids, rather than primarily on lithology. In the Sacramento Mountains, some of Thompson's subdivision can be recognized, and others undoubtedly could be recognized with careful study. However, in this area of rapidly changing lithofacies, the adoption of the Thompson classification would require that the primary approach be paleontologic in nature. The belief that the field mapping of lithologic units can contribute more in a limited time to the interpretation of the assemblage of sedimentary rocks than a study of biofacies caused the writer to reject the Thompson classification for purposes of field mapping.

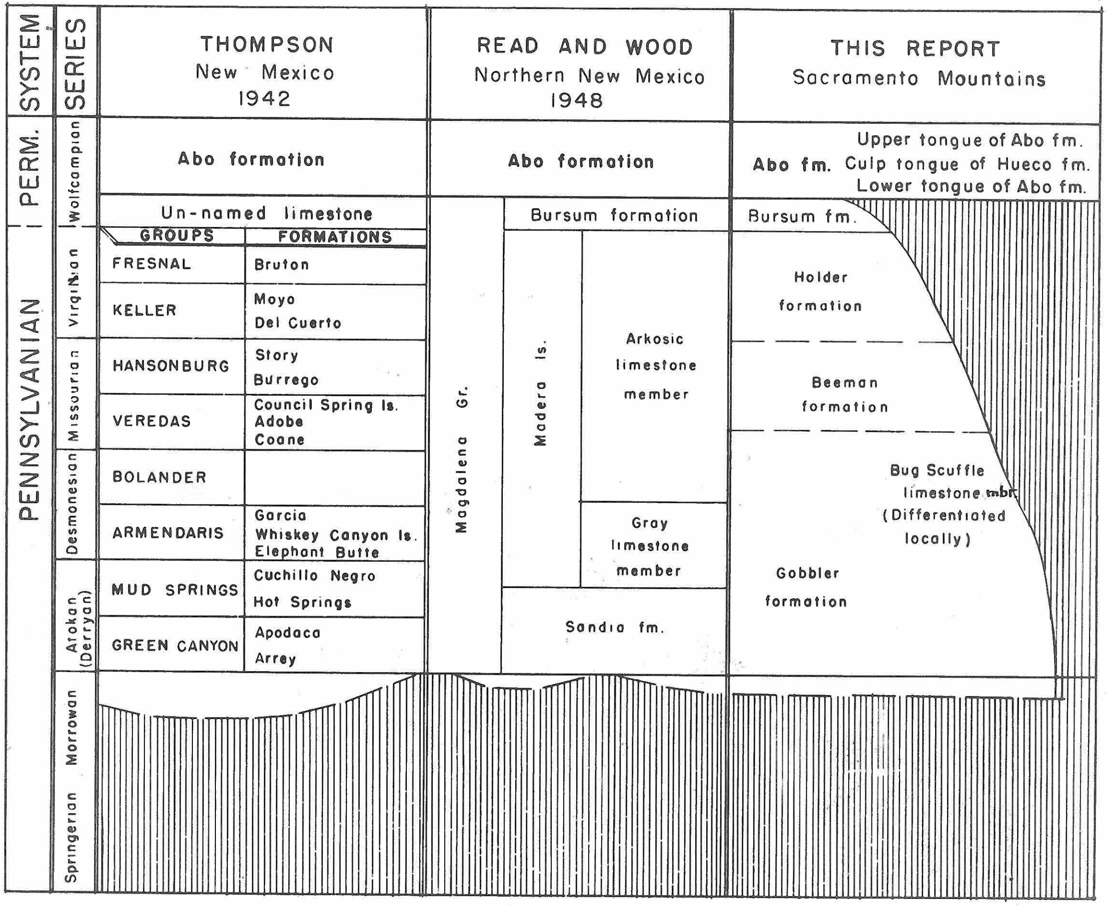


Figure 30. Subdivisions of Pennsylvanian strata in New Mexico.

The subdivision of the Pennsylvanian strata of the Sacramento Mountains as proposed in this report is shown on figure 30, together with the classification of Read and Wood in northern New Mexico and the classification by Thompson. The author is reluctant to introduce additional names into the literature of the Pennsylvanian rocks in New Mexico, but the alternatives seem even less desirable. The series names, Virgilian, Missourian, Desmoinesian, etc., although indispensable as a framework for regional correlation, are essentially time-rock terms. It seems important to clearly distinguish between these units and rock units that can be defined and applied with precision within a local area on the basis of observable field relationships. The formation terms introduced in this report have been found applicable throughout the Sacramento Mountain area. Some of the formations may be recognizable in other nearby areas, but this is incidental to the primary objective of a subdivision of value in field mapping, description, and interpretation of the Pennsylvanian strata within the area of the Sacramento Mountains.

GENERAL FEATURES

The Pennsylvanian system in the Sacramento Mountains forms about 40 percent of the total Paleozoic section of the Sacramento Mountain escarpment. Where the section is complete, the thickness amounts to about 3000 feet. The upper parts of the Pennsylvanian strata have been eroded from much of the area, and the Pennsylvanian section is about 2000 feet. The subdivision proposed in this report consists of three formations, and one member. Figure 31 illustrates the typical strata along much of the west front of the mountains.

The lowest of the proposed formations, the Gobbler, is composed largely of shale, argillaceous limestone, and very coarse grained quartz sandstone in the lower part, and the upper part consists of either massive beds of gray, cherty limestone or of calcareous sandstone and shale. The thickness of the Gobbler formation ranges from about 1200 to 1600 feet. Where the gray, cherty limestone is dominant, sheer

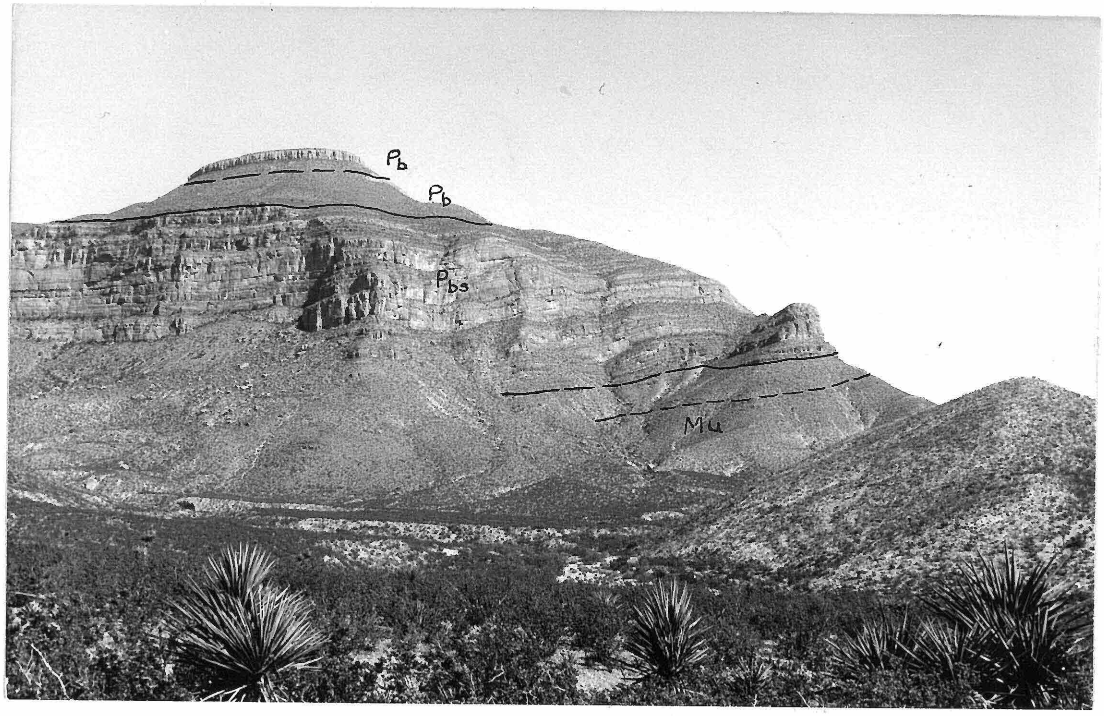


Figure 31. The Pennsylvanian formations on the south side of Nigger Ed Canyon, T. 19 S., R. 11 E. P_h = Holder formation, P_b = Beeman formation, P_{bs} = Bug Scuffle limestone member of the Gobbler formation, M_u = upper Mississippian strata.

cliffs, locally 500 to 700 feet high, mark this part of the section. This conspicuous lithologic unit is termed the Bug Scuffle limestone member. Where the limestone is absent, as in an area north and east of Alamogordo, the Gobbler formation weathers to slopes with only a few thin, cliff-forming units.

The middle formation, the Beeman, ranges from about 350 to 450 feet in thickness, and is composed of shale, and thin bedded, argillaceous limestone and feldspathic sandstone in most of the area along the western escarpment. This weathers to a gentle slope, in marked contrast to the cliffs of the underlying Bug Scuffle limestone member. Toward the east, limestones are predominant in the Beeman formation.

The upper formation, the Holder, is composed largely of white, non-cherty limestone interbedded with sandstone, conglomerate, and red and gray shale. The base of the formation is defined by the base of numerous discontinuous bioherms, 50 to 100 feet thick. The Holder formation is about 900 feet thick in the northern part of the area. Incomplete sections generally less than 300 feet thick, form cliffs that cap the high ridges in the central and southern part of the escarpment.

The writer believes the formation contacts on the geologic maps represent essentially the same horizon throughout the area. The mapped contacts between the Pennsylvanian formations are probably within 50 or 75 feet of the true horizon at most points in the area. In a few areas of abrupt facies changes, structural complexity, or of poor or isolated exposures, the error may be greater. However, the magnitude of even these larger errors is believed not large compared to the thickness of the units.

Any selection of type sections is somewhat unsatisfactory in the Pennsylvanian strata of the Sacramento Mountains, owing to the lateral variation in lithofacies. For precision of definition in an area of changing facies, it seems highly desirable that all of the type sections be parts of a continuous, well exposed sequence. For convenience of other geologists, a short type section is a distinct advantage. The only complete section that can be measured requires following the strata over a distance of about five miles in which there are several interruptions in the section.

The type section for the subdivisions proposed in this report for the Pennsylvanian system of the Sacramento Mountain area lies at the western end of Long Ridge, in the N 1/4 sec. 15 and the NW 1/4 sec. 14, T. 17 S., R. 10 E. The top and bottom of the 1950-foot section are less than a mile apart. This section was selected in part because of good exposures, relative accessibility, and structural simplicity. Further, it contains almost all of the lithologic types and many of the marker beds that are of value in mapping the Pennsylvanian rocks in the Sacramento Mountains. Although the definition of the youngest formation, the Holder, includes all of the Pennsylvanian section above the Beeman formation, the uppermost strata of the Pennsylvanian system are missing from this type section. However, the upper part of the Holder formation in the Sacramento Mountains has been adequately described by Thompson (1942, pp. 73-79) under the name of the Fresnal Group.

The type section of the Gobbler, Beeman, and Holder formations is described below. The graphic log of this section and the unit numbers are shown on plate 12.

Pennsylvanian system

Type section of the Holder, Beeman, and Gobbler formations measured in Mule Canyon and Long Ridge area.

E 1/4 NW 1/4 NW 1/4 sec. 14, T. 17 S., R. 10 E.

Unit No.	Thickness in feet	Description
Top of section		
HOLDER FORMATION		Incomplete. Measured thickness 218 feet. Upper part eroded. Estimated 100 feet more of Holder formation is poorly exposed on Long Ridge east of this point. Section appears to be similar to upper 100 feet of described sedtion.
94	6	Limestone, very light gray, dense.
93	16	Limestone, medium dark gray to brown gray, argillaceous, thin bedded; interbedded with red, very calcareous shale. Fusulinids at top.
92	14	Limestone, very light gray to white, massive.
91	13	Covered; red, calcareous shale near base.
90	1	Conglomerate, dark limestone pebbles and cobbles, and matrix, intraformational.
89	23	Partly covered; light gray limestone in middle.
88	27	Limestone, pale red, thin bedded, argillaceous at base; grades up into very light gray limestone with obscure nodular bedding; fusulinids abundant.
87	17	Limestone, light brown gray, thin irregular beds at base; grades up into light gray massive limestone.
86	25	Limestone, very light gray, massive, some irregular obscure bedding; fusulinids 5 feet above base.

Unit No.	Thickness in feet	Description
85	8	Covered.
	5	Igneous sill.
84	65	Limestone, light gray to very light gray, massive; irregular fossiliferous zones. Igneous sills within the unit as follows: 2 feet thick at 30 feet, 7 feet at 50 feet, 8 feet thick at 68 feet, and 2 feet thick at 82 feet above the base of the unit.
	10	Igneous sill.

BEEMAN FORMATION - 390 feet

Unit No.	Thickness in feet	Description
83	3	Limestone, medium gray, argillaceous, thin bedded; algal (?); probably grades into overlying limestone.
82	13	Covered, probably argillaceous limestone.
	2	Igneous sill.
81	7	Shale, light olive gray, calcareous; top 1 foot fine grained, micaceous, dark green gray, calcareous sandstone.
80	53	Covered, probably same as unit 79.
79	22	Shale, light olive gray, calcareous, poorly exposed.
78	33	Limestone and dolomitic limestone, light to medium dark gray, argillaceous, thin beds 2 inches to 2 feet; interbedded with gray, green, and pale red silty shale. The top 7 feet of dolomitic limestone weather to brown band on hillside just below level of major slumped masses.
77	11	Covered.
76	61	Limestone and minor dolomitic limestone, light brown gray to medium dark gray, argillaceous, thin beds, 2 inches to 2 feet thick, locally nodular; minor interbedded brown gray to green gray calcareous shale.

Unit No.	Thickness in feet	Description
75	5	Limestone, dusky yellow gray, argillaceous, silty, thin bedded, with nodules 1 to 3 inches thick of medium light gray limestone. This unit weathers to a distinctive greenish scarp, and is an excellent marker bed along the length of the Sacramento Mountain escarpment.
74	24	Covered.
73	12	Limestone, medium light gray to light brown gray, dense; 1 foot of limestone conglomerate 5 feet above base, upper 6 feet locally contains limestone pebbles and granules, probably intraformational.
72	8	Covered, probably shale.
		Section above unit no. 71 measured in E 1/2 NW 1/4 NW 1/4 sec. 14, T. 17 S., R. 10 E.
71	20	Limestone, medium light gray, thick bedded; basal three feet argillaceous, thin bedded limestone. Fusulinids near top and at base. This bed is persistent and more massive toward the east, and forms the base of the limestone cliffs of the Beeman formation to the northeast. Thins rapidly toward the west on Long Ridge and all ridges farther south.
70	23	Feldspathic sandstone, light olive gray to green gray, silty, medium grained; minor siltstone beds.
69	35	Siltstone and fine to medium grained feldspathic sandstone, dark gray green to olive gray, thin bedded.
68	13	Shale, olive gray, calcareous; siltstone near top, 6 inch bed of dense, laminated brown limestone near base.
67	15	Sandstone, green gray, silty, micaceous, feldspathic (?), medium to coarse grained, massive.
66	21	Covered.

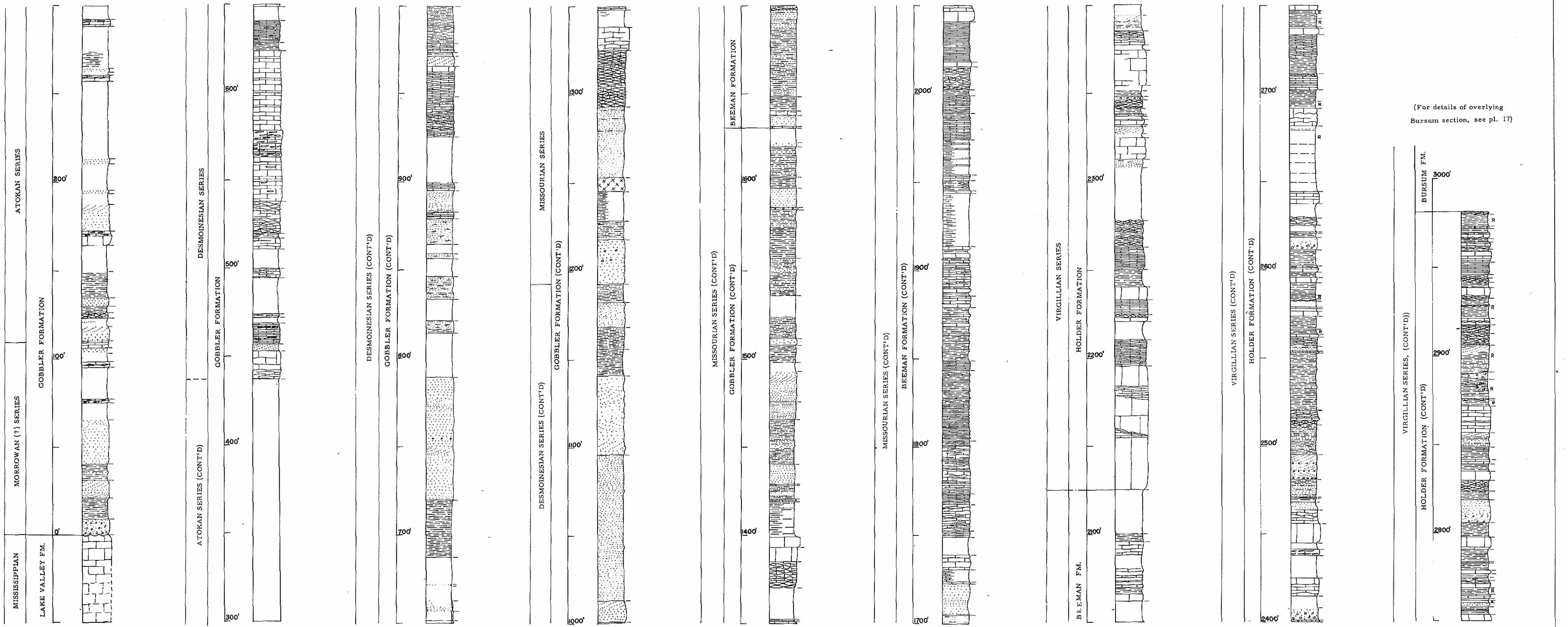
Unit No.	Thickness in feet	Description
65	13	Feldspathic sandstone, green gray, fine to coarse grained; poorly exposed.
64	3	Dolomite, medium gray, finely crystalline; weathers moderate yellow brown.

GOBBLER FORMATION - 1287 feet
Top of section at 6800 feet, in the NW 1/4 NE 1/4 sec. 15, T. 17 S., R. 10 E.

Unit No.	Thickness in feet	Description
63	7	Largely covered; green gray calcareous shale.
62	5	Limestone, medium dark gray, argillaceous; beds 6 inches to 1 foot; fossiliferous, brachiopods.
61	13	Quartz sandstone, gray-olive green, micaceous, fine to medium grained, slightly feldspathic.
60	7	Shale, olive gray, micaceous; minor interbedded dense, argillaceous, medium light gray limestone; beds 6 inches to 1 foot.
59	29	Quartz sandstone, green gray, micaceous, medium to coarse grained, slightly feldspathic; minor granules and interbedded siltstone; petrified wood.
58	8	Shale, silty, olive gray to olive brown, micaceous; minor interbedded dark gray fossiliferous limestone.
57	21	Limestone, medium light to light gray, massive; minor gray chert in center. This limestone forms the conspicuous ledge which caps Steamboat to the northwest.
56	10	Limestone, dark gray, argillaceous, nodular; shaly grades up into unit 57; basal 2 inches silty.
55	41	Limestone, dark gray, silty, slightly nodular; beds 4 inches to 1 foot, thicker at top; brown weathering silicified streaks. This forms distinctive marker in Gobbler formation.

Unit No.	Thickness in feet	Description
54	5	Largely covered; olive gray, calcareous shale and minor thin, crinoidal limestone.
53	12	Limestone, medium dark gray, massive, fossiliferous, algal (?).
52	19	Shale, olive gray, calcareous, minor agillaceous limestone near base and top.
51	16	Limestone, light olive gray, silty, argillaceous, thin bedded, slightly nodular.
50	40	Quartz sandstone, silty, micaceous, fine to medium grained, thin bedded; interbedded with green gray micaceous siltstone.
49	30	Quartz sandstone, green gray, silty, fine to medium grained; interbedded siltstone, cross-lamination.
48	18	Shale, olive gray, calcareous, fossiliferous; 2 inches of argillaceous, crinoidal limestone at top.
47	4	Covered.
46	28	Limestone, dark gray, silty, interbedded with calcareous brown gray to olive black shale; very fossiliferous, brachiopods, bryozoa, crinoids; beds 2 to 18 inches.
45	17	Limestone, crinoidal, medium light gray, 1 inch calcareous shale 4 inches below top. Forms top of series of resistant limestone beds that form major cliff.
44	5	Limestone, medium gray, granular; minor dark chert nodules.
43	16	Limestone, medium dark gray, thin bedded, shaly partings,; scattered fusulinids, abundant horn corals.
42	35	Limestone, medium dark gray, argillaceous, thin irregular beds 6 inches to 1 foot; minor thin crinoidal limestone, interbedded brown black, calcareous shale.
41	9	Limestone, crinoidal, interbedded with dark gray, calcareous shale; brown gray chert near base.

Unit No.	Thickness in feet	Description
40	5	Limestone, medium dark gray, argillaceous.
39	5	Limestone, medium dark gray, granular.
38	5	Limestone, dark gray, argillaceous and silty, interbedded brown black, calcareous shale.
37	7	Limestone, dark gray, argillaceous, 6 inch beds.
36	10	Limestone, medium light gray, lower 6 feet massive, minor chert.
35	26	Limestone, light gray to medium gray, obscurely bedded; gray chert nodules abundant, 1 to 2 foot very argillaceous limestone at base.
34	26	Limestone, light gray to medium gray, obscurely bedded, minor light gray chert; forms lower half of resistant cliff.
33	6	Covered.
32	22	Limestone, light gray, massive and cherty in upper part.
31	12	Limestone, light gray, obscurely bedded, argillaceous limestone near base.
30	8	Limestone, light gray; cherty.
29	4	Limestone, coarsely crystalline, cherty.
28	5	Limestone, medium light gray, argillaceous, thin bedded.
27	43	Limestone, medium gray; obscure beds 2 to 4 inches thick at base, more massive above; forms distinct cliff.
26	16	Covered, probably thin bedded limestone. Above this point, section measured up canyon N. 38° E., eroded along igneous dike.
25	35	Limestone, medium dark gray, thin bedded, grades upward into medium light gray, massive limestone, with gray to white chert nodules. Fossiliferous near base, fusulinids 10 feet above base.



(For details of overlying Bursum section, see pl. 17)

Sections continued from top of the column on the left.

Pennsylvanian section No. 5; measured by M. L. Thompson. Base of section at Indian Wells, in sec. 14, T. 16 S. R. 10 E., Upper 580' measured along north side of road in La Luz canyon, in NW 1/4 sec. 30, T. 15 S., R. 11 E.

Series boundaries determined by M. L. Thompson.

STRATIGRAPHIC SECTION (NO. 5) OF PENNSYLVANIAN FORMATIONS

Unit No.	Thickness in feet	Description
24	11	Covered. Top is at base of cliff N. 76° E. of head of Mississippian outcrops in Mule Canyon.
23	38	Limestone, medium dark gray, argillaceous and silty; interbedded with dark gray calcareous shale; beds 2 inches to 1 foot thick; fossiliferous, productids.
22	4	Limestone, medium dark gray, dense, argillaceous; fusulinids in center of 2 foot bed.
21	22	Largely covered; probably largely dark gray, calcareous shale and argillaceous limestone.
20	14	Shale, olive gray to olive black, silty, calcareous.
19	44	Shale, olive gray, calcareous, micaceous; interbedded with thin 1/2 inch to 6 inch beds of medium dark gray, calcareous siltstone.
18	22	Shale, medium dark gray, calcareous, silty, interbedded with 2 inch to 2 foot beds of dark gray, silty limestone.
17	57	Shale, medium dark gray to dark gray, calcareous, silty; interbedded with 1 to 6 inch beds of calcareous siltstone and silty limestone.
16	5	Limestone, brown gray, dense, fossiliferous, weathers moderate yellow brown.
15	49	Quartz sandstone, coarse to granule size grains, cross-laminated; forms upper of two prominent sandstone ledges.
14	99	Covered; soft, probably largely gray shale.
13	33	Limestone, dark gray, silty, platy to laminated; interbedded with gray shale in 6 inch layers.
	6	Igneous sill
12	39	Shale, medium dark gray, fissile; interbedded with minor thin, dark gray, calcareous, micaceous siltstone.

Unit No.	Thickness in feet	Description
11	4	Limestone, medium crystalline, olive gray, silty.
10	14	Quartz sandstone, green to brown, micaceous, silty; minor interbedded shale.
	7	Igneous sill.
9	32	Quartz sandstone, yellow gray, coarse to granule size grains, minor cross-lamination. Forms lower of two prominent sandstone ledges.
8	105	Covered; upper 40 feet probably soft, medium to coarse grained quartz sandstone.
7	12	Limestone, medium dark gray, massive; argillaceous near base; 1 to 3 inch black chert seam in center, gray chert near top.
6	12	Largely covered; probably as below.
5	6	Shale, medium dark gray, silty, calcareous; and siltstone.
4	18	Quartz sandstone, tan, medium to coarse grained, minor pebble conglomerate.
3	12	Covered; probably soft, medium grained, quartz sandstone.
	4	Igneous sill.
2	4	Shale, dark gray, carbonaceous, fissile; 2 inch dark gray micaceous siltstone, some chert pebbles.
1	1	Shale, silty.

Base of Pennsylvanian formations.

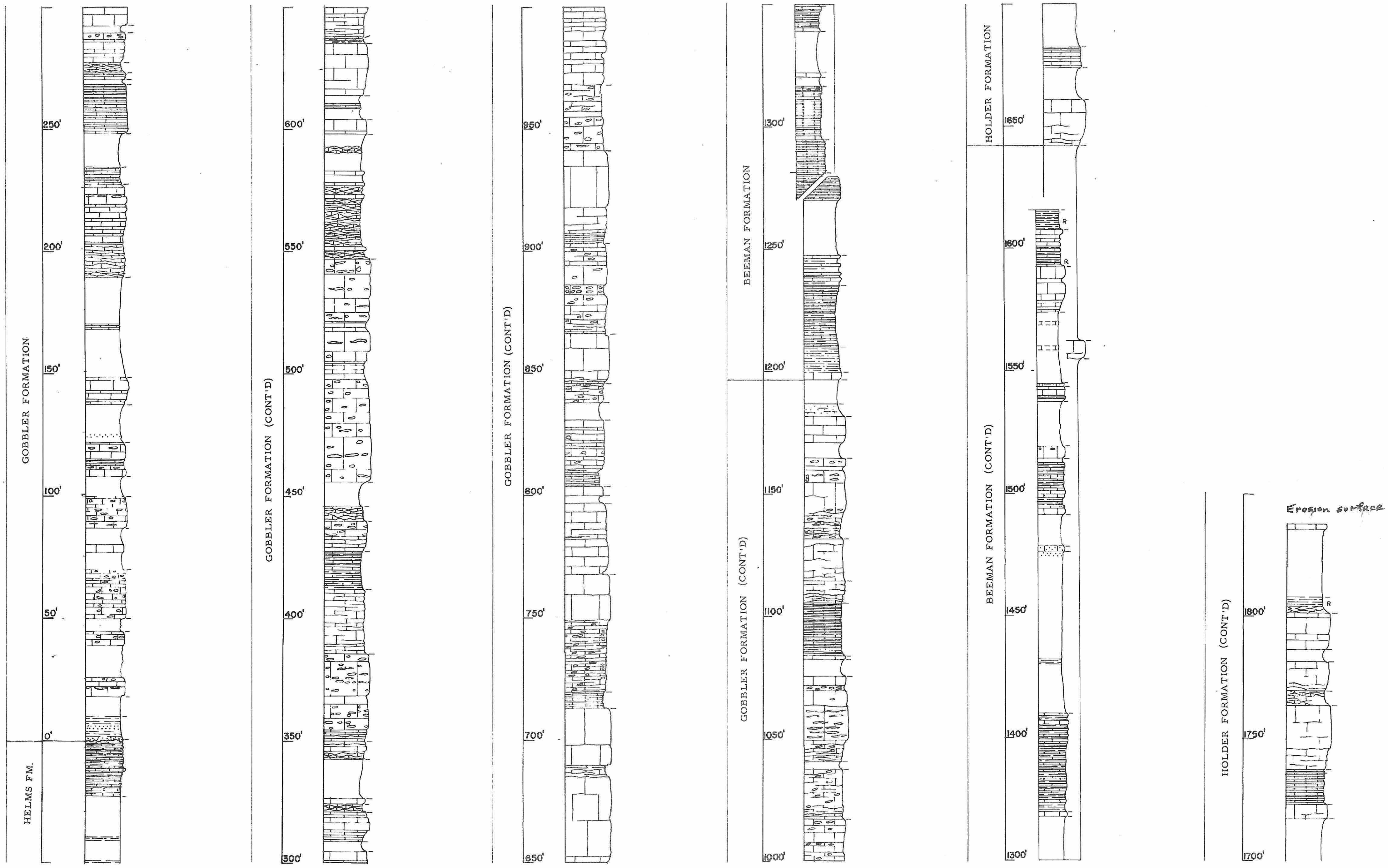
MISSISSIPPIAN FORMATIONS

Rancheria Fm.	13	Limestone, medium gray, silty, beds 6 to 18 inches, cherty, abundant fossils near base. (Rancheria fauna) Loc.
Dona Ana member of the Lake Valley Frm.	20	Limestone, very light gray, crinoidal, light gray chert nodules.

Base of section at 5650 feet, in the NW 1/4 NE 1/4 NW 1/4 sec. 15, T. 17 S., R. 10 E., at junction of Mule Canyon with valley from NE.

For this report, graphic sections of the Pennsylvanian strata measured and described at six essentially complete sequences are reproduced on plates 10, 11, 12, 13, 14, and 15. One of the sections (no. 5, pl. 14) was measured and described by M. L. Thompson, and the writer has plotted the graphic log from Thompson's lithologic descriptions. This is a key section as the Pennsylvanian series boundaries have been determined for this section by Thompson on the basis of fusulinid identifications (see Lloyd, 1949, pp. 35-40). The writer has correlated the lithologic subdivisions used in field mapping with the measured section of Thompson and thus established the approximate age of the formation. Whether or not the age of the lithologic units changes within the area of the Sacramento Mountain escarpment is not known definitely, but the persistence of a few thin marker beds in much of the map area, the small size of the area, and age determinations of a few fusulinids collected elsewhere in the area suggest that the formation boundaries are approximate time lines.

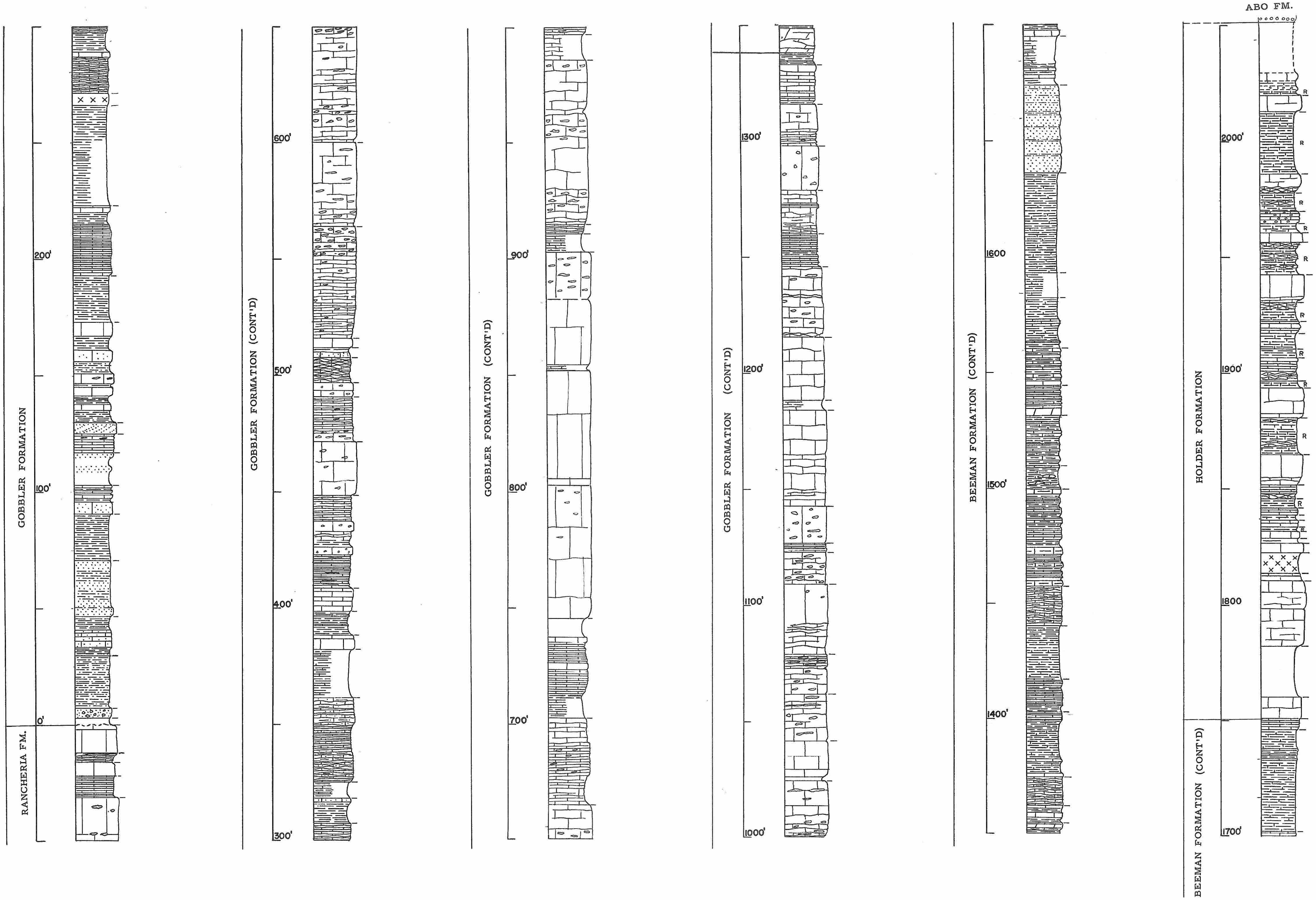
The variation of lithofacies in short distances in the Sacramento Mountains is one of the most interesting phases of the Pennsylvanian stratigraphy. The standard correlation diagrams using graphic sections, such as on plates 10 through 15, tend to emphasize the individual strata and marker beds. It is difficult to visualize the change in lithofacies from one section to the next, and more difficult to obtain a quantitative expression of the changes. A real problem in using this kind of stratigraphic section in the Sacramento Mountain area is caused by an abundance of intermediate rock types, such as marl, very sandy limestone, or very calcareous sandstone. Without close detail, these



Section continued from the top of the column to the left.

Pennsylvanian section No. 1; measured N. 1/4 N 1/4 sec. 18, and SW 1/4 sec. 8, T. 19 S. R. 11 E. Strata from 1280 to 1616' above base measured in N 1/2 SE 1/4 SW 1/4 sec. 31, T. 18 S., R. 11 E.

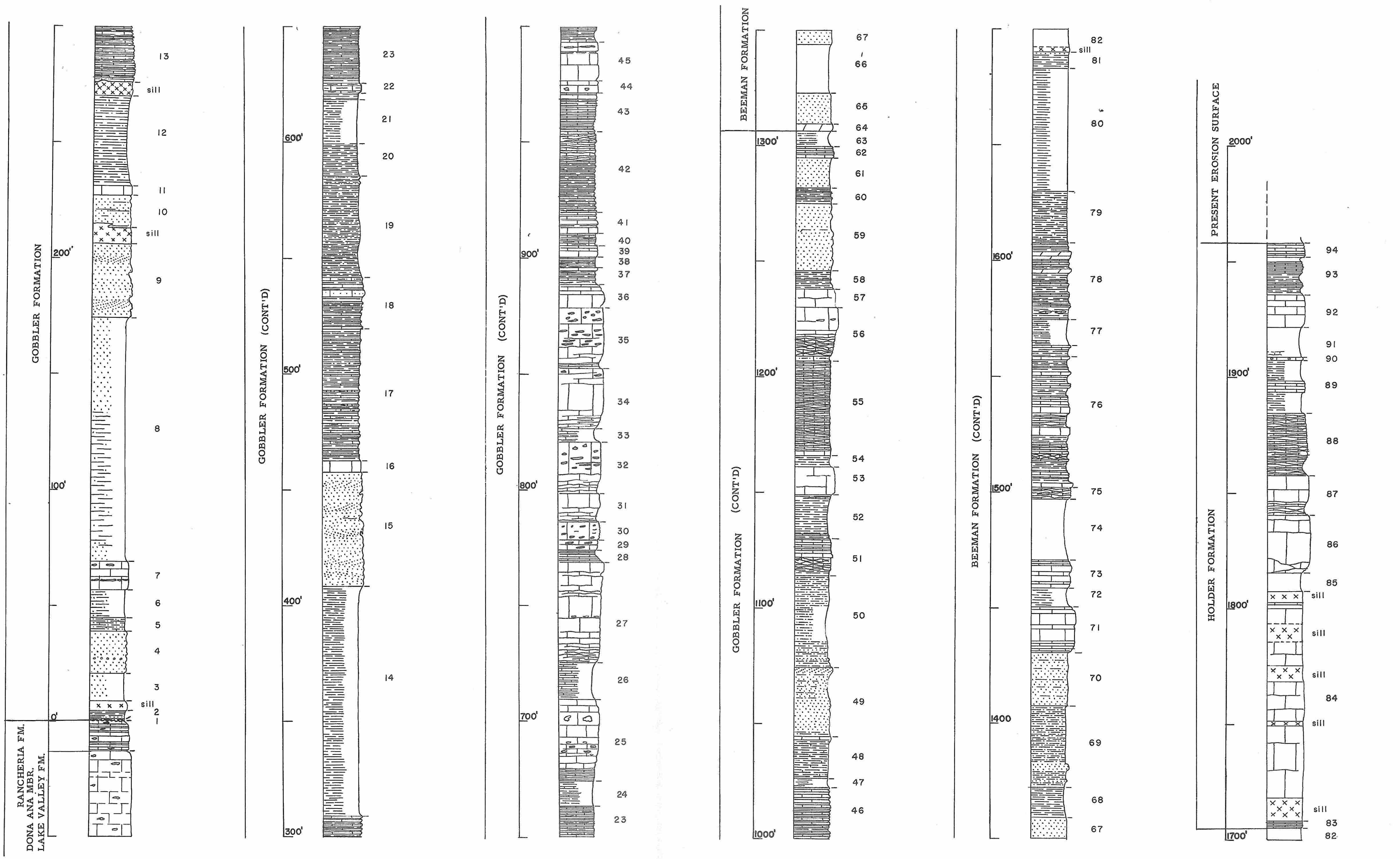
STRATIGRAPHIC SECTION (NO. 1) OF PENNSYLVANIAN FORMATIONS



Section continued from the top of the column to the left.

Pennsylvanian section No. 2; measured in Deadman Canyon. Base of section in SE 1/4 NW 1/4 SW 1/4 sec. 14, T. 18 S., R. 10 E., Beeman formation part measured in SW 1/4 NE 1/4 sec. 14, Holder formation in SE 1/4 NE 1/4 sec. 14.

