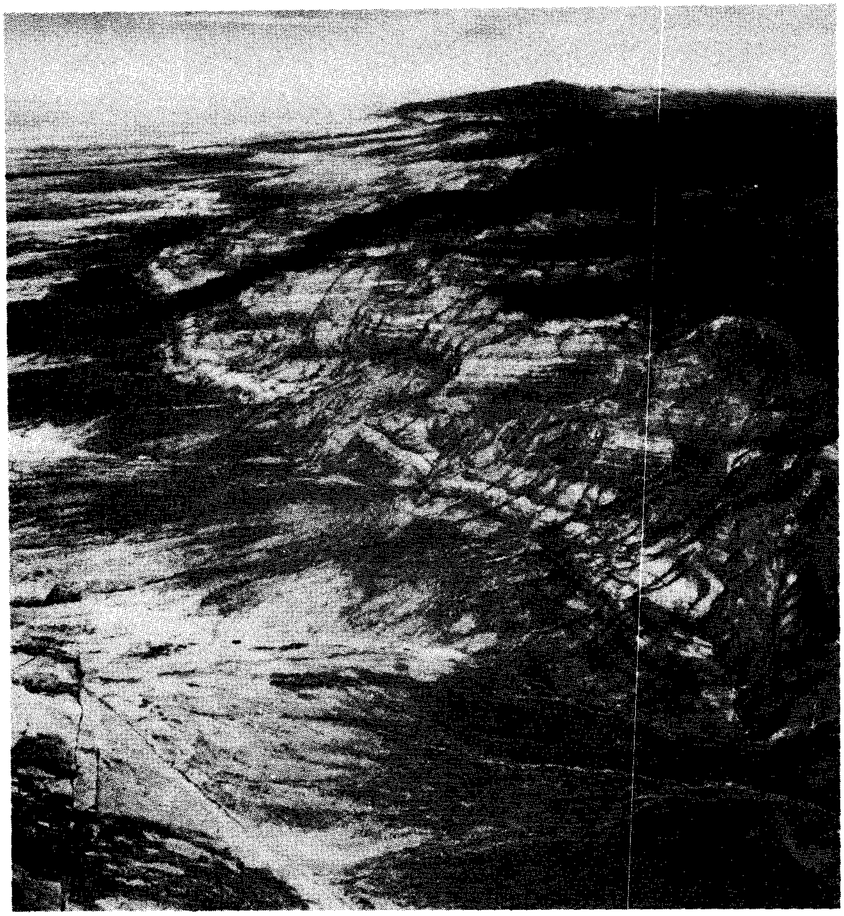
# GEOLOGY OF THE
# SACRAMENTO MOUNTAINS ESCARPMENT,
# OTERO COUNTY, NEW MEXICO



BULLETIN 35

# Geology of the Sacramento Mountains Escarpment, Otero County, New Mexico

*by LLOYD C. PRAY*

1961

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# 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 6,000 feet lower.

The rugged west-facing escarpment has been carved in an uplifted fault block composed largely of sedimentary rocks having an aggregate thickness of about 8,000 feet. Tertiary sills and dikes of intermediate composition are of local importance. The bedrock strata range in age from late Precambrian to Cretaceous, but almost the entire sedimentary section is of Paleozoic age. The strata are largely the product of marine deposition on a stable shelf area. Most of the pre-Pennsylvanian formations are thin and laterally persistent across much of southern New Mexico, and many are separated by disconformities. The Pennsylvanian and Permian units are thicker, and show greater lateral variability as a result of more tectonic instability and diastrophism than prevailed earlier.

The oldest rocks exposed are late Precambrian 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 degrees.

The Lower Ordovician(?) Bliss sandstone forms the base of the Paleozoic sequence, and consists of 110 feet of glauconitic quartz sandstone and minor elastic dolomite. The El Paso formation, 432 feet of sandy dolomite of Lower Ordovician age, may be conformable on the Bliss sandstone, and is separated from the overlying Montoya formation of Middle and Upper Ordovician age by a sharp disconformity. The Montoya formation is 190 to 225 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 dolomite and are of Upper Ordovician age. The Valmont dolomite 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 is overlain by gray to black shales and minor limestone of the Sly Gap formation (Upper Devonian) in the northern half of the escarpment. Black shales tentatively correlated with the Percha formation (Upper Devonian) overlie the Onate in the southern escarpment and fill at least one channel cut in the Sly Gap formation farther north.

The basal Mississippian strata throughout the area consist 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 350 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 400 feet thick in the northwestern part of the escarpment and thins to the east and south. Dark siliceous limestone of the Rancheria formation (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.

Pennsylvanian strata form a complex assemblage of sandstone, shale, and limestone units. In most places the more complete Pennsylvanian sections are about 2,000 feet thick, although 3,000 feet occurs in the northwestern part of the escarpment. Lateral and vertical facies changes, many of which are cyclic, are common. No disconformities have been recognized within the Pennsylvanian strata, although local diastemic breaks are abundant.

The Pennsylvanian section is subdivided into three formations and one member. The basal formation, the Gobbler, consists of 1,200 to 1,600 feet of quartz sandstone, limestone, and shale, and is of Morrowan (?) to middle Missourian age. Light-gray cherty limestone forms a distinctive facies as thick as 1,000 feet within the Gobbler formation and is termed the Bug Scuffle limestone member. It grades abruptly into an equivalent thickness of shale and sandstone. The Beeman formation, largely of upper Missourian age, consists of 350 to 450 feet of feldspathic sandstone, limestone, and shale. The deposits grade from a shallow shelf sequence on the east to those of more basinal aspect on the west. The Holder formation of Virgilian age consists of 300 to 900 feet of cyclic repetitions of limestone, shale, and minor sandstone. Algal limestones are abundant; they form massive bioherms along the basal contact and biostromal layers in the overlying part of the Holder formation. The Pennsylvanian strata record increasing tectonism during the period, with progressive differentiation of a positive area (shelf or emergent) in the east and a more negative area, the Orogrande basin, to the west.

In the northwesternmost Sacramento Mountains, sedimentation was essentially continuous from Pennsylvanian into Permian time. Sedimen tation was interrupted in most of the area in latest Pennsylvanian and earliest Permian time owing to pronounced uplift accompanying major deformation by folding and faulting. Lower Wolfcampian strata of the Bursum (Laborcita) formation grade from a largely marine sequence of limestone and shale in the northwesternmost part of the escarpment southeastward into thinner nonmarine red and gray shales and limestone conglomerates that unconformably overlie the Holder formation. Bursum strata pinch out into the major unconformity at the base of the Abo formation in the north-central part of the area.

The Abo formation of middle and upper Wolfcampian age overlies a marked angular unconformity in all but the northwestern part of the escarpment, and locally was deposited on truncated strata as old as the basal Mississippian deposits. The Abo formation ranges from 250 to 550 feet thick in most of the area. In the northern part the Abo consists of terrestrial red mudstone and coarse arkose, a facies that thickens rapidly toward the northwest. Toward the south, the middle part of the Abo formation grades into brackish to marine limestone and shale of the Pendejo tongue of the Hueco limestone. Upper and lower tongues of Abo red beds persist southward beyond the mapped area and probably correlate with the red beds at the base and in the upper two-thirds of the Hueco limestone.

The Yeso formation of Leonardian age consists of about 1,300 feet of red beds, yellow and gray shale, limestone, silty quartz sandstone, and gypsum. Halite and anhydrite occur in the subsurface. Poor exposures prevented detailed study of the Yeso in most of the escarpment area. The deposits record the fluctuating conditions of a shallow marine back-reef or lagoonal area of regional extent. Carbonate rocks are more abundant toward the south, and red beds and evaporites more prevalent toward the presumed shoreward area farther north.

Most of the crest and high eastern slope of the Sacramento Mountains is capped by the resistant carbonate rocks of the San Andres formation. Marine limestone and dolomitic limestone form most of the rock unit. The San Andres formation has a maximum thickness of about 700 feet in the mapped area, but thicknesses of only a few hundred feet remain beneath the general level of the summit peneplain along most of the crest. Several units of clean, fine- to medium-grained quartz sandstone with an aggregate thickness of 10 feet or less occur within the lower 120 feet of the San Andres. This basal unit is the Hondo member of the San Andres formation. No unconformity was recognized within the Yeso or San Andres formations.

The only known Mesozoic strata of the Sacramento Mountains escarpment occur as a small outlier along the crest of the range near its northern limit, where about 150 feet of quartz sandstone overlies the San Andres formation and underlies thin marine shale of Cretaceous age. The sandstone is considered to be part of the Dakota(?) sandstone.

Quaternary deposits within the mountain block consist of at least three levels of terrace gravels, pediment gravels, travertine, Recent alluvium, and large amounts of slump material. The alluvium of the Tularosa Basin has a minimum thickness of 1,800 feet; in part it may be of Tertiary age.

Tertiary(?) igneous rocks, mostly of a composition between andesite and latite, occur as numerous sills and dikes in the northern and central parts of the escarpment area in the pre-San Andres section. Greenish-gray hornblende trachyandesite porphyry is common. Dikes are steeply inclined and trend northeast-southwest; sills are most abundant in shaly strata of the Devonian, lowermost Mississippian, and basal Pennsylvanian.

The Sacramento Mountains are a fault-block range, tilted about 1 degree to the east and bounded on the west by a gravity fault zone near the base of the present escarpment. Piedmont scarps and numerous small step 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 suggest faulting as the dominant mechanism for the uplift of the range. The estimated minimum displacement along the boundary fault is of the order of 7,0d0 feet for a distance of 18 miles along the escarpment, decreasing to about half this amount at the northern and southern limits of the mapped area.

Many of the structural features of the escarpment were formed prior to uplift of the mountain block. Anticlines, synclines, and high-angle, generally normal faults are conspicuous structures. Most of these features were formed by major diastrophic movements during late Pennsylvanian and earliest Permian (pre-Abo) time. These pre-Abo structural features trend north-south. The anticlines are more sharply defined and narrower than the synclines, and gentle to locally abrupt domes and high-angle faults are common along the anticlinal axes. The intensity of the pre-Abo deformation appears to have increased from west to east toward an area of maximum pre-Abo uplift and erosion. Stratigraphic evidence and some gentle folding and minor faulting indicate that there was a mild continuation of the deformation during Abo deposition, persisting possibly into later Permian time.

Numerous small thrust faults, dipping west 15 to 30 degrees, and some closely related zones of abrupt flexure occur along the base of the escarpment in the older strata. Although these thrusts are older than the cross-cutting Tertiary(?) dikes, their spatial distribution suggests a relationship to the frontal fault system.

Gentle folds and several normal-fault systems with 500- to 1,000-foot displacements downward on the west occur in the higher part of the Sacramento Mountains escarpment. The folds, as well as at least one of the faults, probably formed between late Cretaceous and late Tertiary time, as they affect the Dakota(?) sandstone and shale at the Mescalero fault, and are truncated along much of the crest by the regional surface of erosion, the Sacramento plain, that formed subsequent to a regional uplift, but prior to the major uplift of the Sacramento Mountains fault block.

Based on regional evidence, the major uplift of the Sacramento Mountains fault block is believed to have started in late Tertiary time. Fault scarps in Recent alluvium indicate that the uplift is continuing at the present time.

# *Introduction*

## GENERAL STATEMENT

This report affords an introduction to the salient stratigraphic and structural features of the Sacramento Mountains escarpment of south-central New Mexico. The Sacramento Mountains are part of one of the largest mountain ranges in southern New Mexico. This range extends northward for a distance of about 80 miles and lies midway between the east and west borders of the State (fig. 1). On the east lie the broad expanses of the Great Plains, and on the west is found the more irregular topography of the Basin and Range province, a region of north-trending mountains and intervening 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 altitude of 12,003 feet. The Sierra Blanca and other mountain masses in the northern part of the range are composed largely of igneous rocks intruded into strata that range in age from Permian to Cretaceous. The broader, southern part of the range is known as the Sacramento Mountains.[1] This high mountain mass trends southward for about 35 miles, merging southward and eastward into lower plateaus.

The Sacramento Mountains are essentially a cuesta with a bold, west-facing escarpment and a total relief of more than a mile. The gentle east slope of the Sacramento Mountains extends to the Pecos River, a distance of 80 miles from the crest. Exposed along the steep western escarpment is a thick section of sedimentary rocks that range in age from Precambrian to Cretaceous. Most of the sedimentary units are of Paleozoic age, and it is this thick, well-exposed Paleozoic section that forms the prime focus of geologic studies in the Sacramento Mountains. A variety of structural features, minor igneous intrusive rocks, and land forms add further interest to the geology of the Sacramento Mountains escarpment.

This concise summary is based largely on investigations of an area approximately 28 miles long (north-south) and 15 miles wide, an area that includes most of the Sacramento Mountains escarpment. The writer's geologic studies of this area began in 1947 under the sponsorship of the New Mexico Bureau of Mines and Mineral Resources. During the ensuing 3 years, most of the western escarpment and a part of the crest of the 'range were mapped in the field at a scale of 2 inches = 1 mile.

1. The use of the term "Sacramento Mountains" is somewhat confusing. On some maps this name is applied to the entire mountain range between the latitude of Carrizozo and the northwestern part of the Guadalupe Mountains, a distance of about 80 miles. By this usage the Sierra Blanca is a part of the Sacramento Mountains. On most recent maps, and in this report, the term is applied only to the mountain areas south of Tularosa Canyon, thus excluding the Sierra Blanca and other mountain masses in the northern part of the range.

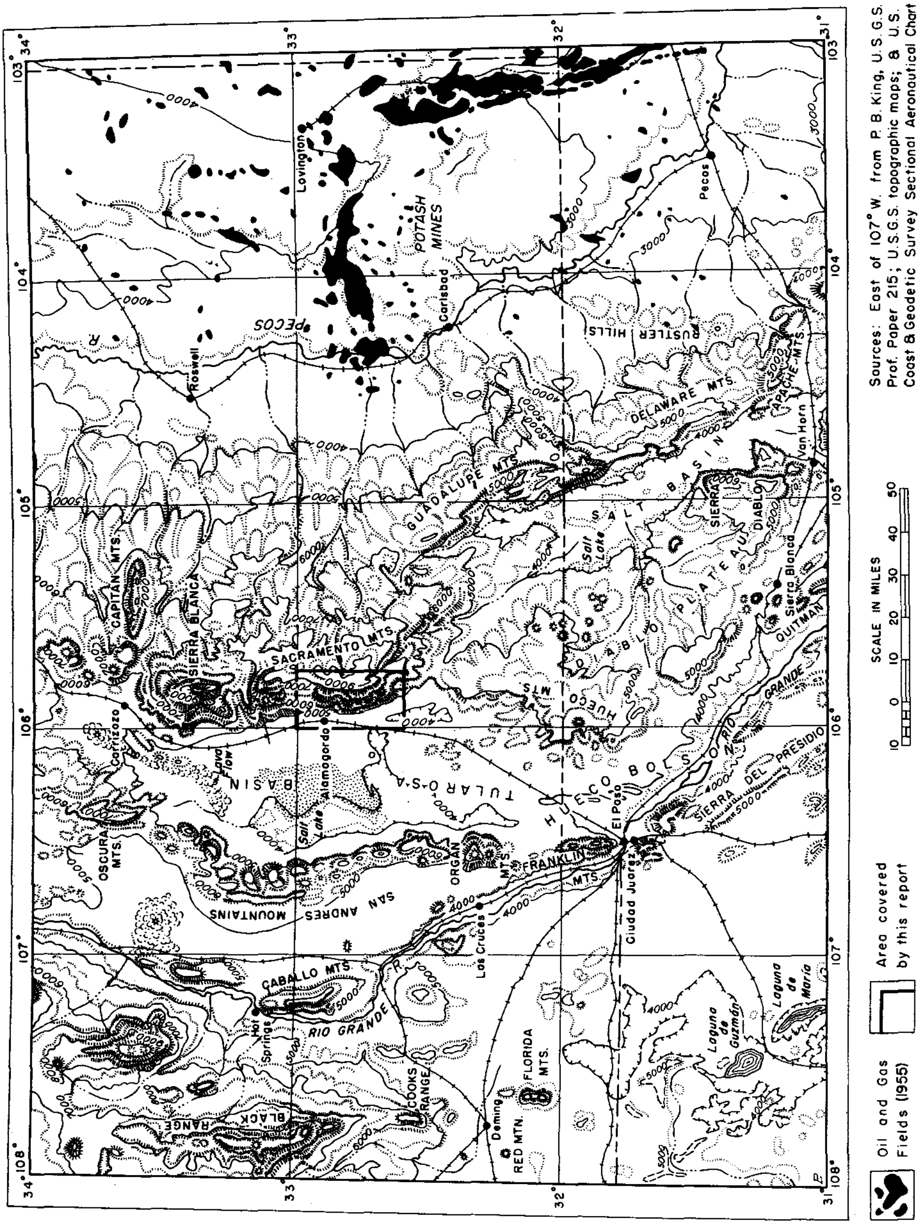



Figure 1

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

The area involved is shown in Plates 1 and 2, and Figures 1 and 2. The initial mapping required about 13 months of field work. Many of the data presented in this report are condensed from a doctoral thesis completed in 1952. That report is available on request from the California Institute of Technology, and is on open file at the New Mexico Bureau of Mines and Mineral Resources. Between 1949 and 1956, more intermittent work in the area was sponsored by the California Institute of Technology. Since 1956, minor investigations have been supported by the Ohio Oil Co. The completion of a geologic report commensurate with the time spent in the field investigations of the Sacramento Mountains has long been delayed. Owing to uncertainty regarding the completion of a full report, the New Mexico Bureau of Mines and Mineral Resources and the writer felt it desirable to publish the maps, cross-sections, and a concise text in the form of this summary report. A previous brief article, entitled "Outline of the Stratigraphy and Structure of the Sacramento Mountain Escarpment," was published in the guidebook of the Fifth Field Conference of the New Mexico Geological Society in 1954. The article in the Roswell Geological Society guidebook of 1959 titled "Stratigraphic and Structural Features of the Sacramento Mountain Escarpment" expanded the coverage of the 1954 article and incorporated some newer data and interpretations. In the 1959 guidebook, approximately 80 pages of geologic road logs provide specific geologic details for many of the roads in the Sacramento Mountains escarpment.

In the present report, the focus is almost entirely on the geologic features and the geologic maps of the western escarpment of the Sacramento Mountains. Relatively little attention is given here to the regional literature on the geology of adjacent parts of New Mexico, the discussion of such material being deferred for subsequent more complete treatment.

The major geologic relationships of the mapped area are shown on the two geologic maps (pl. 1, 2) and the 10 east-west structural cross-sections (pl. 3). A summary of the stratigraphic sequence is given by a composite stratigraphic section (fig. 3). An east-west cross-section near the center of the Sacramento Mountains escarpment summarizes diagrammatically the salient stratigraphic and structural features (fig. 4).