STRATIGRAPHIC SECTION (NO. 2) OF PENNSYLVANIAN FORMATIONS

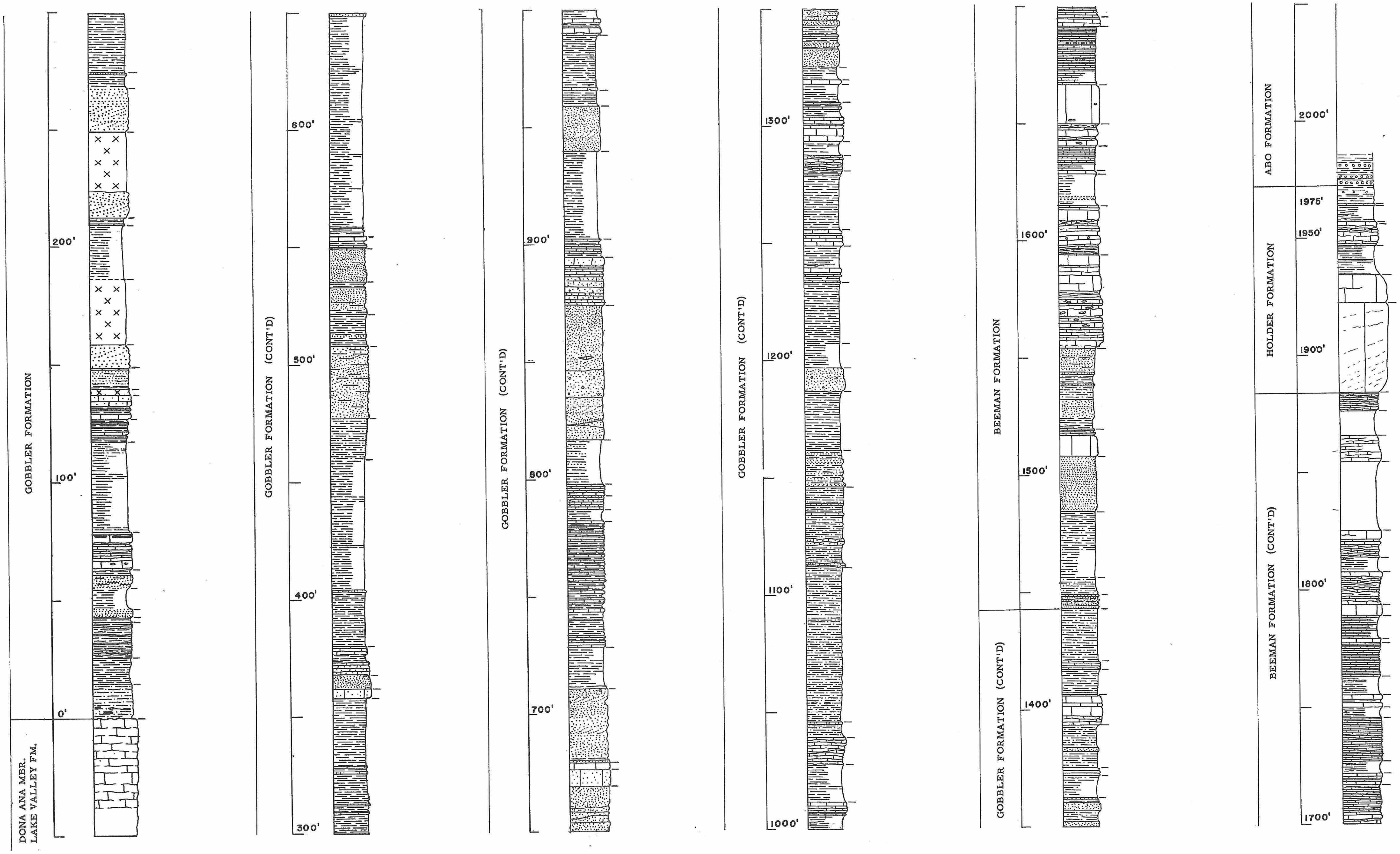


Section continued from the top of the column to the left.

Pennsylvanian section No. 3; measured in Mule Canyon and Long Ridge area. Base of section in NW 1/4 NE 1/4 NW 1/4 sec. 15, T. 17 S. R. 10 E. and section measured in N 1/4 sec. 15. Above 1430' section measured in E 1/2 NW 1/4 NW 1/4 sec. 14, T. 17 S. R. 10 E.

STRATIGRAPHIC SECTION (NO. 3) OF PENNSYLVANIAN FORMATIONS

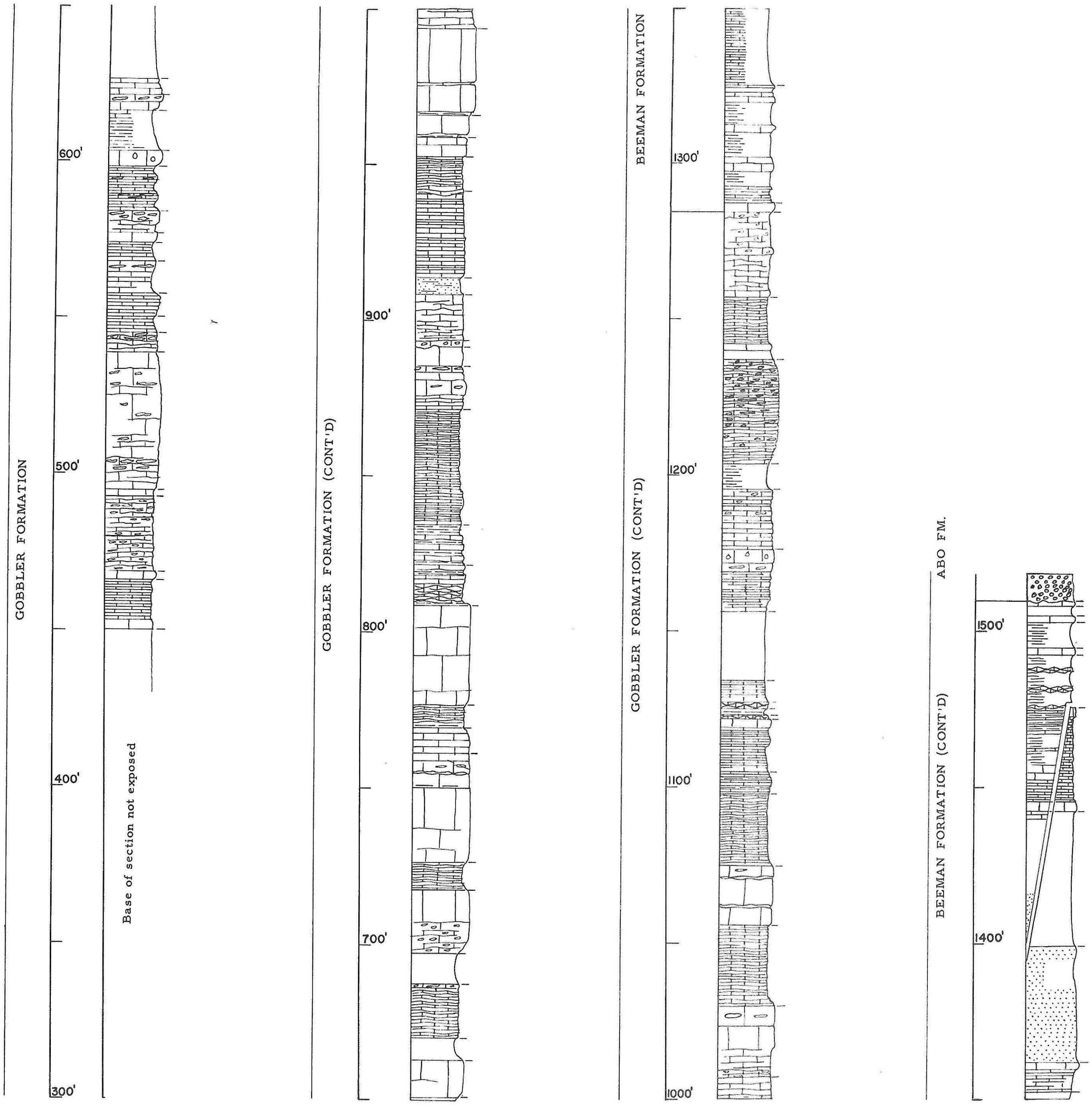
TYPE SECTIONS OF THE GOBBLER, BEEMAN, AND HOLDER FORMATIONS.



Section continued from the top
of the column to the left.

Pennsylvanian section No. 4; measured in upper Alamo Canyon, in N 1/4 S 1/2
sec. 6, T. 17 S. R. 10 E.
11?

STRATIGRAPHIC SECTION (NO. 4) OF PENNSYLVANIAN FORMATIONS



Section continued from the top
of the column to the left.

Pennsylvanian section No. 6; measured in Fresnal Box canyon, along road cuts
where possible, in N 1/4 S 1/2 sec. 6, T. 16 S., R. 11 E.

STRATIGRAPHIC SECTION (NO. 6) OF PENNSYLVANIAN FORMATIONS

are difficult to represent in the standard graphic log, and, if shown, the detail tends to defeat the purpose of getting a general picture of variation in lithofacies.

Krumbein and Sloss (1951, pp. 270-273) and others have analysed sedimentary rocks in terms of the fundamental components, or "non-specific lithotopes" of sand, shale, and limestone. These components or their ratios (clastic ratio, sand:shale ratio) have been used to express the composition of a rock unit. The writer has used the fundamental components in a different manner to illustrate the vertical and horizontal changes of lithofacies within the Pennsylvanian strata of the Sacramento Mountains. Fundamental components, or "non-specific lithotopes" have been determined for each 25 feet of the six measured sections. The percentages of the components were plotted to scale horizontally in sequence at the proper elevation on a columnar log. By connecting similar points after plotting all of a section, the result is a continuous log analysed in terms of the fundamental components. The major changes in lithofacies are easy to visualize from these logs, and the data in a form that can be readily used for a quantitative analysis of the components. The resulting logs can also be of value in correlation, particularly in areas where lithologic marker beds cannot be traced.

Lithofacies logs of all six of the measured sections of plates 10 to 15 are reproduced on plate 16. Quantitative laboratory analysis to determine the components in the different rock units would lead to more precision than that obtained from the field descriptions of the lithologic units. However, the amount of time required may not justify the increased precision.

GOBBLER FORMATION

The name Gobbler is herein proposed for the sequence of strata between the base of the Pennsylvanian system and the base of a thin bed of brown weathering dolomite or dolomitic limestone that lies above the conspicuous limestone cliffs in the middle part of the Pennsylvanian section along the west front of the Sacramento Mountains. The type section is between Long Ridge and the base of Mule Canyon, and lies in the T. 17 S., R. 10 E. At the type section (pl. 12), the Gobbler formation is about 1300 feet thick, and consists largely of shale, argillaceous limestone, and very coarse grained quartz sandstone in its lower half, and gray, cherty, limestone in medium to thick beds in its upper half. The gray, cherty limestone that forms the prominent cliffs in the middle and upper part of the Gobbler formation of the type section is herein named the Bug Scuffle limestone member. This member thickens southward along the mountain front, and forms sheer and imposing cliffs, 500 to 700 feet high.

The names, Gobbler and Bug Scuffle, are geographic names indicated on the U. S. Forest Service topographic map of the Sacramento Division of the Lincoln National Forest. Gobbler is the name of the triangulation station, and of the topographic prominence in the center of sec. 19, T. 18 S., R. 11 E. This dome owes its prominence to the resistance of the limestones of the Gobbler formation. Bug Scuffle is the name of a hill in sec. 15, T. 19 S., R. 11 E., and also is the name of a major canyon a mile west of the hill. The Bug Scuffle limestone caps Bug Scuffle Hill, and is well exposed for several miles along both sides of Bug Scuffle Canyon.

Areal distribution:

The Gobbler formation is the thickest of the Pennsylvanian formations in the Sacramento Mountains, and crops out continuously from the area of Beeman Canyon, northeast of Alamogordo, to Sand Canyon at the southern edge of the map area.

The Bug Scuffle limestone member of the Gobbler formation extends from the south edge of the map area northward to the area east of Alamogordo. Although conspicuous along the west front of the range, it grades laterally to the east into clastic strata. The limits of the member are obscure, as it thins primarily by intertonguing at many levels with lateral clastic facies rather than by the coalescence of the top and bottom. Most of the Gobbler formation exposed in the southern half of the map area consists of the Bug Scuffle limestone member. The Bug Scuffle member forms much of the Gobbler formation in the High Rolls area.

Lithology:

The Gobbler formation contains a wide variety of rock types, most of which are the product of marine deposition. The lower part of the formation consists largely of dark shale, argillaceous limestone, and very coarse grained quartz sandstone, and differs somewhat from the overlying part of the section forming the Bug Scuffle limestone member, and its closely associated clastic facies. The basal part of the Gobbler formation weathers to a slope, and in much of the area is covered by debris from the overlying more resistant parts of the formation. The lowest thick section of incompetent strata of the Paleozoic section are in the Gobbler formation. Most of the Tertiary (?) intrusives of the Sacramento Mountains form sills in this part of the section and are particularly abundant in the vicinity of Alamo Canyon. The general aspect of the formation along the west front of the range is shown in figures 7, 23, and 31.

The type section of the Gobbler formation is shown on plate 12, and the description of the rock units is on pages 189 and 190. Graphic logs of the formation at the other five measured sections in the area are reproduced on plates 10, 11, 13, 14, and 15, and the lithofacies logs of all of these sections are reproduced on plate 16. The range in thickness of the Gobbler formation is from 1630 feet in the section at Horse Ridge (pl. 14), to 1200 feet in the section measured near the south end of the mountains. The sections in which clastic rocks predominate are thicker than those in which the Bug Scuffle limestone is predominant.

The lower part of the Gobbler formation contains some rock types that appear to be restricted to this part of the Pennsylvanian section. Sandstone, composed almost entirely of quartz grains of coarse sand to granule size, is common in the lower part of the formation (units 9, 10, and 15, fig. 12). Rock with this coarse texture, angular, well sorted grains, and clean, glistening appearance has not been observed more than 500 feet above the base of the formation, but is common below that level, especially in the northern part of the area. The sandstone beds are probably separate lenses, rather than blanket deposits of great lateral extent. In many places, this sandstone fills channels cut into the Mississippian formations, and is associated with chert and quartzite conglomerate.

A rock type that is largely restricted to the lower part of the Gobbler formation is dark gray, argillaceous to silty limestone in hard, massive beds that contain black or dark gray chert nodules. For example, see unit 7, fig. 12, or fig. 29. This type of cherty limestone occurs throughout the length of the Sacramento escarpment, and is especially common in the lower 100 to 200 feet.

Near the middle of the Gobbler formation in areas where the Bug Scuffle limestone member is absent, dark argillaceous limestone and calcareous shale in thin beds are common. An excellent marker bed of laminated, dense, silty limestone occurs between 740 and 800 feet above the base of section 4 (pl. 13).

The sandstone of the Gobbler formation changes from pure quartz sandstone near the base to types less quartzose with finer grains, and poorer sorting higher in the section. Green gray, silty, micaceous quartz sandstone and sub-graywacke (Pettijohn, 1949, p. 227) is commonly interbedded with limestone strata in the upper part of the Gobbler formation. This is similar to the green gray sandstones just above the Gobbler formation, but does not contain conspicuous amounts of pink potash feldspar. The distinction is valuable for mapping along much of the escarpment, but must be used with caution as northeastward from the type section, some coarse grained sandstones are rich in feldspar.

Bug Scuffle limestone member and contemporaneous clastic facies[*/]:

In much of the Sacramento Mountain area, the most conspicuous and distinctive feature of the Gobbler formation is the Bug Scuffle limestone member. This member forms the sheer limestone cliffs, locally from 500 to 700 feet high, that are such a prominent part of the Sacramento Mountain escarpment as far north as Alamo Canyon. As indicated on plate 16, the member grades into clastic rocks to the north and east in the Alamo Canyon, Horse Ridge area, but farther to the northeast the clastic rocks grade into limestones characteristic of the Bug Scuffle member. The change in lithology is more gradual in a north-south direction than in an east-west direction (pl. 16).

The Bug Scuffle member is thickest at the south end of the mountains, where about 1200 feet of continuous limestone strata form the member. As a topographic and mappable unit, the essential feature of the member is the presence of limestone to the virtual exclusion of other rock types. At Deadman Canyon (sec. no. 2, pl. 11), the section between the top and bottom of the member is almost entirely limestone in the upper 800 feet (fig. 32).

Although a variety of types of limestone occur in the Bug Scuffle member, one type is predominant, and is believed to be the product of a single depositional environment. This limestone, a lithofacies in the restricted definition given by Moore (1949, p. 8), is light gray, sublithographic to very finely crystalline, and composed almost entire-

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[*/] The writer acknowledges the contribhutions of R. L. Graves who has investigated petrologic and paleontologic features of the Bug Scuffle limestone member and the associated clastic facies as a research project for the California Research Corporation.

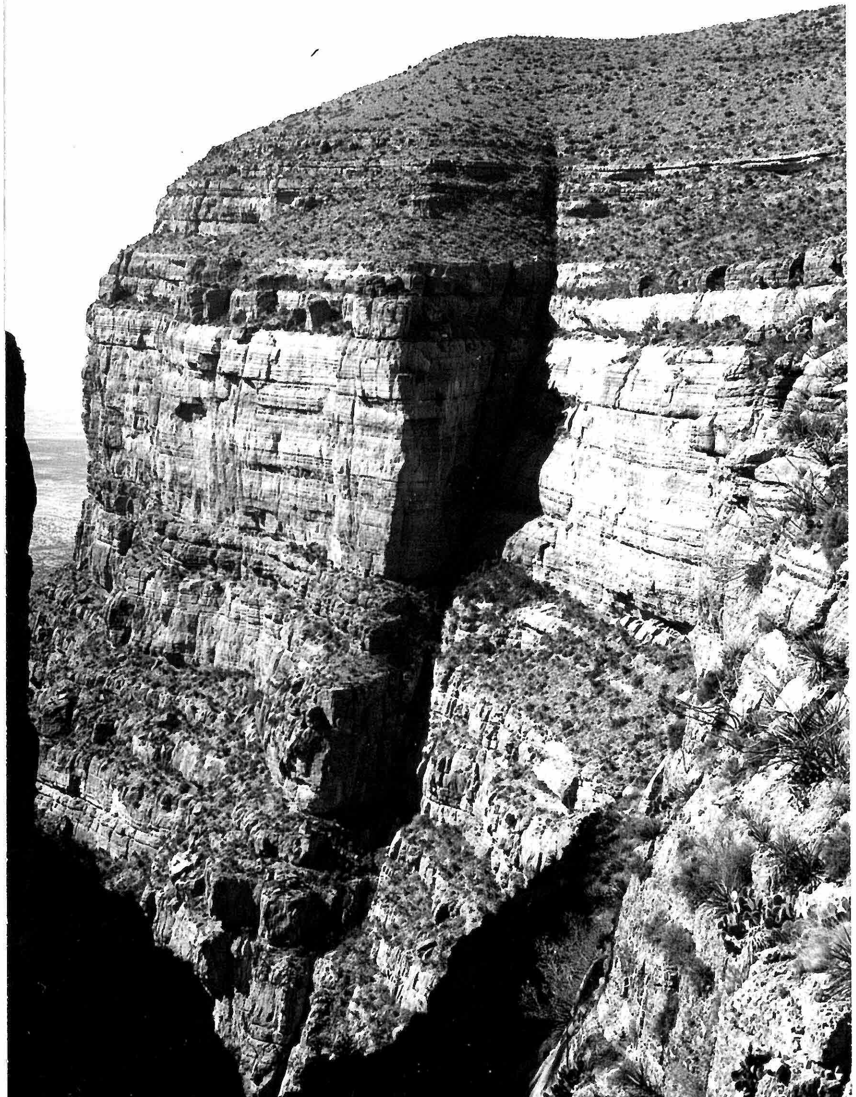

Figure 32. The Bug Scuffle limestone member and lower part of the Beeman formation in Deadman Canyon, sec. 13, T. 18 S., R. 10 E. The sharp niche is caused by relatively rapid erosion of one of many igneous dikes of this area that were intruded along major joints.

ly of calcite. Sand, silt, and clay impurities are either absent, or in small quantities. The rock is massive to thick bedded, although a cyclical repetition from thin bedded, somewhat argillaceous limestone, upward into the much thicker and massive pure limestone is common. Chert nodules, generally light gray in color, are common, but rarely form more than 10 to 20 percent of the rock unit in which it occurs. Fossils are widespread, but only locally form an important part of the rock. Most of the fossils are microfossils. Megafossils are uncommon.

This limestone does not appear to be of biohermal origin. The predominance of"lime mud", the prevailing types (non-colonial) of fossils, the chert, the structure of the beds, and the lateral continuity of the rock are incompatible with this origin. It appears to be of the type Krumbein and Sloss (1951, p. 137) term a "normal marine limestone", that is a limestone that is essentially formed in place, from the precipitation of calcium carbonate, either by chemical or biochemical processes, and in which recognizable fossil material is common, but not predominant. It is believed to be the product of deposition on a stable shelf. Local evidence of scouring and minor channeling, and some thin lenses of limestone, suggests deposition in shallow water. The shelf area of limestone deposition received little or no terriginous clastic material.

No single rock type is predominant in the clastic strata that were deposited contemporaneously with the Bug Scuffle limestone member. The clastic facies is composed largely of shale, sandstone, siltstone, and clastic limestone. The sandstone of the clastic facies is calcareous quartz-muscovite sandstone or subgraywacke, although as previously noted, locally feldspar is a conspicuous constituent. All gradations between sandstone and limestone are represented. Much of the sandstone is highly calcareous. The typical limestones of the clastic facies are calcarenites and contain abundant quartz sand. Calcirudites composed largely of fragments of crinoids, brachiopods and other fossils are common.

Thin limestone strata similar to those of the Bug Scuffle member are interbedded with the clastic facies, but form a minor part of the section, indicating that the environmental conditions favorable for the formation of the Bug Scuffle lithofacies at times prevailed over the entire area of study.

Thompson (1942, p. 18) noted the change from limestone to clastics rocks in the Sacramento Mountains, and states the section changes toward Alamogordo from the south to "almost entirely deltaic to clastic marine sediments" and that the sequence is "thicker and more highly clastic" farther toward the northeast. The concept, however, of a source of detritus to the northeast, and a progressive increase in clastic content and thickness in that direction is probably valid regionally, but is not entirely consistent with features observed in the Gobbler formation in the northern Sacramento Mountains. The section (pls. 15 and 16) measured farthest to the northeast, in Fresnal Box Canyon, is very similar in facies to that at the Long Ridge type section and contains thick massive limestones of the Bug Scuffle member (fig. 33).

The clastic facies in the area between Fresnal Canyon and Long Ridge appears to attain maximum development along a northwest trend

Figure 33. **Resistant limestone ledges of the bluff are part of the Bug Scuffle formation at Fresnal Canyon in the northern Sacramento Mountains. Permian strata of the foreground are separated from the bluff by a major normal fault.**

extending from the upper Alamo Canyon section toward the base of the Horse Ridge section (pl. 16). South of Alamo Canyon, the transition from the massive Bug Scuffle limestone along the west front of the range eastward to a clastic facies can be noted conspicuously in the upper part of San Andres Canyon, and is distinct, but less pronounced throughout the southern part of the area. The persistent increase in clastic material toward the east in all of the area south of Alamo Canyon strongly suggests a source of the clastic material in that direction.

The northeast-southwest symmetry of the clastic facies is best explained by introduction of material along the clastic axis, and a spreading of the material laterally in both directions from this axis into adjacent shelf areas of limestone deposition. No source of Pennsylvanian clastic sediments is known northwest of the Sacramento Mountains for many miles. This suggests that the detritus forming the clastic facies in the area of maximum deposition came from the southeast or east, probably off shore from a major river. It seems to verify the existence of the Pedernal Land Mass (Thompson, 1942, pl. I) to a latitude south of the map area, at least during the time of deposition of the Gobbler formation.

Limestone of the Bug Scuffle member probably formed in areas separated from the shore by areas of clastic deposition. The sharp increase in the clastic rocks along the northwest trend probably occurred off shore from a major river. The conditions that caused the detritus to extend along a sharply defined zone toward the northwest, and caused so little lateral contamination are not known. If the clastic deposition was localized by subsidence, it would probably be much thicker than the lateral non-clastic deposits. Although the clastic sections are somewhat thicker than the limestone sections, the differences are small.

Conditions of deposition:

The conditions prevailing during deposition of the Gobbler formation were more varied than during the deposition of any of the older formations of the Sacramento Mountains. The heterogeneity of the strata clearly indicates considerable variation in conditions of deposition both laterally and vertically in the section. Most of the strata appear to represent deposition under shallow marine conditions. Some poorly preserved plant fossils in the coarse grained quartz sandstones near the base of the formation resemble <u>Lepidodendron</u>. These and other plant fossils suggest at least temporary emergence during the time represented by the Gobbler formation, but the emergence does not appear to have been accompanied by significant erosion, and probably was only a part of a cyclical fluctuation of the seas.

<u>Contact relationships:</u>

The base of the Pennsylvanian system and of the Gobbler formation is a well marked unconformity throughout the Sacramento Mountains. The strata above and below the unconformity are essentially parallel, but the surface of unconformity is irregular. Local relief of the order of 100 feet can be demonstrated. At several places in the area, the Mississippian formations were channeled to depths of 50 to 100 feet prior to the deposition of the Pennsylvanian sediments. The rocks in the channels, and other low areas of the erosion surface, are largely conglomerate containing pebbles and cobbles of chert and quartzite, and very coarse grained quartz sandstone. The cherts in the conglomerates were largely derived from the underlying cherty Mississippian rocks (Laudon and Bowsher, 1949, p. 22), but the quartz and quartzite must have been derived from elsewhere, probably from the Pedernal Land Mass to the east.

The upper contact of the Gobbler formation is at a marker bed of dolomite or dolomitic limestone which is considered a part of a conformable sequence of strata.

Fauna and age:

The Gobbler formation contains an abundant fauna, and some plant fossils, but the writer did not attempt systematic collections except for fusulinids, and these have not been identified to date. The writer's lithologic correlations with the section by Thompson (pl. 14) in the northern Sacramento Mountains indicate the age of the Gobbler formation to range from Morrowan (?) through Atokan and Desmoinesian, and include the lower part of the Missourian.

Correlation and regional relationships:

The Gobbler formation correlates in a general way with the lower part of the Pennsylvanian section in northern New Mexico (fig. 30). The lower part of the Gobbler formation containing the coarse quartz sandstones is about equivalent to the Sandia formation, and the Bug Scuffle limestone member may correlate with the lower part of the Madera limestone, as these are names used by Read and Wood (1947). These correlations, however, represent only a similarity in aspect of the lower Pennsylvanian section, and do not imply detailed equivalence in lithology or time. Strata of age comparable to the Gobbler formation are known from the Hueco, Franklin, San Andres and Oscura Mountains (Thompson, 1942, pl. I). Rocks of probable Morrowan age are known only in the Sacramento and Hueco Mountains.

Lloyd (1949, pl. 7) indicates limestone strata of Des Moines age in the Magnolia Burro Hills well in sec. 31, T. 17 S., R. 20 E., about 50 miles east of the Sacramento Mountain escarpment, but Pennsylvanian beds older than the Virgilian are absent in the Texas Company's Wilson No. 1 well in sec. 29, T. 17 S., R. 18 E. Pennsylvanian beds are also absent in many of the wells drilled in area southwest of the map area, but in the Turner Everett No. 1 well in sec. 34, T. 21 S., R. 13 C. about 1000 feet of Pennsylvanian beds are reported. The exact age of these beds is not known.

No data are available concerning possible Pennsylvanian strata in the area between these wells and the Sacramento escarpment.

BEEMAN FORMATION

The name Beeman is herein proposed for the strata consisting largely of thin bedded, argillaceous limestone, calcareous shale, and feldspathic sandstone that lies between the top of the Gobbler formation and an horizon at the base of many discontinuous bioherms of white to very light gray limestone. The Beeman formation typically forms the slopes between the two major sets of cliffs in the Pennsylvanian section of much of the Sacramento Mountains. The type section is 393 feet thick. The lower 133 feet were measured directly above the type section of the Gobbler formation in the NW 1/4 NE 1/4 NE 1/4 sec. 15, T. 17 S., R. 10 E., and the upper 260 feet are about a quarter mile to the east in the NW 1/4 NW 1/4 sec. 14, T. 17 S., R. 10 E. The name is derived from Beeman Canyon, in secs. 3 and 4, T. 16 S., R. 10 E. as indicated on the maps of the Lincoln National Forest. Much of Beeman Canyon has been carved in the soft strata of the Beeman formation.

Areal distribution:

The Beeman formation is exposed throughout the length of the map area from near La Luz Canyon on the north to the vicinity of Sand Canyon on the south. It is absent from the Pennsylvanian sequence within this area only where removed by recent erosion or by erosion preceding the deposition of the Abo formation of Permian age.

Lithology:

The Beeman formation consists largely of thin bedded, argillaceous limestone and shale. Green gray feldspathic sandstone locally is abundant, especially in most of the map area in the lower part of the formation. The Beeman formation weathers to a gray brown slope much of which is covered by talus and slump masses from the more resistant cliffs of the overlying Holder formation (fig. 31). The thickness at the measured sections within the area ranges from 350 to 450 feet where the complete section is present. The type section is described on pages 180-82. Graphic logs of the six Pennsylvanian sections in the area are reproduced on plates 10 to 15.

A 3 foot bed of finely crystalline dolomite forms the base of the formation at the type section. This basal marker bed, or a similar bed at about the same stratigraphic horizon persists southward throughout most of the escarpment. Locally, the rock is dolomitic limestone, or limestone. The moderate yellow brown color of the weathered surface is distinctive. Several similar beds occur higher in the Beeman formaation locally.

The feldspar content of the sandstones of the Beeman formation is greater than in the Gobbler formation at most points in the area. Below the Beeman formation, the sandstone is composed largely of quartz, muscovite, chlorite, chert, and clay minerals, and corresponds in composition to silty quartz sandstone or to a subgraywacke (Pettijohn, 1949, p. 255). The sandstone above the base of the Beeman formation contains much more feldspar, and the rocks are feldspathic sandstone (10 to 25 percent feldspar) or locally, arkosic sandstone (more than 25 percent feldspar) in the classification by Pettijohn. The exact classification is not as significant as the fact that this change can be used to locate the base of the Beeman formation. The change is not sharp, or within a single bed, but at most sections examined, the feldspar content increases appreciably in less than 50 feet. Locally, as in the area of Arcente Canyon in T. 16 N., R. 11 E., some beds of feldspathic sandstone occur several hundred feet below the top of the Gobbler so this feature must be used with caution, but it is valuable in much of the area, particularly where the yellow brown dolomitic layer can not be recognized.

In the lower part of the formation the thickness and number of sandstone beds increase markedly toward the east throughout the length of the Sacramento Mountain escarpment. On many of the high ridges, strata one or two feet thick can be traced eastward to beds 20 or 30 feet thick in less than a mile. This change is similar to the changes noted in the Gobbler formation.

Most of the Beeman formation is composed of limestone and shale.

The limestone is typically brown gray to dark gray, very argillaceous and in beds a few inches to two feet thick that alternate with beds of brown, gray and green calcareous shale. The only dolomite in the Pennsylvanian strata is in the Beeman formation. Some of the limestones are dolomitic, and weather to a light brown. The limestone is locally nodular, as in the northeastern exposures of the formation. Thin beds of limestone conglomerate, that appear to be intraformational in origin are common near the base of the formation and are in the upper part of the formation in which limestone is the predominant rock type, as in the section of upper Alamo Canyon (pl. 13).

In the upper two-thirds of the Beeman formation, the amount of limestone increases toward the east, the reverse of the relationship in the Gobbler formation. This is best indicated by comparison of the type section with the section in upper Alamo Canyon (pls. 12, 13 and 16). Toward the east, the limestone strata thicken, and become more massive and less argillaceous and shale beds decrease in number and thickness. Thin layers of red shales and limestone conglomerates are a distinctive part of the strata to the east, but are uncommon in the western area. Where the more massive limestone of the Beeman formation overlies the clastic facies of the Gobbler formation, as in upper Alamo Canyon, the lowest prominent limestones cliffs of the Pennsylvanian strata are in the Beeman formation (fig. 33), a complete reversal of topographic aspect of the Pennsylvanian sequence from that only a few miles to the west.

Some of the lithologic units of the Beeman formation are excellent marker beds. One of the best is unit no. 75 of the type section in the

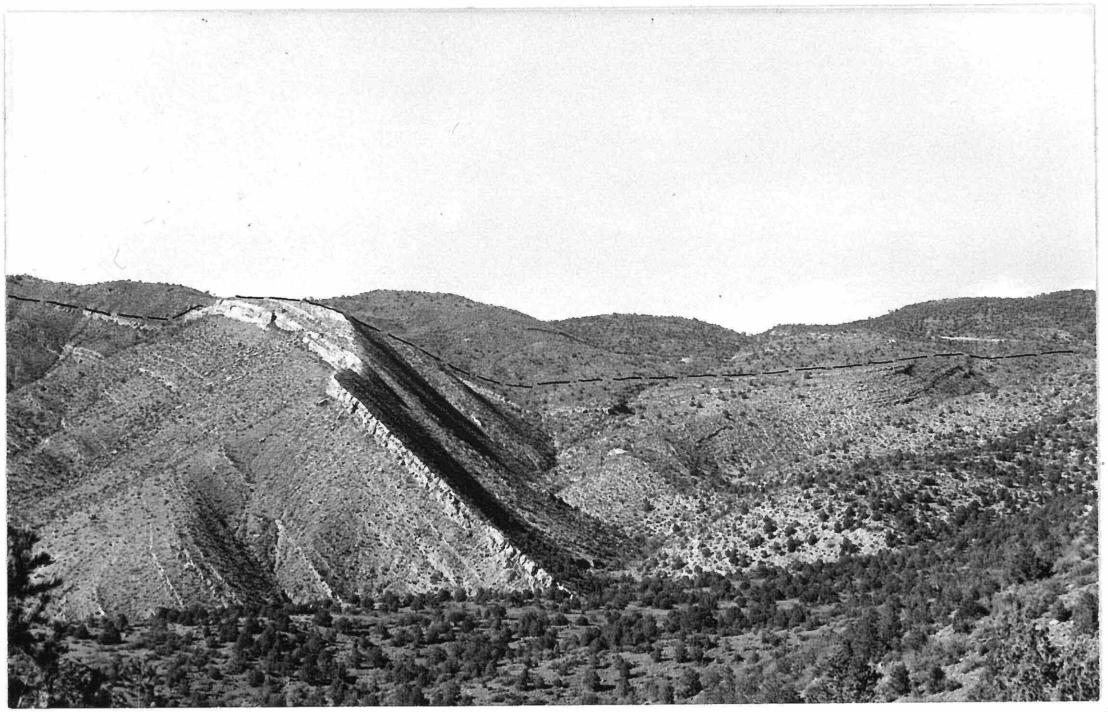

Figure 34. Pennsylvanian strata along the Dry Canyon Syncline. The resistant limestone ledge is the upper part of the Beeman formation. The dashed line is the unconformity at the base of the Abo formation.

middle part of the formation. It consists of silty, greenish weathering, nodular limestone, from 5 to 20 feet thick, that is generally partly siliceous, and can be traced in most of the area.

The lower part of the limestone cliff in the Beeman formation in the eastern part of the area has two features which are distinctive identifying features. The lower one to three feet of this ledge are teeming with fusulinids, and the overlying 20 feet contain minor gray chert. This lower cliff is correlated with unit 71 of the type section. Although the limestone marker cannot be traced continuously in the area because of erosional gaps and covered intervals, a similar ledge of limestone that consistently thins toward the west occurs throughout the length of the area and is believed to be the same unit. The vanishing point occurs along a line that trends slightly west of north from the center of Table Top, in T. 19 S., R. 11 E., between Nigger Ed and Grapevine Canyons to the center of Horse Ridge in T. 16 S., R. 10 E.,

In the southern part of the area, some of the sandstone beds of the lower Beeman formation contain abundant petrified wood. In the vicinity of Sand Canyon, in the NW 1/4 sec. 5, T. 20 S., R. 11 E., logs of petrified wood a foot thick and 10 to 20 feet long occur in shale and sandstone strata.

Conditions of deposition:

The strata of the Beeman formation appear to have formed in large part in a marine environment, and one characterized by constant conditions along north-south lines, and by rapid change from east to west. The increase in amount of amount of sandstone toward the east in most of the area indicates a source in that direction. Some of the strata, such as the sandstones containing abundant petrified wood may be the products of terrestrial deposition. Probably the lower part of the Beeman formation represents shallow marine to deltaic deposition.

The increase in limestone and decrease in clastics toward the east in the upper two thirds of the formation appears anomalous, but is probably consistent with the interpretation of shallower water and a shore line toward the east. It seems significant that the change from east to west in this part of the section is largely from limestone to limestone and shale, and not to sandy deposits. The relatively massive limestone on the east probably were deposited under conditions of active water circulation, or during a time when terrigenous sediments were not abundant. Most argillaceous particles may have been selectively moved beyond this area and deposited from deeper, less turbulent water. The shallower area probably was more favorable for organic growth and precipitation of calcium carbonate than deeper areas, and the argillaceous constituents were therefore diluted in the near shore areas.

Another explanation of the distribution of shale would be that most of the argillaceous material was introduced into the depositional area from some other direction. The many thin, regular beds of limestone and shale in the western areas suggest deposition under uniform conditions of deeper water. The interbedded limestone conglomerates, and reddish shales of the section in the east are suggestive of shallow water deposition.

Contact relationships:

The lower contact of the Beeman formation is conformable with the underlying Gobbler formation. The contact was selected at a persistent marker bed. In the area of clastic deposition, the base of the formation is transitional with the Gobbler formation.

The upper contact of the Beeman formation is believed to be conformable with the overlying Holder formation. In many parts of the Sacramento Mountains, the Abo formation of Permian age overlies the Beeman at a distinct angular unconformity.

Fauna and age:

Fossils are common in the Beeman formation, but have not been systematically collected. R. C. Spivey, of the Shell Oil Company, has kindly determined the age of the fusulinids collected from the rich zone at the base of unit no. 71 in the SE 1/4 SE 1/4 sec. 24, T. 16 N., R. 10 E. His determination of upper middle Missourian appears to corroborate the age determined by lithologic correlation with the section for which Thompson has determined the series boundaries.

Correlation and regional relationships:

No lithologic unit closely comparable to the Beeman formation has been reported from other parts of New Mexico. The Beeman appears to be equivalent in time and in general lithology to the middle part of the arkosic limestone member of the Madera formation in northern New Mexico (Read and Wood, 1947). Strata of the same age are known in the Oscura, San Andres, Organ, and Hueco Mountains (Thompson, 1942, pl. I). Lloyd (1949, pp. 38-39) reports Missourian strata in the Magnolia Burro Hills well in sec. 16, T. 21 S., R. 22 E., about 60 miles east of the crest of the Sacramento Mountains. Missourian strata are absent from the two wells somewhat closer to the Sacramento Mountains; the Texas Company no. 1 Wilson, in sec. 29, T. 17 S., R. 18 E., and Magnolia's Black Hills well in sec. 31, T. 17 S., R. 20 E.

The surface evidence in the Sacramento Mountains for a source of clastic detritus from the east appears inconclusive. It is probable that a land mass existed to the east in lower Missourian time, and during the deposition of the lower part of the Beeman formation, but that during the deposition of the upper part of the Beeman formation, the former land mass was either absent or so low that it did not contribute much coarse clastic material.

HOLDER FORMATION

The name Holder formation is here proposed for the strata that occur between the top of the Beeman formation and the base of the overlying Permian strata of the Bursum or Abo formation. The Holder formation consists largely of light gray to white, non-cherty, massive limestone, which forms conspicuous, light colored cliffs in most of the Sacramento Mountain area and interbedded red shales, nodular limestones and minor coarse clastic rocks. The name is derived from Holder Ridge indicated on Forest Service Maps in sec. 36, T. 17 S., R. 10 E., and sec. 31, T. 17 S., R. 11 E., which is capped by massive limestone of the basal Holder formation. The type section is located directly above that of the Beeman formation, in the NW 1/4 NW 1/4 sec. 14, T. 17 S., R. 10 E. The Holder formation is Virgilian in age and includes the Fresnal and Keller groups in the classification proposed by Thompson (1942).

Areal distribution:

The Holder formation is the most widespread of the Pennsylvanian formations in the Sacramento Mountains, and crops out from the vicinity of Tularosa on the north to beyond the southern limit of the area. At the north and south, the Holder formation occurs along the fringe of the Tularosa valley, but in most of the map area, it occurs largely as isolated, resistant caps on many of the high ridges at the west front of the mountains. The formation is absent along most of the eastern outcrops of Pennsylvanian strata where the Abo formation overlies truncated Pennsylvanian strata older than the Holder formation.

Lithology:

The Holder formation consists of a wide variety of sedimentary rocks, but forms a distinctive lithologic unit within the area of the Sacramento Mountains. In the lower part of the formation, light gray to white, non-cherty, massive limestone is the dominant rock type, and is interbedded with sandstone, red and gray shale and marl, nodular limestone, and limestone conglomerate. Numerous discontinuous, lenticular masses of light colored limestone occur locally at the base of the formation. The proportion of red beds, limestone conglomerates, and nodular limestones increases toward the top of the formation throughout the area.

Graphic sections of the Holder formation at five localities in the Sacramento Mountains are reproduced on plates 10 to 14, and the lithofacies logs of these sections shown in plate 16. Details of the lithology of the type section (pl. 12) are given on pages 179-80. Lithologic descriptions for the upper 560 feet of the Holder formation as defined in this report have been previously published by Thompson (1942, pp. 75-79) as the type section of the Fresnal Group.

The base of the formation contains many lenticular bodies of essentially massive limestone that are believed to be bioherms or reef accumulations. Bioherms is used as a general term in this report for these lenticular limestone masses at the base of the Holder formation. Detailed studies by Wm. J. Plumley of the California Research Corporation of the petrology and paleontology of two of these masses exposed in N 1/4 sec. 4, T. 16 S., R. 10 E. indicate that the mass formed above the level of adjacent contemporaneous sedimentation, and that the growing mass was subject to wave erosion. These are considered reefs[*]. Other masses in the Sacramento Mountains observed by the writer appear to be similar to those studied by Dr. Plumley, but present data are inadequate to consider all of the limestone lenses as reefs. The more general term, bioherms, is used in this report, although not entirely satisfactory as the masses are flatter than the usual connotation of the term mound, which is used in the definition of bioherms (see pp. 133-36).

The maximum observed thickness is about 100 feet, many are from 50 to 75 feet thick. The bodies are essentially flat at the base and convex upward (fig. 35). In the northern part of the area, the

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[*] Plumley, W. J., Personal communication, 1950.