Topographic maps of the Sacramento Division of the Lincoln National Forest, at a scale of 2 inches=1 mile and with a contour interval of 100 feet, provided the base for the geologic mapping. These Forest Service maps were made by planetable method prior to the availability of aerial photographs and do not show the detailed topographic features as accurately as more modern maps. Where the field work indicated the need for only minor corrections of the base map, the geology was adjusted to fit as a matter of expediency. In a few areas where major revisions of the topographic map were necessary, such revisions were

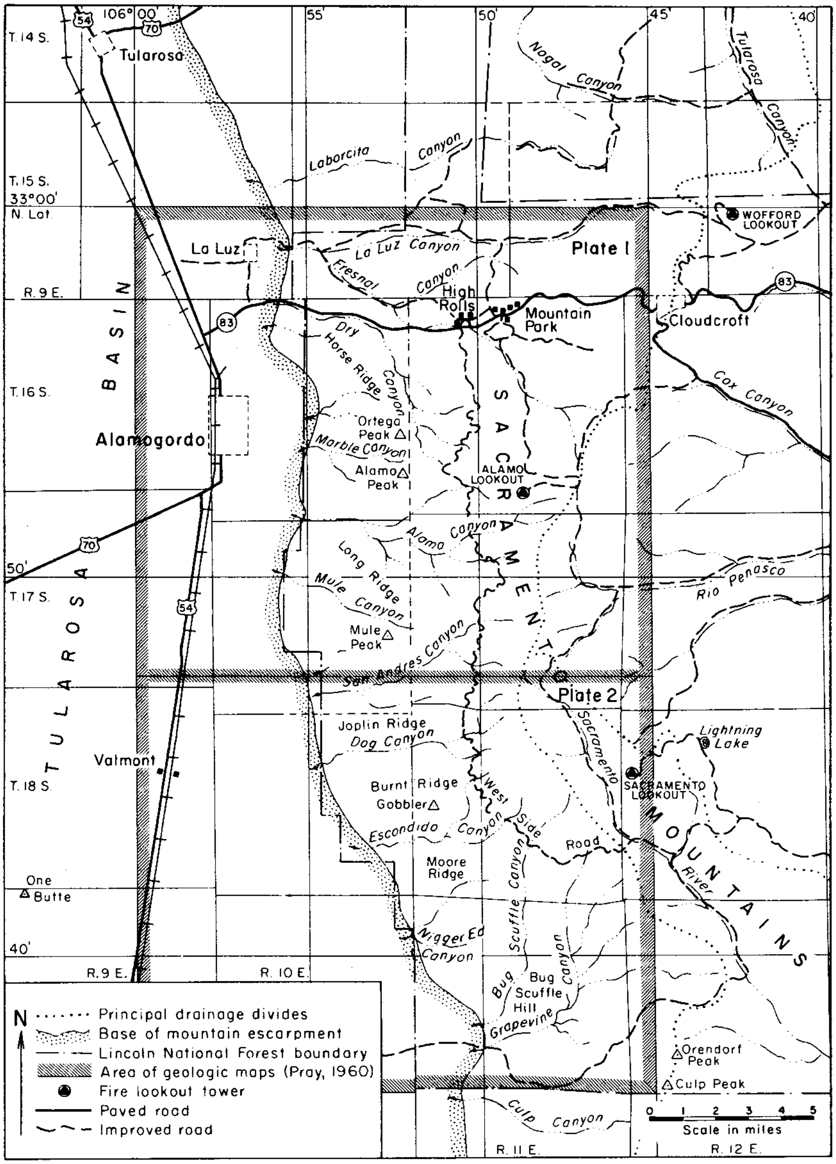



Figure 2

INDEX MAP OF SACRAMENTO MOUNTAINS ESCARPMENT AREA, OTERO COUNTY, NEW MEXICO accomplished by measurements in the field and from the aerial photographs. In 1953, subsequent to the completion of the field mapping and of much of the drafting of the geologic maps, detailed topographic maps, at a scale of 1:25,000 and with a contour interval of 25 feet, were published by the U. S. Army Map Service.

## PREVIOUS GEOLOGIC WORK

Until the 1940's, about the only major geologic investigations of the Sacramento Mountains escarpment were those of Darton (1917, 1928), based on the results of his reconnaissance work throughout the State of New Mexico. In the 1930's and 1940's, most published reports were concerned largely with specific parts of the stratigraphic sequence. These include the excellent regional and local studies of the Mississippian system by Laudon and Bowsher (1941, 1949); of the Devonian formations by Stainbrook (1935, 1948) and Stevenson (1945); and of the Pennsylvanian by Thompson (1942). Since 1950, many geologic studies have been conducted in the area of the Sacramento Mountains escarpment. Those published are cited in the bibliography; most of this more recent work, however, has served as thesis projects for advanced degrees and remains unpublished. Known theses written since 1950 are those of Pray (1952), Lokke (1953), Otte (1954), Bergeron (1957), Oppel (1957), and Reyer (1958). The work of Lokke, Bergeron, Oppel, and Reyer has been part of a continuing research investigation carried on by, and under the supervision of, Dr. Lewis M. Cline, of the University of Wisconsin. Summaries of this work were published in the Roswell Geological Society guidebook of 1959.

Data collected by many petroleum geologists in the Sacramento Mountains area are largely unpublished; exceptions are the article on the Pennsylvanian bioherms by Plumley and Graves (1953), and brief articles in publications of the New Mexico and Roswell Geological Societies. Many of the geologic studies in the area have been sponsored or partially supported by the New Mexico Bureau of Mines and Mineral Resources. Results of the work by Cline, it is expected, will appear in a forthcoming Bureau publication; Otte's work (1959a, 1959b) on the geology of the northernmost Sacramento Mountains has recently been published. Bachman and Hayes, of the U. S. Geological Survey, have done surface mapping in parts of the area in conjunction with the revised geologic map of the State of New Mexico, and have published an article on the Pennsylvanian and Permian stratigraphy of the southernmost part of the Sacramento Mountains escarpment (1958). Material condensed from the writer's unpublished reports was given in Kottlowski's (1960) summary of the Pennsylvanian stratigraphy of southwest New Mexico.

## SIGNIFICANCE OF THE AREA

The geology of the Sacramento Mountains escarpment is of more significance than can be gauged by the size of the range. The exposed stratigraphic section is made up almost entirely of Paleozoic rocks ranging in age from Lower Ordovician to Middle Permian. The exposures are excellent, especially of the pre-Permian strata, so that the stratigraphic and structural features of these formations can be interpreted with confidence. As many units of the Paleozoic sedimentary sequence occur elsewhere in southern New Mexico and are known to extend eastward in the subsurface to the oil fields of southeastern New Mexico and west Texas, stratigraphic studies in the Sacramento Mountains have regional significance. At present, for petroleum geologists, the significance of the area lies largely in interpretations that can be applied to the subsurface geology of the adjacent Permian Basin to the east. However, geologic studies of the Sacramento Mountains, combined with (1) those in the San Andres Mountains farther to the west by Kottlowski et al. (1956), and (2) the record of two wells drilled since 1954 in the intervening Tularosa Basin, indicate the presence of a little-known late-Pennsylvanian and early-Permian basin immediately west of the Sacramento Mountains. This has been termed the Orogrande basin (Pray, 1959). It is of unknown petroleum potential, but reserves could be inferred by analogy with other basins. Petroleum exploration activity in this basin is currently at low ebb, owing in part to the occupation of large parts of the area by military reservations.

Probably the most significant aspect of the geology of the Sacramento Mountains escarpment is unrelated to features of direct economic concern. The writer considers its prime significance to lie in the existence in a small area of a wide variety of stratigraphic features, many of which are unusually well exposed in all three dimensions. Critical future study of the host of stratigraphic features, such as abrupt facies changes, cyclic sedimentation, reefs, and other forms of carbonate buildups, can lead to much-needed elucidation of sedimentary and diagenetic processes. It is hoped that this brief geologic report will serve to call attention to these many fascinating stratigraphic features, and will provide a geologic framework within which they can be interpreted more adequately.

## ACKNOWLEDGMENTS

It is not possible to acknowledge adequately the contributions that other geologists have made toward the data and interpretations presented in this report. The inheritance of the work of such geologists as Bowsher, Darton, Laudon, Stevenson, Thompson, and others has been of much value. The major contributions that are in print are cited in the bibliography. More difficult to acknowledge are the contributions of numerous others who have studied the geology of the Sacramento Moun-

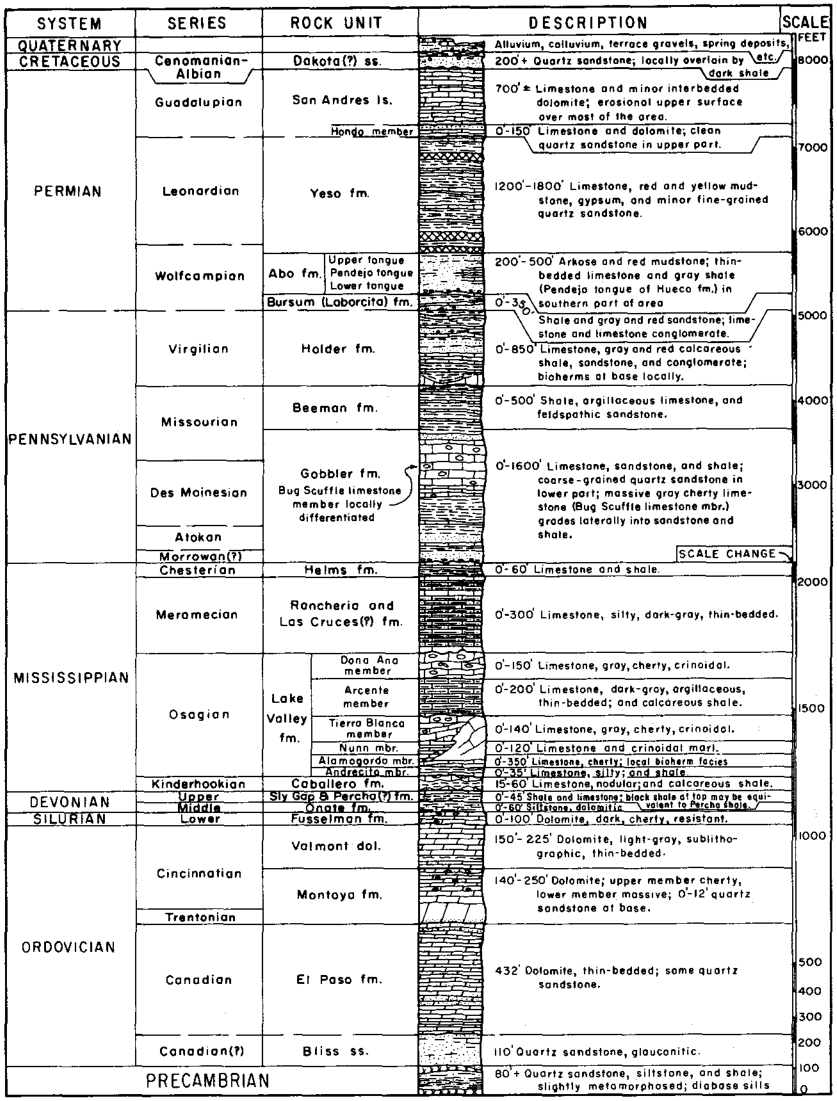



Figure 3

COMPOSITE COLUMNAR SECTION, SACRAMENTO MOUNTAINS, OTERO COUNTY, NEW MEXICO

tains and with whom the writer has had contact since beginning his work in 1947. These geologists include Carl Branson, Jerry Covington, Lewis M. Cline, Roy Graves, Richard C. Northup, E. Russell Lloyd, and Carel Otte; geologists of the New Mexico Bureau of Mines and Mineral Resources, particularly Rousseau H. Flower and Frank E. Kottlowski; the writer's former colleagues at the California Institute of Technology, especially Richard H. Jahns; and Alan Horowitz and Jack Wray, of the Ohio Oil Company. Very real assistance has been rendered by a host of geology students from the California Institute of Technology, with whom the writer had the privilege of associating in five summer field camps devoted to mapping a small area in the central part of the Sacramento Mountains escarpment. Even some of their more bizarre interpretations and observations proved to be correct.

This investigation has been made possible by the generous support of several organizations and many individuals. The New Mexico Bureau of Mines and Mineral Resources sponsored the project continuously since the beginning of field work in 1947. E. Carter Anderson, director of the Bureau from 1945 to 1949, organized the project and provided funds for field and office expenses. Eugene Callaghan, director from 1949 to 1957, made additional Bureau funds available for the drafting of maps, and Alvin J. Thompson, the present director, supported the completion of this report. Richard H. Jahns, of the California Institute of Technology, helpfully supervised the field, laboratory, and office work throughout most of the investigation until 1952. The writer was privileged to have the assistance of a National Research Council Predoctoral Fellowship in Geology from October 1946 to June 1949.

Most of the megafossils collected during the course of the field work were identified by Arthur L. Bowsher, then at the Smithsonian Institution, now with the Sinclair Oil and Gas Co. Although all the above individuals have contributed to the writer's interpretations, final responsibility for the statements made in this report belongs to the author.

Of the many local residents whose hospitality made the field work more enjoyable, Mr. and Mrs. Henry Bell, Mr. and Mrs. Wm. Danley, and Mr. and Mrs. F. S. West deserve particular mention. Acknowledgments would not be complete without mention of my wife, Carrel Myers Pray, whose encouragement and help during and after the field work have been indispensable.

The writer is particularly appreciative of the major assistance provided by Frank E. Kottlowski, of the Bureau staff, in the assembly and technical editing of the manuscript for this report. Drafting of most of the geologic maps and some of the illustrations was by David Willoughby and Ruth Musser. Final drafting of many of the illustrations, as well as editing of the geologic maps, was by William E. Arnold, of the Bureau staff. Edmund H. Kase, Jr., and Glenda K. Niccum, also of the Bureau staff, prepared the manuscript for final publication.

## PHYSICAL FEATURES

The most conspicuous topographic features of southern New Mexico are two major north-south mountain ranges, the Sierra Blanca—Sacramento Mountains range on the east and the San Andres Mountains on the west, and an intervening north-south desert depression, the Tularosa Basin. The Sacramento Mountains are the broad, southern half of the more eastern of these two ranges; they form an abrupt escarpment on the eastern side of the Tularosa Basin for a distance of about 40 miles, and are sharply asymmetric in east-west profile. The western slopes are precipitous in many places, the rise from the Tularosa Basin to the crest occurring within a distance of 7 to 13 miles (fig. 2). Eastward from the crest of the Sacramento Mountains, the land slopes almost imperceptibly toward the Pecos River, 80 miles away and about 6,000 feet lower. The crest of the mountains is arcuate in plan view, and is gently concave toward the east. As viewed in north-south profile, the crest of the Sacramento Mountains forms a gentle arch. It lies above an altitude of 9,000 feet for a distance of approximately 20 miles, the highest point being about 9,700 feet.

Northward from the highest part of the Sacramento Mountains, the crest descends gradually over a distance of about 20 miles to a saddle nearly 8,000 feet in altitude at the headwaters of Tularosa Canyon. From here northward, the mountain range rises into the Sierra Blanca, culminating in a peak 12,003 feet above sea level. To the south, the Sacramento Mountains end rather abruptly as their slopes descend into the lower, broad, flat tableland known as Otero Mesa. This continues south nearly to the Texas—New Mexico State line, where it blends into the rather low-lying Hueco Mountains. To the southeast, from the crest of the Sacramento Mountains the surface descends gradually over a distance of about 40 miles, and then merges into the northern part of the Guadalupe Mountains, a range en echelon with, and structurally similar to, the Sacramento Mountains.

The topography, climate, vegetation, accessibility, nature of the exposures, and other physical features vary greatly within the mapped area. Altitude, the resistance to erosion of the sedimentary units, and the geologic structure are major controls. The physical features are discussed conveniently on the basis of three distinct parts of the map area, the Tularosa Basin, the western escarpment, and the crestal part of the mountains.

The part of the Tularosa Basin that lies within the map area consists of low, coalescing alluvial fans that form a lobate fringe a few miles wide along the mountain base. Wider, nearly flat areas extend westward beyond the lower edges of the fans. The altitude ranges from 4,500 to 5,000 feet at the head of the fans, and the low point of the area is at about 4,000 feet. The fans have rather low gradients, rarely exceeding more than 3 or 4 degrees even near the mountain front. The maximum slope of the fans at the mouths of the larger canyons is only 2 degrees. Mesquite and creosote bush are the major shrubs covering most of the alluvial fans. A few areas of pediments occur locally at the base of the range and are recognizable by the ocotillo, which favors the bed rock rather than alluvial soils. In the western part of the map area, especially toward the south, low dunes of reddish quartz sand are common.

Most of the mapped area forms a part of the abrupt western escarpment of the Sacramento Mountains. This west slope has a distinct two-step profile, which is especially conspicuous in the central and southern parts of the area. The top or "tread" of the lower step forms a broad bench that corresponds closely to the Pennsylvanian-Permian contact. The bench is between 7,000 and 8,000 feet above sea level in much of the area. Toward the north and south, the bench lowers gradually and merges with the level of the Tularosa Basin. Over much of the area, the bench has been dissected deeply to form a series of high, flat-top ridges separated by steep-walled, west-draining canyons spaced several miles apart. The relief from canyon bottom to ridge tops is 2,000 to 3,000 feet in many places. Outcrops are excellent below the level of the bench, but commonly the steep to nearly vertical cliffs impede or prohibit travel between the bench and the base of the escarpment. Above the level of the bench, the slopes rise 1,500 to 2,500 feet to the crest of the range. These upper slopes contrast markedly with the more precipitous slopes below the level of the bench. Their profile is generally smooth, and cliffs are uncommon. Along the upper slopes, particularly at elevations above 7,000 feet, the exposures are poor, and access is hampered by dense brush. Vegetation on the western escarpment ranges from desert type near the base, through the open stands of piñion and ponderosa pine, juniper, and scrub oak at intermediate elevations, to stands characterized by spruce, fir, and aspen in the higher portions. Most of the mapped area along the crest of the range is above 8,000 feet, and a large area is above 9,000 feet. The altitude of this part of the area provides sufficient moisture for forest cover. The exposures along and east of the crest of the Sacramento Mountains, though neither abundant nor good, are adequate guides to the general structural configuration, and the evergreen and aspen forest cover creates little difficulty for access by foot or horseback. The crest in the northern part of the area is a simple drainage divide that separates east-flowing streams with gentle gradients from the steep drainage courses to the west. In the southern part of the area, the divide splits, one fork trending toward the south and the other to the southeast. The Sacramento River system drains the rather narrow area between the forks. Along the Sacramento River system, and in the area east of the main Sacramento Mountains divide, the relief between the valleys and ridges is commonly 500 to 1,000 feet. The valley bottoms are sharp, and the ridge tops generally well rounded.