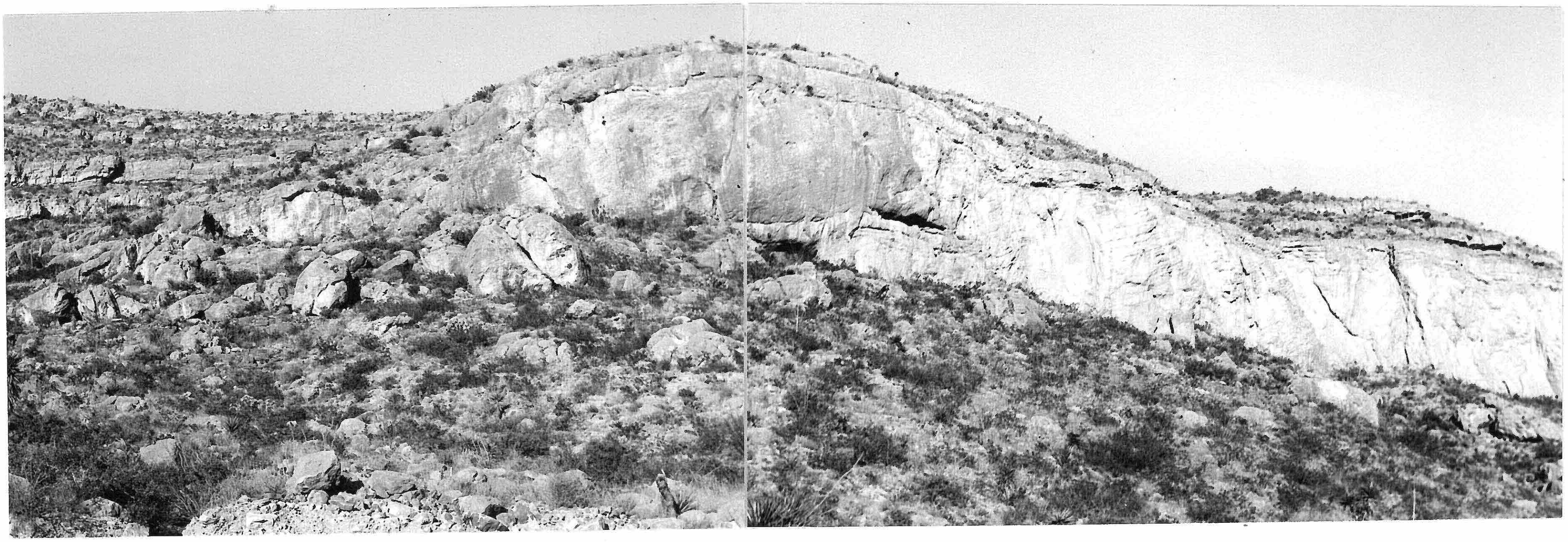


Figure 35. Limestone reef mass at the base of the Holder formation on the north side of Dry Canyon, in sec. 4. T. 16 S. R. 10 E. Note the growth planes dipping to the left in the reef mass. The reef mass is about 100 feet thick in the center and lenses out abruptly on the left.

bioherms appear to be elongate, and extend a mile or more in a north-south direction and as much as 1500 feet east-west. The bioherms appear to be largely restricted to one horizon that occurs from 350 to 450 feet above the base of the Beeman formation. The only exception noted is along the highway in sec. 4, T. 16 S., R. 10 E., where several bioherms are developed at the basal horizon, and another occurs about 100-200 feet higher in the section. Bioherms occur from the area of Dry Canyon on the north southward throughout the map area at least to the area of Sand Canyon in T. 20 S. On the high ridge in the southern part of the area the change from the dark, thin bedded limestone and shale of the Beeman formation to the thick, white, massive limestones of the Holder formation is abrupt, but discrete bioherms are less common than in the north. Massive, white limestones, 20-50 feet thick, mark the base of the formation and persist laterally a mile or more. Bioherms may persist far beyond the Sacramento Mountain area. King and Knight (1945, Sheet II) illustrate a reef mass in the upper Pennsylvanian strata in the Hueco Mountains that is similar in lithology and age to those in the Sacramento Mountain area.

The limestone of the bioherms is white to light gray in color, and contains abundant fossils. Finely laminated growths in some of the rock are interpreted as algal in origin. Recrystallization of calcite obliterates parts of fossils in much of the limestone. The texture of the calcite is highly variable. Obscure layering in some of the masses suggestive of foreset beds is believed to represent phases in the growth of the mass. The observed dips of these layers range from 10 to 30 degrees. Some are visible in the reef mass of figure 35.

Locally the bodies grade laterally into bedded limestone. At other places, the carbonate lens is discrete, and detrital sediments of shale, intraformational limestone conglomerates, and sandstone occur in the flanking deposits. The strata just overlying the bioherms are draped over the resistant cores by the compaction of the lateral facies.

The shape and structures of the bodies, the abundance of fossils, including algal, and the adjacent clastic rocks, derived in part from the masses suggest that these features are bioherms, which probably grew above the level of contemporaneous adjacent sedimentation and formed at least in part in the zone of wave erosion.

Above the level of the bioherms, other white, massive to thick bedded limestones form much of the section, and alternate with brown gray to gray, argillaceous, nodular limestone, and pale reddish brown shale and marl. The sequence is locally cyclical. One common cycle consists of limestone that grades upward into white, massive limestone, and thence gradationally or abruptly to pale reddish brown marl, and thence to nodular limestone. The section of the Holder formation reproduced on plate 11 illustrates this cyclical pattern and some of the variations. Limestone conglomerate is commonly a part of the marly strata, or it occurs at the top of the massive limestone. The sequence is similar to that reported by Wanless (1947, fig. 3, col. 4) at Hartville, Wyoming. Abundant fusulinids in the nodular limestone and massive limestone indicates that these were the production of marine deposition. The red shale and marl may be a near shore deposit, at least partially marine in origin. The abrupt change in the sequence of strata occurs generally at the top of the massive limestone, and locally is an erosional break.

The Holder formation varies in both lithology and thickness along the Sacramento Mountain escarpment. The northernmost section (pl. 14) is 900 feet thick, more than twice the thickness observed to the south (pls. 10-13). Part of this difference is caused by erosion of the upper part of the Holder formation at all localities except the northernmost. However, the differences in lithology of the strata remaining suggest that the Holder formation was probably initially thinner toward the south. In the northern section most of the red shale and nodular limestone occurs in the upper half of the 900 foot section. These rock types are common in the sections to the south, none of which is more than 400 feet thick. Abundant coarse clastic rocks occur in the northern section above the bioherms and below most of the red shales and nodular limestones. Very little sandstone or conglomerate occurs toward the south. This part of the section may be eroded to the south, but the writer believes the coarse clastics rocks feather out rapidly toward the south. The amount of sandstone and conglomerate in the Holder formation in the Dry Canyon area is much less than measured at La Luz Canyon only two miles farther north.

Conditions of deposition:

The Holder formation appears to have been deposited largely in the marine environment. The cyclical repetition of lithologic types, and the abundant evidence of shallow water deposition, indicated many repeated fluctuations of sea level, many of them probably causing emergence of the depositional area for short intervals. The increasing amount of red marls and shales, and of intraformational limestone conglomerates upward in the section appears to reflect a trend toward an increasingly positive area, a trend that began in late Pennsylvanian time, and continued through the time of deposition of the Bursum formation, and concluded with the deposition of the Abo formation under dominantly terrestrial conditions.

The conditions that caused biohermal growth over a wide area at the beginning of the Holder deposition are unknown. The bioherms suggests a uniformity and stability over the broad areas.

Contact relationships:

The basal contact of the Holder formation is everywhere with the Beeman formation and is probably conformable with the underlying Beeman formation. The two formations appear to be parallel, and evidence of a persistent erosional surface at the contact has not been observed.

The upper contact of the Holder formation is with the Bursum formation in the northwestern part of the map area. This contact has been termed a physical unconformity by Thompson (1942, p. 68). The writer believes the Holder may be essentially continuous and conformable with the Bursum formation. The best contact appears to be at a change from fusulinid-bearing red shales and nodular limestone to non-marine or brackish water strata. This is discussed in more detail under the Bursum formation. Where the Bursum formation is absent, the upper contact of the Holder formation is with the Abo formation and is a distinct angular unconformity at most places within the area of outcrop.

Fauna and age:

The Holder formation is rich in fossil remains of many types. Fusulinids are more abundant than in any of the underlying strata, and profuse in the white, massive limestones. A wide assortment of brachiopods, corals, bryozoans, pelecypods and gastropods occur in the formation, and are particularly abundant near the top of the formation in the area between Dry and Fresnal Canyons.

The age of the formation has been determined by M. L. Thompson on the basis of the fusulinids. Thompson places the series boundary between the Missourian and the Virgilian at the base of the "reef-like" massive limestone (in Lloyd, 1949, pl. 4). This corresponds to the base of the Holder formation in the northern Sacramento Mountains. Fusulinids have not been determined from the southern sections of the Sacramento Mountains to determine whether bioherms at the base of the formation are contemporaneous with those to the north. The reef mass reported by King and Knight (1945, Sheet II) from the Hueco Mountains directly overlies upper Missourian strata and beds 200 feet higher are of middle Virgilian age, which strongly suggests contemporaneous formation of the bioherms of the Sacramento Mountains. Thompson (1942, p. 75) states that the upper part of the Fresnal Group (in this report the uppermost part of the Holder formation) represents a part of the Virgilian that is "among the youngest stratigraphic portions of the series known from North America".

Correlation and regional relationships:

No other rock units established in the New Mexico area correspond to the Holder formation. However, as the age ranges from oldest to youngest Virgilian, the rock unit can be easily compared to time equivalents reported elsewhere. Thompson (1942, p. 67) states that the "lithology of the Virgil series in New Mexico varies more markedly geographically than the lithology of any other Pennsylvanian series". Virgilian strata are known in the Hueco, San Andres and Oscura Mountains to the south and west of the Sacramento Mountains (Thompson, 1942, pl. 1). The section of the southern San Andres Mountains is about 2600 feet thick, and consists largely of dark clastic rocks, and some gypsum. Thompson reports a similar section drilled in a well near Newman, at the south end of the Tularosa Valley. These sections contrast strikingly with the exposed Virgilian strata at the south end of the Sacramento Mountains. The section in the Oscura Mountains is only 250 feet thick, and consists dominantly of limestone and red shale.

Lloyd (1949, pp. 37-38) states that the Virgilian series is one of the most widespread, if not the most widespread division of the Pennsylvanian to the east and south of the Pedernal Mountains. East of the Sacramento Mountains, the closest well that penetrates pre-Permian rocks is the Texas Company's Wilson no. 1 in sec. 29, T. 17 S., R. 18 E. Lloyd reports a probable 535 feet of Virgilian rocks, largely sandstone and black and red shale, overlying Mississippian shale. This well record, and the surface sections of the northern Sacramento Mountains contain more clastic material than sections farther to the east or to the northwest or south. Probably the clastic material of this area was derived from an area intermediate . The meagre data suggest the existence of land areas north of the present crest of the Sacramento Mountains during at least a part of the Virgilian time. The regional variation of the Virgilian strata indicates fluctuation and instability of the New Mexico area during this time.

PERMIAN SYSTEM

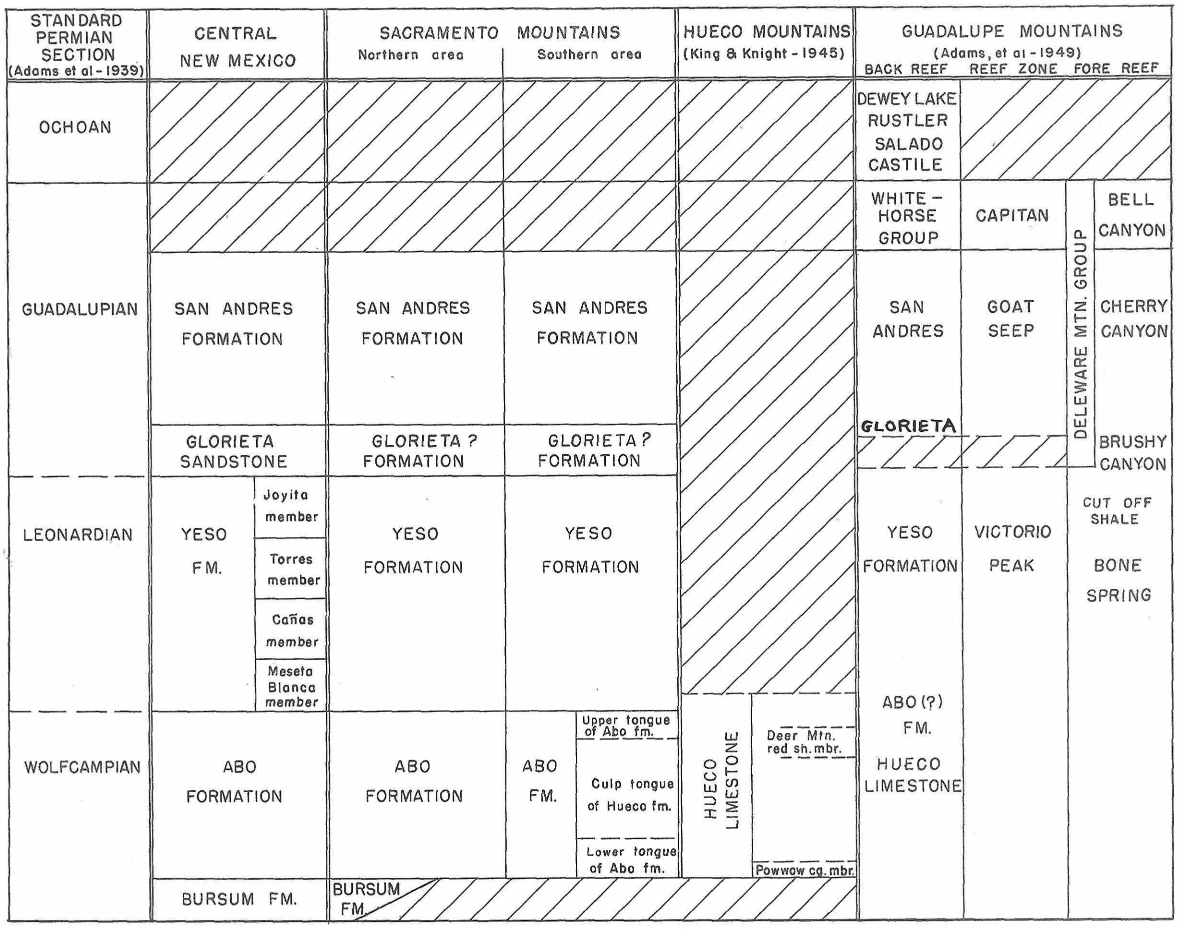
The Sacramento Mountains are on the western edge of the Permian Basin, which in southeastern New Mexico and west Texas contains the thickest known succession of marine Permian strata in the world. During the past quarter century, petroleum geologists have been actively concerned with the classification and interpretation of these strata. King (1942) presented a regional synthesis of much of this information. In 1939, Adams, et al proposed a standard Permian section and subdivided the Permian into four series, from oldest to youngest, the Wolfcamp, Leonard, Guadalupe, and Ochoa, all of which were based on type sections in the southeastern New Mexico-western Texas area. This classification is followed in this report. The United States Geological Survey (King, 1942, pp. 548-549, King and Knight, 1945) considers the Wolfcamp series as Permian (?).

As first pointed out by Lloyd (1929), the deposition of much of this thick succession of Permian strata was greatly influenced by the growth of barrier reefs, such as the impressive Capitan reef. The sedimentary rocks deposited during the time of reef formation are classed in three major facies on the basis of the position of deposition with respect to the position of the growing barrier reefs. The terms, back-reef, shelf, platform, or lagoon have been used to designate deposition behind the barrier reef. The seaward facies have been termed pontic, basin, or basinal, and the third facies is the reef facies consisting of the reef mass and intimately associated rocks (Lloyd, 1949, p. 19). The Sacramento Mountain escarpment lies from 50 to 100 miles northwest of the closest major reef masses of Permian time, and is in the back reef area.

The Permian strata of the Sacramento Mountains range in age from lower Wolfcampian to Guadalupian. The development of Permian reefs was largely during the Leonardian and Guadalupian time. Although all Permian strata of the Sacramento Mountains are referred to generally as back-reef facies, this designation is of fundamental significance only for the younger beds, the San Andres, Glorieta (?), and Yeso formations. The classification used in this report of the Permian strata of the Sacramento Mountains and the classifications in pertinent adjoining areas are indicated on figure 35a. Permian strata of the Sacramento Mountains are similar in general lithology to those existing over broad areas of central New Mexico, and the same formation names are used in both areas. The correlation of these rock units with the type sections of the major series of the Permian is somewhat uncertain largely due to the rapid changes in facies in the areas of reef development. The investigation in the Sacramento Mountains for this report has resulted in some new evidence on the problems of correlation, but for the most part the correlations depend on data from beyond the limits of the Sacramento Mountains.

BURSUM FORMATION

Thompson (1942, p. 20) identified fusulinids of lower Wolfcampian age in strata overlying the Pennsylvanian at many localities in central New Mexico. In 1946 these Wolfcampian strata were given three different names the Red Tanks member of the Madera limestone in the



PERMIAN CORRELATION CHART

Figure 35a,

Lucero uplift (Kelley and Wood, 1946); the Agua Torres formation in the Los Pinos Mountains (Stark and Dapples, 1946, p. 1154); and the Bursum formation (Wilpolt, et al, 1946) in the Los Pinos Mountains. The name Bursum formation is preferred by the New Mexico Bureau of Mines and Mineral Resources, and is used in this report. The type locality of the Bursum formation is designated at the Bursum triangulation station in sec. 1, T. 6 S., R. 4 E. Bates, et al (1947, pp. 24-25) describe two detailed sections of the Bursum formation in the vicinity of Abo Canyon, T. 2 N., R. 4 E. Graphis sections of one of these and of a section of the Bursum measured in the Oscura Mountains are reproduced in Lloyd (1949, pl. 2), and have been shown in the regional comparison of plate ~~20~~ 17 of this report.

In the northwestern part of the Sacramento Mountains about 300 feet of beds between the known Pennsylvanian strata and beds referred to the Abo formation were initially described by Thompson (1942, p. 82), as the Bursum formation.

<u>Areal distribution:</u>

The Bursum formation is only recognized in the northwestern part of the Sacramento Mountain escarpment. These strata extend as a narrow band from the area between Fresnal and Dry Canyons in the center of sec. 1, T. 16 S., R. 10 E., to the northwest along Fresnal Canyon for four miles to the northern border of the map. The strata have not been mapped farther to the north, but probably can be followed along the strike toward Tularosa for several miles. The Bursum formation has not been identified at Tularosa Canyon, six miles north of the map area.

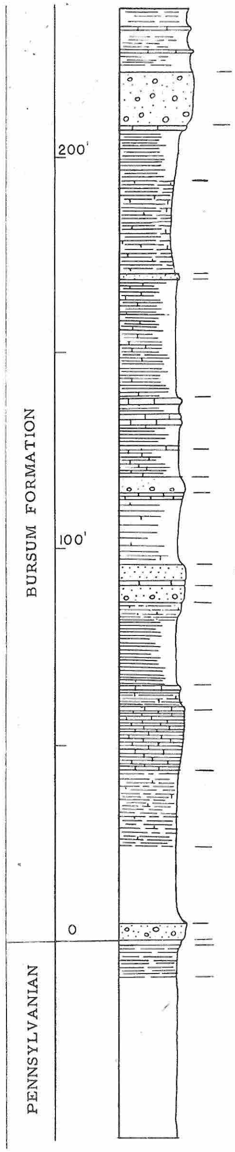
South of sec. 1, T. 16 S., R. 10 E., rocks considered to be the Abo formation directly overlie an angular unconformity that truncates Pennsylvanian and a part of the older rocks. The Bursum formation is absent from these areas.

Lithology:

The Bursum formation exposed in the northern Sacramento Mountains is an aggregate composed largely of thin and laterally discontinuous strata of gray and red calcareous shales, thin bedded, dark gray, argillaceous to sandy limestone, sandstone, and pebble to cobble conglomerate. Many of the beds can be traced laterally only a few hundred yards before lensing out, or grading into another rock type. Transitions along a bed of sandstone to limestone, or to conglomerate, are common. In contrast to the many lenticular, or discontinuous strata, some others appear to persist laterally for several miles.

Details of the sequence of Bursum strata near the northern end of the map area are indicated on plate 17. This section directly overlies the complete Pennsylvanian section measured by Thompson (pl. 14). At this point the Bursum formation is 342 feet in thickness; a section measured across the contact of the Bursum and Abo formations at a point only 500 feet east of the 342 foot section, is also indicated on plate 17. Comparison of these sections indicates the lenticularity and channeling at the contact of the Bursum and Abo formations. The Bursum formation appears to thicken toward the north within the map area.

The sandstones of the Bursum are dominantly of quartz. Pink potash feldspar is common and probably both quartz sandstone and feldspathic sandstone are present. The conglomerates are composed largely of limestone fragments. Some of these are gradational into solid beds of limestone, and appear to represent normal intraformational limestone conglomerate. Other thicker and

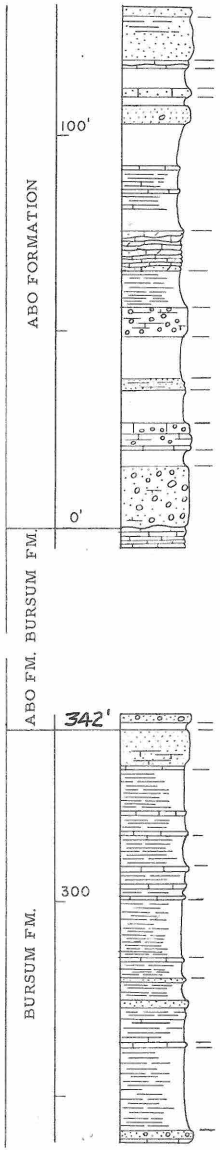


20	16'	Poorly exposed; largely greenish yellow claystone with minor interbedded dark silty limestone, fossiliferous.
19	14'	Conglomerate, sandy, pebbles and cobbles of limestone and chert. Overlying section measured N. 20 E. of base of Bursum section.
18	1'	Limestone, medium gray, argillaceous.
17	11'	Covered; probably gray shale.
16	25'	Claystone, red, very calcareous.
15	2'	Quartz sandstone, calcareous, brown weathering; few chert pebbles.
14	30'	Largely covered; probably gray, calcareous claystone.
13	12'	Limestone, olive gray, argillaceous, thin bedded, probably interbedded shale.
12	8'	Covered; non-red
11	4'	Conglomerate, granules and pebbles of limestone; grades upward into calcareous, medium grained quartz sandstone.
10	18'	Largely covered, probably yellowish claystone.
		Quartz sandstone, medium grained, calcareous; argillaceous limestone at base.
9	6'	Conglomerate, sandy, calcareous, pebbles of limestone and chert.
8	3'	Overlying section measured along strike about 500' to the north.
7	5'	Claystone and siltstone, dusky yellow, calcareous, few 1 to 2" layers of argillaceous limestone.
6	18'	Covered; probably similar to underlying unit.
5	6'	Poorly exposed; light yellowish gray calcareous claystone, minor argillaceous limestone.
4	15'	Limestone, medium dark gray, silty, thin bedded; upper 5' weathers yellowish gray, carbonaceous; streaks of chert, pebbles and quartz sand in middle part.
3	19'	Shale and siltstone, dark gray, calcareous, carbonaceous; grades into overlying limestone.
2	20'	Covered; probably dark shale.
1	4'	Quartz sandstone, and pebble conglomerate; pebbles largely limestone and chert.

Contact: Sharp lithologic break from nodular limestone and shale to sandstone and pebble conglomerate. Traced laterally, lithologic distinctions between underlying and overlying strata are not sharp. Contact is interpreted as diastem, rather than as major surface of unconformity.

Limestone, medium gray, partly nodular; overlies greenish gray and reddish shale. This is the top of the type section of the Fresnal Group of M. L. Thompson.

Base of Bursum section is near center of sec. 30, T. 15 S., R. 11 E., 20' NE of road in second arroyo NW of road junction from La Luz and Fresnal Canyons. Section measured up arroyo toward NE



Section continued from the top of the column to the left.

Section above unit 16 poorly exposed, but consists largely of dark red brown mudstone, minor conglomerates and sandstone.

16	12'	Sandstone, calcareous; and dark red brown mudstone; locally conglomeratic.
15	2'	Limestone, medium gray, argillaceous; slightly nodular.
14	5'	Covered.
13	2'	Limestone, dark yellow brown, sandy, fragmental, dense.
12	2'	Covered.
11	5'	Sandstone, calcareous, thin bedded; minor pebbles; forms resistant ledge.
10	26'	Poorly exposed; probably largely red brown mudstone, minor exposed beds of gray and red brown mudstone, calcareous sandstone, and argillaceous limestone nodules.
9	10'	Limestone, dolomitic, silty, argillaceous; bedding nodular to obscure, weathers mottled yellow brown and reddish.
8	7'	Mudstone, red, calcareous, minor sandstone and limestone.
7	7'	Limestone, calcareous, sandy; and pebble and cobble conglomerate, about 40% quartzite fragments.
6	12'	Mudstone, very calcareous, moderate red brown.
5	3'	Sandstone, fine to medium grained, calcareous, thin bedded; minor limy streaks and soft shale.
4	8'	Poorly exposed; probably largely red brown calcareous mudstone.
3	7'	Limestone and limestone conglomerate; medium gray, sandy limestone at base grades up into limestone pebble and cobble conglomerate.
2	4'	Covered.
1	15'	Conglomerate, cobbles of quartzite (40%), limestone and chert; matrix sandy, calcareous. Channel at base.
		Limestone, medium gray, argillaceous; thin bedded to nodular; teeming with large fusulinids of Wolfcampian age. This horizon is identified as unit no. 23 of Bursum section measured about 500' to the west.

Section measured from point in NE 1/4 SW 1/4 NE 1/4 sec. 30, T. 15 S., R. 11 E. toward NNE in shallow draw.

	2'	Conglomerate, sandy; pebbles and cobbles of limestone, quartzite, and chert. Unit forms local cap and eastern dip slope of hill.
	2'	Covered
30	10'	Quartz sandstone. fine grained, calcareous. Light gray silty limestone at base grades upward into sandstone. Unit forms resistant rim of hill, thickens to the NW.
29	17'	Shale, olive gray, calcareous; 6' above base, 6" layer of gray argillaceous limestone, fossiliferous.
28	7'	Shale, medium gray, calcareous, fossiliferous - brachipods
27	9'	Limestone, medium dark gray, silty; interbedded with calcareous, medium gray, silty shale. Abundant fusulinids (Schwagerina)
26	15'	Poorly exposed; largely non-resistant olive gray calcareous shale.
25	5'	Shale, olive gray, calcareous; capped by 6" argillaceous limestone. Abundant brachiopods, gastropods, pelecypods.
24	17'	Shale, olive gray, calcareous, with interbedded feldspathic quartz sandstone, and siltstone; carbonaceous.
23	1'	Limestone, pale red brown, very argillaceous, massive.
22	21'	Poorly exposed; largely non-resistant, olive gray, very calcareous shale.
21	3'	Limestone, medium gray; grades upward into sandy limestone conglomerate.

STRATIGRAPHIC SECTION OF THE BURSUM FORMATION more abundant conglomerates are composed of pebbles and cobbles of limestone, chert, and quartzite. The limestone cobbles are in part of Pennsylvanian rocks, and appear to be interformational in origin. The composition of the conglomerates is one of the best guides the writer has found to distinguish the Bursum from the overlying Abo formation. In the northernmost Sacramento Mountains conglomerates dominantly of quartzite are part of the Abo formation. Conglomerates in which the pebbles and cobbles are composed largely of limestone are probably Bursum, but some occur within the Abo formation.

At the base of the measured section about four feet of pebble conglomerate and sandstone overlie nodular limestone and shale containing Virgilian fusulinids. The contact has been interpreted by M. L. Thompson (1942, p. 68) as a physical unconformity. The writer believes the contact may represent only a diastemic break, and not a major unconformity.

One of the more persistent beds of the lower part of the Bursum formation is a layer of dark gray, silty limestone (unit 4 of plate 17). This bed and associated dark shales can be traced toward the southeast for two miles and possibly somewhat farther. From a point less than a quarter of a mile north of the measured section where this unit consists of light to medium gray limestone resembling a normal marine type, this unit changes progressively toward the southeast to limestone and shale containing abundant plant fossils. At the center of sec. 2, T. 15 S., R. 11 E., some layers a few inches thick are almost coals. This transition suggests that a marine basin of deposition lay to the west and/or north, and that positive areas existed to the east and/or south.

The change of the overlying part of the Bursum formation indicates a trend from marine to non-marine deposition toward the southeast. At the section of plate 17 red beds form less than 10 percent of the formation. An incomplete section measured about two miles farther to the southeast near the north center line of sec. 3, T. 16 S., R. 10 E., consists of 240 feet of Bursum strata, of which about 60 percent consists of red shale. Bursum sections a mile farther to the southeast are almost entirely of red shale and of limestone cobble conglomerate. The thicknesses of the complete sections are unknown in these southeastern outcrops.

Near the top of the Bursum formation at the measured section a zone (unit 23, pl. 17) containing abundant fusulinids has long been known to geologists interested in the area. Thompson (1942, p. 82) and others have identified these as Schwagerina and Triticites genera, and equivalent in age to the fusulinids in the Bursum formation of central New Mexico, which is lower Wolfcampian. A mile to the north several zones of fusulinids occur. Fusulinids have not been observed south of La Luz Canyon, although a rich zone crops out under a thick quartzite rich cobble conglomerate at the north side of La Luz Creek in the NE 1/4 NW 1/4 SW 1/4 sec. 29, T. 15 S., R. 11 E. This absence toward the south may be caused by erosion prior to deposition of the Abo formation. It can also be interpreted as another indication of marine deposition toward the northwest and of non-marine deposition toward the southeast.

Contact relationships:

The positions of both the upper and the lower contacts of the Bursum formation in the Sacramento Mountains are somewhat uncertain. The lower contact is selected at the top of the Pennsylvanian section measured by Thompson (1942, p. 68), who described the contact as an obvious physical unconformity. At this contact four feet of non-fossiliferous sandstone and conglomerate overlie fusulinid-bearing shales and nodular limestone of Virgilian age. This particular break in the section may be a major unconformity, or it may represent only a diastem. A few hundred yards south of the measured section the basal bed of the measured section appears to be just one of several thin, intercalated clastic zones within a sequence of limestone and shale, and no evidence of a major unconformity was observed. Tracing the contact northward from the measured section, the writer and Jerry Covington, of Humble Oil Company, discovered fusulinids in limestone strata that appeared to be from a horizon 10 to 20 feet above the base of the Bursum formation. These were identified by R. C. Spivey of Shell Oil Company as Virgilian forms. If the tracing is correct, either the top of the Virgilian strata is higher in the section than indicated on plate 17, or an unconformity with 10 to 20 feet of relief exists in this area at the top of the Virgilian strata. The writer favors the suggestion that the contact between the Bursum and the Holder formation (Virgilian) in this area either is transitional or that any unconformity represents only a minor erosional break in this area.

The only diagnostic Permian fossils in the strata called the Bursum are in the upper 40 feet. Between the base as indicated on plate 17 and this zone the Pennsylvanian-Permian boundary is not definitely established. However it appears probable that the contact is not higher than the carbonaceous limestone and shale about 30 feet above the base of the measured Bursum section on plate 17. The <u>Callipteris</u> flora (basal Permian) reported by King and Read in King (1942, p. 676) from east of Alamogordo in the upper Magdalena shales probably was derived from these beds. Megafossils collected from a zone about 30 feet above the dark carbonaceous limestone have been identified as probably of Wolfcampian age. Regardless of age, the best mappable contact of this part of the section occurs just above the cyclically bedded red shales and nodular limestone that contain abundant fusulinids of Virgilian age and below the dark carbonaceous shale and limestone. The highest fusulinids in the section appear to be essentially a single stratigraphic horizon, or within an interval not thicker than 50 feet for a distance of 3 miles, and the dark shale and limestone occurs just above this cutoff for most of this distance. This change probably represents a change from marine deposition to either brachisk or freshwater deposition.

The upper contact of the Bursum formation with the Abo formation has been considered an angular unconformity in the Sacramento Mountains by the writer (Lloyd, 1949, p.32), but the evidence is not entirely satisfactory. The contact appears unconformable locally. Other local evidence suggests a transition from the Bursum formation to the red shales and quartzite-rich conglomerates of the Abo formation. The contact is discussed in detail under the Abo formation.

Fauna, flora, and age:

The age of the Bursum strata in the Sacramento Mountains is determined as early Permian (Wolfcampian) on the basis of the fauna and flora.

The fusulinids near the top of the Bursum formation have been identified as species of *Triticites* and *Schwagerina* by many geologists including Thompson (1942, p. 82), Henbest and Skinner (in King, 1942, p. 675) and Bowsher (in King, et al, 1949, p. 61). The association of *Triticites* and *Schwagerina* indicates Wolfcampian age. Thompson (1942, p. 20) states that the fusulinids from the unnamed limestone (now the Bursum) in New Mexico are lower Wolfcampian. Lloyd (1949, p. 33) also states the age of the Bursum fusulinids is lower Wolfcampian.

The evidence for the age of the upper part of the Bursum formation in the Sacramento Mountains is better than for the lower part. The writer has collected a fauna from beds about 30 feet above the level of the dark, carbonaceous limestone of the Bursum formation (unit no. 4, pl. 17) that has been identified by A. L. Bowsher to include the following:

Loc. 139. Road cut on south of highway east edge of NE 1/4 SW 1/4 sec. 32, T. 15 N., R. 11 E.

4	*Aviculopectin* cf. *A. basilicus* (Newell)
1	*Pleurophorus*, n. sp.
1	*Strobeus* sp.
1	*Ananias* sp.
1	*Glabrocingulum* sp.
1	*Enteletes* sp. indet.
1	*Nuculopsis* sp.
2	*Nuculana* sp.
4	*Neospirifer Kansasensis* (Girty)
9	*Linoproductus cora* (d'Orbigny)
1	*Septimyalina* sp.
2	*Myalina (Orthomyalina) subquadrata* (Shumard)

Bowsher states this fauna is either very late Pennsylvanian or very early Permian in age, but concludes the age is probably Wolfcampian.

Fossil plants collected by C. B. Read east of Alamorgordo in the upper unit of the Magdalena group in association with the *Schwagerina* and *Triticites* belong to the *Callipteris* floral assemblage, which is considered to be basal Permian by Read (in King, 1942, p. 676). The exact locality of these collections is unknown, but they undoubtedly were obtained within the unit considered in this report as the Bursum, and may well have come from the shales and limestones rich in plant remains near the base of the Bursum formation.

C. C. Branson, A. L. Bowsher, and the writer collected abundant small gastropods referable to the genus Taosia from the upper part of the Bursum section (unit 25, pl. 17), which are considered to be Wolfcampian in age.

Correlation and regional relationships:

On the basis of the similarity of stratigraphic position, lithology, fauna and flora the strata of the Sacramento Mountains have been correlated with the Bursum strata, known from surface outcrops over much of central New Mexico. A regional comparison of the Bursum formation in the Sacramento Mountains with sections exposed in the Oscura Mountains and in the Gran Quivera quadrangle is indicated on plate 20. The two western sections are generalized from Lloyd (1949, pl. 2). The Bursum formation recognized in surface sections of central New Mexico may include at least part of the lithologically similar Bruton formation named by Thompson (1942, pp. 81-82) in the Oscura Mountains.

The Bursum section in the Sacramento Mountains is thicker, and contains fewer red beds than surface sections of the Bursum formation exposed farther to the northwest.

East and southeast of the Sacramento Mountains Wolfcampian fusulinids are recognized in many wells. The strata locally are differentiated into lower Wolfcampian, which is correlated with the Bursum formation, and upper Wolfcampian strata considered to be Hueco formation (Lloyd, 1949, p. 33). The Bursum formation of the subsurface areas consists largely of limestone. Red shale and sandstone are predominant near the Padernal Mountains.

King and Read (1942, p. 675) consider the Bursum strata of this report and possibly some of the underlying red beds as the upper unit of the Magdalena group. They believe these strata "mark a transition from the marine conditions of Magdalena time to the non-marine conditions of the Abo time". The writer is in complete agreement with this interpretation in those localities where a complete or essentially complete section is present. However, the conclusion by King and Read (King, 1942, p. 677) that the upper Magdalena group is traceable southward into the Hueco limestone, and that in most places the sequence from the Magdalena to the Abo formation is unbroken is neither compatible with observed field relationships in the area of the Sacramento Mountains, nor with the available paleontologic data. The major deformation of the Paleozoic Era in the region of the Sacramento Mountains occurred after the deposition of the Pennsylvanian strata and prior to the deposition of the Abo formation. A major, angular unconformity occurs in most of the area of the Sacramento Mountains. The possible exception is in the small northwestern area in which the Bursum formation occurs. The Abo formation can be traced southward to correlate with the Hueco formation. The strata King and Read term the upper unit of the Magdalena group were either removed by erosion or were never deposited in most of the area, and cannot be traced southward to the Hueco formation (pl. 20).

The paleontologic evidence appears incompatible with the correlation of the upper unit of the Magdalena with the Hueco as the upper unit of the Magdalena (Bursum) is dated as lower Wolfcampian and is older than the Hueco formation which is middle or upper Wolfcampian in age (Lloyd, 1949, p. 33).

ABO FORMATION

The strata now considered to be Pennsylvanian and Permian that crop out over wide areas of central and southern New Mexico were divided into two principal units by the early stratigraphers. The lower unit, composed largely of gray limestone and sandstone, was named the Magdalena group by Gordon (1907, p. 506). The overlying unit of red beds and associated strata had been named the Manzano series by Herrick (1900, p. 4), and was designated the Manzano group by Gordon (1907, p. 506). Lee (1907) and Gordon considered these two major divisions of strata to be separated by an unconformity. Lee (1909, p. 12) proposed three formation names for lithologic units of the Manzano group. Listed in ascending order the formations are the Abo, the Yeso, and the San Andres.

The Abo sandstone was defined by Lee (1909, p. 12) as coarse grained sandstone, dark red to purple in color, and usually conglomeratic at the base, with a subordinate amount of shale. The name was derived from Abo Canyon at the south end of the Manzano range.

The formation names introduced by Lee are in current usage. The type sections of these formations in the Manzano group were not described in the detail sufficient for modern stratigraphic studies. To correct this, Needham and Bates (1943) described detailed sections of the Abo, Yeso, and San Andres formations which now serve as type sections of these formations. The type section of the Abo formation is located near the village of Scholle, in Abo Canyon, in T. 2 N., R. 5 E., and consists of 811 feet of red shale, sandstone, arkose, and conglomerate. Shale predominates in the section and, therefore, the name has been changed from Abo sandstone to Abo formation by Needham and Bates (1943, p. 1654). The base of the type section overlies limestone of the Bursum formation. In the description by Needham and Bates (1943, p. 1655) the Abo section included 104 feet of pinkish sandstone at the top, but at the recommendation of Read, this uppermost unit has been assigned to the Yeso formation (Bates, et al (1947, p. 26).

The Abo formation in the type area and other parts of central New Mexico consists largely of red beds of continental origin (Needham and Bates, 1943, p. 1657). In the northern part of the Sacramento Mountains a sequence of strata 250 to 500 feet thick consists of reddish brown mudstone, arkose, and conglomerate, and contains no marine fossils and little limestone or dolomite. These beds are in the same stratigraphic position as the similar beds of the Abo formation in central New Mexico and are considered to be the Abo. The reddish brown to dusky red brown color is diagnostic of the Abo formation. In the central and southern part of the Sacramento Mountain escarpment thin beds of gray limestone and shale form a wedge that thickens markedly toward the south, and separate thinning tongues of Abo red beds (pl. 18).

The Abo formation in central New Mexico is unconformable on Bursum and older strata (Thompson, 1942, pl. II), but at most places the beds above and below the unconformity are essentially parallel. The unconformity at the base of the Bursum formation in these areas is that recognized as separating the Manzano group and the Magdalena group by Lee (1909, pp. 21-23). In the Sacramento Mountains the unconformity at the base of the Abo formation is sharply angular in many places and the deformation by both folding and faulting of the pre-Abo formations is in marked contrast to the apparent lack of deformation of pre-Abo strata in areas of central New Mexico. The deformation probably occurred largely during the early Wolfcampian time, but probably began in late Virgilian time. Continued mild deformation influenced deposition of the Abo strata.

Areal distribution:

In the Sacramento Mountains the Abo formation crops out continuously from the vicinity of Tularosa southward throughout the entire map area and forms the front of the low mountain escarpment at the mouth of Culp Canyon in the middle part of T. 20 S., R. 11 E. The Abo forms the lower part of the slopes that rise from the level of the resistant pre-Permian rocks.

From Tularosa to the northern part of the map area the Abo crops out in a belt three to four miles wide between the older rocks that form the low western front of the mountains and the steeper slopes of the Yeso and San Andres formation three to four miles to the east. From the vicinity of High Rolls in the northern part of the map area the outcrops extend southward as a band a quarter to a half mile wide at the base of the slope that rises to the crest of the range. Locally, the Abo formation extends westward as narrow tongues overlapping the upturned edges of beveled Pennsylvanian strata on the high ridges. In the southern part of the escarpment the outcrop area widens to one to two miles, and curves toward the southwest to the front of the mountains at Culp Canyon in the central part of T. 20 S., R. 11 E.

A few isolated remnants of Abo formation occur west of the continuous band of outcrops. The formation does not crop out east of the crest of the Sacramento Mountains.

Lithology:

The lithology of the Abo formation changes within the area of the Sacramento Mountains escarpment from continental red beds containing coarse arkosic sediments in the northern part of the area to a section composed dominantly of brackish to marine deposits of limestone and shale at the southern part of the area. The thickness of the Abo formation at the north is 400 to 500 feet; it ranges from 250 to 500 feet in the cental part of the escarpment; and thickens progressively toward the south. Generalized stratigraphic sections of the Abo formation along the length of the Sacramento escarpment are indicated on plate 18. A stratigraphic section measured a mile northeast of High Rolls in sec. 5, T. 16 S., R. 11 E., that is representative of the Abo formation in

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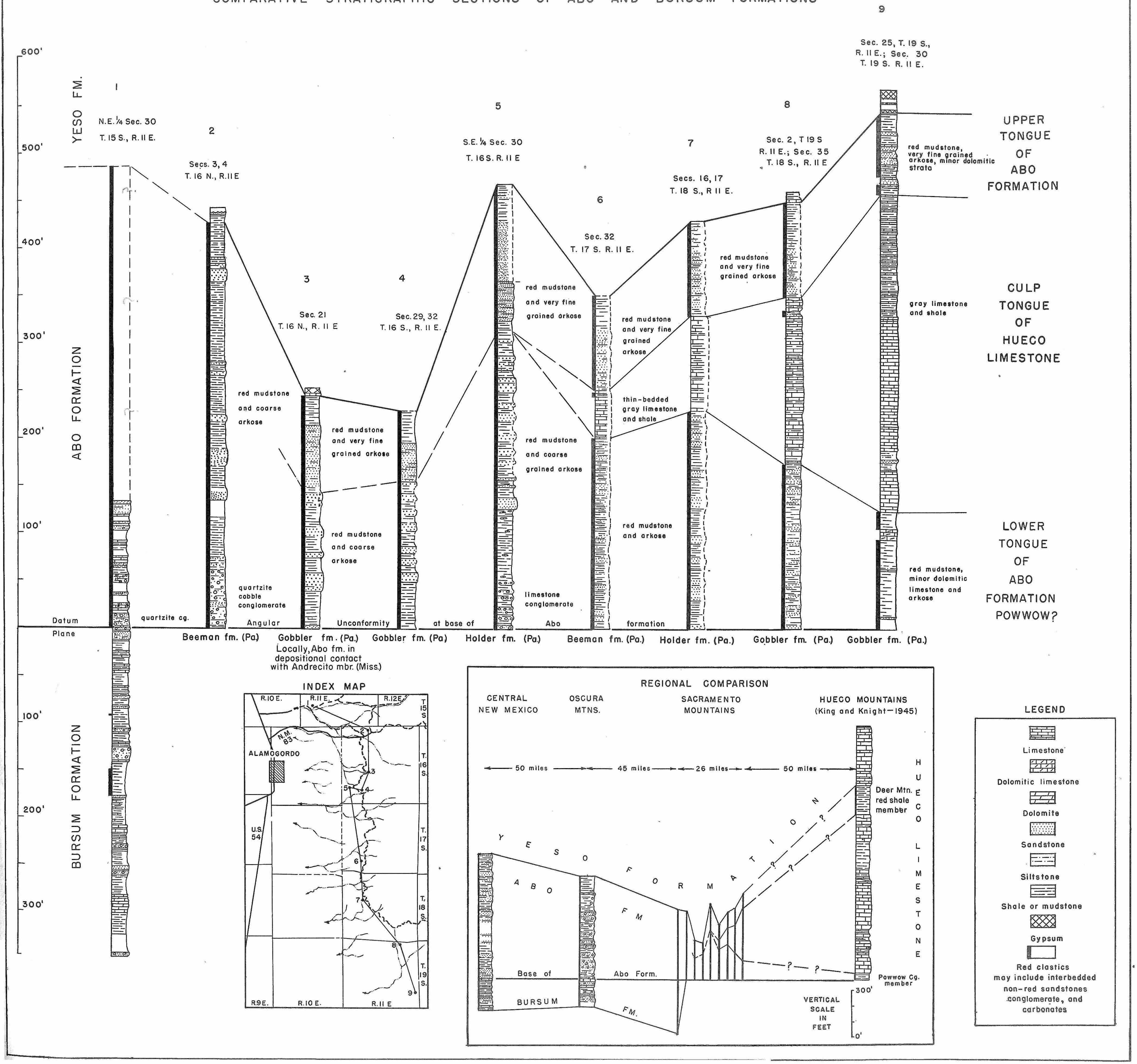
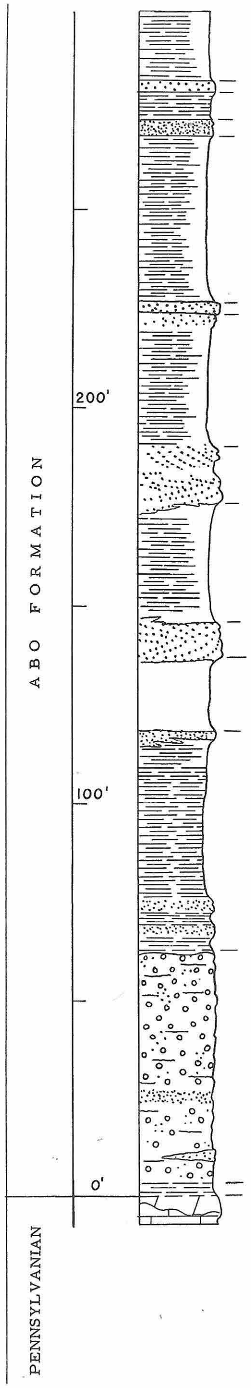
COMPARATIVE STRATIGRAPHIC SECTIONS OF ABO AND BURSUM FORMATIONS

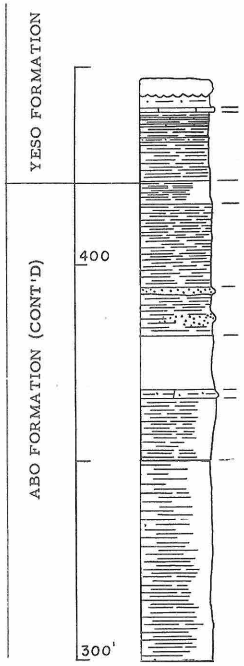




14	51'	Poorly exposed; largely mudstone, very dark reddish brown; minor 2 to 3' thick beds of coarse arkose.
13	3'	Arkose, coarse grained; base shaly
12	7'	Mudstone, dark reddish brown.
11	4'	Arkose, fine-grained.
10	42'	Poorly exposed; largely reddish brown mudstone and interbedded coarse-grained arkose.
9	3'	Arkose, coarse-grained, resistant, cross-laminated.
8	33'	Poorly exposed; largely reddish brown mudstone, minor coarse grained arkose.
7	15'	Arkose, coarse grained, resistant, cross-laminated; interbedded reddish brown mudstone.
6	30'	Poorly exposed; largely reddish brown mudstone.
5	9'	Arkose, coarse grained, resistant, cross-laminated; few pebbles of quartzite and microcline granite.
4	19'	Covered, probably reddish brown mudstone.
3	55'	Mudstone, dark reddish brown; minor interbedded lenticular fine to medium grained sandstone.
2	59'	Conglomerate, quartzite cobbles predominate, sub-rounded; minor interbedded dark reddish brown sandstone and mudstone.
1	3'	Poorly exposed; largely reddish brown mudstone.

Contact: Angular unconformity. Top 1 to 5' of underlying gray nodular limestone strata replaced by dolomite. Angular discordance slight; about 60' of Pennsylvanian strata (Beeman formation), largely thin-bedded limestone and shale, truncated by angular unconformity along stream bottom to NW for one quarter mile.

Base of measured section in canyon bottom 700' south of the NE corner sec. 5, T. 16 S., R. 11 E. Section measured northeast to road.



Section continued from the top of the column to the left.

Recent spring deposit of travertine caps local section. 1000' to the east, units 21 and 23 are overlain by pale reddish brown mudstone and gypsum.

23	3'	Shale, silty, yellowish gray, calcareous.
22	1'	Limestone, silty, yellowish gray, thin bedded
21	18'	Mudstone, yellowish gray to gray; calcareous in upper part; 1' of red brown sandstone 11' above the base.
20	6'	Poorly exposed; mudstone, dark reddish brown, gray at base.
19	21'	Mudstone, reddish brown; minor gray mudstone
18	12'	Mudstone, dark reddish brown; interbedded minor coarse grained, shaly arkose.
17	14'	Covered, probably reddish brown mudstone. Overlying section measured east of road 500'.
16	2'	Siltstone, dolomitic
15	33'	Poorly exposed; largely mudstone, dark reddish brown.

STRATIGRAPHIC SECTION OF THE ABO FORMATION IN THE NORTHERN SACRAMENTO MOUNTAINS much of the northern part of the Sacramento Mountains is reproduced on plate 19.

The basal part of the Abo formation in an area from about one mile south of High Rolls to the northern edge of the map consists largely of quartzite cobble conglomerate that directly overlies the truncated edges of Pennsylvanian strata ranging from the Gobbler formation to the Holder formation. Toward the northwest, in the area where the Bursum formation crops out, quartzitic pebbles and cobbles occur in conglomerates of the Pennsylvanian formations, and the Bursum formation, but nowhere forms monolithologic conglomerates as at the base of the Abo formation. However, a marked increase in quartzite content of conglomerates occurs at essentially a continuous stratigraphic horizon and is used to define the Bursum-Abo formation contact toward the northwest where a basal unconformity is otherwise obscure.

Above the basal zone in the northern part of the mountains, the section consists almost entirely of reddish brown mudstone and of coarse grained to conglomeratic arkose that is commonly cross-laminated, and well sorted. The mudstone predominates, but is less conspicuous than the arkose. The feldspar locally forms more than half of the arkose and consists largely of pink orthoclase and microcline. Most grains of the arkose are 1-3 mm. in diameter, and angular to subangular. The coarse texture, the abundance of feldspar, and good sorting distinguish the Abo arkose from any of the less feldspathic clastic rocks of the Pennsylvanian or Bursum strata. Pebbles of quartzite, granite, and of rhyolite porphyry occur in some beds of arkose, but are uncommon.

In the section of the Abo formation observed east of Tularosa, six miles north of the map area, the pebbles and cobbles of quartzite, granite, and porphyry are much more abundant and larger than within the map area, which suggests a source area of these pre-Cambrian rocks nearby, probably to the northeast.

The arkose is most abundant in the Abo from 50 to 150 feet above the base of the formation in the northern areas, and forms resistant ledges a few feet to twenty feet thick. Individual beds are lenticular. Locally abrupt channel fillings of arkose occur in the mudstone.

From the vicinity of High Rolls southward for about 15 miles, some of the coarse arkose contains local concentrations of lead, zinc, and copper. The deposits are of the typical "Red Beds" type except that lead rather than copper predominates. The lead ore minerals are largely galena, anglesite, and cerrusite. The copper minerals include chalcocite, some chalcopyrite and bornite, malachite, azurite, and other oxidized copper minerals. Cuprodescloizite, a copper vanadinate, and smithsonite are present along fractures in the arkose. The ore minerals are disseminated through the arkose. Barite forms a matrix for quartz and feldspar grains in the arkose at the Warnock mine. To judge from the distribution of prospect pits, small workings, and visible ore minerals, most of the lead is in the thicker arkose ledges near the base of the Abo formation.

The major workings are at the Courtney mine in the SW 1/4 NE 1/4 sec. 17, the Warnock or Holmes mine, in the SE 1/4 SW 1/4 sec. 30, and the Ady Culp mine in the SW 1/4 SE 1/4 sec. 32, all in T. 16 N., R. 11 E. Most of the production has been from the Holmes or Warnock mine, which produced an estimated 1,600,000 pounds of lead in the period from 1922-1932 (Lasky and Wooton, 1933, p. 86). Since that time mining has been intermittent and small scale. About 2000 tons of ore shipped from the Warnock mine in 1947-48 contained 5 to 6 percent lead, about 0.5 percent copper, and 2 to 3 percent zinc.

In the north central part of the escarpment, two major subdivisions of the Abo formation can be recognized (pl. 18). The lower unit consists of reddish brown mudstone and coarse arkose, similar to the complete section farther north except that conglomerate at and near the base consist largely of pebbles and cobbles of limestone rather than quartzite in a matrix of feldspathic sandstone. The upper subdivision consists largely of very fine grained, dolomitic sandstone and reddish brown mudstone. The sandstone is pale red brown, and distinctive because of small scale cross-lamination, and abundant worm (?) borings (fig. 37). The laminae rarely exceed one inch in length. The grains are of coarse silt and very fine sand sizes and composed largely of quartz. Feldspar forms about one third of the sand grains. Dolomite locally forms as much as half of the rock. Some plant fossils occur within these beds.

The thickness of the Abo formation in the north central part of the escarpment varies markedly, as indicated by sections 4 and 5 of plate 18. The thickness doubles in less than one mile between these two sections. The thickness variations are related to the structural features of the area. The thick sections occur along the synclinal axes of the major folds formed during the pre-Abo*/ deformation, and

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*/The term pre-Abo deformation or erosion is used for convenience in referring to the deformation or erosion that occurred after the deposition of all strata below the Abo formation and before deposition of the basal Abo formation.

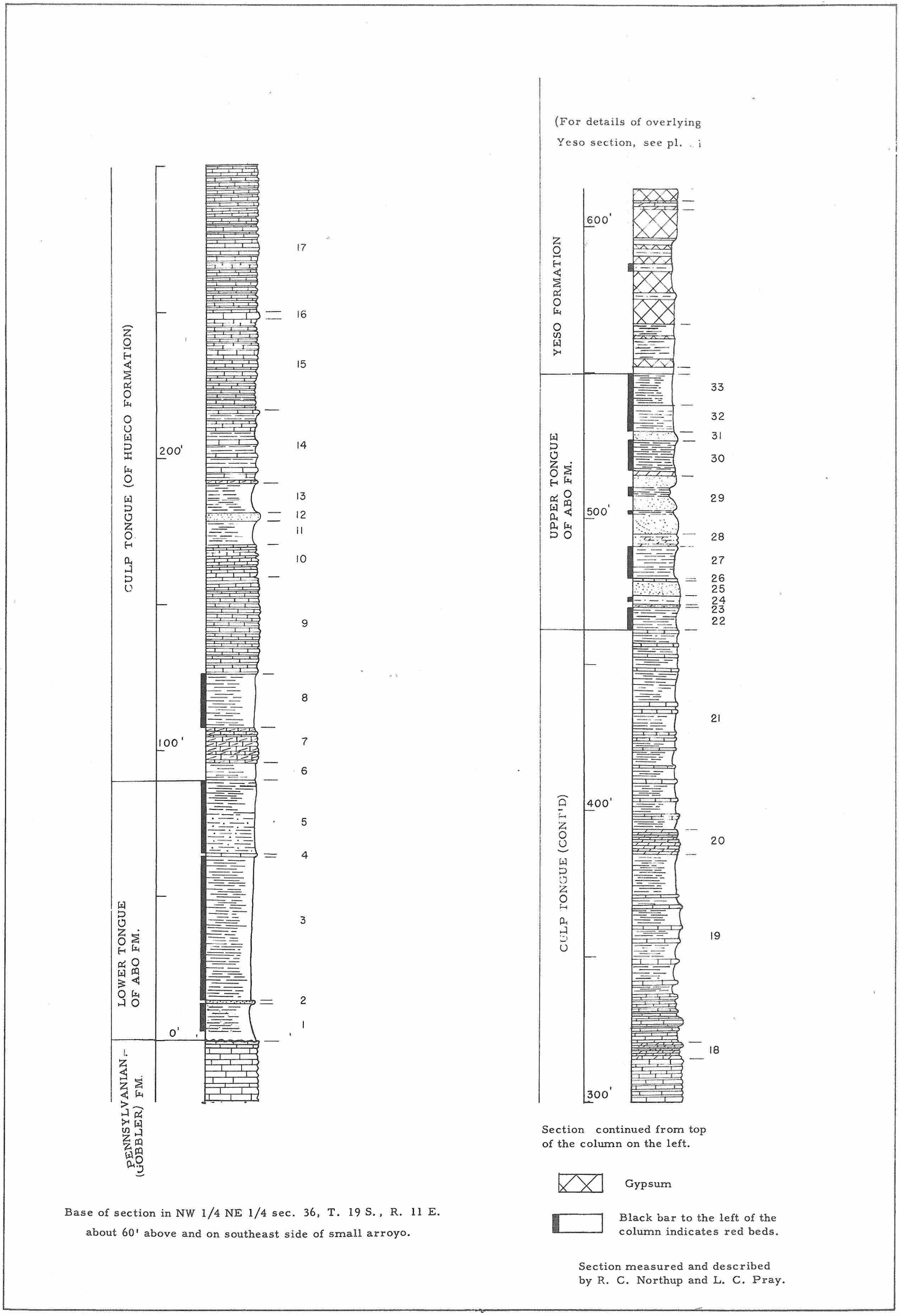
Figure 36. Sandstone of the upper tongue of the Abo formation. The abundant borings and delicate cross-lamination are characteristic features.

the thinner sections occur along the anticlinal axes or other structural highs caused by the pre-Abo deformation. The variation in thickness occurs in all parts of the Abo section. Most of the thickening is believed to be caused by continued minor folding during the deposition of the Abo formation along about the same axes and in the same direction as the pre-Abo deformation. Some may be related to initial highs on the pre-Abo erosion surface over the anticlinal crests.

In the central part of the Sacramento Mountain escarpment at about the middle of T. 17 S., thin bedded gray limestone and shale occurs in the Abo formation. This unit forms a wedge or tongue that thickens progressively toward the south (pl. 18). Much of the thickening of the limestone and gray shale tongue is accompanied by a corresponding decrease in the thickness of the underlying Abo red beds. The overlying red beds also decrease somewhat in thickness.

The three divisions of the Abo formation in the central and southern part of the escarpment form distinctive lithologic units and are differentiated on the geologic maps. The upper and lower units are largely of red beds, and representative of the more completely Abo formation to the north. These are herein designated the upper and lower tongues of the Abo formation. The middle unit of gray limestone and shale is herein termed the Culp tongue and is referred to the Hueco formation. The name Culp is derived from Culp Peak, about a mile southeast of the type section, in the SW 1/4 sec. 32, T. 19 S., R. 12 E., as indicated on the 1/31,250 map of the Sacramento Division of the Lincoln National Forest. Discussion of the correlation of this tongue of limestone and shale with the Hueco formation is deferred to the section on age, correlation, and regional relationships.

The type section of these three tongues is in sec. 25, T. 19 S., R. 11 E., and sec. 30, T. 19 S., R. 12 E., and is reproduced on figure 37. The same section, more generalized, is indicated as section 9 of plate 18. The lithologic description of the section is given below.



(For details of overlying Yeso section, see pl.

Section continued from top of the column on the left.

Base of section in NW 1/4 NE 1/4 sec. 36, T. 19 S., R. 11 E. about 60' above and on southeast side of small arroyo.

Section measured and described by R. C. Northup and L. C. Pray.

STRATIGRAPHIC SECTION OF THE ABO FORMATION IN THE SOUTHERN SACRAMENTO MOUNTAINS

Figure 37

Stratigraphic section of the Abo formation of the southern Sacramento Mountains (see figure 37 for graphic log). Measured by R. C. Northrup and L. C. Pray.

Unit No.	Thickness in feet	Description
	Top of section at the south edge of SW 1/4 NW 1/4 SE 1/4 sec. 30, T. 19 S., R. 12 E., and is continuous with base of measured section of the Yeso, Glorieta (?), and San Andres formations (pl. 21).	
	Top of section	
YESO FORMATION	(details of overlying section on page 268.)	
		Gypsum and minor gray silty shale. Pink shale 34 feet above the base. One foot gray dolomitic limestone 42 feet above base. Basal 15 feet poorly exposed.
	2	Covered
UPPER TONGUE OF ABO FORMATION - 89 feet		
33	11	Shale, reddish brown and green gray; poorly exposed.
32	9	Shale, reddish brown; minor green gray shale beds, dolomitic.
31	3	Sandstone, tan, very fine grained; thin, delicate cross-lamination and ripple marks.
30	12	Shale, reddish brown; thin silty dolomite at base, minor gray shale.
29	20	Sandstone, buff, very fine grained, dolomitic, thin, delicate cross-lamination; minor reddish shale.
28	4	Siltstone, dolomitic, gray to parle red; some pebbles and coarse sand streaks.
27	11	Shale, reddish brown, silty at top.
26	1	Limestone, dolomitic, silty, nodular.
25	6	Sandstone, buff to brown, very fine grained; medium bedded; resistant.

Unit No.	Thickness in feet	Description
24	3	Shale and siltstone, reddish brown, thin bedded.
23	1	Siltstone, dolomitic; mottled green gray, and red.
22	8	Shale, reddish brown.
	CULP TONGUE (of Hueco formation) - 376 feet.	
21	70	Shale, gray, and limestone, light gray, argillaceous, thin bedded; minor dolomitic limestone weathers pale brown. Shales are poorly exposed.
20	9	Dolomite, gray, argillaceous, and dolomitic limestone.
19	67	Limestone, light to dark gray, argillaceous, thin bedded, interbedded with poorly exposed gray shale.
18	6	Limestone, dolomitic, dark gray, argillaceous, weathers pale brown.
17	65	Limestone, light to dark gray, argillaceous, fossiliferous; probably interbedded gray shale.
16	2	Limestone, medium gray, weathers dark gray. Forms cap of hill. Above section measured east of canyon.
15	31	Limestone, light to dark gray, thin to medium bedded, bryozoans at base; probably interbedded gray shale.
14	25	Shale, gray, and medium to dark gray, thin bedded limestone, small fossils; basal one foot dolomitic limestone.
13	10	Largely covered; silty gray shale.
12	3	Sandstone, very fine grained, and siltstone; micaceous, green gray; excellent local marker bed.

Unit No.	Thickness in feet	Description
11	8	Largely covered; silty shale.
10	11	Limestone, medium to dark gray; fossiliferous (gastropods).
9	33	Limestone, light gray, thin bedded, dense, small fossils; probably interbedded gray shale.
8	18	Shale, reddish brown, thin limestone near base.
7	12	Limestone, dolomitic, light gray, thin to medium bedded; weathers pale brown.
6	6	Covered; probably gray shale.

LOWER TONGUE OF THE ABO FORMATION - 89 feet

Unit No.	Thickness in feet	Description
5	25	Shale, reddish brown; poorly exposed; lower half fine grained red sandstone and siltstone.
4	1	Limestone, dolomitic, silty; weathers light gray.
3	49	Shale, reddish brown; minor fine grained reddish brown sandstone; minor gray shale near top; reddish-purple; poorly exposed.
2	1	Sandstone, fine to medium grained, shaly.
1	13	Covered; probably reddish brown shale, and minor sandstone

PENNSYLVANIAN SYSTEM - GOBBLER FORMATION
Limestone, medium gray, thin to medium bedded, very fossiliferous (brachipods, gastropods, cephalopods) Underlain by gray limestone, brown and green gray silty sandstone.

Base of section about 5800 feet, located in NW 1/4 NE 1/4 sec. 36, T. 19 S., R. 11 E., about 60 feet above and on southeast side of small arroyo. Section measured to east.

The lower tongue of the Abo formation is 89 feet thick at the southernmost measured section. It ranges from about 50 feet to 100 feet in thickness in the southern half of T. 19 S., and thickens toward the north. This tongue can be traced northward continuously into the Abo formation in the northern mountains. The amount of coarse clastic rocks and the size of the grains decrease markedly toward the south. The southernmost coarse to very coarse grained arkose beds observed are in T. 18 S. The source area for the clastic parts of the Abo formation apparently lay toward the north or northeast. Petrified wood is abundant in the lower few feet of the Abo formation in the SE 1/4 NW 1/4 NE 1/4 sec. 36, T. 18 S., R. 11 E., a short distance south of the measured section. The upper contact of the lower tongue is not "line-thin". It has been arbitrarily mapped at the top of the highest red beds more than a foot or two thick. The limestone and the red beds are generally interbedded in a gradational zone. The carbonate beds that occur in the red beds section are generally dolomitic limestone, probably reflecting deposition in shallower warmer waters than the limestones (Twenhofel, 1932, p. 346).

The Culp tongue of the Hueco formation is 376 feet thick at the type section (fig. 37), and consists largely of light to dark gray, argillaceous, sublithographic to very finely crystalline limestone and gray to greenish shale. Thin, very fine grained sandstone and siltstone, dolomitic limestone and dolomite form a minor part of the sequence. Chert is absent from the Culp tongue. The Culp tongue forms resistant light gray to yellowish hills in the southern part of the Sacramento Mountains (fig. 38). The type section contains an abundance of small fossils, mostly gastropods. Fusulinids were not observed within the map area, but Lloyd (1949, p. 29) reports that Walter Warren of Standard Oil Company of Texas has obtained Hueco-type fusulinids from this limestone and shale unit several miles farther south.

The upper tongue of the Abo formation is composed largely of reddish brown mudstone or shale and the very fine grained dolomitic sandstone similar to that which occurs as far north as T. 16 S. In the south the color appears to be more orange than the reddish brown farther north, but the delicate cross-lamination, and borings are characteristic features. Some of the strata are silty dolomite. The contact with the underlying Culp tongue is gradational, and has been mapped at the base of the sequence of strata in which red beds predominate.

The upper tongue of the Abo formation has a constant lithology in most of the southern Sacramento Mountains, but except for the color of the shale, it does not closely resemble the typical Abo of the northern Sacramento Mountains. Some geologists have suggested this unit correlates with the Yeso formation. The red beds overlying the Culp tongue can be traced in the field into similar red beds overlying the coarse arkose in the north central part of the Sacramento Mountain escarpment and thence northward to a section containing more of the coarse arkose and less of the finer sandstones. Throughout the length of the escarpment the lithology of the basal part of the Yeso formation is essentially unchanged. The Abo-Yeso contact of the section (pl. 19) in the northern Sacramento Mountains appears to be at the only logical position. If this is accepted as correct, either the upper tongue of red beds pinches out toward the north by progressive overlap, or the upper tongue grades into the Abo formation. The absence of an erosional break between the Abo and the Yeso formation in the northern part of the area favors the hypothesis of gradation. Two feet of dolomitic siltstone (unit 16, pl. 19) are believed to be a thin remnant of the upper tongue of the Abo formation. The available evidence favors clearly assigning the upper tongue to the Abo formation rather than the Yeso.

Conditions of deposition:

The conditions prevailing during the deposition of the Abo formation of the Sacramento Mountains span the range from continental deposition to normal marine deposition. The plant fossils, the lenticular shape of the beds, local abrupt channel fillings, the extensive cross-lamination, the prevailing color, and the absence of charactersitics suggestive of a marine environment all suggest that the Abo formation of the northern Sacramento Mountains is a continental deposit. It probably was deposited largely on broad flood plains. Some was probably deposited in ephemeral lakes, and in fresh or brackish shallow water at the edge of a sea that bordered the area to the south. Thin beds and nodules of dolomite in the Abo formation in the northern Sacramento Mountains suggest minor periods of advance of the seas. Some of the red sandstones in the southern Sacramento Mountains contain marine fossils.

The Culp tongue of the central and southern part of the mountain escarpment is probably the product of deposition in marine and brackish waters that lay to the south of the northern land area. The intertonguing between the Culp tongue and the enclosing red beds indicates repeated minor fluctuation of the shore line during the deposition of the Abo formation.

The upper tongue of the Abo formation contains the distinctive very fine grained, dolomitic sandstone and siltstone, with the delicate cross-lamination and abundant borings. The small scale of the lamination, the apparent absence of marine fossils, the occasional plant fossils, the prevailing red color, and abundant borings are compatible with deposition in a littoral environment, where constant advance and retreat of tides over a broad, flat area reworked and sorted the fine sediments.

Contact relationships:

The base of the Abo formation in the Sacramento Mountains is at the major unconformity of the Paleozoic strata of this area. Marked deformation by fold and faulting preceded the deposition of the Abo formation. As Virgilian strata are locally present below the unconformity, the time of the deformation must have been restricted in the Sacramento Mountain area to the interval between middle Virgilian and the time of deposition of the Abo formation, believed to be middle or upper Wolfcampian.

The angular discordance is locally as high as 60 degrees, but is generally less than 10 degrees. The pre-Abo faults and folds trend roughly north-south, and are oblique to the prevailing north-northwest trend of the base of the mountains, defined by Cenozoic faulting. The faults have displacement up to about 1000 feet, most dip steeply, and are normal or gravity faults.

The intensity of the deformation and uplift appears to have increased from west to east, and the western two to three miles of the mountain escarpment in the northern part of the area appear little affected by the deformation. Thus in the northwest part of the Sacramento Mountains, near the west front, the Abo formation lies in depositional contact with the Bursum formation, and unequivocable evidence of an angular unconformity or of a major unconformity is lacking. But only two miles farther to the east, at the top of the bluff above Fresnal Box Canyon (fig. 33), the Abo lies unconformably on strata of the Beeman formation. The evidence in the northwest corner of T. 16 S., R 11 E., west of High Rolls suggests that most of the pre-Abo deformation and erosion was confined to the Wolfcampian time, rather than late Virgilian time. The Bursum and Holder formations are preserved on the downthrown side of the pre-Abo Fresnal Canyon fault and were eroded prior to the deposition of the Abo formation on the upthrown side of the fault.

In the north central part of the escarpment along the synclinal axes of the pre-Abo formation, the Abo formation overlies the Holder formation. Along the anticlinal axes and the domical uplifts, the Abo formation generally overlies the Beeman or Gobbler formation of Pennsylvanian age. The angular unconformity of the Abo formation in the Caballero Canyon area is indicated on figure 34.

At upper Arcente Canyon in sec. 21, T. 16 S., R. 11 E., the entire Pennsylvanian section has been removed by pre-Abo erosion from the upthrown side of the Arcente Canyon fault, and the Abo formation unconformably overlies strata as low in the section as the Andrecito member of the Lake Valley formation.

The pre-Abo erosion surface appears to be channeled in the northwestern part of the area, but elsewhere the surface appears to be of low relief.

The upper contact of the Abo formation with the Yeso formation is believed to be conformable and is placed at an abrupt change in lithology to gypsum, gray shales, siltstones, and limestone from reddish brown strata of the Abo formation.

Fauna and flora:

Vertebrate fossils and plants have been collected from the Abo formation in central New Mexico. Plant fossils occur locally within the Abo formation in the Sacramento Mountains, especially in the upper tongue. Most of the invertebrate fossils occur in the Culp tongue of the Hueco limestone, and are largely gastropods, but these have not been collected or studied. Fusulinids were not observed in the Culp tongue, but are reported to be abundant a few miles farther south. A few fossils occur in sandstones near the base of the lower tongue of the Abo formation. These beds are believed to be the source of the gastropods Phanerotoma pretiosum and Pleurotomaria planicostata reported by Girty (1937) from the Abo (?) sandstone of the southern Sacramento Mountains.

Age, correlation and regional relationships:

The age of the Abo formation is one of the major problems in stratigraphy of central and southern New Mexico. The evidence of the age of the formation is derived from the flora, the vertebrate fauna, and from the invertebrate fauna of the marine strata into which the Abo formation grades laterally. The Abo formation has been considered to be either Leonardian, Wolfcampian or both. Thompson (1942, pl. II) and Needham and Bates (1943, p. 1657) are among the recent writers who assign the Abo formation to the Wolfcampian. P. B. King and Read (in King, 1942, p. 676), and R. E. King (1945, pp. 16-17) advocate a Leonardian age for the Abo formation. Lloyd (1949, p. 31-34) and Adams, et al (1949, pp. 87-88) indicate both Leonardian and Wolfcampian ages. The writer believes the Abo formation is largely Wolfcampian in age and directly equivalent to much of the Hueco limestone of western Texas.

The age of the Abo formation of the Sacramento Mountains and in central New Mexico is partly dependent on the stratigraphic relationship between the Abo formation and the Hueco limestone. The Hueco limestone was initially defined by Richardson (1904) in the Hueco Mountains of Texas, and included beds now known to range in age from Mississippian into the Permian. The history of the name is outlined by King (1942, pp. 557-561). In summary, the term was applied by Girty to a distinctive fauna that is now considered to be largely Wolfcampian. The Hueco limestone, as currently defined (King and Knight, 1945, sheet II), is about 1600 feet thick, and consists of a thin basal member, the Powwow conglomerate, overlain by limestone divided into lower, middle and upper divisions. The Deer Mountain red shale member forms the basal part of the upper division. The age of the Hueco limestone is considered to be upper Wolfcampian by Lloyd (1949, p. 31) but may include middle Wolfcampian, and some strata of Leonardian age near the top.

Most of the age determinations of the Abo formation have been based on field correlations in the area between the southern Sacramento Mountains and the Hueco Mountains. This intervening area is somewhat faulted, and partly covered by alluvium. The reported results vary widely.

The writer has not traced the beds in the intervening area, but mapping of the subdivisions of the Abo formations of the Sacramento Mountain escarpment, and the recognition of the regional significance of the pre-Abo unconformity are the key to the correlation presented here. Much of the confusion of the past has resulted from the tracing of only the upper tongue of Abo red beds toward the south, and by considering this tongue as the entire Abo formation. This has been one of the principal reasons for the statements that the Abo formation overlies the Hueco limestone. The writer believes the two are essentially equivalent; that the lower tongue of Abo correlates with the Powwow conglomerate; the Culp tongue is directly correlative with much of the Hueco limestone; and it seems probable that the upper tongue of the Abo formation correlates with the Deer Mountain red shale.

Evidence that supports these correlations is listed below:

1. The major Paleozoic unconformity of western Texas is at the base of the Hueco formation of lower Permian age. The major Paleozoic unconformity in the Sacramento Mountain area is at the base of the lower Permian Abo formation. It appears logical to consider the deformation essentially synchronous in all of western Texas and southeastern New Mexico.

2. The lithology of the Culp tongue in the Sacramento Mountains appears to grade southward into limestones similar to those of the Hueco. The progressive thickening of the Culp tongue within the area of the Sacramento Mountains is at a rate compatible with the difference in thickness of the total Abo formation at the southern Sacramento Mountains and of the Hueco limestone.

3. Lloyd (1949, p. 29) reports that Walter Warren of the Standard Oil Company of Texas collected Hueco-type fusulinids a few miles south of T. 19 S. from the unit termed the Culp tongue in this report.

4. C. C. Branson, of Shell Oil Company, has collected ammonoids of upper Wolfcampian age that correlate with ammonoids in the Hueco limestone in the type area from dolomitic limestone and shale in T. 22 S., R. 10 E., about 15 miles south of the map area.

5. The Powwow conglomerate and overlying Hueco limestone

were mapped by C. C. Branson*/ as far north as Sand Canyon, at the south end of the area mapped for this report. Strata considered by Branson to be the Powwow conglomerate match closely with the lower tongue of the Abo formation; the strata considered by Branson to be the Hueco correspond with the Culp tongue; and his "Abo" red beds correspond directly with the upper tongue of the Abo formation in this report.

6. Girty has reported finding the Hueco fauna above the Abo sandstone in the southern Sacramento Mountains (in King, 1934, p. 747). These are interpreted to be collected from above the lower tongue of the Abo sandstone. It is significant that if these fossils came from the only other beds of this area that might be called the Abo sandstone, they came above the upper tongue, which indicates an even older age for the Abo.

7. Subsurface information in several wells indicates the persistence of upper and lower red beds and a thick intervening sequence of limestone and dolomitic limestone in the area south and southeast of the southern Sacramento Mountains. Wells include the Turner Everett No. 1 in T. 21 S., R. 13 E., the Union McMillian No 1 in T. 25 S., R. 13 E., the Hunt McMillian in T. 25 S., R. 16 E. The lower tongue or Powwow conglomerate is not everywhere represented.

8. Although Darton (1928, p. 20) reported the Abo to thin and die out near the Texas line, King (1942, p. 677) reports other geologists have traced the feather edge of the Abo beyond this point and into the Deer Mountain red shale member of the Hueco limestone. The unit traced southward is probably the upper tongue of the Abo formation. If these tapering red beds are not the upper tongue of the Abo formation, they must represent lower red beds of the Yeso, as suggested by Adams et al (1949, p. 88). If so, the Abo is necessarily not younger, but equivalent to an older part of the Hueco limestone.

Some evidence conflicts with the assignment of the Abo formation to the Wolfcampian on the basis of the correlation with the Hueco limestone. Read has identified plants of the Supaia floral assemblage in

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*/ Branson, C. C., Personal communication, September 1949.

Abo Canyon, in the Oscura and San Andres Mountains, and in the southern extension of the Abo between the Sacramento and the Hueco Mountains (King, 1942, p. 690). These probably came from the upper tongue of the Abo formation. The <u>Supaia</u> assemblage is indicated by King (1942, pl. 2) as Leonardian. Read*/ has reported collecting plants of this assemblage from the basal Abo strata in Caballero Canyon, in the central part of the Sacramento Mountains.

The vertebrate fossils from the Abo formation, collected largely in central and northern New Mexico have been reviewed by Romer and Price (1940, p. 29) who concluded the fossils are the same age as the vertebrates in the upper part of the Wichita group of central Texas. King (1942, pl. 2) indicates this to be Leonardian in age. Recent studies by Langston (1949, p. 1903) indicate that the fauna from the Abo formation in northern New Mexico is somewhat more primitive than that found in the Clear Fork or Wichita groups of central Texas. This may indicate Wolfcampian age.

Lloyd (1949, pp. 28-31) reports a series of carbonate rocks can be traced in the subsurface of southeastern New Mexico north and west into red clastics rocks of the Abo type adjacent to the Pedernal Mountains of Permian time. From some wells, Leonardian fusulinids have been obtained. This forms the basis for his correlation of the Abo formation with the Leonardian. The writer has no evidence concerning the subsurface strata. However, if as Lloyd states (1949, p. 28) one of the sections, either the subsurface sequence of southeastern New Mexico or the limestone unit (Culp tongue) of the southern Sacramento Mountains is not the Abo formation, the writer believes it more probable that the

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*/ Read, C. B., Oral communication, July 1950.

term Abo should not be applied to the subsurface section. This is in a depositional basin at least partially isolated from the depositional basin of central New Mexico by the Pedernal Mountains of Permian time. No known positive areas intervened between the area of the northern Sacramento Mountain escarpment and the type area of central New Mexico. The field relationships (pl. 18) indicate that if the Culp tongue in the southern Sacramento Mountains is not gradational with the Abo formation farther north, the Culp tongue must be younger than the strata termed the Abo formation in the northern Sacramento Mountains, which necessarily dates these Abo strata as older than the Hueco limestone.

In summary, the field relationships and paleontologic evidence indicate a direct correlation of the Abo of the Sacramento Mountains with the Hueco limestone in western Texas. As the Hueco limestone is correlated by abundant marine faunas with the type Wolfcampian farther to the southeast, the writer favors the Wolfcampian age of the Abo formation. The evidence from the plant fossils conflicts with the invertebrate evidence. As the type sections of the Permian series are marine, the invertebrates should be more reliable for correlation than the plants. If the upper part of the Hueco limestone is proven to be Leonardian, the uppermost Abo formation may likewise be Leonardian. Perhaps this will resolve the conflicting data for the age of the flora, as most of it was collected from the upper part of the Abo formation, and also for the Leonardian age of the subsurface Abo formation.

YESO FORMATION

The Yeso is the name applied by Lee (1909, p. 12) to a 100- to 2000-foot thick section of sandstone, shale, earthy limestone, and gypsum overlying the Abo formation of the Manzano group. The name was derived from Mesa del Yeso, 12 miles northeast of Socorro. Needham and Bates (1943, pp. 1657-61) have redescribed the Yeso formation in the type area and report a thickness of 593 feet. C. T. Smith*/ reports part of the Yeso formation is missing by faulting at the section measured by Needham and Bates.

In central and northern New Mexico, the Yeso formation is now divided into four members, which in ascending order are the Meseta Blanca, Torres, Canas, and Joyita. The Meseta Blanca sandstone member, named by Wood and Northrop (1943, p. 1657) is applied to orange sandstone at the base of the formation. This sandstone was included by Needham and Bates in the Abo formation (1943, p. 1657). The Torres member consists of interbedded sandstones, siltstones, limestones, and gypsum, and was named by Wilpolt, et al (1946). The Canas gypsum member and the Joyita sandstone member were named by Needham and Bates (1943, p. 1660).

Darton (1922, p. 176) reduced the rank of the Yeso and San Andres formations to members with the introduction of the term Chupadera formation for the part of the Manzano group above the Abo formation. This was a convenience in reconnaissance mapping, but is a name now abandoned by the U. S. Geological Survey (King, 1942, p. 687). The Nogal formation was named by Fiedler and Nye (1933, p. 70) for strata

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*/ Smith, C. T., Oral communication, 1950.

in the Sacramento Mountain area the equivalent of the Yeso formation of this report. This term has been little used by geologists in New Mexico, and was abandoned by the U. S. Geological Survey (Lang, 1937, p. 850).

The Yeso formation is a distinctive lithologic unit in the Sacramento Mountains. The four members recognized in central New Mexico are difficult to distinguish, and do not form practical subdivisions.