Access by roads in the mapped area is limited severely by the terrain.

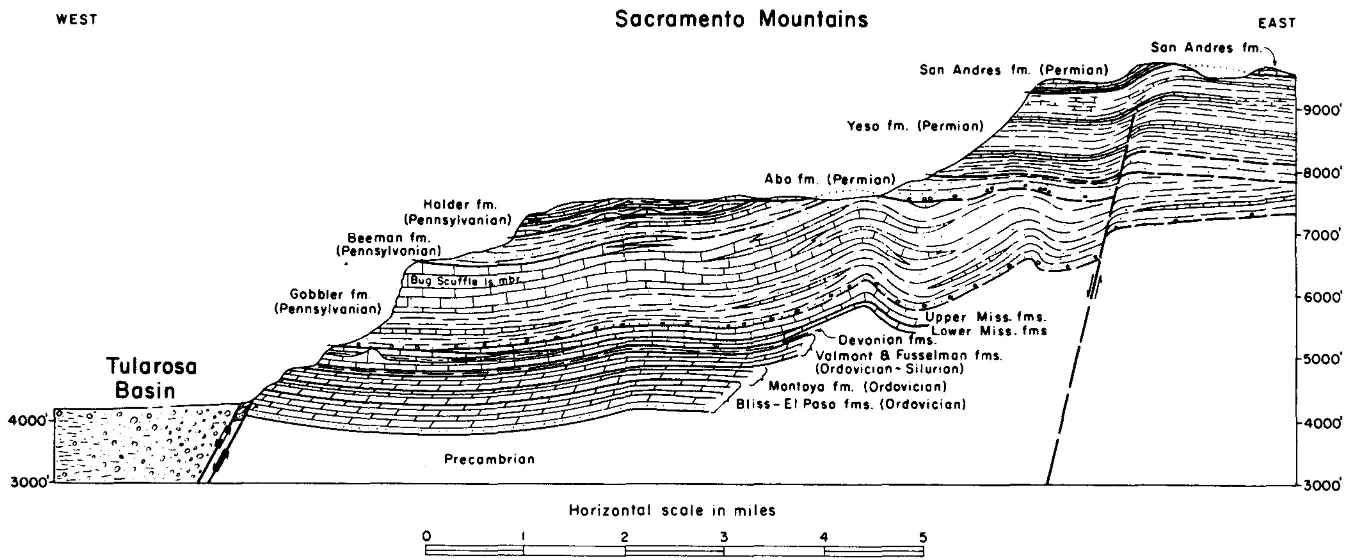



Figure 4

DIAGRAMMATIC CROSS-SECTION, CENTRAL PART, SACRAMENTO MOUNTAINS ESCARPMENT

New Mexico Highway 83, in the northern part of the escarpment, provides the major east-west route between the base and the crest of the range. East-west travel, except by foot or horse, is not possible throughout most of the southern two-thirds of the escarpment area. North-south travel in the map area is facilitated by roads along the alluvial fringe of the Tularosa Basin, a single road (the West Side Road) along the bench between the base and the crest of the escarpment, and a system of roads near and east of the crest of the range.

# *Stratigraphy*

## GENERAL FEATURES

The strata of the Sacramento Mountains range in age from Precambrian to Cretaceous and have a composite thickness of about 8,000 feet. The actual thickness in most places along the escarpment is closer to 5,000 feet, and the exposed section consists entirely of Paleozoic rocks. A summary of the stratigraphic section of the Sacramento Mountains escarpment is given in Figure 3. The general character of the stratigraphy and structure is illustrated by Figure 4, a diagrammatic east-west cross-section of the western escarpment near the center of the map area. The typical appearance of most of the pre-Permian strata along the escarpment is shown in Figure 5.

The oldest rocks exposed in the Sacramento Mountains are about 100 feet of shales, siltstones, and quartzites that crop out in a small area near the southern end of the escarpment. These rocks are considered of Precambrian age, are slightly metamorphosed, and are intruded by igneous sills. They are separated from the overlying Paleozoic strata by an angular unconformity of about 10 degrees discordance.

The thick Paleozoic stratigraphic section can be grouped conveniently into three major parts or sequences, each of approximately equal composite thickness (fig. 3). The lowest of the three sequences includes strata ranging in age from early Ordovician through Mississippian. These strata are composed mostly of carbonate rocks of marine origin, interpreted as having been deposited on a relatively stable, broad shelf area. The Ordovician through Silurian section is composed mostly of dolomite and minor quartz sandstones. These strata have a relatively constant lithologic character throughout the area. The Devonian units form a thin and variable succession of limestone and shale, with minor quartz sandstone and siltstone. The Mississippian strata are composed of marine limestone and minor shale. These strata vary considerably within the mapped area, owing largely to abrupt changes in depositional facies associated with biohermal complexes, and to variations caused by erosion during later Mississippian and early Pennsylvanian time.

The middle third of the Paleozoic section of the Sacramento Mountains consists of Pennsylvanian strata. These form a complexly interbedded sequence of limestone, sandstone, and shale, which is largely, but not exclusively, of marine origin. Rapid changes in depositional facies, together with cyclic sedimentation and local bioherms, are interesting and important features of this Pennsylvanian section. The later Pennsylvanian and early Permian strata record the effects of deformation and uplift of the eastern part of the area in contrast to subsidence and more continual deposition in the western part. This differential tecton-

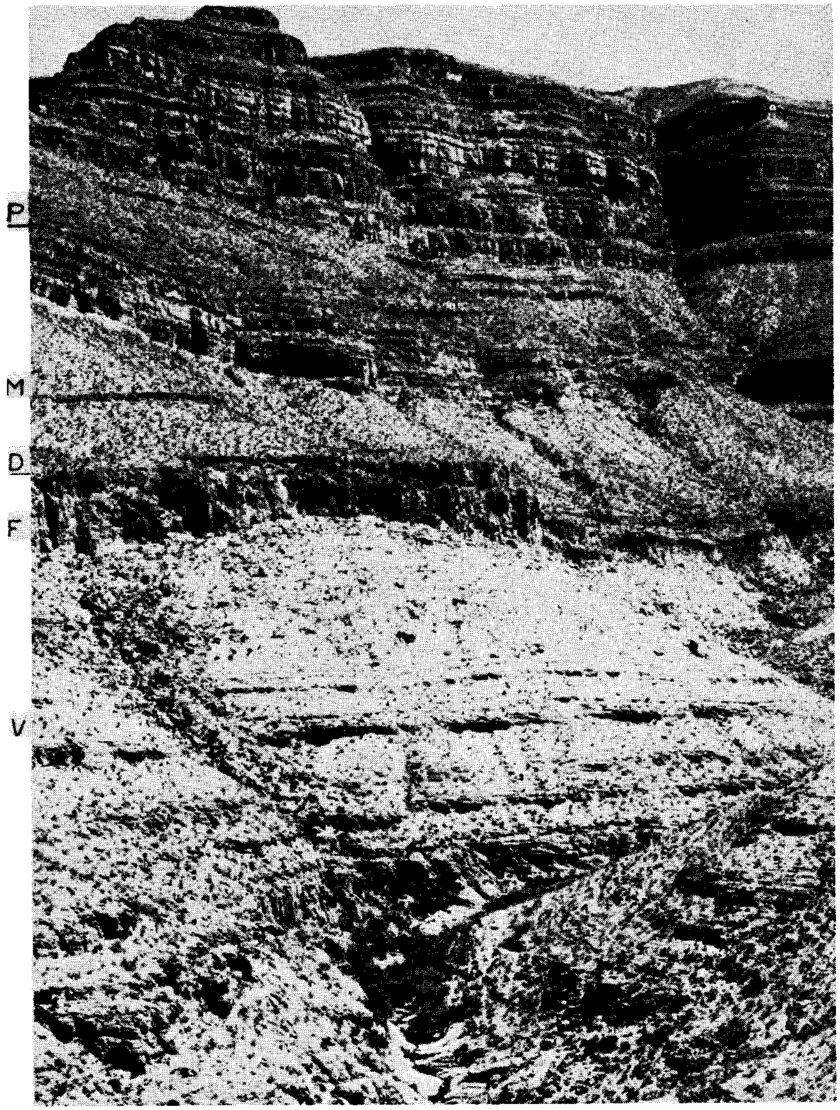



Figure 5

PALEOZOIC SEQUENCE IN DOG CANYON, SOUTH-CENTRAL SACRAMENTO MOUNTAINS

About 2,000 feet of strata shown; bases of units designated are: V, Valmont dolomite; F, Fusselman formation; D, Devonian beds; M, Mississippian formations; and P, Pennsylvanian rocks. Upper sheer cliffs are Bug Scuffle limestone member of the Gobbler formation.

ism has profound effects on the stratigraphic record. The Pennsylvanian strata range in thickness from 2,000 to 3,000 feet where not appreciably thinned by pre-Permian erosion. In much of the mapped area, pre-Permian erosion has removed part of the Pennsylvanian strata, and in one locality has cut out the entire Pennsylvanian section.

The upper third of the Paleozoic section is composed of Permian strata. These include both marine and nonmarine units, with a general progression from nonmarine to marine with decreasing age. Reel beds are conspicuous in the lower two-thirds of this sequence, and evaporites, largely anhydrite and gypsum, occur in the middle part of the sequence.

Known post-Paleozoic strata in the escarpment area are limited to a few outcrops of Cretaceous sandstone and shale along the northernmost part of the Sacramento divide, and to late-Cenozoic surficial deposits.

Several dry holes drilled since 1952 in the immediate vicinity of the Sacramento Mountains escarpment have furnished pertinent subsurface information that supplements available outcrop data. The closest three are the following: (1) Southern Production Co. No. I Cloudcroft, sec. 5, T. 17 S., R. 12 E.; (2) Sun Oil Co. No. 1 Pearson-Federal, sec. 35, T. 20 S., R. 10 E.; and (3) Plymouth Oil Co. No. 1 Federal, sec. 15, T. 20 S., R. 9 E. The Southern Production Company test is located near the crest of the Sacramento Mountains. It affords a valuable subsurface record of the entire Paleozoic section that can be compared directly with the outcrop record along the escarpment only a few miles farther to the west, and also provides a valuable link between the many subsurface tests farther east and the outcrop area. The other two wells are in the Tularosa Basin near the southern end of the Sacramento Mountains escarpment and are valuable for evidence relating to the late-Paleozoic Orogrande basin.

## STRATIGRAPHIC APPROACH AND STANDARDS

The writer's work has been concerned primarily with the physical aspects of the stratigraphy of the Sacramento Mountains; little effort was made to obtain extensive faunal collections or to do faunal zonation. Intensive effort was placed on determining the physical characteristics of the stratigraphic section, the subdivision of the sequence into mappable units, and the detailed tracing of those units in the field. The detailed paleontologic studies that Flower (1957, 1959) has been making represent a type of work long overdue in New Mexico. This approach, combined with detailed physical stratigraphy, should ultimately result in a much better understanding of the age and correlation of the many rock units of the region.

Most of the stratigraphic sections included in this report are described by a graphic log accompanied by a word description of the lithology. Although the graphic logs are necessarily diagrammatic, they were plotted in the field, and attempts were made to plot the bedding and other lithologic features to scale, insofar as possible. Where not drawn to scale, the relative size of features such as sand grains or chert nodules is indicated by the size of the symbol. Most sections were measured by hand leveling by means of the Hewett technique (Hewett, 1920). The National Research Council Rock-Color Chart (Goddard et al., 1948) was used throughout the work. Except where the precise color code number seems to be of diagnostic value, the colors are referred to by the chart names. Detrital grain sizes are recorded in the terminology of the Wentworth grade scale (Wentworth, 1922). The Payne (1942) adaptation of this scale for crystal sizes of carbonate rocks was adopted and has been used consistently with dolomites, where detailed crystal size is a valuable diagnostic feature. Crystal sizes in the limestones exhibit much greater range than in the dolomites or detrital rocks and, in general, have not been described in detail. The grain size of the limestones of obvious clastic nature generally is designated by classification as calcilutite, calcarenite, or calcirudite; where further distinction seemed important, a more specific size grade within the calcarenite ($^1/_{16}$ to 2 mm) or calcirudite (-I- 2 mm) size range is designated. Petrographic study of the limestones described during the course of the field work would probably reveal that many that were described simply as limestone are calcisiltites or calcarenites, but petrographic description of the wide range of limestone types within the thick carbonate sections, such as those of the Pennsylvanian or Permian, was beyond the scope of the original work.

In most descriptions, the thickness of bedding is given in numerical terms and, where feasible, is shown to scale on the graphic log. Where general terms were used, "thick bedded" was applied to a separation of principal bedding planes of more than 3 feet, "medium bedded" to separations of from 1 to 3 feet, "thin bedded" to separations of one-quarter inch to 1 foot, and "laminated" to rock with layering closer than one-quarter inch. The term massive has been applied where the rock layer is devoid, or nearly so, of lithologic discontinuities.

For the purposes of this brief report, most of the lithologic units are described in detail at a single locality deemed to have the most representative and best exposed section. Lateral variations within the mapped area are discussed briefly, but additional detailed sections within the area are not included in this report. Such details are available in the earlier unpublished report (Pray, 1952). In the discussions of the various rock units, the aspects generally are treated in the following sequence: general statement, area of outcrops, lithologic details and thickness, depositional environment, contacts, and age and correlation. The lower contact of each rock unit is discussed in detail as a part of the treatment of the overlying section.

## PRECAMBRIAN ROCKS

The oldest rocks exposed in the Sacramento Mountains are of sedimentary origin. These are largely shale, siltstone, and fine-grained quartz sandstone that have been but slightly metamorphosed. The only outcrops known in the mapped area occur near the southern end of the escarpment. Appropriately enough, in view of the overall cuesta structure of the Sacramento Mountains, the Precambrian rocks occupy the lowest area of bedrock outcrop along the range front. The exposed sedimentary sequence is approximately 80 feet thick. Igneous intrusive rocks of basic to intermediate composition occur in the section, mostly in the form of thin sills. Some of these are porphyritic, locally with such large and abundant phenocrysts that they bear a superficial resemblance to plutonic intrusive rocks and apparently were so interpreted by earlier geologists. The intrusive rocks as well as the associated sedimentary rocks are interpreted to be of Precambrian age.

The Precambrian outcrops occur in a narrow band at the base of the escarpment on both sides of the head of the alluvial fan at Negro Ed Canyon. The width of outcrop between the alluvial fringe and the overlying Paleozoic section is generally less than 500 feet, and the total length only about a mile and a half. The best exposures are in minor gullies. Over most of the outcrop area, the strata strike north and dip gently east, but toward the western limit of outcrop, the dip is locally reversed by drag effects along the interpreted boundary fault zone of the range.

The section shown as Figure 6 represents the rocks exposed in the northern and broadest part of the outcrop belt, and is representative of the rocks of the entire area. Of the Precambrian sedimentary rocks, gray-green shales and siltstones are dominant. Layers of quartz sandstone, commonly only a few inches thick, form a conspicuous but minor part of the sequence. Many beds are delicately crosslaminated. The sandstones are generally fine-grained, clean, well-sorted rocks. Some fucoidal markings, other obscure structures, and mud cracks occur. Diagnostic fossils have not been discovered. The lithologic character of the strata suggests slow deposition in shallow water. Feldspar forms only a small proportion of the detrital particles.

### STRATIGRAPHIC SECTION OF PRECAMBRIAN ROCKS EXPOSED NEAR AGIJA CHIOIJITA CANYON

**Section (fig. 6) measured eastward up slope from point on west line of sec. 1, 2,000 feet south of NW. corner of sec. 1, T. 19 S., R. 10 E.**

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| | *Bliss sandstone* | |
| 2 | Quartz sandstone, light-brown, medium-grained; partly crosslaminated, worm(?) borings common | 12 |

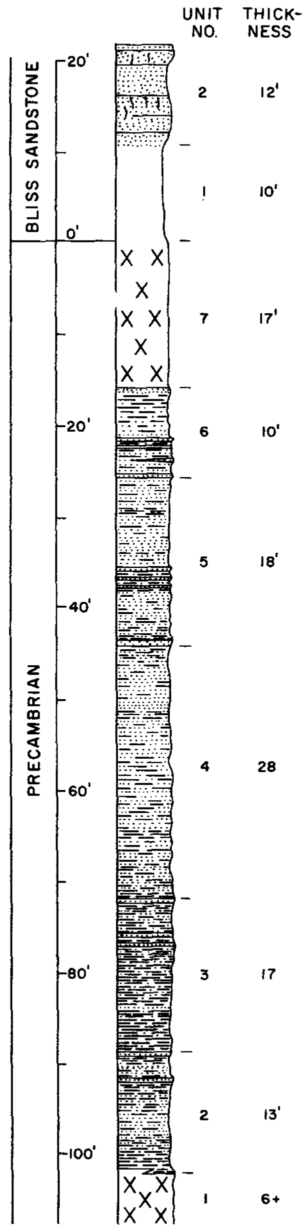



**Figure 6**

STRATIGRAPHIC SECTION OF PRECAMBRIAN ROCKS EXPOSED NEAR AGUA CHIQUITA CANYON

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| 1 | Covered; 4,000 feet S. 30° E. of the section, at or near this interval, an angular unconformity (10° discordance) separates the overlying sandstones from underlying finer grained quartzites, siltstones, and intrusive sills | 10 |
| | **PRECAMBRIAN ROCKS** | |
| 7 | Diorite sill, dark, fine-grained | 17 |
| 6 | Quartzite, fine- to medium-grained; interbedded siltstone; spotted shales near contact with sill | 10 |
| 5 | Quartzite, mottled red and green, fine-grained; 1- to 2-inch beds; siltstone; shaly partings; some "fucoids" | 18 |
| 4 | Siltstone, gray-green, thin-bedded, micaceous; fine-grained sandstone; shaly partings, slightly spotted by contact metamorphism | 28 |
| 3 | Shales and siltstone, gray-green, thin-bedded, micaceous; some fine-grained quartzite beds less than 1 in. thick; argillaceous layers distinctly spotted by contact metamorphism | 17 |
| 2 | Quartzite, gray-green, fine-grained, thin-beddd; siltstones; shaly partings | 13 |
| 1 | Diorite porphyry, intrusive into sedimentary beds and causing slight contact metamorphism; base of sill(?) and underlying sediments not exposed | 6 |

The igneous rocks that are closely associated with the Precambrian sedimentary strata are dark hypabyssal rocks of basic to intermediate composition. They are referred to here under the field term of diabase. In detail, many of these rocks differ from a strict definition of diabase, as they are somewhat more silicic and commonly have an intersertal, rather than ophitic, texture. The most abundant intrusive type is finely crystalline, nonporphyri tic rock, composed of about equal quantities of dark and light minerals. Andesine is the predominant feldspar. Chlorite, probably formed by alteration of augite and biotite, is usually the most abundant of the dark minerals. Augite and biotite are subordinate varietal minerals; apatite, magnetite, and ilmenite are abundant accessory minerals. Some of the intrusives are porphyritic, with phenocrysts of andesine as large as a centimeter. Potash feldspar occurs in some rocks as a minor constituent of the groundmass. On the south side of Negro Ed Canyon, a local mass of porphyritic rock has been observed in which altered potash feldspar phenocrysts are as large as 2 centimeters across and form nearly half the rock.