Areal distribution:

The Yeso formation is more widely distributed in the Sacramento Mountain area than any of the underlying formations. It extends from north of Tularosa southward to far beyond the southern Sacramento Mountains. The upper part of the formation is 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 escarpment are carved in large part in the soft strata of the Yeso formation. Nearly complete sections of the Yeso formation are exposed in the southern part of T. 19 S., but northward from here to beyond the northern limit of the map area much of the formation is covered by slope wash, landslides, and soil cover.

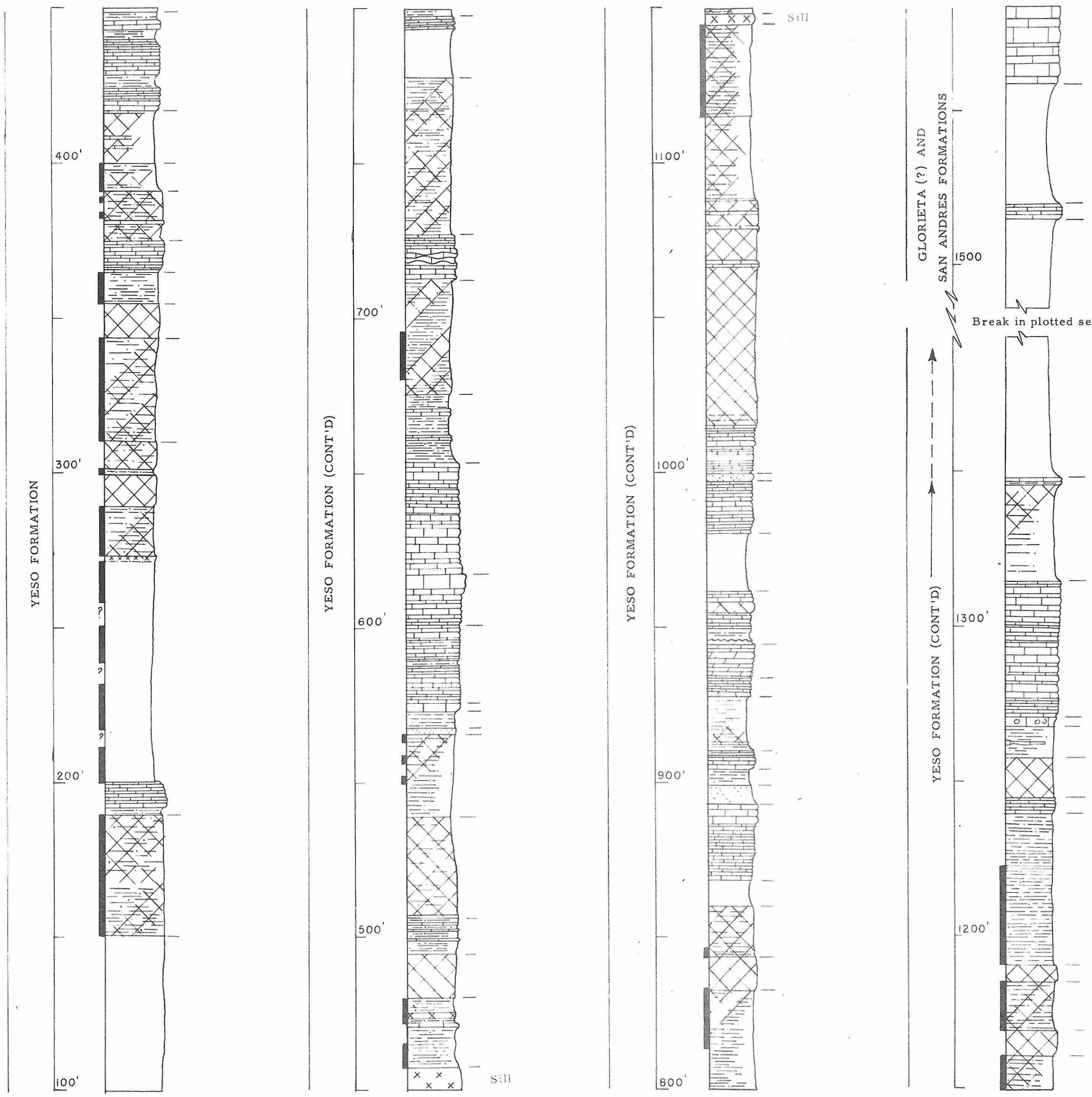
Lithology:

The Yeso formation of the Sacramento Mountain escarpment consists of about 1300 feet of limestones, shales, gypsum, and sandstones, many of which are of types only found in the Yeso formation or largely restricted to the Yeso formation in the Paleozoic section of this area.

The Yeso beds are pale red, pink, yellowish, or gray in color, and contrast with the dark reddish brown of the underlying Abo formation. The colors and the abundance of evaporites, shales, and silty sandstones differentiate the Yeso formation from the overlying Glorieta (?) and San Andres formations. Most of the rock units are thin. The red beds and beds of gypsum are coarsely lenticular, as are some of the limestones. However, at least one limestone unit, nearly 100 feet thick, appears to persist throughout the area. The amount of gypsum and red beds decreases toward the south, and the amount of carbonate rocks increases proportionately.

Two stratigraphic sections of the Yeso formation were measured and described by R. C. Northup of the New Mexico Bureau of Mines and Mineral Resources, and the writer for the use of E. Russell Lloyd. These sections were reproduced by Lloyd (1949, pl. 3) and are shown in somewhat more detail in this report (pls. 20 and 21). The northern section is incomplete, as the underlying Abo and the overlying Glorieta (?) formations are covered. However, the 1200 feet of the Yeso formation described and measured probably represents 90 percent of the total section. This section (pl. 20) was measured 11 miles north of the map area but is believed to be representative of the Yeso formation in much of the northern Sacramento Mountains.

The only good, continuous exposures of the Yeso section are in the southern part of the escarpment, in the southern half of T. 19 S., R. 11 and 12 E. (fig. 38). A continuous section from the Pennsylvanian to the San Andres formation was measured and described in this area. The part of the section above the Abo formation is indicated on plate 21, and is described below:



Top of section N. 1° W. of
ent, N. Mex. Post Office.

Yeso - Glorieta (?) - San Andres formation contacts not exposed.

Base of section not exposed.
Estimated 100' to top of
Abo formation

Sections continued from top of the column on the left.

Section measured in N 1/2 sec. 27, and E 1/2 sec. 22, T. 13 S., R. 11 E.
Base of section N. 19° E. of highest peak west of Nogal Canyon, on north side of U.S. 70.

▨ Gypsum

▮ Black bar to the left of the column indicates red beds.

Section measured and described by R. C. Northup and L. C. Pray.

STRATIGRAPHIC SECTION OF THE YESO FORMATION IN THE NORTHERN SACRAMENTO MOUNTAINS

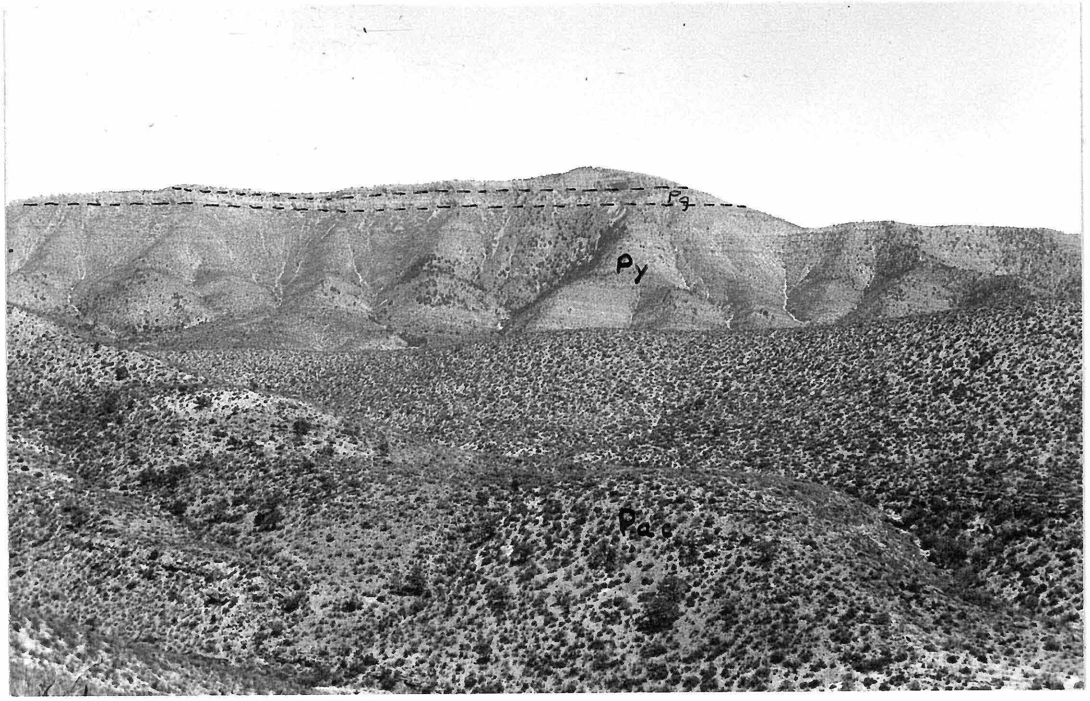
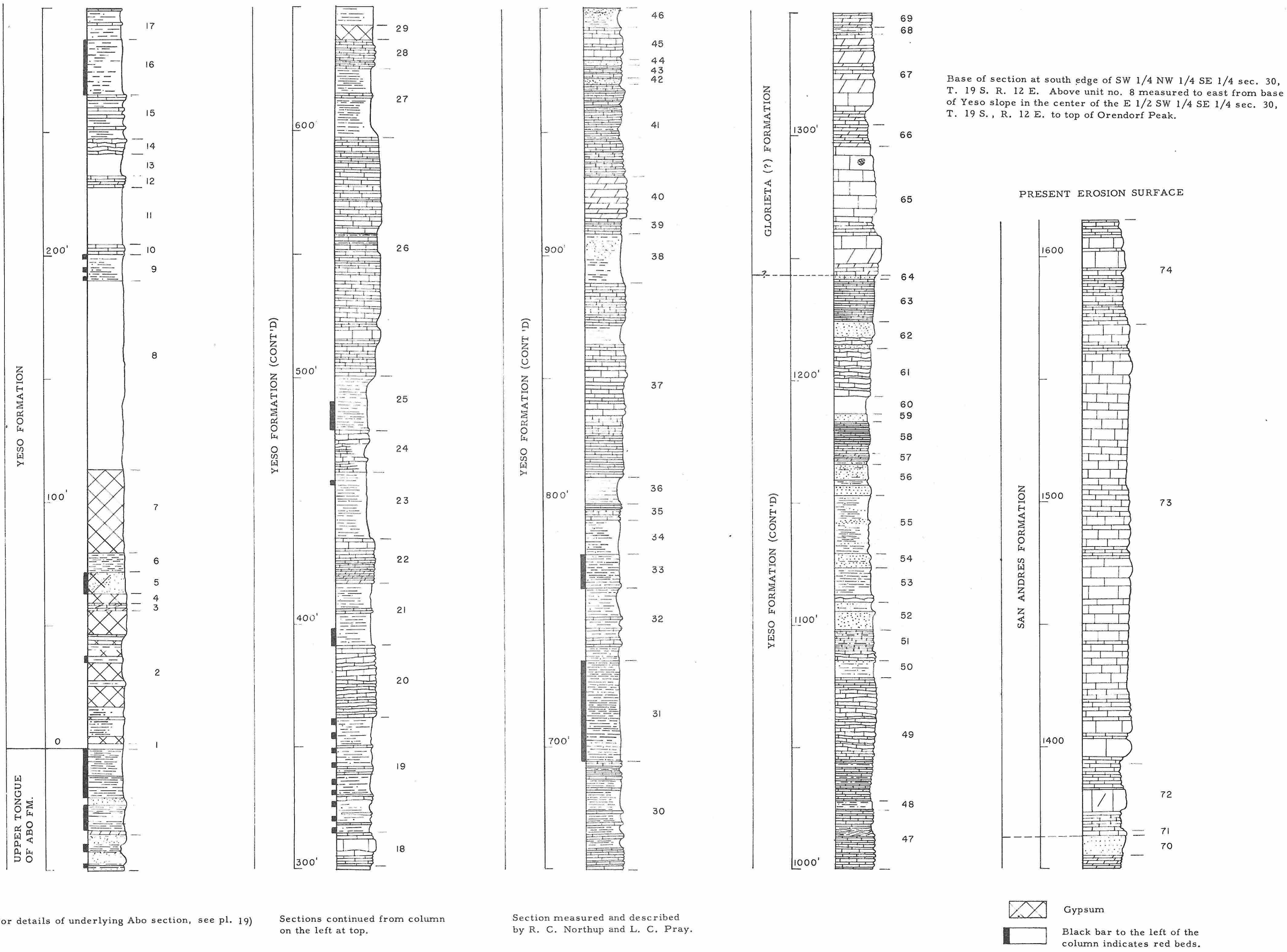


Figure 38. Permian escarpment at the southern end of the Sacramento Mountain escarpment, T. 19 S., R. 11 and 12 E. The light colored slopes in the foregound are the Culp tongue of the Hueco formation (P_{ac}). The dark distant slopes are underlain by the Yeso formation (P_y) and are capped by the Glorieta (?) formation (P_g) and a partial section of the San Andres formation form the lower and upper cliffs.



Base of section at south edge of SW 1/4 NW 1/4 SE 1/4 sec. 30, T. 19 S. R. 12 E. Above unit no. 8 measured to east from base of Yeso slope in the center of the E 1/2 SW 1/4 SE 1/4 sec. 30, T. 19 S., R. 12 E. to top of Orendorf Peak.

(For details of underlying Abo section, see pl. 19)

Sections continued from column on the left at top.

Section measured and described by R. C. Northup and L. C. Pray.

▨ Gypsum

▮ Black bar to the left of the column indicates red beds.

STRATIGRAPHIC SECTION OF THE SAN ANDRES, GLORIETA (?), AND YESO FORMATIONS OF THE SOUTHERN SACRAMENTO MOUNTAINS

Unit No.	Thickness in feet	Description
	Top of section	
	SAN ANDRES FORMATION - 252 feet (incomplete section). Present erosion surface - Orendorf Peak.	
74	42	Limestone, light olive gray; many small fossil fragments; beds one to six feet.
73	181	Limestone, brown gray to medium gray, forms conspicuous upper cliff below Orendorf Peak.
72	27	Limestone, dolomitic, light olive gray, small vugs lined with calcite.
71	2	Limestone, brown gray.
	GLORIETA (?) FORMATION - 121 feet	
70	8	Quartz sandstone, white, fine to medium grained, calcareous, clean.
69	12	Dolomite, light olive gray, very finely crystalline; beds 1 foot thick.
68	3	Limestone, argillaceous shale and minor fine quartz sandstone.
67	34	Limestone, brown gray to olive gray, obscure beds 1 - 3 feet thick, some dolomite. Calcite vugs.
66	12	Dolomite, light olive gray, thin bedded, minor dark limestone.
65	52	Limestone, light olive gray to brown gray, fossiliferous; large calcite vugs, forms conspicuous lower cliff below Orendorf Peak.
	YESO FORMATION - 1239 feet	
64	2	Limestone, sandy; weathers yellowish.

Unit No.	Thickness in feet	Description
63	17	Limestone, light to dark gray, slumped (?).
62	11	Sandstone, buff, fine grained, calcareous; three feet gray limestone near base.
61	20	Limestone, dark gray, obscure beds, forms ledge.
60	7	Covered.
59	3	Sandstone and siltstone, buff, calcareous.
58	13	Limestone, dark gray, thin bedded.
57	4	Dolomite, gray to tan, thin bedded, silty base.
56	12	Sandstone, fine grained, calcareous, some interbedded shale. Basal four feet coarser; brown spotted, good marker bed.
55	24	Poorly exposed; silty shale, and minor fine brown sandstone.
54	6	Sandstone, silty, buff to light brown; ripple marks.
53	14	Silty shale, light gray; minor sandstone, sandy limestone at base.
52	11	Sandstone, buff, silty, fine grained, thin bedded.
51	13	Limestone, gray-tan, silty.
50	7	Shale, buff, silty; sandy at top.
49	50	Limestone, light gray, thin bedded; silty, especially in lower 17 feet.
48	3	Siltstone, buff, calcareous.
47	24	Limestone, dark gray, thin bedded.
46	8	Sandstone, buff, very fine grained, silty.
45	13	Limestone, dark gray, thin to medium bedded.
44	2	Sandstone, buff, silty to very fine.

Unit No.	Thickness in feet	Description
43	5	Limestone, light gray, thin bedded.
42	3	Sandstone, buff, silty to fine grained, calcareous.
41	38	Limestone, light to dark gray, thin bedded; interbedded silty shale in middle.
40	17	Limestone, light gray, dense.
39	6	Limestone, dark gray, thin bedded.
38	20	Poorly exposed, limestone, silty sandstone near top.
37	79	Limestone, light to dark gray, silty, thin bedded; minor silty shale.
36	10	Shale, silty, buff.
35	7	Limestone, light gray, silty, thin bedded.
34	13	Covered, non-red shale (?).
33	14	Shale, silty, pink to red.
32	30	Shale, light gray to buff, silty; interbedded limestone.
31	41	Shale, silty, pink to red; interbedded minor siltstone.
30	50	Limestone, gray to buff, thin beds; interbedded with gray silty shale, poorly exposed at base.
29	6	Gypsum.
28	12	Limestone, light to dark gray, thin bedded.
27	28	Largely covered; silty limestone in middle.
26	97	Limestone, dark to medium gray, thin to medium bedded; this unit forms conspicuous dark cliff in middle of Yeso that can be traced for miles.
25	22	Shale, silty, pink lower half.

Unit No.	Thickness in feet	Description
24	17	Limestone, light gray, medium bedded; and gray shale.
23	27	Shale, silty, buff to gray; pink 22 feet above base.
22	18	Limestone, light to dark gray, silty; light gray, dense dolomite near base.
21	25	Poorly exposed; gray silty shale, pink at base; minor silty limestone.
20	28	Limestone, light to dark gray, thin to medium bedded; lighter color and more massive at top.
19	48	Silty Shale, poorly exposed; gray and pink, and interbedded limestone, gray to buff, thin bedded.
18	14	Limestone, dark gray, thin bedded at base; weathers light gray, forms prominent ledge.
17	11	Shale, silty, gray; minor buff limestone.
16	23	Shale, silty, pin; poorly exposed.
15	18	Limestone, light to dark gray, thin bedded; interbedded gray shale.
14	6	Limestone, dark gray to red, obscure bedding.
13	9	Covered; probably gray shale.
12	5	Limestone and dolomite, light gray to tan, thin to medium bedded.
11	23	Covered; probably gray shale.
10	4	Limestone, light gray, thin to medium bedded.
9	11	Shale, silty, pink and light gray.
8	77	Covered. Base of overlying section in E 1/2 SW 1/4 SE 1/4 sec. 30, T. 19 S., R. 12 E., S 72 W. Sections correlated by unit No. 15. Overlying section measured directly up slope to east.

Unit No.	Thickness in feet	Description
7	34	Gypsum, interbedded pink shale.
6	7	Shale, silty, pink.
5	9	Sandstone, buff, very fine grained, and gypsum.
4	4	Gypsum, silty, mottled.
3	3	Limestone, dolomitic, medium gray, thin bedded.
2	54	Gypsum and minor gray silty shale. Pink shale 34 feet above base, 1 foot gray dolomitic limestone 42 feet above base. Basal 15 feet poorly exposed.
1	2	Covered.

ABO FORMATION (upper tongue)

Unit No.	Thickness in feet	Description
	11	Partly covered; maroon and gray shale.
	9	Shale, maroon; minor gray green beds.
	3	Sandstone, tan, very fine grained, dolomitic; delicate cross-lamination.
	12	Shale, maroon to red; thin silty dolomite at base.
	30	Sandstone, buff, very fine grained, dolomitic (?), delicate cross-lamination; minor maroon shale.

Base of section at south edge of SW 1/4 NW 1/4 SE 1/4 sec. 30, T. 19 S., R. 12 E.

The basal part of the Yeso formation in the Sacramento Mountains consists largely of gypsum, gypsiferous pinkish and pale red silty shales, gray shales, and thin beds of yellow gray limestone. This is in marked contrast to the lower part of the Yeso in the nearby Oscura Mountains, and beyond in much of central and northern New Mexico where the base consists of the Meseta Blanca sandstone member.

Evaporites and red beds occur throughout the Yeso section in the northern part of the area, but are restricted to the lower 800 feet of the southern section and are only abundant in the lower 500 feet. Some of the gypsum occurs in massive, pure beds, and some occurs mixed with clay and silt in all proportions. Local contorted structures in the gypsum suggest at least part of it has formed from anhydrite. In the subsurface to the southeast and east anhydrite is reported, rather than gypsum. Fiedler and Nye (1933, p. 73) describe anhydrite in a surface section measured in the area near the section of plate 20.

Water from wells in the upper Penasco River area, T. 17 S., R 12 E., east of the crest are locally salty so halite is undoubtedly a part of the evaporite deposits. Fiedler and Nye (1933, p. 75) report halite in wells north and east of the map area.

Most of the limestone of the Yeso formation is medium to dark gray, thin bedded, argillaceous, and sublithographic to very finely crystalline. Freshly broken surfaces commonly have a petroliferous or fetid odor. Fossils, largely brachiopods and mollusks, occur in some of the limestones and interbedded dark shales. Obscure algal growths are common in some limestone beds. Between 500 and 600 feet above the base of the Yeso formation in the northern and southern measured sections (unit 26, pl. 21), a series of dark limestones about 100 feet thick form a resistant ledge in the Yeso slope. This ledge can be recognized for at least 10 miles in the southern part of the map area. Although it can not be traced continuously to the northern section it seems probable that the thick limestone units of the two sections are equivalent.

Near the base of the Yeso formation fine to coarsely crystalline limestone, generally yellowish gray in color, is common in thin beds. Much of this contains irregular cavities and pits, perhaps caused by solution of gypsum or anhydrite similar to rock described in detail by Fiedler and Nye (1933, p. 68).

Dolomite and dolomitic limestone is uncommon in surface sections, although this is typically found in sections of red beds and evaporites (Pettijohn, 1949, p. 356). The distribution within the formation at any one section appears erratic. One 17-foot bed of dolomite (no. 40, pl. 21) changes to limestone in only 500 feet laterally. Dolomite is more abundant toward the south, a relationship also noted in the subsurface (Lloyd, 1949, p. 24).

Sandstone forms only one percent of the Yeso section in the northern Sacramento Mountains, and about five percent of the southern section. It is largely restricted to the upper half of the formation. Most is very fine to fine grained silty, quartz sandstone with a distinctive yellow to yellow brown color. The uppermost part of the Yeso formation in T. 18 S., R. 11 and 12 E., and the northern part of T. 19 S. consists largely of fine grained, yellow to brown to reddish brown silty, quartz sandstone, locally as much as 70 feet thick and forms an excellent marker. This sandstone unit somewhat resembles the Joyita sandstone member at the top of the Yeso formation of central New Mexico. It is not continuous in the Sacramento Mountains, and correlation with the Joyita does not appear justified. Quartz grains of sand size are common in many of the shales and mudstones of the Yeso formation.

In the central part of the escarpment, a few pieces of coarse grained arkose resembling that of the Abo formation were observed in the lower 100 feet of the Yeso formation. The exposures where observed are too poor to determine whether or not these represent float from a thin layer of arkose in the lower Yeso or are transported Abo rocks.

Conditions of deposition:

The Yeso formation is believed by Lloyd (1949, p. 27) and others to represent at least in part a back reef deposit, formed contemporaneously with the growth of the Victorio Peak reef along a northeast trend in the southern Guadalupe Mountains, and with the deposition of the upper part of the pontic Bone Spring formation farther to the southeast. The distribution and nature of the deposits comprising the Yeso formation in the Sacramento Mountains and other parts of central and southern New Mexico are suggestive of deposition in a broad area lying between a source of clastic materials to the north and northeast and the open sea to the south or southeast. At times, normal marine deposition of limestone or of clastics prevailed over much of the area of the Yeso formation. At other times, circulation of normal marine waters was restricted, probably by the reef toward the southeast. The effect of evaporation over the entire back reef area, and of an influx of normal marine waters at the southeast caused circulation toward the shoreline and increasing salinity in that northern direction, resulting in deposition of evaporites in the shoreward areas and contemporaneous deposition of carbonates closer to the reef and open sea. Repeated advance and retreat of the shoreline is probably a major factor in the repetitious interbedding of limestone and gypsum. The deposition of clastic material was independent of the salinity and probably in part independent of the shore line. It generally increases to the north, as would be expected.

The predominance of gypsum (anhydrite) indicates that the circulation of sea water, and/or influx of fresh waters was sufficient to prevent deposition of the bulk of the halite or of the more soluble salts. Most of the subsurface data indicates anhydrite rather than gypsum.

The work of Posnjak (1940) indicates that anhydrite always forms rather than gypsum if the temperature is above 42° C. and that it forms at lower temperatures if the salinity is higher than that sufficient to start precipitation of calcium sulphate from sea water. With normal temperatures of sea water, gypsum will precipitate first. The observed relationships in most evaporite deposits do not agree with these experimental data as Pettijohn (1949, p. 359) states that in most deposits, gypsum appears to be later than anhydrite. This appears to be true in the Sacramento Mountains, but detailed petrographic studies are needed.

The uniformity in thickness of the Yeso formation and general similarity of lithology over broad areas indicates that deposition in most of the area of the Yeso formation took place on a stable shelf. Minor exception to this appears to occur locally in the Sacramento

Mountains as the Yeso formation appears to be thinner in the northern and north central part of the range where pre-Abo uplift was marked, and possibly minor uplift continued during the Yeso deposition in these areas. However, the exposures are so poor in this area that the apparent thinness of the Yeso section perhaps is caused by structural features not observed.

Contact relationships:

The Yeso formation does not appear to be separated from the strata above and below by erosional breaks. The contacts are placed at major changes in lithology, which appear in detail to be gradational.

The base of the Yeso formation is placed at the major lithologic change from the strata typical of the Abo formation to the strata more characteristic of the Yeso formation. The upper part of the Abo formation consists largely of dark reddish brown mudstone. Associated with the dark colored mudstone in different parts of the area is coarse arkose, or one to two foot thick layers of very fine grained dolomitic sandstone, or thin layers of sandy dolomite. The reddish brown color is diagnostic of the Abo formation throughout New Mexico. Strata of gypsum, gray or yellowish shale, or of limestone have not been observed more than 20 feet below the highest reddish brown mudstones or sandstones. The contact, therefore, is placed to best separate these types of rocks. In some places the change appears abrupt as in the section reproduced on plate 21. At most places where the exposures permit detailed examination, the change in lithology is transitional. In field mapping, the contact has been placed at the point of major change, as in the section of plate 19.

The transitional zone between the Abo and Yeso formations probably records fluctuations of a major northward advance of the seas at this time.

The upper contact of the Yeso formation in the Sacramento Mountains is not as clearly defined as the lower. The writer places the contact at the top of the highest red shale, silty yellow sandstone, or non-gray limestone, or other type of rock that is characteristic of the Yeso formation and which is not present in the overlying thick series of gray limestones and dolomitic limestones.

Fauna and flora:

Although invertebrate fossils occur within the Yeso formation, they have not been collected and studied. Fusulinids have not been observed. Fossil plants from the Yeso formation in central New Mexico were reported by White (1926, p. 1046), but none have been observed in the Sacramento Mountain area. Read has not reported them elsewhere in New Mexico.

Age, correlation, and regional relationships:

No evidence of the age or correlation of the Yeso formation has been obtained in the Sacramento Mountain investigation, excdpt that which results from the correlation of the Abo formation with the Hueco limestone. The Yeso overlies the Abo formation southward from the

Sacramento Mountains. Perhaps the lower part correlates with the uppermost part of the Hueco limestone as defined by King and Knight (1945, Sheet II). The Yeso formation is considered to be Leonardian in age by nearly all writers on the Permian of southeastern New Mexico and western Texas, including Lloyd (1949, fig. 3) and Adams (1949, fig. 5).

The regional relationships of the Yeso formation are discussed by Lloyd (1949, pp. 23-28). His correlations and discussion are based on the sections measured by R. C. Northup and the writer in the Sacramento Mountain area, and on much other information not available to the writer. The following brief summary of regional relationships is derived largely from Lloyd (1949).

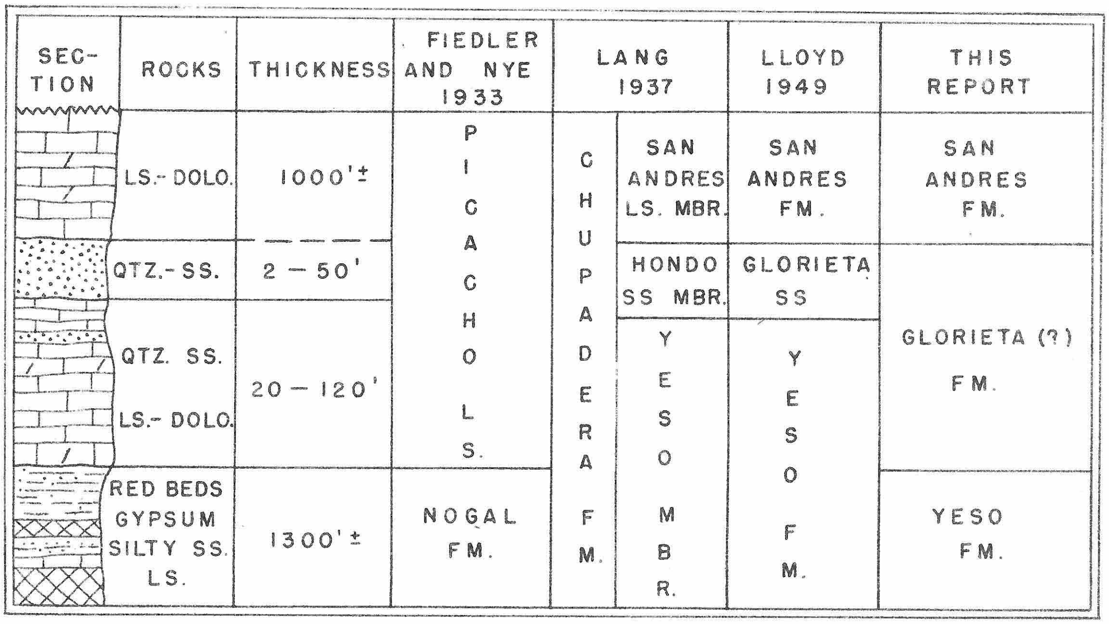
The Yeso formation ranges from about 500 to 1000 feet in the central and northern part of New Mexico. Evaporites are largely absent, limestone is uncommon, and sandstones are dominant in the Yeso formation in northern New Mexico. The Yeso thickens toward the south, is about 1200 feet in the Oscura Mountains, about 1300 feet in the Sacramento Mountains, and in the subsurface sections farther to the east is commonly 2000 feet thick. The members of the formation recognized in central New Mexico have been identified locally in the subsurface, as in the Pure Federal Fee No. 1, in sec. 31, T. 3 S., R. 28 E., where the Torres, Canas, and Joyita members form less than the upper half of a section 2140 feet thick. The Yeso formation grades southeastward into sections composed largely of dolomite and persistent thin beds of fine grained sandstone, and is an important source of petroleum in Lea and Eddy Counties.

GLORIETA (?) FORMATION

Keyes (1915, p. 2, 7) applied the term Glorieta to the main body of the Dakota series (Cretaceous) around the southern end of the Rocky Mountains. The derivation of the name was either from Glorieta Mesa or the town of Glorieta in San Miguel or Sante Fe Counties in north central New Mexico. It is now known that Cretaceous rocks do not occur in this region. The name Glorieta was applied to the conspicuous sandstone of Glorieta Mesa by Hager and Robitaille (1919, cited in Wilmarth, 1938, p. 831) who considered it Permian and the top member of the Yeso formation. Rich (1921, p. 295) first considered the Glorieta sandstone as a formation between the San Andres limestone and the Yeso formation, which is the current usage of the New Mexico Bureau of Mines and Mineral Resources. The U. S. Geological Survey classes the Glorieta sandstone as a member of the San Andres formation.

Needham and Bates (1943, p. 1662) designated a type section of the Glorieta sandstone at Glorieta Mesa in the south central part of T. 15 N., R. 12 E., one mile west of Rowe, San Miguel County, New Mexico. At the type section, the Glorieta sandstone is 136 feet thick, consists of medium to coarse grained quartz sandstone between the Yeso formation and a thin section of San Andres limestone.

Along the Sacramento Mountain escarpment strata of lithology similar to the Glorieta sandstone are thin, and do not separate rocks typical of the Yeso formation from rocks typical of the San Andres formation, but instead appear to be slightly above the base of the lowest limestone and dolomite of the San Andres type. The correlation of these sandstones with the Glorieta formation has been widely accepted by petroleum geologists, but detailed studies are needed. The subdivisions that have been used in the Sacramento Mountain area and the subdivision used in this report are summarized in figure 39.



SECTION	ROCKS	THICKNESS	FIEDLER AND NYE 1933	LANG 1937		LLOYD 1949	THIS REPORT
	LS.- DOLO.	1000'±	PICACHO LS.	CHUPADERA FM.	SAN ANDRES LS. MBR.	SAN ANDRES FM.	SAN ANDRES FM.
	QTZ.- SS.	2 — 50'			HONDO SS MBR.	GLORIETA SS	GLORIETA (?) FM.
	QTZ. SS. LS.- DOLO.	20 — 120'			YESO MBR.	YESO FM.	
	RED BEDS GYPSUM SILTY SS. LS.	1300'±	NOGAL FM.				YESO FM.

Figure 39. Nomenclature of the upper part of the Manzano group in the Sacramento Mountains.

The Manzano group above the Abo formation in the Sacramento Mountains appears to consist of two major parts, a lower section of red beds, shales, evaporites, silty sandstones, and interbedded limestones and dolomite with minor amounts of interbedded quartz sandstone. The contact between these two major parts of the upper Manzano group is well defined in most of the Sacramento Mountain area, and is selected as the top of the Yeso formation. The resulting Yeso section appears to agree closely with the type Yeso in central New Mexico.

The best horizon for surface mapping in the Sacramento Mountains or for subsurface correlation in the adjacent areas is the top of the highest bed of quartz sandstone. Along the crest of the Sacramento Mountains, at most places, two thin beds of sandstone occur in the strata above the Yeso formation. The sandstone is not used as a separate unit owing to the difficulty of determing the lower contact. Locally, other thin layers or minor streaks of quartz sand occur in the underlying dolomite or limestone. No evidence for a major erosional break at the base of any of the sandstone beds has been observed. The limestones and dolomites appear to have been a part of the same depositional sequence as the sandstones. It appears logical to consider this entire unit as the Glorieta, a conclusion reached earlier by Skinner (1947, p. 1863), and suggested by Lloyd (1949, p. 23).

The correlation of the sandstone with the Glorieta is based largely on the subsurface record from northern New Mexico southward to the east side of the Sacramento Mountains (see Lloyd, 1949, pl. 5). The entire unit may correlate with the San Andres formation, as this contains a few thin beds of sandstone in the lower part farther to the west and northwest in New Mexico. The unit is referred to as the Glorieta (?) formation until the correlation can be clearly established.

Areal distribution:

The Glorieta (?) formation is widely distributed throughout the higher parts of the Sacramento Mountains from Tularosa Canyon on the north throughout most of the map area, and continues far to the southeast to the northern Guadalupe Mountains. The Glorieta (?) formation is rarely exposed along most of the west facing escarpment. In the southern part of the escarpment the Glorieta (?) crops out on isolated high parts of the western divide. East of the crest the formation crops out around the heads of the numerous canyons and eastward along the sides of the valley.

Lithology:

The Glorieta (?) formation in the Sacramento Mountain escarpment consists dominantly of gray and olive gray limestone and dolomite, with minor beds of white to yellow gray, calcareous, fine to medium grained, well sorted quartz sandstone. The formation ranges in thickness from 121 feet at the southern end of the escarpment to about 60 feet in the northern Sacramento Mountains. Details of the Glorieta (?) formation at the southern end of the escarpment are given on page 264 and a graphic log of the section is reproduced on plate 21.

The quartz sandstone of the Glorieta (?) formation is an excellent stratigraphic marker in the Permian section of the Sacramento Mountains because of its distinctive lithology and wide horizontal and limited vertical distribtution in the section. The composition and texture of the sandstone are nearly uniform throughout the area. About 98 percent of the clastic particles are of quartz and the remainder largely potash feldspar. Detrital chert particles and quartz grains showing abraded secondary overgrowths are absent. The rock is tightly cemented by calcite in most of the area.

The texture is similar to that of many pure quartz sandstones. It is well sorted. Clastic particles larger than 1/2 mm. or smaller than 1/8 mm. (fine to medium sand) form but a small amount of the rock. Most grains are rounded to well rounded (Pettijohn, 1949, p. 52) and equant in shape. The coarse particles are the better rounded, and the surfaces of these are commonly frosted.

The layers of sandstone are massive, but thin. The individual layers of sandstone beds are only 2 to 3 feet thick at most places. The maximum thickness of a layer observed is 10 feet. The aggregate thickness of sandstone in the Glorieta (?) formation at most sections is less than 10 feet. Thicker sections are reported to the north, east and west from the crest of the Sacramento Mountains. The individual layers of quartz sandstone do not appear to persist throughout the area, but all appear to be confined to a stratigraphic interval less than 50 feet thick.

Most of the Glorieta (?) formation is composed of limestone, dolomitic limestone, and dolomite. The beds are commonly medium to thick bedded. The rock ranges in color from medium to light gray to olive gray, and is dense. Thin sections of this rock that were examined consisted of finely divided fossil fragments that form about two thirds of the rock, and an interstitial matrix of sublithographic to finely crystalline calcite. This rock probably represents an authochthonous accumulation of fossil material and lime mud.

In much of the southern and central part of the escarpment 30 to 60 feet of limestone or dolomite occurs at or somewhat above the base of the Glorieta (?) formation, and locally forms a resistant ledge. A zone of Dictyclostus brachiopods is a useful marker at the top of this ledge in much of the area. Above this zone and below the lowest sandstone bed that can be identified are less resistant dolomites and dolomitic limestone from 20 to 50 feet thick that are light olive gray and contain numerous small vugs.

Sandstones of the Glorieta formation were not identified in the area west and northwest of Cloudcroft. The sandstones are either not present or so thin that a bed cannot be identified.

Springs are one of the best markers of the top of the Yeso formation and the base of the Glorieta (?) formation in the Sacramento Mountains, especially in the valleys east of the crest. They occur at several horizons in the Yeso formation, but the highest and most numerous are almost everywhere less than 100 feet below the top of the Glorieta (?) formation. The ground water is believed to seep downward along joint planes in the San Andres and Glorieta (?) formations to the first continuous layer of shale in the Yeso, and thence migrates downdip to the surface. The sandstones are tightly cemented.

Conditions of deposition:

The Glorieta (?) formation records a new phase of Permian deposition. The site of deposition continued to be a stable shelf area, but the circulation of marine waters in the Sacramento Mountain area apparently was not sufficiently restricted to produce evaporite deposits. The change in the clastic deposit from shale and silty sandstone of the Yeso formation to only well sorted, fine to medium grained sandstone probably reflects differences of available detritus and to the selective removal of the finer particles as a result of the increased circulation and turbulence.

The Glorieta sandstones have been interpreted by many as the basal deposits of a transgressive sea, but in the Sacramento Mountain area they appear to be only a phase of marine deposition that began with the formation of the limestone and dolomite. The sandstone is coarser and thickens toward northern New Mexico and the source area must have been in this direction. The limestone and dolomite of the Glorieta (?) formation of the Sacramento Mountain area thins toward the north and either pinches out in this direction or grades into coarse clastic rocks.

The predominance of well rounded quartz grains indicates a severe abrasional history and is generally considered to be the product of more than one cycle of sedimentation (Pettijohn, 1949, p. 432). However, other characteristics of secondary origin such as chert grains, or grains of quartz that show abraded secondary overgrowths have not been observed. The rounding of the grains and elimination of all but resistant, stable minerals probably occurred as a result of extensive reworking across a broad shelf area. The beds of sandstone in the Sacramento Mountain area may represent times during which the seas receded toward the south, and clastic sediments could be transported farther to the south.

Contact relationships:

The basal contact of the Glorieta (?) formation is interpreted as a change in the type of deposition, but is not considered to indicate a period of non-deposition or of erosion.

The upper contact of the Glorieta (?) formation has been interpreted as an unconformity, in some of the surrounding areas to the east but no persistent erosional break has been observed in the area of the Sacramento Mountain escarpment.

Fauna:

Dictyoclostus brachiopods are locally abundant within the Glorieta (?) formation, and by careful collecting, probably a large invertebrate fauna could be collected. Some of the Guadalupian fauna collected by Girty probably came from the limestone and dolomite of the Glorieta (?) formation. Fusulinids have not been identified in the Glorieta formation.