The igneous rocks are clearly intrusive into the sedimentary rocks, as evidenced by apophyses, sedimentary inclusions, local crosscutting relationships, and contact metamorphism adjacent to the igneous bodies. Most of the igneous bodies appear to be sills. The largest sill of which both contacts are exposed is about 30 feet thick and can be traced for a quarter of a mile.

The metamorphic effects adjacent to the igneous contacts are relatively minor. The major effect has been the development of spotted slates from the more argillaceous layers. The spots are caused by the formation of more coarsely crystalline sericite and chlorite. Some of the metamorphic effects in the rocks may be related to low-grade regional metamorphism.

There is little evidence by which to establish closely the age of these oldest sedimentary rocks and the associated intrusive rocks. The most significant field relationships are that these rocks are below the Bliss sandstone, herein considered of Lower Ordovician age, and are separated from the Bliss strata by an unconformity with an angular discordance of approximately 10 degrees (fig. 7). The igneous rocks and the contact metamorphism appear to be restricted to rocks below the unconformity. It is possible that the sedimentary strata and associated igneous intrusive rocks here described are of early Paleozoic age, but the assumption of a late Precambrian age seems more probable on the basis of known regional relationships.

Small outcrops of probable Precambrian rocks occur in the vicinity of Bent, in the northernmost part of the Sacramento Mountains, about 10 miles north of the mapped area. These outcrops, in and near section 25, T. 13 S., **R.** 11 E., were discovered and interpreted as Precambrian by Bachman (1954; also Dane and Bachman, 1958). The Precambrian rocks are overlain by lower Permian strata of the Abo formation. The writer has not seen these exposures. To judge from their geographic position, the reported stratigraphic relationships, and the geology of the area mapped by the writer to the south, it is probable that they occur on the western part of an uplifted pre-Abo fault block, and that much or all of the pre-Permian Paleozoic section was eroded from this uplifted block during latest Pennsylvanian and early Permian time. The Bent outcrops are described briefly by Foster (1959). According to Foster, Kottlowski identified the basement rock as granodiorite and quartzite, and stated that another intrusive rock composed of fine- to coarse-grained quartz diorite just south of Bent, which had been mapped as Tertiary by Bachman, may also be of Precambrian age.

According to the writer's interpretation, the Southern Production Co. No. 1 Cloudcroft oil test (sec. 5, T. 17 S., R. 12 E.) penetrated about 100 feet below the base of the Bliss sandstone. The pre-Bliss section consists largely of relatively unmetamorphosed quartz sandstone and contains two bodies of "diabasic" intrusive rocks that are remarkably similar to those exposed in the Precambrian section in the vicinity of Negro Ed Canyon.

Many details regarding the subsurface Precambrian rocks of the Sacramento Mountains region have been given by Foster (1959) and are not reviewed here. These are of particular value for the evidence they bear on the extent and geographic position of the late-Paleozoic Pedernal landmass.

Two aspects of the Precambrian rocks found in the Sacramento Mountains escarpment and in the closer of the drill holes that penetrate such rocks in the subsurface are of importance from a regional point of view. The more significant is that the pre-Bliss rocks are composed predominantly of sedimentary detrital rocks that have been metamor-

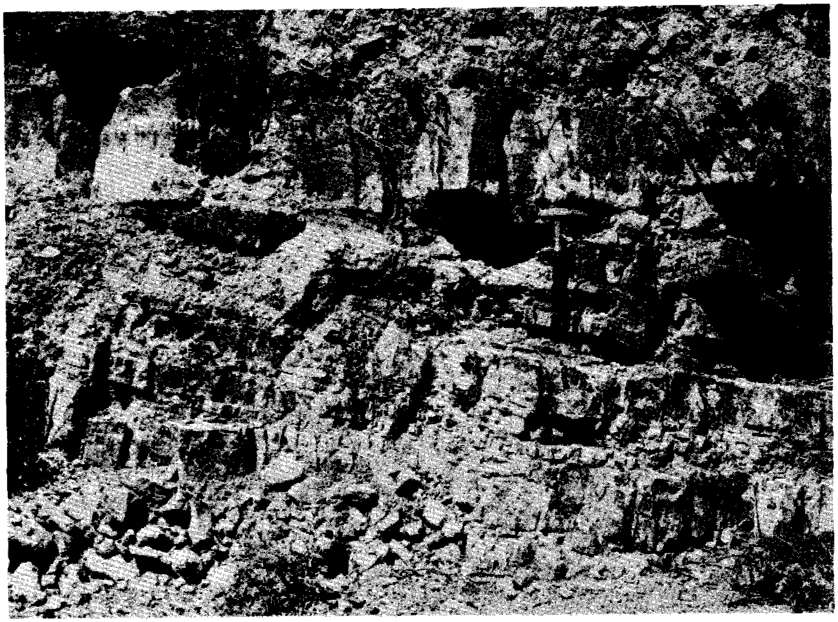


Figure 7

UNCONFORMITY BETWEEN PRECAMBRIAN ROCKS AND OVERLYING BLISS SANDSTONE, AGUA CHIQUITA CANYON

phosed only slightly. This is in contrast to the plutonic or more highly metamorphosed Precambrian rocks that occur in much of the San Andres Mountains to the west (Kottlowski et al., 1956), and to the volcanic types found farther to the east (Flawn, 1956). The second aspect is the occurrence in the Gulf No. 1 Chaves "U" well (sec. 10, T. 18 °S., R. 16 E.) of a thick section of relatively pure dolomite below strata interpreted as the Bliss sandstone. The precise interpretation of the 450 feet of section below the base of the Bliss sandstone is uncertain. This section includes, however, several hundred feet of relatively pure dolomite and some igneous intrusive rocks. The writer believes that igneous intrusive rocks have created contact-metamorphic zones in the carbonate sequence, forming such minerals as talc and zoisite. This contact-metamorphosed rock may be the same as that identified by Flawn (1956) as an altered flow or tuff; it well deserves further study, as it contains the only occurrence known to the writer of relatively pure carbonates underlying the Bliss sandstone in southern New Mexico. The assignment of Precambrian age to the entire pre-Bliss section is uncertain, but the similarity of the igneous rocks to those in the Southern

Production Co. No. 1 Cloudcroft well and to the Sacramento outcrops, makes a Precambrian age appear reasonable (cf. Foster, 1959; Flawn, 1956).

## BLISS SANDSTONE

The Bliss sandstone forms the basal unit of the Paleozoic sequence in the Sacramento Mountains, as in other parts of south-central New Mexico. The main exposures of this unit are at the base of the escarpment in the southern part of the Sacramento Mountains. The strata assigned to the Bliss sandstone are composed largely of quartz sandstone, with minor dolomitic sandstone and sandy dolomite. The section is about 110 feet thick and is similar in general character to the type section near El Paso, Texas. The age is considered Lower Ordovician by Flower (1959), but age-diagnostic fossils have not been obtained in the area of the Sacramento Mountains.

The only significant outcrops of Bliss sandstone recognized in the Sacramento Mountains are low in the southern part of the escarpment on both sides of Negro Ed Canyon, in Tps. 18 and 19 S., R. 10 E. Here the outcrop belt extends a distance of 2 miles. The Bliss sandstone overlies the Precambrian rocks and extends laterally somewhat beyond the exposed limits of the older rocks. The only other outcrop area of Bliss sandstone recognized by the writer occurs in a narrow faulted zone at the base of the escarpment in section 20, T. 17 S., R. 10 E. Other reported outcrops of Bliss sandstone in the Sacramento Mountains (Darton, 1928; Roswell Geological Society, 1953, p. 15) are interpreted by the writer as quartz sandstones within the overlying El Paso formation.

## STRATIGRAPHIC SECTION OF THE BLISS SANDSTONE

Measured (fig. 8) in the NW1/4 sec. 1, T. 19 S., R. 10 E. Units 1-6 measured directly above the Precambrian section (fig. 6) at a point 2,000 feet south of NW. corner of sec. 1. Units 6-12 measured in main channel of Agua Chiquita Canyon, beginning on west line of sec. I, 1,400 feet south of NW. corner of sec. 1.