Age, correlation, and regional relationships:

The age of the Glorieta sandstone is considered by Lloyd (1949, pp. 20-22) to be either uppermost Leonardian, or lowermost Guadalupian. The determination of the age of the Glorieta sandstone is largely dependent on lithologic tracing and paleontologic work in the complex reef areas of southeastern New Mexico and western Texas and studies in the Sacramento Mountain area do not contribute directly to this problem. The age of the Glorieta (?) formation as the term is used in this report is believed to be about the same as the age of the sandstone discussed by Lloyd.

The Glorieta sandstone is considered to be equivalent to the DeChelly sandstone of northeastern Arizona by Read (in Needham and Bates, 1943, p. 1664). Lloyd (1949, p. 25) correlates the Glorieta sandstone with the San Angelo sandstone in western Texas, but states that some geologists correlate both the upper Yeso and the Glorieta sandstone with the San Angelo sandstone.

Needham and Bates (1943, p. 1666) describe thin beds of sandstone similar to the Glorieta sandstone in the lower part of the San Andres formation above the thicker Glorieta formation in the San Andres Mountains, on Chupadera Mesa in central New Mexico, and in the Zuni Mountains of northwestern New Mexico. It is possible that the Glorieta formation pinches out north and west of the Sacramento Mountains and that the strata termed the Glorieta (?) formation in the Sacramento Mountain area actually are the lower part of the San Andres formation. Detailed studies of the areas to the northwest and northeast of the Sacramento Mountain escarpment are needed to evaluate this alternate correlation.

The Sandstones of the Glorieta (?) formation appear to be thinner along the crest of the Sacramento Mountains than elsewhere to the west, north, and east. The following thicknesses have been reported from the region surrounding the Sacramento Mountain escarpment: central New Mexico in the Gran Quivera Quadrangle, 230 feet (Bates, et al, 1947, p. 34); Oscura Mountains, 40 feet (Lloyd, 1949, p. 22); northeast of the Sacramento Mountain escarpment in the Rio Hondo area, 50 feet (Lang, 1937, p. 850); east of the escarpment in the Texas Company Wilson No. 1 well in sec. 29, T. 17 S., R. 18 E., 70 feet (Lloyd, 1949, pl. 7); and on the southeastern extension of the Sacramento escarpment in sec. 24, T. 19 S., R. 16 E., 25 feet (Skinner, 1946, p. 1863).

East of the Texas Company Wilson No. 1, the Glorieta sandstone and the Yeso are not clearly distinguishable (Lloyd, 1949, p. 23). Skinner (1946, p. 1864) traced the Glorieta sandstone eastward along the southeastern extension of the Sacramento escarpment, and reports it thins and is not present in sec. 3, T. 24 S., R. 20 E.

The thickening of the Glorieta formation toward the north is a reflection of the northern source of the sediments. The local thinning of the sandstones at the crest of the Sacramento Mountains as compared to the east flank possibly reflects a slight positive tendency of this part of the depositional area and is perhaps the last record of the deformation and uplift that occurred during late Pennsylvanian and early Permian time, and appears to have been a factor of decreasing importance in Permian time.

SAN ANDRES FORMATION

The San Andres[*/] is the youngest of the formations of the Manzano group. It was named by Lee (1909, p. 12) and the name derived from the San Andres Mountains. Needham and Bates (1943, pp. 1664-66) have redescribed the type section of the San Andres formation in the Northern San Andres Mountains in sec. 29, T. 12 S., R. 2 E., where 593 feet of strata occur between the Glorieta (?) formation and the present erosion surface.

The San Andres is the youngest Paleozoic formation of the Sacramento Mountains and forms the crest of the range. Fiedler and Nye (1933, p. 55) named these strata and the underlying Glorieta (?) formation the Picacho limestone (fig. 39), but this name has been abandoned (Lang, 1937, p. 849).

[*/] Lee spelled the name San Andreas, but the spelling has since been changed to conform to the approved spelling of the geographic feature for which it was named.

Areal distribution:

The San Andres formation forms the resistant cap of the Sacramento Mountain escarpment and of the eastern slope for a distance of 60 miles to the east to where the San Andres is covered by alluvium or by younger Permian formations. From the divide east of the Sacramento River in the southern part of the mountains, the San Andres formation can be traced southeastward along the progressively lower escarpment to the northern Guadalupe Mountains. Lang (1937, p. 854) outlines the distribution of the San Andres formation in the area southeast of the Sacramento Mountain escarpment.

Within the map area the San Andres formation extends from the northern boundary to the southern part of T. 18 S., R. 12 E., and is everywhere above the 8000 foot contour. Farther south the formation occurs at high points along the divide between the Sacramento River and the western slope. The southernmost exposure along this divide is at Orendorf Peak, at 7500 feet in sec. 29, T. 19 S., R. 12 E.

Lithology:

Gray limestone forms most of the San Andres formation in the Sacramento Mountains. The upper part of the formation has been eroded from the crest of the Sacramento Mountains. The thickness in the subsurface to the east is about 1400 feet. The maximum thickness observed in the map area is about 700 feet, below the Alamo Fire Tower in sec. 34, T. 16 S., R. 11 E., Only a few hundred feet of the San Andres formation remain at most places along the crest.

Exposures of the San Andres formation are poor in most of the area, especially in the higher central part of the range. The description of the section measured at Orendorf Peak at the southern end of the escarpment is given on page 264 and a graphic log of this section is reproduced on plate 21. Two stratigraphic sections of the Picacho limestone measured north and northeast of the limit of the map have been described by Fiedler and Nye (1933, pp. 55-60, 72-73). One, in the vicinity of Picacho in T. 11 S., R. 17 E., includes the lower 265 feet of the San Andres formation. The other section includes 621 feet of the San Andres formation and was measured near Bent, in T. 13 S., R. 10 E., near the area of the Yeso section of this report (pl. 20). The sections of Fiedler and Nye, the Orendorf Peak section at the southern end of the escarpment, and the field observations in the intervening area indicate that the lithology of the San Andres formation is essentially constant throughout this area.

Limestone is predominant in the San Andres formation that is exposed along the Sacramento Mountain escarpment. Dolomitic limestone forms about a tenth of the observed sections, and dolomite is very uncommon. Most of the rocks are light olive gray to olive gray, but the colors include light to dark gray and brown gray. Bedding planes are sharply defined and even. The beds range from a few inches to about 6 feet thick, but generally are from 1 to 3 feet thick. Freshly broken surfaces of many of the darker limestones have a petroliferous odor. Many limestones are argillaceous, but beds of shale are largely absent. Some of the limestones of the San Andres are oolitic, others appear to contain detrital particles of limestone. Limestone conglomerates are uncommon.

Fossils are only locally conspicuous on the outcrop. A few thin sections that are believed to be representative of most of the limestones consist largely of very fine fossil debris, some of complete microfossils and some of fragmental larger forms, enclosed in a subordinate, finely crystalline matrix of calcite. Like the limestone of the Glorieta (?) formation, most of this is rock believed to be an authochthonous accumulation.

Chert is uncommon in the San Andres formation. Smooth, rounded, siliceous nodules, some as large as 6 inches thick and 2 to 3 feet across, occur locally in the lower part of the formation. These appear to be similar to the siliceous nodules of the Valmont formation, except that the carbonate mineral that formed the bulk of the nodule has been leached out resulting in a cellular, porous, siliceous mass. The nodules and beds (?) of this material weather to pale reddish brown fragments, and locally form distinctive stratigraphic markers, as in the SW 1/4 sec. 24, T. 18 S., R. 11 E., where a unit about 20 feet thick occurs 100 feet above the base of the formation.

As the lower contact is placed at the top of the highest quartz sandstone, most of the sandstone in the strata above the Yeso formation is excluded from the San Andres formation. The exposures are so poor in some of the area along the west facing escarpment that the position of the San Andres-Glorieta contact for a mile or two is dependent on a few pieces of quartz sandstone float. To use the highest sandstone as a valid horizon marker, it was necessary to establish that sandstones of similar type are restricted in vertical distribution to a thin stratigraphic unit. The major source of quartz sandstone float invariably occurs less than 150 feet above strata considered to be the Yeso formation. Careful checking of the strata overlying this zone of sandstone resulted in discovery of higher quartz sandstone at only one place, where a two inch bed of quartz sandstone crops out about 250 feet above Yeso strata in the NW 1/4 NW 1/4 sec. 10, T. 18 S., R. 11 E. Undoubtedly more thin layers of sandstone occur within the San Andres formation above the major sandstone zone, but sandstone is the exception in the formation. A thin bed of quartz sandstone has been reported about 200 feet above the Glorieta sandstone near the center of T. 17 S., R. 13 E.[*/]. Detailed work probably will indicate more in the areas east of the crest of the Sacramento Mountains.

Conditions of deposition:

The uniformity and widespread distribution of the San Andres formation indicates deposition on a stable shelf, and the rock types and fauna present indicates deposition from seas of normal salinity. The virtual absence of clastic material and the known distribution of the formation suggests that the land areas were far to the north and no longer supplied abundant detritus as during the earlier Permian times. The uniformity of the bedding and the scarcity of clastic limestones, bioherms, or other features characteristic of shallow water deposition suggests deposition in deeper water than prevailed during the deposition of the Yeso formation. Although the San Andres is believed to have formed contemporaneously with the Victoria Peak reef, the

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*/ Covington, Jerry, Oral communication, 1949.

reef did not restrict the circulation of marine waters sufficiently for the formation of evaporites in the area of the Sacramento Mountain escarpment.

Contact relationships:

Field relationships indicate that the uppermost quartz sandstone at various local sections is not the same layer throughout the area. As no persistent erosion discontinuity has been observed, the basal contact of the San Andres formation is believed to be transitional with the Glorieta formation. Skinner (1946, p. 1863) reported an eight foot zone of limestone conglomerate overlying the Glorieta sandstone in sec. 24, T. 19 S., R. 16 E., southeast of the map area. He indicates an unconformity between the Glorieta and the San Andres formations in southeastern New Mexico in his correlation diagram, but does not indicate his specific interpretation for the Sacramento Mountain area.

The top of the San Andres formation is defined by the present erosion surface in the western Sacramento Mountains.

Fauna:

Darton (1928, p. 207) reported a large fauna collected by Girty, Fisher, Richardson, and Darton in railroad cuts west of Cloudcroft. This is believed to be largely from the San Andres formation. Dictyoclostus brachiopods were the type observed most commonly during the field work for this report, but the writer did not attempt to make any systematic faunal collections. Fusulinids have not been observed, although they have been reported in chert of the lower San Andres by Skinner (1946, p. 1865) along the southeastern part of the Sacramento Mountain escarpment.

Age, correlation, and regional relationships:

The age of the San Andres formation has been a major problem in the stratigraphy of the southern Permian Basin. It was considered Leonardian (King, 1942, sheet II; Bates, et al, 1947, p. 34; and others), but is now believed by most students of the problem to be lower Guadalupian (Lloyd, 1949, p. 20; Adams, et al, 1949, fig. 5; Skinner, 1946, Clifton, 1945; Lewis, 1941). No direct evidence of the age of the formation has resulted from this investigation.

The San Andres formation is widespread in New Mexico. The formation thickens from northern New Mexico where it is overlain unconformably by the Triassic rocks to southeastern New Mexico where it is overlain by younger Paleozoic rocks. In the northern part of the state it consists largely of limestone and is rarely over 100 feet thick. At Chupadera Mesa, in central New Mexico, the formation is 200 to 300 feet thick and contains some quartz sandstone and gypsum (Bates, et al, 1947, pp. 33-34). Nearly 600 feet of the San Andres formation is present in the northern San Andres Mountains (Needham and Bates, 1943, p. 1666), but farther to the south in the Organ and Franklin Mountains, the San Andres is absent. The formation is about 700 feet thick along the western Sacramento Mountain escarpment, and consists largely of limestone. To the east in the subsurface of southeastern New Mexico Lloyd (1949, pls. 5, 6, 7) indicates the San Andres formation is from 1260 to 1560 feet thick. The lithology toward the southeast is dominantly of dolomite. Northeast of the Sacramento Mountains the San Andres contains red beds and evaporites.

QUATERNARY

Sediments of Quaternary age form the surface deposits of about one third of the area included on the geologic maps. The surface deposits have been grouped into three general categories for convenience in mapping, and are the older terrace deposits; recent alluvium, younger terrace deposits, sand dunes, and spring deposits; and landslides, talus accumulations, and related deposits.

OLDER TERRACE DEPOSITS

The most conspicuous terraces observed in the Sacramento Mountains occur between High Rolls and Tularosa in the broad area of low relief that separates the steep slopes of the Yeso formation on the east from the low western front of the mountains. Throughout this area the higher of the interstream areas are capped by light colored limestone gravels that contrast markedly in color with the underlying dark reddish brown strata of the Abo formation. These isolated terrace cappings are all parts of a broad sheet of fluviatile gravels that formerly extended continuously between the Yeso slopes and the Tularosa Basin. The terrace surface is now 200 to 300 feet above the level of the present stream bottoms, and is here named the Laborcita terrace. The name is derived from Laborcita Canyon, which drains to the west through the middle part of T. 15 S., R. 10 and 11 E., and along which the terraces are well exposed. The slope of the surface is 300 to 400 feet per mile, and decreases toward Tularosa.

The gravels of the terrace deposits consists almost entirely of gray limestone, undoubtedly derived from the San Andres formation. Cobbles and pebbles are the prevailing sizes. The maximum observed thickness of the terrace gravels is about 50 feet.

Limestone terrace deposits also occur in the southern part of the mountains from 50 to 200 feet above the level of present stream bottoms at and near the base of the steeper Yeso slopes. These terraces probably are the same age as the Laborcita terrace of the northern Sacramento Mountains. Both are designated older terrace deposits on the geologic maps. Figure 40 shows the characteristic appearance of some of the terraces in the southern part of the area. The terraces are easily recognized by the sparse vegetation.

RECENT ALLUVIUM, SAND DUNES, YOUNGER TERRACE DEPOSITS, AND SPRING DEPOSITS

Nearly all of the Quaternary sediments of the map area occur in the Tularosa Basin, adjacent to the mountain block. The surficial deposits are largely clay, silt, sand, and gravel deposited on the alluvial fans by intermittent floods from the mountains. Toward the southwest, much of the surface is covered by low reddish sand dunes that rarely are more than 10 feet high.

The depth of the alluvium in the Tularosa Basin adjacent to the mountain front is unknown. Low isolated outcrops of Permian rocks at a horizon near the base of the San Andres formation occur at widely spaced intervals along a line about 10 miles west of the mountain front. The alluvium thickens between this line of rock outcrops and the mountain front. Well records reported by Meinzer and Hare (1915, pp. 6465)

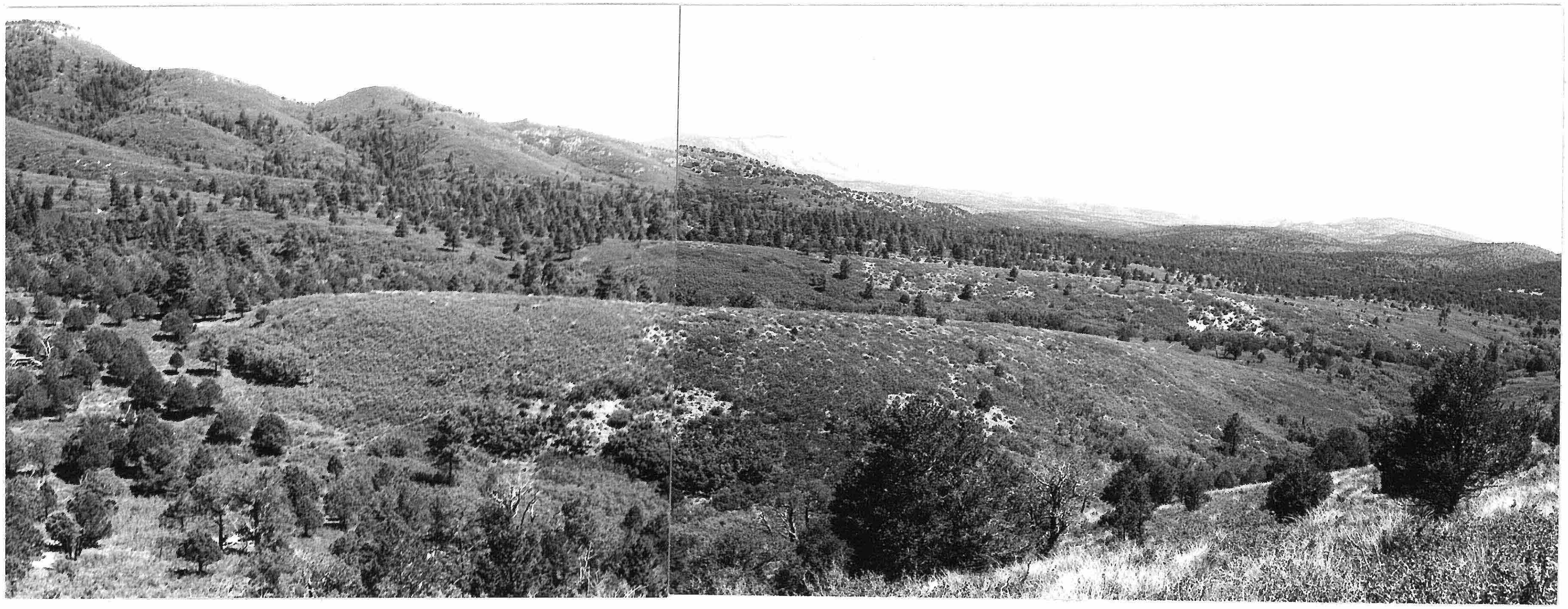

Figure 40. Terraces in the southern Sacramento Mountains.

at Alamogordo and at Valmont are as follows:

> "The Alamogordo deep well (NW1/4, sec. 26, T. 16 S. R. 9 E) was carried to a depth of a little over 1000 feet without reaching the bottom of unconsolidated fill . . . In 1910 two test wells were drilled about one-half mile north of Dog Canyon (now Valmont) station NE1/4 sec. 14, T. 18 S., R. 9 E.) . . . the first well reached a depth of 1235 feet and the second about 1800 feet, apparently without reaching the bottom of the unconsolidated valley fill."

The well logs published by Meinzer and Hare for the Alamogordo well and for the 1235 foot well at Valmont are very similar. Both consist largely of red clay or "red clayey material." In the Valmont well, several intervals of sand and gravel form about a tenth of the column, and no other material is reported except for gypseous adobe and gypsum in the uppermost 25 feet. The Alamogordo well has minor intervals of yellow or blue clay, and sand or gravel is restricted to the upper part of the column. The only indication of limestone in any well is "limerock", a 5-10 foot thick layer about 130 feet below the surface of the Alamogordo well. It was interpreted by Meinzer and Hare as a caliche zone.

The drilling records are admittedly inadequate, but the interpretation that these wells penetrate only valley fill seems justified. The only older strata likely to be confused by drillers with valley fill would be parts of the soft, reddish, gypsiferous Yeso formation, or possibly parts of the Abo formation. It seems highly improbable that a 1000 foot drill record would not show some limestone or dark shale within the Yeso or Abo formations in this area. Their absence seems to constitute good evidence that the wells were drilled in valley fill, and not through any part of the Paleozoic section.

The depths of valley fill material in the wells only indicate the minimum thicknesses and it is probable that the amount of fill is locally much thicker. Deep wells drilled in other parts of the eastern Basin and Range province indicate alluvium may occur to depths of at least a mile. Thus a well in the Hueco Bolson near El Paso, Texas, penetrated 5000 feet of relatively unconsolidated alluvium (Jones, 1949, p. 28).

The age of the alluvial material of the Tularosa Basin is undetermined by fossil evidence. It is probable however, that Tertiary as well as Quaternary alluvium is present. At El Paso where the valley fill materials are partially dissected by the Rio Grande, Pliocene fossils have been reported from clays, sand, and gravels that underlie the surficial deposits (Sayre and Livingston, 1945). In central and northern New Mexico along the Rio Grande depression, late Tertiary alluvial deposits are commonly referred to loosely as the Santa Fe formation. Simpson (in Colbert, et al, 1950, pp. 81-85) reports that Miocene and Pliocene vertebrate faunas have been collected from these strata, but little has been published to date.

Alluvium within the mountain block is negligible in volume. Most of it occurs in local, shallow concentrations along drainage courses where softer rocks have been eroded from behind barriers formed by more resistant rocks. Bed rock crops out at many points in the bottom of all of the major canyons.

Terrace deposits lower than the level of the Laborcita terraces occur locally along the major canyons in the northern and southern parts of the area and are grouped with the Quaternary alluvium on the geologic maps. Two terrace levels can be recognized in La Luz Canyon, in the northern part of the map area. The higher is the better developed and forms Burro Flats in sec. 20 and 21, T. 15 S., R. 11 E., about 100 feet above the level of the present dissection.

Spring deposits of travertine are abundant in upper Alamo Canyon, and along the Sacramento River. These are included with Quaternary alluvium on the geologic map. Most spring deposits above the Permian contact are not differentiated on the geologic maps.

LANDSLIDES, TALUS, AND RELATED DEPOSITS.

Rock debris in the form of landslides, talus accumulations, and slumped masses locally covers areas sufficiently extensive to be differentiated on the geologic map. Along the west front of the range, the major accumulations are of debris from the limestone cliffs of the Bug Scuffle limestone member of the Pennsylvanian Gobbler formation. The western one to two miles of Escondido, Dog, and San Andres Canyons are clogged with this debris which is now being actively eroded. Higher along the western escarpment, smaller areas of debris from the Holder formation cover much of the Beeman formation.

Most landslides are along the Yeso slopes in the central part of the escarpment. Local hummocky topography, enclosed depressions, chaotic structures, and lobate tongues of transported debris that extend downslope far beyond the point of outcrop all clearly indicate the existence of landslides and large slumped masses. Some include areas of a square mile. Because of the inaccessibility of most of the Yeso slope, the lack of local stratigraphic markers by which to distinguish bed rock from slumped material, and the low yield of pertinent geological data resulting from the delineation of the separate slide and slump masses, these masses are not differentiated in areas underlain by Permian rocks. Solution of the evaporites of the Yeso formation contributes to the prevalence of slump phenomena on these slopes. It also results in many local structural anomalies caused by the settling of limestone strata that overlie the more soluble evaporites.

At present most landslides and talus masses appear to be undergoing dissection. Evidence of accumulation under the present conditions is slight and largely limited to talus accumulations. It appears probable that most of the landslides and rubble accumulations were formed under different and more moist climatic conditions, possibly those prevailing during the late Pleistocene. The landslide mass at the top of Stark Hill in sec. 5, T. 17 S., R. 11 E. is an example of an old accumulation. It is composed of Yeso and/or San Andres limestone, and now occurs capping lower and upper members of the Abo formation. The slide mass is now isolated from the retreating mountain slope, and probably is only a small remnant of a much larger mass.

An accumulation of rubble of igneous rock derived from the Ortega sill covers about a quarter square mile in the northeastern part of sec. 14, T. 16 S., R. 10 E. This material has accumulated on and apparently been moved across a slope of about ten degrees, some for nearly a mile from the source. The material appears at present to be undergoing erosion, and may represent material moved by solifluction during a wetter, and probably colder period than the present.

OUTLINE OF STRUCTURAL FEATURES

REGIONAL STRUCTURAL FEATURES

In the landscape of southern New Mexico, the contrast between the Basin and Range Province in the west and the Great Plains province in the east is largely a reflection of differing structural histories during the Cenozoic era. The area of the Great Plains to the east has been relatively stable, whereas the western area has been broken into a number of blocks that have been shifted up or down relative to one another. The deformation is dominantly one of high-angle faulting. The faults are not abundant and their displacements are not great; in terms of intensity of deformation, the area is intermediate between the California Coast Ranges and the Colorado Plateau. The major structural features of southern New Mexico and West Texas have been indicated by King (1942).

The Sacramento Mountains form a part of the boundary between the Basin and Range Province and the Great Plains, and the structure of these mountains reflects this boundary condition. The Sacramento Mountain block has been uplifted along a fault zone with respect to the Tularosa Basin block on the west. The western portion of the range is structurally similar to the scarps of Basin Ranges. The eastern portion, however, is quite different. From the crest of the mountains, the strata dip a degree or two to the east, and can be traced for more than 50 miles with but few deviations caused by warping and minor faulting for more than 50 miles to the east. Thus this part of the mountains possesses a general attitude and a structural continuity that is characteristic of the Great Plains regions.

The Sierra Blanca and the smaller mountains farther to the north are a northward topographic continuation of the Sacramento Mountains (Figure 1). However, structure contours on the top of the San Andres limestone, a Permian horizon below the main mass of the intrusive rocks in the Sierra Blanca region, do not define a northward continuation of the Sacramento Mountain "high;" instead, the Sierra Blanca region is a structural basin, as indicated by Darton (1928, p. 215). King (1942) interprets the western escarpment in the Sierra Blanca as the product of en-echelon faulting in a zone parallel to, but northeast of, the faults along the Sacramento Mountain escarpment.

The main trend of the Sacramento Mountain frontal fault system continues north-northwest from Tularosa, and is probably represented 40 miles farther to the northwest by the frontal fault on the west side of the Oscura Mountains, another large east-dipping fault block. South of the Sacramento Mountains, the frontal fault system either dies out, or continues with only a fraction of the displacement known to the north, as faulting is but a minor feature in the region east of Oro Grande and along the western edge of Otero Mesa. The boundary fault system of the Sacramento Mountains is oriented en echelon with respect to that bordering the western edge of the Guadalupe Mountains, 50 miles to the southeast (King, 1948, p. 117).

The Tularosa Basin is the major geographic lowland in south-central New Mexico. It appears to be more a topographic than a structural unit. In its central portion, which lies between the main mass of the San Andres Mountains on the west and the Sacramento Mountains on the east, the Basin is essentially a graben. Beyond this central area, however, the structure is less simple. Many of the major structural trends of the region are not parallel to the edges of the Tularosa Basin, but project obliquely into the Basin, and perhaps are continuous from one side to the other. The dominant topographic trend of the Tularosa Basin is essentially north-south, and the prevailing structural trends appear to lie somewhat west of north. The major elements of this structural pattern in areas surrounding the Tularosa Basin are as follows:

1. The east face of the San Andres Mountains for a distance of 50 miles from T. 13 S. through T. 20 S.
2. The west face of the Sacramento Mountains for a distance of about 40 miles between T. 14 S. and T. 20 S.
3. Many faults of the northern San Andres Mountains are exposed between T. 13 S. and the northern terminus of the range (Darton, 1928).
4. The boundary fault at the southwest side of the Oscura Mountains, and some of the faults east of this boundary fault (Darton, 1928).
5. The structurally high area that projects northward and somewhat westward from the Hueco Mountains of southern New Mexico and Texas to the general area of the Jarilla Mountains in T. 21 and 22 S. R. 8 E. (King, 1942). Isolated rock outcrops rise above the alluvium of the Tularosa Basin north of the Jarilla Mountains. The most prominent of these are three peaks, the Tres Hermanas has a relief of several hundred feet and lie 6 to 10 miles southwest of Valmont. The easternmost of these is intrusive rock, but the two mounds farther west are composed of Permian strata. A thin remnant of San Andres limestone caps the Glorieta sandstone and the Yeso formation of both buttes. */ Northward from here, other isolated smaller outcrops rise much less conspicuously above the alluvium. Cerrito Tularosa, a low knob about 6 miles west of Tularosa, also consists of Permian strata (Darton, 1928, p. 217). These low mid-basin knobs are in a belt that is essentially parallel to the west face of the Sacramento Mountains, and may well be a continuation of the Hueco-Jarilla structural "high."

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*/ Covington, Jerry; personal communication, 1948

One of the anomalies of the regional structure is at the northern end of the San Andres Mountains. These mountains extend in a nearly straight line slightly west of north for a distance of more than 50 miles, and are a west-tilted fault block. Near the north end, however, the trend swings sharply to the northeast for about 10 miles, beyond which the range continues a few miles farther to its northern terminus. Only a few miles to the northeast are the Oscura Mountains, an eastward tilted fault block that is structurally similar to the Sacramento Mountains. The northernmost part of the San Andres Mountains is structurally complex. It lies along the trend of the Hueco-Jarilla arch, and essentially represents a structurally high area. These relationships suggest that the Hueco-Jarilla arch extends diagonally across the Tularosa Basin. Further, the trend of the Sacramento Mountain front from La Luz to Tularosa extends directly into the trend of the southern Oscura Mountains, and the two mountain blocks have similar structural attitudes.

It may be significant that two topographic "lows" are present in the Tularosa Basin. The principal one is at Lake Lucero, near the southern end of the White Sands and close to the southern end of the San Andres Mountains. This receives nearly all of the drainage in the basin area. The second and minor depression lies in the area between Valmont and the Jarilla Mountains east of the Tres Hermanas. Although this topographic depression may be due to shifting of dune sands (the writer has not examined the area in the field), it may well record continuing depression of the floor of the basin in the region east of the Hueco-Jarilla arch. The low point need not be the most actively depressed area in this region, but would be simply the point at which the excess of depression over the amount of fill material is a maximum.

STRUCTURAL FEATURES OF THE SACRAMENTO MOUNTAIN ESCARPMENT

The general aspect of much of the Sacramento Mountains is cuesta-like, as the range is essentially a block that has been uplifted along a fault on the west, and tilted one to two degrees to the east. The uplift appears to be nearly uniform along the western escarpment for a distance of about 20 miles south of Alamogordo, where the minimum displacement is of the order of a mile and a half. North and south from this central area the displacement along the fault decreases, which causes a plunge to the north and south of the mountain block, and the escarpment becomes lower. The outcrop pattern of the formations is that of broad shallow arcs, concave to the west, arranged with progressively younger formations forming successively larger arcs away from the central zone of maximum uplift. Thus the overall structure of the Sacramento Mountains escarpment is that of the east half of a gentle dome that is elongate in the north-south direction.

The uplift of the range, however, is only the result of the latest period of tectonic activity in this area, and is probably of late Cenozoic age. Earlier periods of deformation are recorded in the rock units of the Sacramento Mountains. Most of the internal structural features of the mountains were formed during late Pennsylvanian and early Permian time. This deformation is herein referred to as the pre-Abo deformation. Some mild tectonic activity has occurred several times prior to the pre-Abo deformation, and these deformations are referred to as the pre-Bliss deformation, the pre-Gobbler deformation, etc., depending on the name of the formation directly above the unconformity resulting from the tectonic activity. Structural patterns that have developed during later Permian, Mesozoic, and early Cenozoic times are but imperfectly known, owing to the absence of sedimentary rocks representing this time interval. Some physiographic evidence suggests a period of deformation and erosion in the post-Permian, pre-Cretaceous interval, and regional evidence indicates the probability of deformation in this area during the early Cenozoic, a deformation that was essentially synchronous with major mountain making movements in the area of the Rocky Mountains.

BOUNDARY STRUCTURAL FEATURES

The present Sacramento Mountains are the result of mountain forming activity that occurred during late Cenozoic time. The writer believes the major uplift of the Sacramento Mountain block with respect to the Tularosa Basin has been caused by movement along a normal or gravity fault that lies at or close to the foot of the present escarpment. The present western escarpment is considered to be an eroded fault scarp, in the sense that its topographic expression is the direct result of the fault movement. Although the top of the escarpment is as much as 12 miles east of the probable fault zone, the present base of the escarpment is believed to be within a quarter of a mile of the fault zone throughout much of its length.

Interpretation of the boundary feature of the Sacramento Mountains as a gravity fault is in agreement with data on most earlier maps and in published statements (for example, see Herrick, 1904; Meinzer and Hare, 1915; DeFord, in Bates, 1942; Laudon and Bowsher, 1949; Lloyd, 1949). Darton (1928, p. 210) emphasizes the major anticlinal aspect of the mountains, although some of his structure sections indicate a probable fault origin for the western escarpment, but suggests the possibility that the escarpment is the result of the selective erosion of the steep western limb of a large asymmetric anticline, a process that left the gentle eastern flank as the present mountain mass.

Abundant evidence favors the hypothesis of a major normal fault or fault zone near the base of the Sacramento Mountain escarpment. This evidence is described and interpreted in the ensuing paragraphs, followed by a summary discussion of the problem.

Piedmont scarps

Piedmont scarps were defined by Gilbert (1928, p. 34) as scarps that are caused by dislocation on the piedmont slope. Piedmont scarps have been recognized by the writer along much of the west front of the Sacramento Mountains from Tularosa to points south of Grapevine canyon, and may be present farther away in both directions. Piedmont scarps in the area mapped are as much as 80 feet in height, although most are not more than 20 to 30 feet high. Few individual scarps can be traced laterally more than one or two miles, and most are recognizable for less than a mile. A few mark boundaries between bed rock and alluvium, but most lie entirely within alluvium at the surface. Nearly all are within a few hundred feet of the base of the western escarpment, and all those observed face away from the mountains.

In early reports, Hill (1891, p. 96), Tarr (1891, p. 524), and Herrick (1904, p. 185) recognized some low cliffs that fringe parts of the Tularosa Basin and interpreted them as terraces or beaches developed in or along a Pleistocene lake that Herrick named Lake Otero. Meinzer and Hare (1915, p. 42) discussed these earlier observations, reported a

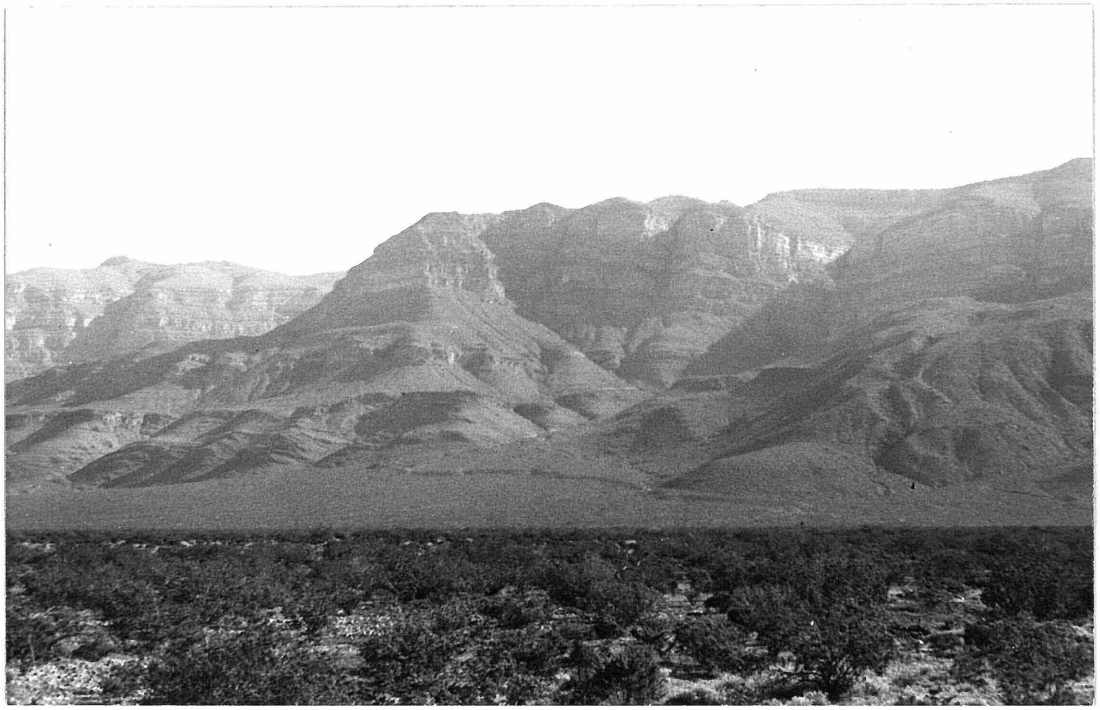


Figure 41. Piedmont scarp on the alluvial fan one mile south of Escondido Canyon. The scarp has a maximum height of about 40 feet. Note smaller scarp at extreme right.

fault scarp fringing the base of the mountains between Alamogordo and La Luz, and some terraces or scarps in the area southeast of Dog Canyon. They considered these to be possibly of lacustrine origin, but concluded "that the prominent cliff and terrace features were caused, at least for the most part, by faulting."

Along the part of the Tularosa Basin within the area of this report, most of the low, valley-facing scarps at the base of the mountains are interpreted as of dislocation origin; i.e., as piedmont scarps. A few are clearly erosional in nature, and were formed by lateral cutting on an alluvial fan. Others are the lunate ends of landslide debris. None of the observed scarps, however, is believed to be of lacustrine origin. Of the many features indicating a fault origin, as opposed to a lacustrine origin, one of the most compelling is the lack of correlation between the trace of the scarp and the general topography. Tectonic scarps are relatively straight in plan and are not influenced by elevation of the ground, whereas scarps of wave origin should follow the topography at constant or near-constant levels; in an area of coalescing alluvial fans, they should be very irregular in plan. Features of lake origin may well be represented lower in the Tularosa Basin, but none were recognized in the map area. Particularly striking scarps of undoubted fault origin are preserved near the head of the alluvial fan at the mouth of Mule Canyon, where a scarp about 80 feet high trends directly across the fan, and in the area a mile south of Escondido Canyon (Figure 41).

Some of the scarps separate alluvium on the west from bed rock to the east. Examples of these occur in the reentrant of the mountain front northeast of Alamogordo at the mouth of La Luz Canyon, and on both sides of Nigger Ed Canyon.

The piedmont scarps occur within a few hundred feet of the present base of the escarpment, with the exception of two localities. West of the line of piedmont scarps, the graded profiles of the alluvial fans give no indication of late movement on buried faults. Although this localization only proves that the latest faulting has been along a zone close to the base of the escarpment, it is reasonable to interpret the present piedmont scarps to mark the major fault zone. Some evidence for this has recently been furnished by geophysical investigations along the eastern side of the Franklin Mountains, near El Paso. Sayre and Livingston (1945, p. 36) report that resistivity measurements indicate a subsurface fault of 400 feet of displacement is marked at the surface by a piedmont scarp that ranges from 10 to 50 feet in height. The two areas of the Sacramento Mountains where the piedmont scarps occur more than a few hundred feet west of the present base of the escarpment are northeast of Alamogordo near Indian Wells Canyon, and at the mouth of Grapevine Canyon, near the southern end of the range. Evidence from scattered outcrops on the upthrown side of these localities indicates that the areas between the piedmont scarps and the base of the escarpment are essentially pediments, thinly veneered with alluvium. Both areas are beyond the central part of the escarpment and only Pennsylvanian and younger beds have been eroded.

The piedmont scarps are of course obliterated where the present main drainage lines of the alluvial fans cross the trace of the fault, but the mere existence of any alluvial scarps on the present fans indicates recent faulting. The 30 foot high scarp across the mouth of Grapevine Canyon is capped by 2 to 4 feet of caliche-cemented alluvium. This suggests a relatively stable period preceding the latest faulting of that fan.

The alluvial fan at the mouth of Deadman canyon shows no scarp, but has a local increase in the westward gradient about 500 feet west of the mountain front. This indicates either a fault buried beneath enough alluvium to prevent dislocation at the surface, or an older scarp that has been considerably modified by erosion and deposition. Except for this single occurrence of local anomalous steepening, no deviations were noted from the smooth, very gently concave profiles of other alluvial fans in the area. This further supports the conclusion that at least the recent uplift of the mountain block has taken place along faults very close to the present base of the mountain escarpment.

Sympathetic structural features

Some of the best evidence for a fault origin of the present Sacramento Mountain escarpment, and for revealing the probable nature of the fault zone, is furnished by the sympathetic structural breaks exposed near the western mountain front. The bulk of this evidence indicates a normal or gravity frontal fault zone, with a moderate west dip and a dominant dip-slip component of movement.

The abundance of faults and fractures increases along almost all canyons or ridges, and displacements are progressively greater toward the west front. Step faults, such as near the west front south of Marble Canyon or between Mule and Arrow Canyons, have displacements of several hundred feet. These faults dip 50 to 75 degrees to the west. Plates 1, 2, 3, and 4 show clearly the greater abundance of faults and larger fault displacements along the west front than in areas farther to the east. At the mouth of Muleshoe canyon, in sec. 28, T. 17 S., R. 10 E., the westernmost outcrops reveal a narrow splinter of steeply dipping Lake Valley strata

(Mississippian) in fault contact with Ordovician strata, which indicates a displacement of 400 to 500 feet.

The best exposure of what may be a major fault along the west front is a few hundred feet north of the mouth of Deadman Canyon, in sec. 22, T. 18 S., R. 10 E. Here lateral erosion between the head of the fan and the mountain front has cleaned off a fault surface that dips 55° to 70° west. Slickensides and mullion structure indicate dip-slip movement. The eastern block consists of El Paso dolomite, and the fragments in the cemented fault breccia are limestone and dolomite. As the limestone is believed to be either Mississippian or younger in age, as it probably originated from the downthrown block, the displacement indicated along this fault is not less than 600 feet, and may be much more.

Another indication of a major normal fault or fault zone near the present base of the escarpment is the common occurrence of abrupt west dips in the westernmost outcrops. This occurs in only the outermost 100 feet or less of outcrops and presumably is the result of drag along a major frontal fault.

Truncation of sculpture of the mountain front

The truncation of sculpture of the mountains by the western escarpment is strong evidence that faulting is of primary importance. If the mountain front were due only to erosion of either an anticline or of a wide homocline that once extended far to the west of the present escarpment, erosion would have been most rapid in areas of the least resistant rocks, whether the lack of resistance is inherent in the original lithology of the rocks, or is due to tectonically induced weaknesses. The resulting position of the scarp would be influenced by the inequalities in resistance to erosion of the mountain block. Along the west front of the Sacramento Mountains, the irregularities in plan appear unrelated to the erosional resistance of the various rock units. For example, from Alamogordo toward Tularosa, less resistant strata are progressively closer to the level of the Tularosa Basin. The trace of the mountain front, however, is nearly straight over much of this distance, and trends out into the topographic depression of the Basin toward the north, rather than being indentate toward the mountains in the area of the less resistant strata. The trace is more plausibly explained by faulting control.

It is significant that along most of the mountain front, the alluvial apron on the west does not overlap appreciably onto the mountain block. The mouths of a few canyons are locally clogged with alluvium, but this condition is exceptional, and the alluvial materials are but thin veneers. Most of the canyon bottoms are carved in bedrock. Gilbert (1928, p. 47) clearly analyzed the tectonic versus the erosional origin of scarps, and states that an erosional, stream carved escarpment must be indentate, with the alluvial debris continuing into the major canyons whether the erosion was caused by a stream parallel to the front or by streams emerging from the mountains. The major stream along the west side of the escarpment, Tularosa Creek, is in bedrock to the edge of the low western escarpment of the non-resistant strata about a mile east of Tularosa. If the scarp were erosional rather than tectonic, this broad valley area would logically be alluviated.

Terraces which lie a few tens of feet to several hundred feet above the present drainage, are common in the mountain area, and many of them occur close to the western front. The Tularosa Basin has no external drainage, and probably has not had such drainage during the relatively recent time when the terraces were formed. Continued deepening dissection of a mountain block adjacent to an aggrading basin seems to be good evidence for relative uplift of the mountain block with respect to the valley block, particularly where the valley gradients in the mountain and valley block are relatively low. The same reasoning can be applied to the two local pediments now being dissected, one in the reentrant northeast of Alamogordo and the other at the mouth of Grapevine canyon. In these localities a thin and discontinuous veneer of alluvial material rests on a graded surface cut onto bed rock of the mountain block in an area that lies between the base of the steeply rising mountain slope and the depositional area of the alluvial fan.

Truncation of internal structure

The present mountain front truncates much of the internal structure of the range, a feature characteristic of many faulted Basin Ranges. The most striking example of this in the Sacramento Mountains is at the mouth of Nigger Ed Canyon, where the south-trending Gobbler arch intersects the northwesterly trend of the western escarpment. This is well shown from the air (see frontispiece). Another south-trending arch formed prior to the uplift of the range that is obliquely truncated by the present front of the range is the Joplin arch, which emerges south of the mouth of Dog Canyon (Plate 2).

The overall trend of the west front of the Sacramento Mountains is somewhat west of north, but is irregular in detail. This irregular trace is a common characteristic of mountains bounded by gravity or normal fault systems, and is not generally the plan of a mountain front where the fault movement has an appreciable strike-slip component. There is no evidence along the western escarpment of an axis of major folding such as might be expected if the present front is the result of erosion along such a fold. Furthermore, the area which has the most persistent west dips along the escarpment is east of Alamogordo, a portion of the mountain front that is a major reentrant, rather than a salient.

Geophysical evidence

Unpublished findings of regional gravity meter surveys reportedly indicate a marked high anomaly under the crest of the mountains, and a corresponding low anomaly near the base of the escarpment. This suggests either a sharp flexure or a fault to be the determining structural feature of the Sacramento Mountains.

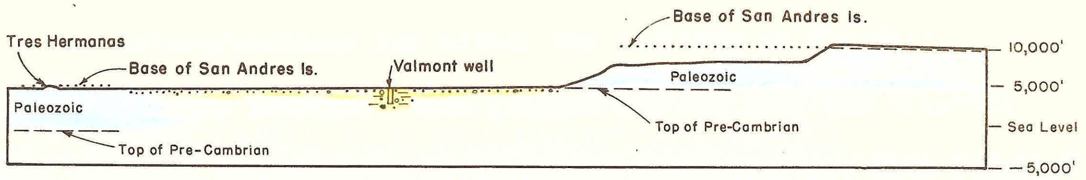
Analogy with other mountains in the region

Various lines of evidence have led other investigators to consider the boundary structures of many other mountains in the region to be of fault origin, generally of the normal type. For example, the west side of the Hueco Mountains (King, 1945, Sheet II); the Franklin and Hueco Mountains. (Jones, et al, 1949, cross-section), Sayre and Livingston (1945, pp. 34, 46); the San Andres Mountains, Bryan (1938, p. 209). In all of these but the San Andres, the faulting is considered to be the mechanism of differential uplift. Although Darton's cross sections (1928, p. 193) of the San Andres Mountains show a faulted anticlinal structure, the faulting appears to be at least as significant as folding in forming the eastern escarpment.

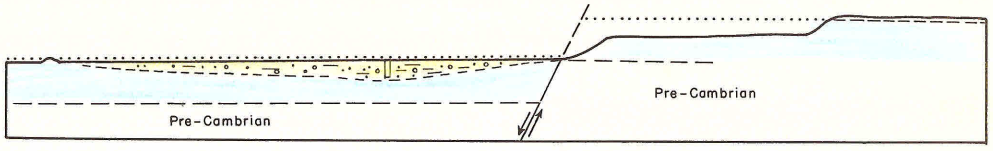
Summary of the evidence for faulting

The basic difference in elevation of the strata that form the Sacramento Mountains and those that underlie and locally crop out within the Tularosa Basin can be explained by either faulting or folding, or a combination of these two processes. The actual relationship between the mountains and the valley can only be inferred as alluvial deposits mask a critical zone of 10 to 15 miles in width between the base of the mountains and the bedrock outcrops of the Tularosa Basin. The writer believes the evidence favors faulting as the dominant structural control. The presence of an active zone of normal faulting along the base of the escarpment is established by evidence discussed above such as piedmont scarps, truncation of sculpture, and sympathetic structural features. The extrapolate from the known normal faulting which involves vertical displacements of as much as 500 feet along the edge of the escarpment to similar fault displacements at a scale sufficient to explain the present mountains appears logical. The possibility that folding has contributed to the present apparent displacement can be neither eliminated nor proved by the available data. Along the central part of the escarpment, folding is believed to be of minor significance.

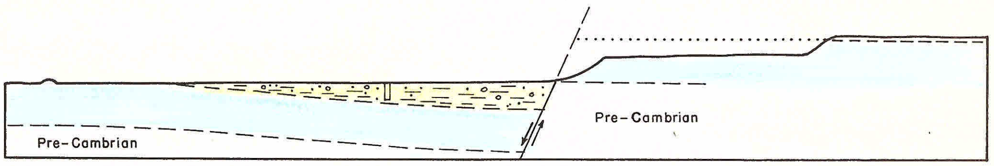
The stratigraphic and structural data pertinent to a discussion of the nature of the boundary structural feature of the Sacramento Mountains are indicated on figure 42A, an east-west cross section from the crest of the Sacramento Mountains to the isolated outcrops of Permian strata in the Tularosa Basin. The strata of the mountain area and where exposed in the valley are essentially flat-lying, and equivalent strata are about one mile higher in the mountain area. The simplest structural configurations for the faulting and folding hypotheses are sketched on figure 42.



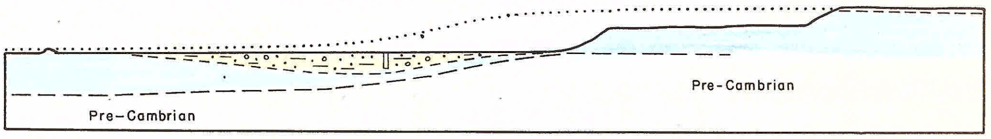
A. Summary of available data



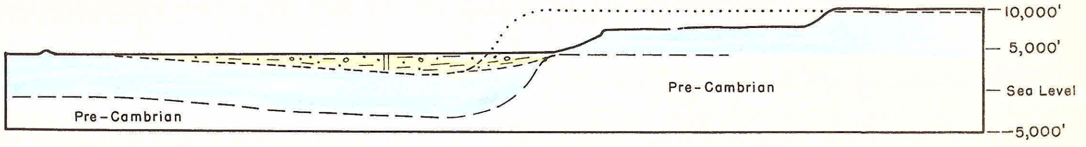
B. Fault hypothesis, valley fill at Valmont occupies an erosional depression



C. Fault hypothesis, valley fill at Valmont occupies a structural depression

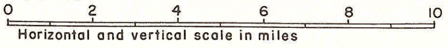


D. Folding hypothesis, valley fill at Valmont occupies erosional depression.



E. Folding hypothesis, valley fill at Valmont occupies a structural depression.

Figure 42. Data and alternate configurations for the boundary structure of the Sacramento Mountain escarpment and adjacent Tularosa Basin.



The presence of alluvium* in the 1800 foot well at Valmont is subject to two interpretations for either the faulting or the folding hypothesis. By one interpretation (figure 42B and 42D) the alluvial material has been deposited in an erosional depression cut into Paleozoic strata after the uplift of the range. By the other (figure 42C and 42E) the alluvial material was deposited in a structural depression formed contemporaneously with the uplift of the range relative to the basin. The latter interpretation of deposition in a structural depression appears more reasonable. To have the alluvium deposited in an erosional depression requires erosion to a depth now less than 2200 feet above sea level, nearly 2000 feet below the present rim of the Tularosa Basin. Although major shifts in level are possible in a technically active area, this erosion would require a system of through drainage not known on the basis of other geologic evidence in the region. It is particularly difficult to conceive of this much erosion in the area of Valmont as this lies east of the projected Hueco-Jarilla area, and therefore is somewhat isolated from possible lines of regional drainage. Furthermore, it appears improbable that small islands of San Andres and Yeso rocks at the Tres Hermanas would not be eroded during or since the removal of about 2000 feet of older strata at Valmont, a few miles to the east. Regional stratigraphic evidence suggests that prior to Cenozoic deformation much of this part of New Mexico consisted of Cretaceous sediments deposited on a peneplain cut on the San Andres limestone, or locally on friable, thin sections of earlier Mesozoic strata overlying the San Andres limestone. There are geologic data to suggest that the present area of the Tres Hermanas would have been covered by a more resistant or by a thicker series of strata than the area at or near Valmont.

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* The interpretation that the drilling penetrated only alluvial materials has been discussed previously in this report (p. 297).

As it appears probable that the alluvium accumulated in a structural depression, the simplest interpretations of the boundary structure of the Sacramento Mountains are those indicated diagrammatically by figure 42C and 42E. Baker (1928, p. 367) suggested the possibility that the present escarpment has resulted by the selective erosion of the tectonically weakened crest and the more steeply dipping western limb of a large asymmetric anticline. This would correspond to the interpretation indicated diagrammatically by figure 42E. This appears improbable. Although Baker states that erosion has progressed so far that no direct evidence of faulting can be noted along the front of the Sacramento Mountains, direct evidence of faulting is widespread and has been discussed above.

A major weakness of the folding hypothesis is the absence of erosional remnants of the hypothetical steeper limb of the anticline. The only surface evidence of beds dipping to the west at moderate to steep angles along the base of the present escarpment can best be related to drag effects along a normal fault zone. Evidence of dislocation is abundant. The absence of upturned edges of the resistant pre-Permian strata in the area west of the present escarpment is significant. Water wells drilled several hundred feet at the Boles Ranch in T. 17 S., R. 10 E., and at the mouth of Alamo Canyon have penetrated only alluvial materials. These wells are less than a mile from the base of the mountains, close enough to be in the area of resistant upturned strata. To erode a thickness of nearly a mile of resistant strata along more than 20 miles of the Sacramento Mountain escarpment and leave no trace of this part of the fold either at the surface or where the wells have been drilled seems highly improbable. This amount of erosion would have to take place along the base of the escarpment in the same time in which probably less than 1000 feet of less resistant

Mesozoic strata have been eroded from the highest parts of the Sacramento Mountains. A major drainage system, such as the Rio Grande, could conceivably cause accelerated erosion at the base of an escarpment, but other evidence for such a system is lacking. Even with such a system of through-flowing drainage, the absence of a nearby confining topographic feature to the west in the Tularosa Basin makes the erosional hypothesis improbable.

The concept that the strata on the crest and steeply dipping part of a fold would be highly fractured and thus subject to accelerated erosion may be valid, but the effect would be minimized in a section predominantly of carbonate rocks, and in any event, would hardly be sufficient to explain the tremendous amount of differential erosion required by the folding hypothesis. The escarpment of the Sacramento Mountains appears to be similar to those of the Guadalupe, Franklin, and San Andres Mountains of the surrounding region. A common fault origin appears more probable than an origin by selective erosion of folded structures, a hypothesis that requires somewhat unusual circumstances.

The boundary faulting of the Sacramento Mountains is believed to be normal, as indicated in figure 42C, rather than reverse faulting. Best evidence for this is the overwhelming predominance of normal faulting in the westernmost part of the mountain block. The observed faults range in dip from 30° west to 80° east, but most faults dip from 55° to 70° west. With few exceptions, the western block is downthrown with respect to the eastern block. Interpretation of the major role of normal faulting in the formation of the Sacramento Mountains is in accordance with conclusions reached by studies in other parts of the Basin and Range province that have been critically reviewed by Nolan (1943).

If the configuration indicated by figure 42C is accepted as the most probable interpretation of the boundary structural feature of the Sacramento Mountains, the minimum stratigraphic displacements can be estimated along the mountain front and are given in the table below:

TABLE IV

Estimated minimum stratigraphic displacements

Tularosa Canyon	3599'
La Luz Canyon	4500'
Beeman Canyon	5000'
From a point east of Alamogordo Southward to Escondido Canyon	6500-7000'
Nigger Ed Canyon	7000'
Grapevine Canyon	3500'

The displacements indicated above are based on the following assumptions:

1. Faulting is the structural control west of the escarpment.
2. The thickness of the alluvium of the Tularosa Basin is 2000 feet for the area from Nigger Ed Canyon to Alamogordo and diminishes toward the north from this central area to 500 feet at Tularosa and to nothing east of the Jarilla mountains.
3. The base of the alluvium is at the base of the San Andres limestone. This assumption probably gives a low estimate of the displacement.

The direction of movement of the Sacramento Mountain block along the frontal fault system has been upward with respect to the Tularosa Basin block to the west. This is relative movement and the direction of actual movements is uncertain. The Sacramento Mountains merge eastward into the stable area of the Great Plains. The altitude changes from nearly 10,000 feet to about 3500' in 80 miles. Although the Great

Plains may have been epirogenically uplifted with respect to sea level in late Cenozoic time, the amount is necessarily much less than the present elevation. Thus it appears probable that the Sacramento Mountain block has been uplifted during late Cenozoic time. The actual direction of movement of the Tularosa Basin is not known. Alluvium now occurs at altitudes at least as low as 2200 feet above sea level, but this can be explained by either actual subsidence, or by having no change in absolute altitude of the valley and uplift of the surrounding regions. However, near El Paso in the Hueco Basin, alluvium occurs to depths of more than 1000 feet below sea level (Jones, 1949, p. 28) which suggests an actual subsidence of this area with respect to sea level of late Cenozoic time.

Low-angle thrusts and related folding

Low-angle thrusts and folds associated with incipient thrusting are common small-scale deformational features along the west front of the escarpment. These have been observed in the area from Alamo Canyon on the north to a point a mile south of Nigger Ed Canyon. The features appear to be restricted to westernmost part of the escarpment, and therefore are discussed as boundary features. However, they formed prior to the normal faulting of the range, and do not appear to be related to the main uplift of the present range.

In detail, these small-scale features show much variety. In some the faulting is clearly defined, and little or no folding has occurred. Sharp folding occurs elsewhere, with or without a clearly defined fault break. Most of the faults have been observed in the Valmont and Fusselman (?) formations, but are known to affect strata ranging in age from early Ordovician to Pennsylvanian. Displacements are small, and in few places exceeds 200 feet. Single faults generally can not be traced more than a quarter of a mile along the strike. The fault planes strike about parallel to the mountain front, and dip west at angles of 15 to 30 degrees; most of them dip about 20 degrees. Wherever the features have been observed, the hanging wall block has moved eastward relative to the footwall block. A typical view of a well exposed fault and associated folds is shown in figure 43.

Some of the larger thrusts have been plotted on the maps (Plates I and II), but most are too small in scale to be indicated conventionally. However, the deformation generally has caused some of the strata to dip to the east at moderate to steep angles. On the geologic maps, therefore, an attitude indicating a anomalous high dip to the east of the strata at

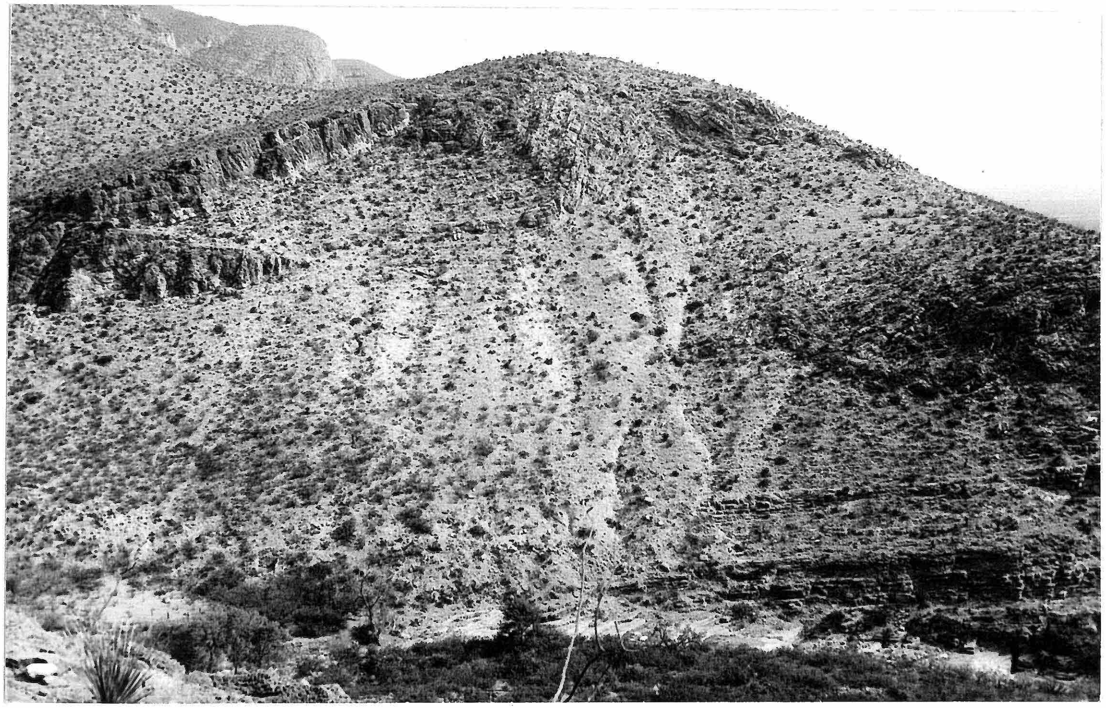


Figure 43. Low-angle thrust and associated folding of the Montoya, Valmont, and Fusselman (?) formations on the south side of San Andreas Canyon in the center of sec. 33, T. 17 S., R. 10 E.

the front of the range generally indicates the presence of a thrust or the associated folds.

Most of the thrusts occur in pre-Devonian strata, and very few of the faults are continuous from the Fusselman (?) and older formations through the Devonian and Mississippian strata. Exceptions noted occur on the north wall of Alamo Canyon and on the south side of Muleshoe Canyon, where the Mississippian-Pennsylvanian contact is displaced a few tens of feet. This displacement is only a small part of that shown along what is believed to be the same faults in the pre-Devonian strata. Invariably, where folding is associated with faulting, the strata of the hanging wall are more deformed than those of the footwall block (Figure 43). The direction of easiest relief of pressure probably was upward, and the relatively incompetent strata of the Devonian and lower part of the Mississippian section have absorbed most of the effects of the deformation of the underlying strata.

The restriction of the thrusts to only the front of the range is puzzling, as pre-Devonian strata are only exposed close to the front along much of the length of the escarpment the absence of thrusts in the younger strata exposed on the higher ridges does not prove a restriction of the thrusts to the west front. But in those areas where the pre-Devonian formations can be followed eastward along the deeper canyons, the only thrusts noted are at or very near the west front of the mountains. Thus in Alamo Canyon the Fusselman (?) formation is continuously exposed eastward for about four miles, and the only thrusts occur in the western half mile. The only locality where more than one thrust plane or planes of incipient thrusting have been observed is at the mouth of Alamo Canyon. On the south wall of the canyon a plane of incipient thrusting occurs at the canyon mouth, and a second parallel plane of faulting occurs 500 feet farther to the east.

The age of the thrusting and associated deformation is not closely known. It is earlier than the normal faulting along the front of the range, as sympathetic normal faults displace the thrust planes. The thrusts appear to be earlier than the intrusion of the trachyandesite dikes that are locally abundant along the western escarpment and which are dated tentatively as early Tertiary. The youngest rocks affected are Pennsylvanian, so the thrusting might be of any age from Pennsylvanian to early Tertiary. The thrusts may be related to the pre-Abo deformation that must also have involved east-west compressional forces, but there is no evidence of low-angle thrusting in the areas most affected by the pre-Abo deformation. The association of these thrusts with the present front of the range is suggestive that they somehow are related to forces involved in forming the mountain block. Possibly these thrusts are related to compressional forces that caused an initial uplift of the Sacramento Mountain region during the early Tertiary prior to the igneous intrusions, but evidence is lacking. King (1937) reports that some post-Cretaceous folding preceded Eocene igneous activity in the Glass and Davis Mountains of west Texas.

INTERNAL STRUCTURAL FEATURES

The block faulting of late Cenozoic age that formed the present mountain range uplifted an area that had been subject to intermittent deformation throughout geologic time. Those structural events that have occurred since the deposition of the earliest strata now exposed can be interpreted from the nature of the successive deposits, the unconformities within the section, and in part from the geomorphology of the present range. Internal structural features consists largely of moderately tight to open folds, and high angle faults with observed displacements ranging up to 1500 feet. Most of these structural features are believed to have formed prior to the uplift of the range, many of them in late Pennsylvanian-early Permian time. This interpretation differs from that of Darton (1928) who discusses and illustrates some of these structure features, but appears to have considered their development to have been contemporaneous with the uplift of the present mountains.

The major folds and faults are indicated on the geologic maps and cross-sections (Plates 1, 2, 3 and 4). Some of these features can be dated closely by unconformities in the geologic column, but the ages of others that involve all of the Paleozoic strata are less definite. The internal structural features are discussed below in chronological order insofar as that sequence is now known.

PRE-CAMBRIAN (?)

The earliest tectonic activity recorded in the area of the Sacramento Mountain escarpment is the tilting or folding of the pre-Cambrian sedimentary strata exposed in the small outcrops at the south end of the escarpment. The angular discordance at the base of the Bliss sandstone of

Cambrian (?) age is about ten degrees, and thus it is probable that the present attitudes indicate the pre-Bliss folding or tilting caused the oldest strata to dip about ten degrees to the east. No evidence is available to date this movement with respect to the closely associated diabasic intrusives, which are also believed to be older than the Bliss sandstone. This activity can only be dated as pre-Bliss in age, and could have been in either late pre-Cambrian or earliest Paleozonic time. The degree of metamorphism of the pre-Bliss strata, and the degree of deformation indicated by low angular discordance of the basal Paleozonic unconformity are similar to that known in adjacent areas where late pre-Cambrian sedimentary strata occur, as near El Paso, Texas (Richardson, 1909, p. 3) or in central and northwestern Arizona (Wilson, 1939).

PALEOZOIC

The structural evolution of the mountain block during Paleozoic time can be reconstructed on the basis of the lithology and the unconformities within the 7500 foot thick sedimentary sequence of Paleozoic age. Table V contains summary data on the unconformities that have been observed within this sedimentary sequence in the area of the Sacramento Mountain escarpment. Some of the disconformities may not have been caused by structural developments in this area but by eustatic changes in sea level. Evidence is not available at present to differentiate among these processes. Only those unconformities that appear to be of particular significance are discussed in the sections to follow. The details of the various unconformities have been presented in the stratigraphic discussion of the formations.

TABLE V. Unconformities of the Paleozoic section

Rock unit above the unconformity	Rock units below the unconformity	Nature of the unconformity and remarks
Bliss ss.	Pre-Cambrian sediments and diabase	Angular unconformity Discordance about 10°
El Paso fm.	Bliss ss.	Probable disconformity Several inches of channeling
Montoya fm.	El Paso fm.	Disconformity; sharp, smooth surface, persistent in much or all of southern New Mexico
Valmont fm.	Montoya fm.	Local erosional breaks in Sacramento Mountains, probably no disconformity
Fusselman (?) fm.	Valmont fm.	Disconformity; sharp in Sacramento Mountains, possibly more erosion of Valmont fm. in northern than southern Sacramento Mountains
Onate fm.	Fusselman (?) fm. Valmont fm.	Disconformity; sharp in south central New Mexico
Sly Gap fm.	Onate fm.	Probable disconformity noted in northern Sacramento Mountains
Percha (?) sh.	Sly Gap fm. Onate fm.	Disconformity probable. One pre-Percha channel 30-40 feet deep in northern Sacramento Mountains
Caballero fm.	Percha (?) sh. Sly Gap fm.	Disconformity; sharp, angular discordance over Percha (?) sh. in channel in northern Sacramento Mtns.
Andrecito mbr. of Lake Valley formation	Caballero fm.	Disconformity; angular discordance of few degrees noted locally, but not persistent laterally
Arcente mbr. of Lake Valley fm.	Alamogordo, Nunn, Tierra Blanca mbrs. of Lake Valley fm.	Disconformity probable, more apparent in southern Sacramento Mountains
Rancheria and Las Cruces (?) fms.	All mbrs. of Lake Valley fms. Caballero fm.	Angular unconformity; discordance of 1-3 degrees. Underlying strata tilted toward southeast

TABLE V. (Continued)

Rock unit above the unconformity	Rock unit below the unconformity	Nature of the unconformity and remarks
Helms fm.	Rancheria and Las Cruces (?) fm.	Disconformity probable
Gobbler fm.	Helms Rancheria and Las Cruces (?) fm. All members of the Lake Valley fm. except the Andrecito mbr.	Major disconformity Irregular erosion surface with local relief of 100 feet
Bursum fm.	Holder fm.	Basal contact ranges from no recognised unconformity to local angular unconformity
Abo fm.	Bursum fm. Holder fm. Beeman fm. Gobbler fm. All mbrs. of the Lake Valley fm.	Major angular unconformity except in northwestern most part of Sacramento Mountains

PRE-GOBBLER DISTURBANCE

The base of the Gobbler formation, the oldest rock unit of Pennsylvanian age in the Sacramento Mountains is at a major erosional break of the Paleozoic section. The relief of the surface of erosion is locally of the order of 100 feet, much more than that observed along any of the erosional surfaces lower in the Paleozoic section. Several north-south trending channels now filled with chert conglomerates and other coarse detrital material are cut as much as 80 feet below the general level of the adjacent erosion surface. The presence of abundant coarse quartz detritus in the basal Pennsylvanian strata implies major structural disturbance of an adjacent area, the first notable indication of an increasing tectonic activity in southern New Mexico during late Paleozoic time. The amount of coarse detrital material, and the relief of the erosion surface increases toward the north in the area of the Sacramento Mountain escarpment, suggestive of major uplift in that direction. Field data is insufficient to determine differences in an east-west direction, but as the closest uplifts of later Paleozoic time are in an area to the northeast, it is probable that the pre-Cambrian source areas for this coarse detritus lay to the northeast. The structural disturbance within the Sacramento Mountain area appears to have only involved general uplift and later submergence, as the Pennsylvanian strata are essentially parallel to the older formations, and no faults have been observed to terminate at the disconformity. The amount of relief of the pre-Gobbler disconformity is another indication of the increased tempo of tectonic activity compared to that prevailing earlier in the Paleozoic era. If such relief had been produced during previous cycles of erosion, the transgressing seas were able to plane the erosion surface to one of much lower relief, probably because of a much slower rate of transgression.

Although Thompson (1942) refers to unconformities separating the Pennsylvanian series in the Sacramento Mountain area, the writer has observed no evidence of persistent erosional breaks within the Pennsylvanian deposits, and doubts their existence.

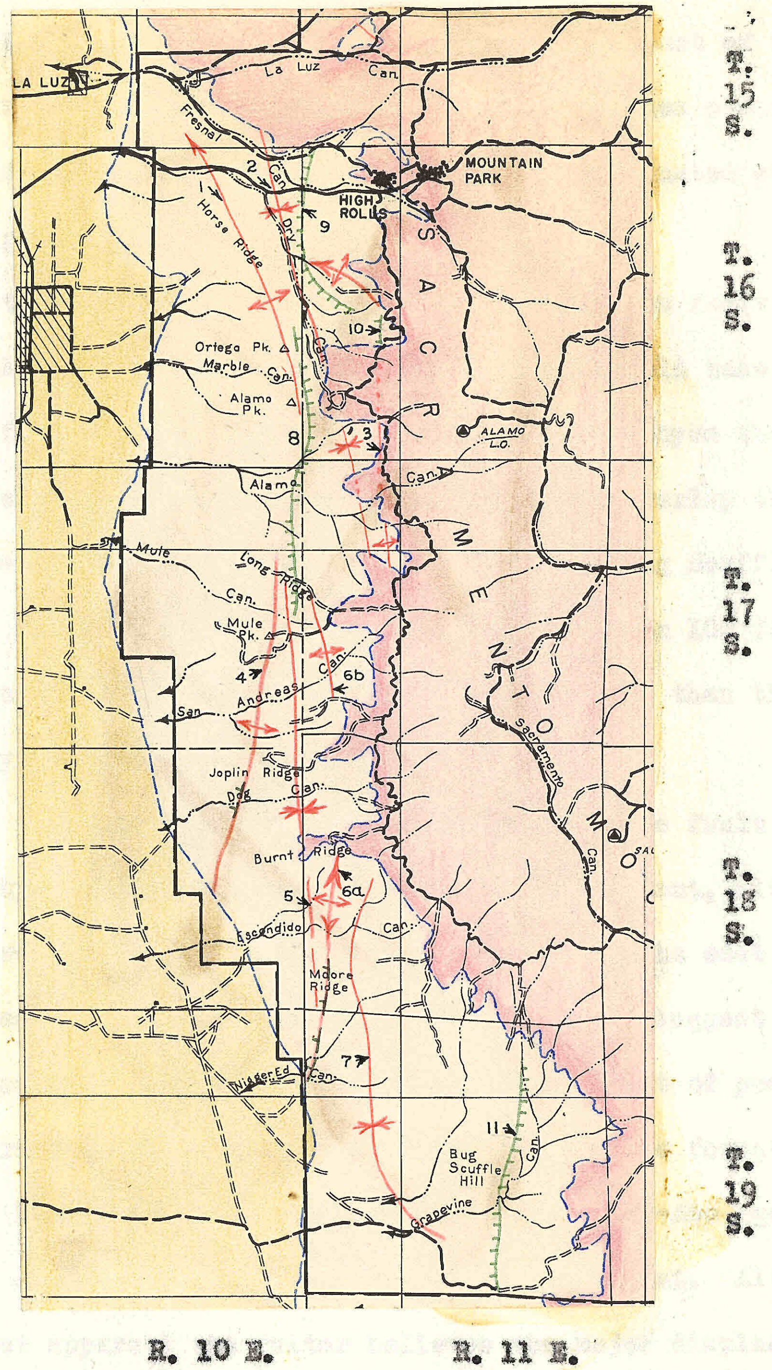
PRE-BURSUM DEFORMATION

The Bursum formation is only known in the northwestern-most part of the Sacramento Mountains, in a five mile long line of outcrops along and north of Fresnal Creek. In most of this area, no unconformity can be demonstrated although a change in the type of sedimentation occurs along a rather persistent stratigraphic horizon. At the southeastern-most outcrops of the Bursum formation, the Bursum may overlie an angular unconformity that bevels the uppermost Holder formation. Thinning of the Holder formation and local occurrence of terrestrial deposits in the Holder and Bursum formations to the south and east are suggestive of uplift in this direction during late Pennsylvanian and pre-Bursum Permian time.

PRE-ABO DEFORMATION

The major angular unconformity within the Paleozoic sequence of the Sacramento Mountain escarpment occurs at the base of the Abo formation. In contrast to the earlier structural disturbances of Paleozoic time that caused uplift or minor tilting, the pre-Abo deformation caused major folding and high angle faulting. The intensity of the deformation appears to increase toward the east across the narrow belt of pre-Permian outcrops and the area most influenced by this deformation probably lies farther to the east where it is concealed by the younger Permian deposits. The major faults and folds that are believed to have formed during the pre-Abo deformation are indicated on figure 43, and are shown in more detail on the geologic maps and cross-sections (plates 1, 2, 3 & 4).

Bug Scuffle Fault: The southernmost of the pre-Abo structural features is a north-trending scissors fault, termed the Bug Scuffle fault for the hill of the same name in the center of T. 19 S., R. 11 E. In the eastern part of sec. 27 the displacement has caused the El Paso formation to the east to be in fault contact with the lower part of the Gobbler formation to the west, a stratigraphic separation of nearly 1000 feet. The strata east of the fault are folded into a sharp half dome. Along the same fault one mile to the north in the SE¼ of sec. 22, a more gentle half dome occurs west of the fault. Here the Fusselman (?) formation on the west is in fault contact with the middle part of the Gobbler formation to the east, indicating a stratigraphic separation of about 1000 feet. Traced to the north, the displacement along the fault diminishes rapidly, and appears to be less than 200 feet in the northernmost three miles of the fault in T. 19 S., R. 11. E. The direction of displacement



1. La Luz anticline
2. Dry Canyon syncline
3. Caballero anticline
4. Joplin arch
5. Escondido syncline
6a. Gobbler arch
6b. Gobbler arch extension
7. Table Top syncline
8. Alamo fault
9. Fresnal fault
10. Arcente fault and anticline
11. Bug Scuffle fault

Figure 43. Major lines of pre-Abo deformation. The area indicated in red is covered by Abo and younger Permian formations, and the area in yellow represents the surficial deposits of the Tularosa Basin.

is relatively down on the west along the northern part of the fault. Several minor tightly folded anticlines and synclines occur along the western side of the Bug Scuffle fault and are terminated obliquely by the fault plane.

Most of the deformation along the Bug Scuffle fault seems to be a phase of the pre-Abo deformation. The fault and fold zone can be traced southward for a mile beyond the map area to Sand Canyon where slightly arched basal beds of the Abo formation appear to overlap the intensely deformed Pennsylvanian strata. At the north the Bug Scuffle fault displaces the basal beds of the Abo formation less than 100 feet and the deformation recorded in the Abo strata is much less than that shown by the underlying Pennsylvanian beds.

The puzzling half domes along the Bug Scuffle fault would be easily explained by a major component of strike-slip movement, with the west side moved toward the north about one mile relative to the east side. However, the observed drag and slickensides along the fault suggest predominant dip-slip displacement. It is possible that the movement of pre-Abo age was largely strike-slip and that it took place after the formation of a simple dome. The later and less intense movements of post-Abo age could have caused the observed evidence of dip-slip displacement. Although the mechanism is not apparent the writer believes the major displacement was of dip-slip nature and occurred prior to the deposition of the Abo formation.

Gobbler arch: The name Gobbler arch is used for the structural feature in the southern part of the area that extends from the mouth of Nigger Ed Canyon to Gobbler dome, a distance of about six miles(figure 43, 6a). The most conspicuous feature along this line of folding and faulting is the

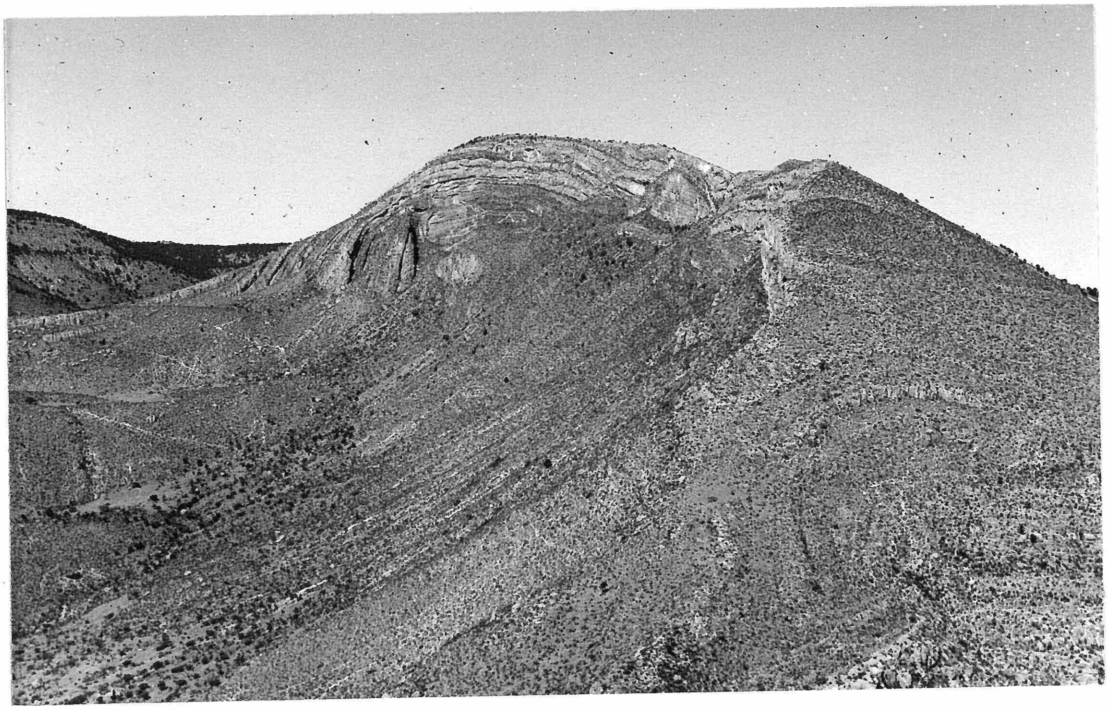


Figure 44. The Gobbler dome, near the center of sec. 19, T. 18 S., R. 11 E. The resistant limestone strata are the Bug Scuffle limestones of the Gobbler formation. The abrupt increase in dip near the base of the exposed dome on the west (left) in interpreted to indicate faulting below the level of present exposures.

Gobbler dome which is shown in (figure 44). Northward from this sharp dome, the anticlinal trend is absent for about three miles, but a gentle anticlinal arch extends along this same trend for about two miles in the western part of T. 17 S., R. 11 E., (Fig. 43, 6b), and may represent a continuation of this structural feature.

Both faulting and folding are represented along the Gobbler arch. The sharp Gobbler dome is eroded on the southwestern side and is structurally assymetric. The nearly vertical beds on the west (fig. 44) are interpreted to indicate that a high angle fault probably occurs below the strata now visible in the partially eroded dome. The Gobbler dome might be explained as a result of intrusive doming, but no evidence of igneous activity was observed in that area. The structure is considered to have formed largely during the pre-Abo deformation on the basis of the angular unconformity at the base of the Abo formation on Burnt Ridge, one mile north of the Gobbler dome (structure section E-E', plate 4). Projection of the present basal Abo erosion surface toward the Gobbler dome indicates that either this resistant dome projected above the general level of the adjacent erosion in pre-Abo time, or that the folding has been accentuated by post-Abo deformation. The Abo formation is but mildly folded and faulted on the ridge to the north, suggestive of this latter explanation. On the other hand, the present top of the Gobbler dome appears to be slightly beveled toward the east (fig. 44), suggestive of an exhumed erosion surface, similar to many known in the northern part of the Sacramento Mountains. Reasoning by analogy with other structures of similar pattern and trend in the area, for which better evidence is available to date the deformation, most of the present structural configuration is believed to have formed prior to the deposition of the Abo formation. Some additional faulting and folding has probably occurred at later times. The anticline to the north that possibly represents an extension of the Gobbler trend can be dated as pre-Abo in age.

Joplin Arch: The Joplin arch is one of the more persistent anticlines of the escarpment area. Where the trend intersects the present west front of the range in sec. 22, T. 18 S. R. 10 E. the fold is very gentle and the crest only 100-200 feet higher than the trough of the broad syncline a mile to the east. Toward the north the folding is more pronounced. The crest rises toward the north, culminating in a gentle dome at Mule Peak. For most of the length of this structural trend the configuration is that of a simple arch, as on Joplin Ridge, for which the structural feature is named. Below Joplin Ridge on the steep north side of Dog Canyon, but 1000 feet lower, the Bug Scuffle limestone member of the Gobbler formation is broken

Figure 45. Faulted strata of the Bug Scuffle limestone member on the north side of Dog Canyon in sec. 14, T. 18 S., R. 10 E. Overlying strata of the Beeman formation are folded along the ridge above this fault.

by a normal fault with a stratigraphic separation of about 200 feet (figure 45). This change from a fold to fault with increasing depth appears to characterize many of the pre-Abo structural features.

The Abo formation does not overlap any of the Joplin arch. However, to the north the fold is closely associated with the alamo fault, and the adjoining syncline and anticline to the east. These are overlain unconformably by the Abo formation, and it appears likely that the Joplin arch formed at the same time as these other structural features.

Synclines of the Southern Part of the Sacramento Mountain Escarpment: The two synclines that separate the Joplin, Gobbler and Bug Scuffle anticlinal trends in the southern Sacramento Mountains differ from the anticlines in that they are generally much less sharply defined. They appear to be more of the nature of sags occupying areas between lines along which sharp uplift has occurred. The position of the axes on the maps does not necessarily correspond exactly to the position of the pre-Abo synclines, as later regional tilting of a few degrees which has undoubtedly occurred since the first deformation would cause a large shift in the position of the trough of these synclines.

Alamo Fault: The Joplin and Gobbler (?) arches and the intervening syncline converge toward the north and are not individually recognizable north of Long Ridge in the northeastern part of T. 17 S., R. 10 E. From the area of convergence, and extending northward for 5½ miles the major structural feature is the Alamo fault, a high angle scissors fault. At Long Ridge the eastern side has been displaced upward along the essentially vertical fault a distance of 500 feet with respect to the western side, as indicated on the cross section X-X', plate 3. Northward from Long Ridge the displacement

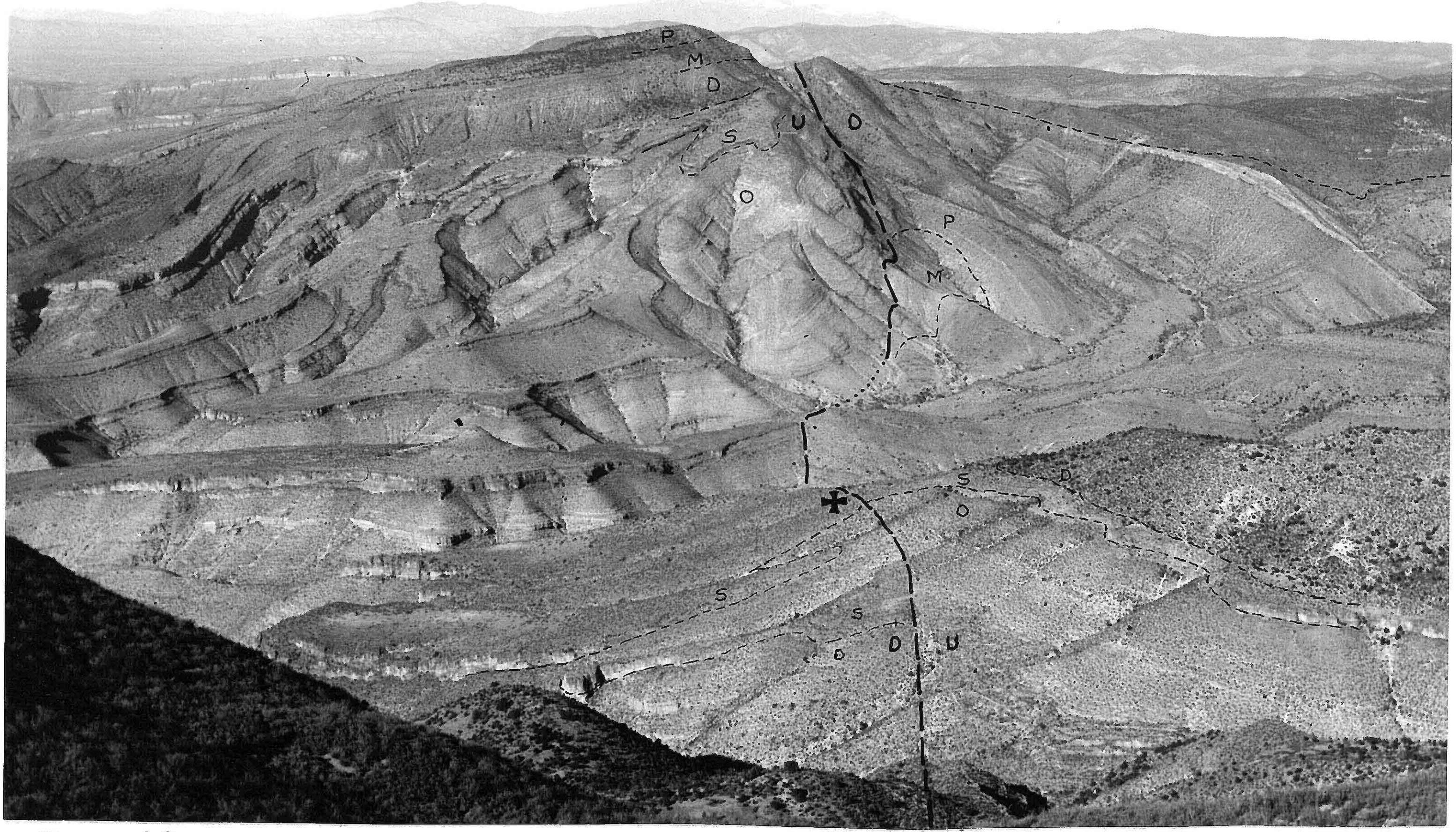


Figure 46. Alamo Peak and the Alamo fault as viewed from Long Ridge on the south side of Alamo Canyon. The trace of the Alamo scissors fault is indicated by the dashed line in the center of the picture, and the cross marks the hinge line. North of the hinge line Pennsylvanian (P) and Mississippian (M) strata are faulted down to the east against Devonian (D), Silurian (F) and Ordovician (O) strata. The dashed line to the right indicates the angular unconformity at the base of the Abo formation.

decreases to a hinge line about 500 feet south of Alamo Canyon, and from thence toward the north the eastern block is downthrown with respect to the western block. East of Alamo Peak, the stratigraphic separation is about 1500 feet. The fault is cut off abruptly a mile north of Alamo Peak by the intrusive body of the Ortega Peak area, that post-dates the fault. No fault has been observed on the north edge of the intrusive body, two miles farther to the north, but stratigraphic relationships on along the projected trace of the fault necessitate a minimum of 500 feet of dip-slip displacement a mile north of mappable limit of the fault. The monoclinal flexure along Fresnal Creek in T. 15 S., R. 10 E. is possibly a surface reflection of faulting at depth along a buried extension of the Alamo fault.

The northern part of the exposed Alamo fault is older than the early Tertiary (?) intrusives that occur along its trace but are unbroken by the faulting. It seems probable that the Alamo fault north of the hinge line formed at the same time as the major folding of the Dry Canyon syncline to the east and both involve relative uplift to the west.

The movement along the southern part of the Alamo scissors fault definitely occurred during the pre-Abo deformation. Abo strata on the top of Long Ridge in sec. 12 T. 17 S. R. 10 E. occur 100 feet east of the Alamo fault, and have been deposited across truncated edges of strata dragged down along the fault. More conclusive evidence is afforded by the position of the Abo formation with respect to the direction of fault movement (cross-section X-X', pl. 3). The Abo strata occur only on the upthrown, eastern side of the fault. The downthrown strata that abut the fault from the west along the top of the ridge are a part of the Holder formation that lies about 500 feet above the youngest Pennsylvanian strata east of the fault.

This relationship necessitates fault movement and erosion prior to the deposition of the Abo formation.

La Luz anticline: The La Luz anticline extends from near Alamo Peak to the north-northwest for a distance of about six miles. The fold becomes progressively flatter toward the north and its continuation north of Dry Canyon is uncertain. The overall structure can be considered to represent a northward continuation of the Joplin arch, but the complications by faulting prevent the connection of these structures by an anticlinal axis. Conclusive proof that this structural feature formed during the pre-Abo deformation is lacking. Its close association with the Alamo fault and the Dry Canyon syncline along part of its trend suggests that it was at least partially defined during this period of movement.

Dry Canyon syncline: In contrast to the broad synclines of the southern Sacramento Mountains, the Dry Canyon syncline (fig. 43) is sharply defined in the pre-Abo strata over most of its length. The syncline can be traced in pre-Abo strata about eight miles, and probably extends farther in both directions, but the Abo and younger deposits conceal the pre-Abo features. A major angular unconformity occurs between the Pennsylvanian and Abo strata along the southern six miles of this syncline and is well exposed on the south side of Caballero Canyon (fig. 34). The limbs of the syncline commonly dip 30 to 50° and locally are nearly vertical. The folding was intense enough to form a series of drag folds along the west side of Dry Canyon, the axes of which are commonly spaced 200 to 500 feet apart. The trough of the syncline is irregular. A low point along the trough occurs south of Caballero Canyon in the SE¼, sec. 31 T. 16 S., R. 11 E., and a high point occurs between Ortega Peak and Arcente Canyon in sec. 19, T. 16 S., R. 11 E. Over the northern five miles of exposures of the pre-Abo fold, the plunge is gentle to the north. Although the major folding occurred during the pre-Abo deformation, later minor folding along the same lines occurred during and after the deposition of the Abo formation.

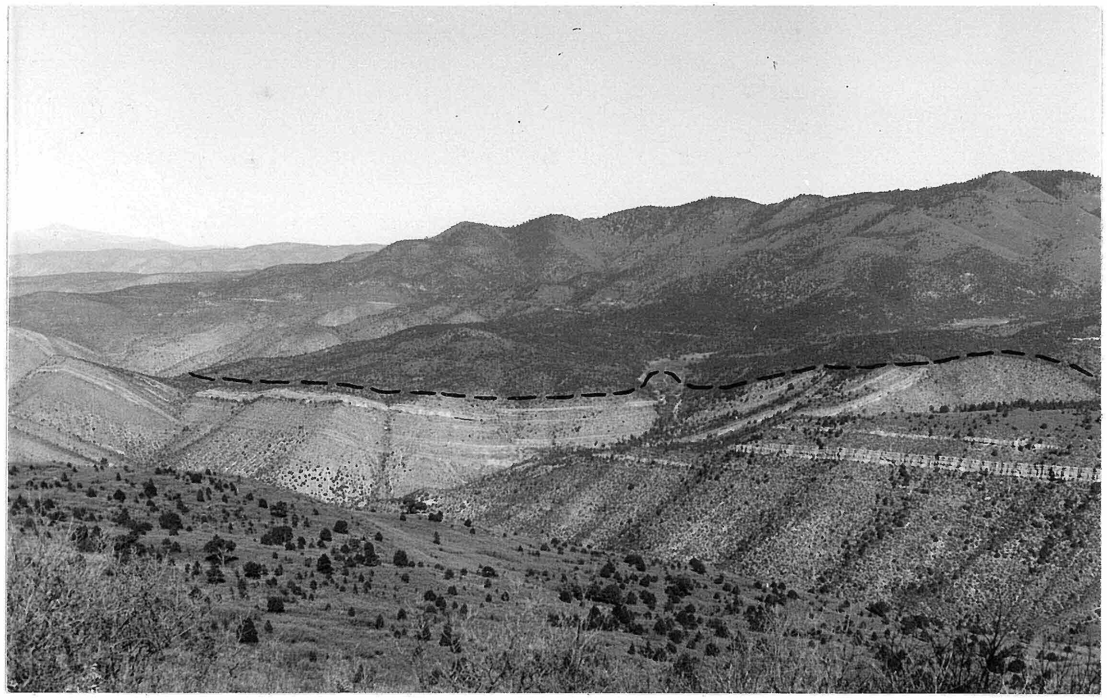


Figure 47. View of upper Alamo Canyon area, T. 17 S., R 11 E. Basal Abo unconformity is indicated by dashed line. Note at the right the truncated limestone beds of Pennsylvanian age on the west flank of the Caballero anticline.

Caballero anticline: The Caballero anticline is a sharply defined structural feature that lies from half a mile to a mile east of the Dry Canyon syncline. The strata near the crest of the anticline are tightly folded, and minor faulting occurs along the southern part of the fold. The crest of the Caballero anticline is gently domed in Caballero and Cherry Canyons and it plunges toward a saddle in the intervening area. On the north sides of both of these low domes the basal Abo strata also plunge gently to the north, which suggests that some of the crestal irregularity may be due to post-Abo folding. The major folding was during the pre-Abo deformation as is clearly indicated by the angular unconformity at the base of the Abo strata throughout this area (fig. 47).

Arcente fault and anticline: In upper Arcente Canyon (sec. 20, T. 17 S., R. 11 E.) the major structural feature is the Arcente fault, a north-trending normal fault that dips to the west about 75°. The eastern side of the fault is upthrown bringing Paleozoic strata as old as the Lower Ordovician El Paso formation into fault contact with Pennsylvanian strata on the west. The overall structure is that of a gentle elongate dome, faulted along the north-south axis. This faulted dome occurs directly on the trend of the Caballero anticline and undoubtedly represents a continuation of this structural feature. At Arcente Canyon the stratigraphic separation along the main fault is of the order of 750 feet and displacement predominantly dip-slip. At least two subsidiary faults a few hundred feet west of the main fault complicate the structural pattern. One reverses the direction of displacement and uplifts west-dipping Silurian, Devonian and Mississippian strata along the bottom of Arcente Canyon (see plate 1).

The Arcente canyon fault was formed during the pre-Abo deformation. The basal strata of the Abo formation can be traced across the southern end of the exposed Arcente Canyon fault, and little or no displacement has occurred in the Abo strata. On the upthrown block, the Abo rests in depositional contact with beds as old as the Andrecito member of the Lake Valley formation. To the west, the Abo was deposited on the truncated edges of all formations of the Pennsylvanian system. Uplift by folding and faulting occurred prior to erosion of the basal Abo unconformity.

Northward from Arcente Canyon the Arcente fault dies out within a half mile, but a gently folded anticline can be traced from this area toward the northwest for about two miles. This appears to be a northward continuation of the Caballero anticline and Arcente Canyon structural high. Although not directly overlapped by Abo strata the position of the basal Abo surface in this vicinity can be reasonably inferred from adjacent Abo outcrops. Pre-Abo deformation is indicated along this anticlinal trend.

<u>Fresnal fault</u>: The most spectacular topography resulting from faulting within the Sacramento Mountains occurs along the northwestern edge of T. 16 S., R. 11 E., a mile west of High Rolls. Here the resistant strata of the Bug Scuffle limestone member of the Gobbler formation are exposed along a west-facing bluff (fig. 33), that rises abruptly above less resistant, younger Pennsylvanian and Permian rocks to the west. The Fresnal fault is exposed continuously over a length of about five miles. It extends in an arc that is concave to the northeast from the SE¼ sec. 18, T. 16 S., R. 11 E. to the center of sec. 34, T. 15 S., R. 11 E. The southern part of the Fresnal fault is shown by figure 48. An isolated exposure of deformed Pennsylvanian strata north of La Luz Canyon suggests that the Fresnal fault continues as a buried structural feature at least for an additional two miles.

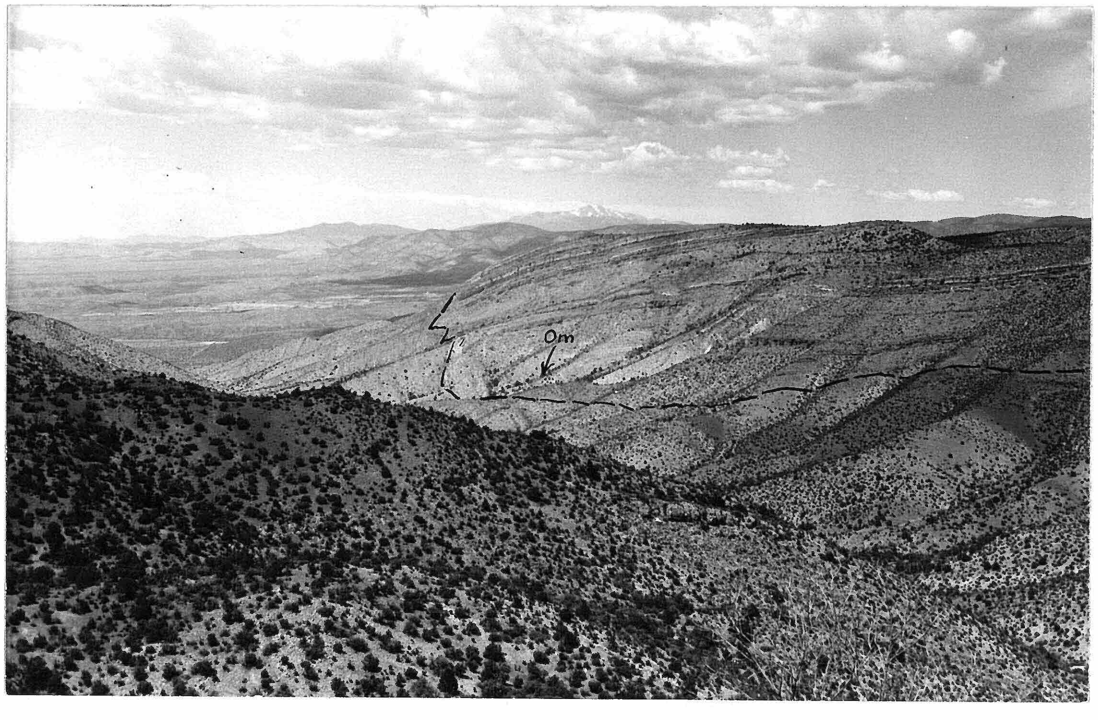


Figure 48. View to north across the Dry Canyon syncline in T. 16 S., R. 11 E. Trace of Fresnal fault is indicated by dashed line. Flat surface on skyline right of the fault is an exhumed pre-Abo erosion surface. Recent erosion has exposed strata as old as the Montoya formation (Om) at the mouth of Pig Canyon, where a pre-Abo anticline on the upthrown side of the block intersects the fault.

The Fresnal fault dips to the west from 70 to 80°, and is a normal fault. The stratigraphic separation along the fault is a maximum of about 1500 feet along Fresnal Box Canyon, and the displacement appears to decrease both to the north and south.

The Abo strata are in depositional contact with beds of the Beeman and Gobbler formation on the upthrown side of the Fresnal fault. On the downthrown side, the Beeman and Holder formations of Pennsylvanian age and the lower Permian Bursum formation are in normal stratigraphic succession below the Abo formation. This indicates at least 1000 feet of strata were eroded from the upthrown side of the fault prior to the deposition of the Abo formation and requires uplift during the pre-Abo deformation. Some of the uplift could result from folding, but faulting probably was predominant.

Later uplift along the Fresnal fault has occurred since the deposition of the Abo formation in the area adjacent to and south of Fresnal Canyon. This is necessary to explain the present elevation of the Abo formation east of the fault with respect to its restored position west of the fault, where the thickness of the Bursum formation is probably not more than 300 feet. The later uplift decreases to the north. The west dips of the Abo formation north of the pre-Abo outcrops probably reflects this later movement.

Mechanism of the pre-Abo deformation: Review of the individual structural features formed during the pre-Abo deformation indicates certain characteristics that are indicated below:

1. The trend is north-south for most faults and folds.
2. The sharpest and most persistent features appear to be along lines of general uplift. Anticlines are sharply defined compared to the synclines in most of the area.
3. The axes are uneven, and some abrupt domical features are common along the lines of uplift.

4. Faults are high angle gravity types, and with the possible exception of the Bug Scuffle fault, the displacement appears to be of dip-slip nature. Scissors types of faults are unusually common.
5. Local evidence indicates that some folds change to faults at depth.

The general prevalence of gravity type faults, transitions from folds to faults at depth, and sharply defined anticlinal folds as compared to synclines are features characteristic of a Plains type of deformation (Powers, 1925). These features are most logically ascribed to a predominance of vertical movements rather than to a predominance of lateral compression of the folded area.

The Dry Canyon syncline and anticline are tightly folded, and lateral compression appears to be necessary for the development of these structural features. It appears that the pre-Abo deformation involved both lateral compression, the effects of which are predominant in the northeastern part of the area, and vertical adjustments by normal faulting in the pre-Cambrian rocks. Some of the faulting is reflected by folds in the upper Pennsylvanian strata. Whether the vertical adjustments and lateral compression were contemporaneous is not known, but the common trend and the direction of movement suggests they formed simultaneously. The doming probably reflects simultaneous lateral compression and vertical uplift. Possibly two major pre-Cambrian faults served to localize the effects of rotation forces developed during the pre-Abo deformation and have resulted in the Bug Scuffle and Alamo scissors faults. Parallelism of folds and faults, and the general absence of strike-slip displacements are more suggestive of development of the compression by directly apposed east-west forces than by a rotational couple.

POST-MIDDLE PERMIAN STRUCTURAL FEATURES

The youngest strata of the range, the Abo, Yeso, Glorieta and San Andres formations of Permian age, are gently folded and somewhat faulted in the area of the Sacramento Mountain escarpment. Dating of the structural activity that caused the present configuration of these strata is less certain than for the earlier events, as the next younger sedimentary deposits in the area are surficial deposits of Quaternary age.

Sacramento River fold and fault: The course of the Sacramento River in the area mapped is along the axis of a syncline in Permian strata in the southeastern part of the area. The syncline is asymmetrical, and the steeper eastern limb dips from 10° to 45° to the west. Locally, gravity faults with the western side downthrown with respect to the eastern side are closely associated with the area of the steepest dips. This is the northwestern part of the structural feature referred to by Darton (1928, p.211) as the Sacramento River fault. It is probable that the fold and fault observed in the San Andres and upper Yeso formation is largely a normal fault zone in the underlying more competent strata. This interpretation is indicated on the cross sections of plate 4. The trend of the fold and fault zone is north-northwest, and the downthrown side is to the west. The amount of throw indicated by the folding and faulting in T. 19 S. R. 11 E. is of the order of 1000 feet, and it decreases to the north. This structural feature probably developed at the time of the major uplift of the range and is en echelon with the boundary faults of the Sacramento and Guadalupe Mountains.

Another indication of the late date of this structural activity is afforded by the evidence of stream capture of formerly easterly flowing streams in T. 19 S. R. 12 E. by the steep southwesterly flowing tributaries of the Sacramento River. At present, the capture of the upper 10 miles of the Sacramento River system is imminent by the headwaters of Grapevine Canyon, which flows westward into the Tularosa Basin. In sec. 16, T. 19 S., R. 12 E., the Sacramento River is only 250 feet below? above the divide, and less than a quarter mile from the nearest tributary of Grapevine Canyon drainage.

Grapevine fault system: Several small and nearly vertical faults occur in upper Grapevine Canyon and toward the northwest to the center of T. 18 S. R. 11 E. (pl. 2). The faults strike generally northwest. The movement on the largest of these indicates a throw of about 300 feet, with the east side dropped with respect to the west side. Directions of movement on the other faults are less, and not uniform with regard to direction of displacement. This fault system is parallel to the Sacramento River structure, and may have developed at the same time, but good evidence of the age of these faults is lacking.

Other folds and faults: The present shape and position of the pre-Abo erosion surface indicates some gentle folding and faulting has occurred since the deposition of that formation. Dips on the flanks of the gentle synclines and anticlines are locally as high as 20°. The folding is along axes essentially the same as those established by the pre-Abo deformation. Gentle folds occur on the crest and high eastern slope of the range, and are indicated on plates 1 and 2. The largest single fold is the Cloudcroft arch, an anticlinal dome with a vertical closure of about 250 feet and an area of closure of about six square miles, that occurs in the eastern part of T. 16 S.

The time of formation of these gentle folds and of minor post-Abo faults is uncertain. The folding appears to be older than the formation of an erosion surface of low relief that is now evidenced by the concordance of summits of the ridges on the crest and the higher parts of the eastern slope of the Sacramento Mountains. In this area the former erosion surface truncates the gentle folds as is indicated by comparison of structural contours and topographic contours of the restored erosion surface. This erosional surface may correspond to the summit peneplain recognised in the Guadalupe Mountains by King (1948, p. 140), which was interpreted by him to be an exhumed unconformity at the base of a former cover of Cretaceous sedimentary rocks. Cretaceous rocks are known in the Sierra Blanca to the north, and probably were continuous over all of southeastern New Mexico (Fielder and Nye, p. 95). No remnants of Cretaceous rocks are known in the Sacramento Mountains. The present evidence is not sufficient to establish the age of the erosional surface of the higher Sacramento Mountains. It could be exhumed basal Cretaceous unconformity. On the other hand, the gentle folds could have formed during the early Tertiary, as folding, faulting, and wide spread subsequent erosion are known in other parts of New Mexico (Bryan, 1938).

The continuity of the high erosion surface of the Sacramento Mountains is interrupted in the Sacramento River area by the zone of folding and faulting described above. In most of the area of Sacramento River drainage the present topography is roughly coincident with structural contours based on the top of the Glorieta sandstone. This suggests the folding and faulting of the erosion surface in this area at a relatively late date, corroborating the other evidence cited for the age of this structural feature.

SUMMARY AND CONCLUSIONS

Prior to the present investigations, the only published reports concerned with the overall geologic relationship of the Sacramento Mountains were those of Darton published in 1917 and 1928, based on his early reconnaissance in this area and adjacent parts of southern New Mexico. Since that time, the only studies reported in geologic literature concern a few parts of the Paleozoic stratigraphic section. The primary purpose of the studies by the writer have been to provide more detailed information about the entire Paleozoic sequence of the Sacramento Mountains than has hitherto been available, and to interpret these data critically in order to better understand the nature and sequence of events that form the geologic record of the Sacramento Mountain escarpment. This report contains the stratigraphic data, a structural summary, and as much interpretation as appears to be warranted on the basis of the present data. Detailed treatment of some of the more interesting regional stratigraphic problems, such as the paleogeography, is handicapped by the absence of similar stratigraphic details elsewhere in southern New Mexico.

As with most investigations, the writer's studies have solved some of the previous stratigraphic problems, brought other previously known problems into sharper focus, and have uncovered many new problems. From the viewpoint of regional stratigraphic interpretation, the new problems are less critical than those known previously. However, from the viewpoint of advancement of the science of geology, many of the newer problems are of prime significance. If this report can serve to focus attention on the some of these problems a secondary objective will have been achieved.

PRINCIPAL NEW INTERPRETATIONS RESULTING FROM THE INVESTIGATIONS

PRE-CAMBRIAN ROCKS

Prior to the present investigation the oldest strata of the Sacramento Mountains were considered to be plutonic igneous and metamorphic rocks of the type characteristic of older pre-Cambrian rocks in New Mexico and Arizona. Instead, the oldest rocks exposed are but slightly metamorphosed shales and sandstones similar to the late pre-Cambrian rocks of the Apache Group of Arizona and to the rocks of late pre-Cambrian age in the vicinity of El Paso, Texas. Rocks of this type have not been reported below the known Paleozoic section in the pre-Cambrian outcrop areas of southern New Mexico. The igneous rocks associated with these oldest sedimentary strata are intrusive sills of diabase type, and although younger than the oldest sediments, appear to be restricted to the oldest sediments and are therefore considered also of late pre-Cambrian age.

UPPER ORDOVICIAN AND SILURIAN STRATIGRAPHY

Attempts to locate and map the units recognized by Darton of the Upper Ordovician and Silurian strata in many of the mountain areas of south-central New Mexico have resulted in confusion in the location and interpretation of the contact between the Montoya and Fusselman formations. In the Sacramento Mountains, the rocks units recognized by Darton can be identified, but the interpretation differs. The only persistent erosional break between the base of the Montoya formation and the top of the Fusselman formation occurs between the two rock units referred to by Darton as the upper and lower members of the Fusselman formation. This erosional break is considered a disconformity. The distinctive lithology and the lateral persistence of the lower member is recognized by renaming the unit as an independent formation, the Valmont dolomite. No faunal evidence was formerly available to date this rock unit, and it was considered to be of Middle Silurian age. Fauna from the Sacramento Mountains indicate an Upper Ordovician age for the lower part of the Valmont dolomite, and the entire formation probably is the same age. Previously known fossils from the strata above the disconformity were considered to be of Middle Silurian age by Darton. More abundant faunas now suggest this rock unit is of Lower Silurian age. Pending further regional investigations, the rock unit is referred to as the Fusselman (?) formation. Lower Silurian faunas have not been reported in New Mexico or adjacent parts of west Texas. If further work confirms the age identification, existing paleogeographic maps of Lower Silurian deposition will have to indicate seas several hundred miles west of formerly known limits. Other strata now identified as Middle Silurian in New Mexico and west Texas may well include rocks of Lower Silurian age.

DEVONIAN STRATIGRAPHY

Detailed studies of the lateral variation of the Devonian rocks modify the interpretations and the distribution of the two principal Devonian formations, the Onate and the Sly Gap as outlined by Stevenson (1945) for this area. Revision of the boundary used by Stevenson to separate these formations in the northern Sacramento Mountains results in more readily mappable lithologic units. The boundary now used possibly represents a disconformity in this area.

Mapping of the Devonian strata of the central and southern part of the Sacramento Mountain escarpment has resulted in correlating them with the Onate formation rather than with the Sly Gap formation as proposed by Stevenson.

MISSISSIPPIAN STRATIGRAPHY

Geologic mapping of the Mississippian strata has resulted more in shifting the distribution of previously recognized units (Landon and Bowsher 1941, 1949) than in major changes of interpretations within those units. Most changes have been concerned with the strata of Upper Mississippian age, the Las Cruces (?), Rancheria, and Helms formations. The Helms formation (Chesterian) had previously been recognized in surface outcrops only in the Franklin, Hueco and southern San Andres Mountains (Landon and Bowsher, 1949). It occurs in the southern Sacramento Mountains as far north as Escondido Canyon.

Rocks of Meremecian age have been found to extend northward as far as Alamo Canyon as a thin wedge of strata representing the Las Cruces (?) and/or the Rancheria formations, although these were formerly known only in the southern Sacramento Mountains. In the Franklin Mountains, these two formations have been differentiated on the basis of an observed angular unconformity between the two similar rock units. Several angular discordances within rocks of this age in the southern Sacramento Mountains have been recognized, and traced locally, but little orogenic or regional significance is assigned to these discontinuities. They appear to represent intraformational submarine erosion.

PENNSYLVANIAN STRATIGRAPHY

The principal contribution to the Pennsylvanian stratigraphy of the area has been the added detail resultingfrom the field mapping of lithologic subdivisions of the 2000 to 3000 feet of Pennsylvanian strata. A new terminology for rock units of the Pennsylvanian is proposed. Abrupt lateral change in lithofacies of these rocks, especially of the pre-Virgilian strata, has been of major interest. The Bug Scuffle limestone member grades abruptly into sandstone and shale. The area of clastic deposition lies east of the zone of limestone deposition in the central and southern part of the area and extends sharply westward along a zone on the north side of Alamo Canyon. Although these areas of clastic deposition shifted slightly in time, they were essentially constant throughout Des Moinesian and part of Missourian time. The large amount of sandstone and shale in the clastic facies appears to require a source area of pre-Cambrian rocks. The abruptness of the change from clastic to carbonate rocks in an east-west direction along much of the length of the escarpment suggests proximity to a north-south shoreline. Pennsylvanian strata occur in wells drilled 50 miles and farther to the east, which appears to indicate that the land mass supplying the clastic sediments of the Sacramento Mountain escarpment occurred in the crestal and higher parts of the eastern slope of the Sacramento Mountains. Presence of a land mass during Pennsylvanian time to the northwest of the Sacramento Mountains has been previously indicated but the land mass had not been indicated to extend southward as far as the southern end of the escarpment. The existence of this land mass is of economic as well as geologic significance, as oil rights are currently leased on much of the land from the crest of the Sacramento Mountains eastward. If the present interpretation is correct, in much of this area latest Pennsylvanian or Permian strata lie directly on pre-Cambrian rocks, and the potential pre-Permian reservoir rocks are absent.

Limestone bioherms of Virgilian age form the base of a mappable unit throughout much of the length of the Sacramento Mountain escarpment. These bioherms are of both stratigraphic features and potential economic significance, but have not been previously reported. They are well exposed and similar to larger structures that form major petroleum reservoirs of Pennsylvanian age in adjacent parts of the Permian Basin to the east.

LATE PENNSYLVANIAN AND EARLY PERMIAN DEFORMATION

The Abo formation lies in angular unconformity on older strata along nearly the entire length of the Sacramento Mountain escarpment. Evidence of major deformation by both folding and faulting prior to the deposition of the Abo formation is clearly recorded in the area. The Abo formation is in depositional contact with strata as old as the Andrecito member of the Lake Valley formation (Lower Mississippian). The pre-Abo deformation appears to be more intense toward the east in the area of the Sacramento Mountains than to the west. Most of the internal structural features of the Sacramento Mountains can be related to this period of deformation.

Baker (1920, p. 106) and Blanchard and Davis (1920, p. 965) reported an angular unconformity at the base of the Abo formation. However, Darton and most later workers in this area either considered these reports to be erroneous or emphasized the local nature of the reported unconformity. Proof of the wide extent of this angular unconformity at the base of the Abo formation is one of the most important results of the geologic mapping in the Sacramento Mountains. This angular unconformity is of regional extent, and correlates with a similar unconformity at the base of the Hueco formation of west Texas (Pray, 1949, pp. 1914-15).

Recognition of this unconformity is the key to the solution of many otherwise puzzling geologic relationships in this part of south-central New Mexico.

PERMIAN STRATIGRAPHY

Most new interpretations of significance to the Permian stratigraphy resulting from this investigation are related to the recognition of the pre-Abo deformation and the angular unconformity at the base of the Abo formation.

Deposition in the northwesternmost part of the area appears to have been essentially continuous from uppermost Pennsylvanian into upper Wolfcampian time, but conditions were changing in the depositional area from those of marine to terrestrial conditions. The Pennsylvanian deposits of this area are predominantly marine, the lower Wolfcampian Bursum deposits are transitional and record fluctuating marine and nonmarine conditions, and the middle and upper Wolfcampian Abo deposits are predominantly terrestrial. This interpretation differs from that of Thompson (1942, p. 68), who considers Pennsylvanian and Permian deposits to be separated by a "physical unconformity", but agrees with King and Read (in King, 1942, p. 675). However, the latter authors believe the Bursum formation can be traced southward throughout the Sacramento Mountains. The Bursum formation only occurs in the northwesternmost five miles of the map area, and the Abo formation lies with angular unconformity on pre-Bursum strata throughout the remaining part of the map area.

The Abo formation of the northern Sacramento Mountains has been proved to grade southward into three lithologic units. The upper and lower units are southward tapering tongues of red beds.

The middle unit consists of a northward-wedging tongue of limestone and shale. The wouthward variation of these lithologic units of the Abo formation, and the recognition of the basal unconformity afford strong evidence for the suggested, but heretofore rather uncertain correlation of the Abo formation of the Sacramento Mountains with the Hueco formation in West Texas. Previous work in the area to the south resulted in conflicting evidence in the suggested correlation of the Abo and Hueco formations, as some geologists in that area appear to have considered the upper tongue of red beds as the entire Abo formation. Thus the fauna from the underlying limestones was considered to underlie the Abo formation. As now interpreted, the faunas were derived from the limestone tongues of the middle part of the Abo formation to the north and now confirm rather than preclude the correlation of the Abo and Hueco formations.

STRUCTURAL DEVELOPMENT OF THE SACRAMENTO MOUNTAINS

Most geologists have considered the escarpment of the Sacramento Mountains to have formed by block faulting. The field investigations have contributed the first detailed evidence in support of this interpretation. The uplift is believed to have occurred along a normal fault system located at or close to the base of the present escarpment. Piedmont fault scarps are recognized along most of the length of the escarpment, and indicate that the major uplift of the mange has continued to the present.

Most of the internal structure of the Sacramento Mountains has been proved to be of late Pennsylvanian and early Permian age. Some mild later deformation has occurred in Mesozoic (?) time, and probably in the early Cenozoic. The dating of most of the internal structural development of the Sacramento Mountains as Paleozoic in age is one of the more significant results of the work, and is contrary to the prevailing ideas prior to this work.

RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

Many interesting geologic problems observed during the field studies could not be investigated adequately because of the time limitations. The inaccessibility of much of the area and the time available did not permit more than a few points to be revisited since the first mapping, which was accomplished at an average rate of slightly less than a square mile per day. The main objective during the work was the completion of the mapping and the interpretation of the stratigraphic features of the entire section, rather than a sampling of the most interesting geologic features. The work that has been completed, however, furnishes an excellent background for evaluating possible directions of future research in this area and the surrounding region.

The problems that appear to be the most promising either in the interpretation of the geology of south-central New Mexico or toward a better understanding of basic geological processes are outlined below.

1. Detailed stratigraphic and structural studies of the late Permian record in the northwesternmost part of the Sacramento Mountain escarpment. This area extends from Fresnal Canyon on the south to a point three miles north of Tularosa. In most of this area, deposition appears to have been essentially continuous from late Pennsylvanian into early Permian time, and the formations deposited, the Holder, Bursum, and Abo, do not appear to be separated by unconformities. However, in the southeastermost part of this area, the Abo formation rests with angular unconformity on pre-Holder strata. In the intervening area the Bursum formation appears to grade from a predominantly marine sequence southeastward to a terrestrial sequence. Evidence suggests that the deformation

on the southeast was episodic and began in late Pennsylvanian time but culminated in major folding and faulting in post-Bursum-pre-Abo time. Exposures from the area of uplift and deformation to that of continuous deposition are sufficiently good to establish detailed stratigraphic and structural control. The interpretation of the rapid lateral and vertical variations of lithofacies and biofacies in this area should form a significant contribution to understanding geological processes of the late Paleozoic era.

2. Bioherms of the Mississippian strata. The mode of growth of these structures is unknown. They appear to consist largely of crinoidal debris, and at least locally, can be demonstrated to have formed topographic prominence on the sea floor at the time of growth. The mechanism that permits accumulation of loose crinoidal material in a steep, wave-resistant structure is unknown. In nearly all known bioherms, that have accumulated above the level of adjacent contemporaneious deposition, some binding growth, such as colonial corals, bryozoans, or algae is abundant and believed to have permitted the growing structure to form a resistant structure. The problem is particularly acute in the interpretation of bioherms as large as the one in Muleshoe Canyon (Fig.24). To date, no such organism has been found in the Mississippian bioherms, and flanking strata. The biohermal complex that is illustrated by figure 26 is anomalous from the viewpoint of any conventional explanation of bioherm growth. Detailed field examination and with laboratory studies of the petrology and faunas are needed to better understand these curious structures. During the past five years, bioherms have been of rapidly increasing significance as petroleum reservoirs. Contributions toward their interpretation are important

to petroleoum geology as well as to the science of stratigraphy.

3. Lithofacies of the Gobbler formation. Exposures of the lateral and vertical transition from the nearly pure carbonate rocks of the Bug Scuffle limestone member of the Gobbler formation into the predominantly clastic facies of sandstone and shale are abundant and would furnish excellent data for a detailed petrologic study of these abrupt facies changes. The work of the writer has been largely confined to a general understanding of the major relationships. Work by the California Research Corporation on these facies realtionships has investigated some of the faunal and petrologic aspects, but an integrated program of detailed field mapping and laboratory investigation would lead to a much better understanding of these lithologic transitions than obtains at present.

4. Stratigraphic features of the Holder formation (Pennsylvanian). Two problems of major interpretive interest in the Holder formation concern the bioherms at the base of the formation, and the cyclical deposition which characterizes much of the upper part of the formation. The bioherms of the Dry Canyon area have been investigated by W. J. Plumley of the California Research Corporation, but the results may remain confidental, and do not exhaust the research potential of these features. The problem of the cyclical deposition of the Pennsylvanian has not been thoroughly studied in the New Mexico area, and exposures throughout the length of the Sacramento Mountains are adequate to permit a detailed investigation. The cycle appears to include the transition from normal off-shore marine deposition to deposition and erosion of the littoral zone. The cyclical deposition is more conspicuous and appears to consist of increasing proportions of shallow water deposits and

erosional breaks are more conspicuous toward the top of the Pennsylvanian section. The sequence appears to indicate an early response to the orogeny that is so clearly recorded by the angular unconformity at the base of the Abo formation. A correlation between these minor changes of strand line with the start of orogeny would be of general interest.

5. Although there is nothing unique about the Sacramento Mountains for detailed studies of the origin of chert and dolomite, the exposures of the cherts and dolomite of the lower Paleozoic are excellent. Many of the local rock units of these formations can be traced without interruption for miles along the canyon walls. Detailed field studies of the types and distribution of chert within thin rock units, supplemented with detailed laboratory investigations may contribute to an ultimate understanding of the origin of chert. The nature and origin of the dolomite that contains the chert would be a logical problem to study at the same time, as the genesis of the two rock types is probably interrelated.

6. Of the many problems of critical regional interest, the greatest contribution to stratigraphy of southern New Mexico could be made by detailed examination of the pre-Devonian rocks in the Franklin, Hueco, Organ, and San Andres Mountains, and comparing the stratigraphic relationships to those obtained in the Sacramento Mountains. Until this additional detail is available interpretations of the conditions of deposition and the paleogeography will be severely handicapped.

Collection and study of faunas was distinctly subordinate to the mapping and lithologic study of the rock units during the present investigations. A major contribution to the stratigraphy of New Mexico and adjacent areas could be made by careful collecting and examination of the invertebrate faunas of the mapped rock units, especially those of the lower Paleozoic section. Though, in general, fossils are neither abundant nor well preserved in the dolomites of the El Paso, Montoya, Valmont, and Fusselman (?) formations, it is probable that by acid treatment of large amounts of fossilerous dolomite much more complete faunas could be obtained than are known to date. The excellent exposures and general lack of structural complexity of the lower Paleozoic strata along much of the Sacramento Mountain escarpment insure close stratigraphic control form all faunal collections. As the New Mexico area is intermediate in geographical position between the well known Paleozoic sections of the Ozarks and the Upper Mississippi Valley and the comparatively little known lower Paleozoic sections of the western Basin and Range province, the results of detailed paleontologic studies in the Sacramento Mountains can be of significance over a wide area.

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