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| | *El Paso formation* | |
| | Dolomite, light- to medium-gray, finely crystalline; beds 6 inches to 2 feet thick; minor argillaceous dolomite and gray chert | 72 |
| | Quartz sandstone, coarse-grained, light-brown; few quartz pebbles near base; basal contact locally channeled a few inches | 1 |
| | *Bliss sandstone*—110 feet thick | |
| 12 | Quartz sandstone, light-tan, medium- to coarse-grained, quartzitic, cross-laminated; abundant worm(?) borings; 2 inches of fine-grained quartz sandstone 2 feet above base; unit forms dark-weathering low cliff | 7 |
| 11 | Quartz sandstone, light-tan, fine-grained | 10 |
| 10 | Quartz sandstone, tan, fine-grained; interbedded with minor, sandy, medium-crystalline dolomite; obscure, small organic(?) nodules; beds average 1 foot thick; minor crosslamination | 19 |

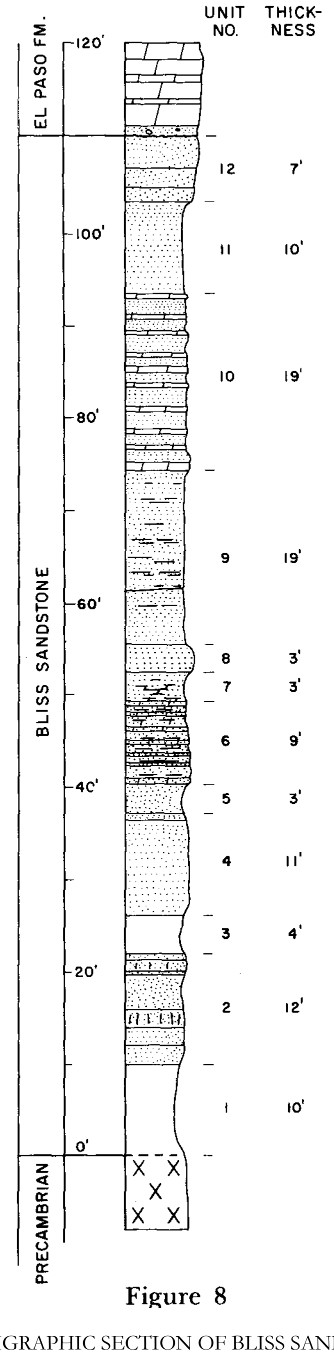



**Figure 8**

STRATIGRAPHIC SECTION OF BLISS SANDSTONE,
AGUA CHIQUITA CANYON

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| 9 | Quartz sandstone, tan to greenish-gray, fine-grained; some interbedded siltstone; minor fault 6 feet above base, so that a few feet of section may be missing | 19 |
| 8 | Quartz sandstone, green, medium-grained, massive, glauconite-rich | 3 |
| 7 | Quartz sandstone, dolomitic, fine-grained, laminated; weathered surfaces have distinctive "combed" texture | 3 |
| 6 | Dolomite, tan, medium-crystalline, sandy, glauconitic; interbedded with minor glauconitic siltstone and shale; dolomite beds, 2 to 6 inches thick, form about half of the unit; upper contact gradational | 9 |
| 5 | Quartz sandstone, green, glauconite-rich, poorly exposed | 3 |
| 4 | Quartz sandstone, deep-purple to green, medium-grained, glauconitic; this unit is a distinctive marker of the lower Bliss sandstone | 11 |
| 3 | Covered | 4 |
| 2 | Quartz sandstone, light-tan, medium-grained, crosslaminated, partly quartzitic; worm(?) borings abundant in top and middle beds | 12 |
| 1 | Covered; 4,000 feet to S. 30° E., at or near this interval, an angular unconformity separates Bliss sandstone from underlying Precambrian rocks | 10 |

**PRECAMBRIAN ROCKS**

**Diorite porphyry sill**

The Bliss sandstone of the Sacramento Mountains consists mainly of quartz sandstone. Thin beds of clastic dolomite form about a quarter **of** the section. Siltstone and shale occur in minor quantities. Details of the stratigraphic section exposed on the north side of Negro Ed Canyon are shown in Figure 8. Most of the quartz sandstone is fine to coarse grained, clean, and rather well sorted. The grains are commonly sub-rounded. Glauconite, mostly in the form of discrete grains, is a conspicuous part of some of the sandstone layers. Feldspar grains are uncommon. Accessory minerals are largely the stable assemblage of zircon, tourmaline, and garnet. Some strata are friable and porous in marked distinction to sandstones of the underlying Precambrian section, but others are tightly cemented with silica. Many beds are crosslaminated. Boring structures 0.1 to 0.2 inch in diameter and 3 to 6 inches long, generally nearly vertical, are common features. These are frequently interpreted as worm borings, but they could have been produced by other types of burrowing organisms.

Dolomitic quartz sandstone and sandy dolomite, commonly in thin beds with minor laminated structures, occur in the middle and upper parts of the Bliss section. These are commonly glauconitic and weather to a brownish color. Differential weathering of the quartzose and carbonate laminae produces a distinctive "combed" appearance.

The coarsest detrital particles of the Bliss section were noted in the 1 1/2-foot-thick bed of granule-pebble conglomerate directly overlying the basal angular unconformity (fig. 7). The coarser clasts were quartz and chert. This basal layer was not exposed farther north where the section of Figure 8 was examined.

Several of the beds in the Bliss sandstone, particularly in the upper part of the section, weather dark reddish brown, owing largely to the glauconite. Oolitic iron ore, which forms a part of the Bliss section in several areas in south-central New Mexico, has not been recognized in the Sacramento Mountains.

The section of Bliss sandstone penetrated in the Southern Production Co. No. 1 Cloudcroft oil test is essentially similar to that of the outcrop.

Fossils are scarce in the Bliss sandstone of the Sacramento Mountains, and those found to date have little diagnostic value. A few poorly preserved linguloid brachiopods, identified by Bowsher as *Lingulepsis* sp. indet., have been collected from the lower part of the section. These are similar to fossils recovered from the Bliss at the type section near El Paso, as well as from other localities, all of which are currently interpreted by Flower (1959) as of Canadian (Lower Ordovician) age. The vertical borings so abundant in some layers have not been identified as to age or type of organism.

The lower contact of the Bliss sandstone with the underlying Precambrian rocks is well exposed only at one locality (fig. 7). At this locality (about 2,200 ft E. of NW. cor. of sec. 12, T. 19 S., R. 10 E.), an unconformity, with an angular discordance of about 10 degrees, is exposed for a distance of 35 feet. The sedimentary strata below this contact are lithologically similar to Precambrian strata of the area and are intimately associated with intrusive sills. The strata above the contact consist of a basal layer of granule-pebble conglomerate and sandstone overlain by silty shale and minor medium-grained sandstone, and are interpreted as Bliss sandstone. The unconformity, which appears to be of very low relief, is considered the base of the Paleozoic section of the Sacramento Mountains. The upper contact of the Bliss sandstone cannot be fixed with assurance. Any of several minor breaks in the lithologic section could be selected as the contact. One or more of these may represent disconformities, but it is equally possible that no disconformity occurs.

## EL PASO FORMATION

The El Paso formation in the Sacramento Mountains is of Lower Ordovician age. It consists of about 430 feet of dolomites, minor sandy dolomite, and dolomitic quartz sandstones. The El Paso formation overlies the Bliss sandstone and is either transitional with the Bliss or separated from it by a minor disconformity. The upper contact with the overlying Montoya formation is a sharply defined, regional disconformity.

Outcrops of the El Paso formation are nearly continuous along the base of the escarpment in the central and southern parts of the Sacramento Mountains. In addition, the formation is locally exposed in several areas east of the mountain front, where erosion has cut deeply into structurally high areas. Most of these areas lie within a few miles of Alamo Peak, in the north-central part of the mapped area. One outcrop occurs in Grapevine Canyon, near the southern border of the mapped area. Despite the extensive exposures of the El Paso formation, the only complete sections occur near Negro Ed Canyon in the southern part of the escarpment. Nearly 400 feet of the El Paso, an almost complete section, occurs along the base of the range just south of Alamo Canyon, in T. 17. S.

The complete El Paso section is best exposed about a mile north of Negro Ed Canyon, where the formation is 432 feet thick. The graphic section is shown in Figure 10, and the lithologic description is given below. The sections occurring in the subsurface, as shown from two oil tests adjacent to the mapped area (Southern Production Co. No. 1 Cloudcroft unit, sec. 5, T. 17 S., R. 12 E., and the Plymouth No. 1 Federal, sec. 15, T. 20 S., R. 9 E.) and partial surface sections elsewhere in the Sacramento Mountains, are closely comparable to the El Paso section of Figure 10.

The El Paso formation in the Sacramento Mountains consists largely of light-gray to light olive-gray, very finely to medium-crystalline dolomite. The most typical single lithology of the El Paso is light olive-gray, finely crystalline dolomite. Thin to medium beds predominate in most of the formation; only a few units are massive bedded through a thickness of as much as 10 feet. Dolomitic quartz sandstone is common in the interval between 100 and 160 feet above the base. Minor amounts of dolomitic quartz sandstone and somewhat more abundant layers of sandy (quartzose) dolomite occur in this same interval; they are also common in the uppermost 100 feet of the section. Occasional thin units of sandy dolomite occur sporadically in the remainder of the section. Except in the basal few feet of the formation, glauconite is absent. Chert is a relatively minor constituent of the El Paso formation, but is common as sporadic nodules and lenses in the middle third of the sequence. Discrete nodules and seams of chert, normally light- to medium-gray, are rarely more than 2 to 3 inches thick.

The El Paso formation weathers to a light-colored slope, in distinct contrast to the overlying dark, steep cliffs of the lower part of the Montoya formation. These contrasts in color and topographic expression (fig. 9) serve to differentiate the El Paso from the Montoya in most of the outcrop area. Locally, low resistant ledges occur on the El Paso slope, formed by the more massive or thicker bedded dolomite units or by zones of dolomitic quartz sandstone.

The lithologic characteristics of the El Paso formation in the Sacramento Mountains suggest accumulation of the initial sediment on a broad open-marine shelf, in shallow, moderately turbulent water. The dolomite content and the other lithologic characteristics suggest deposition in warmer and shallower water than prevailed in the area of the type section farther to the south (Cloud and Barnes, 1948).

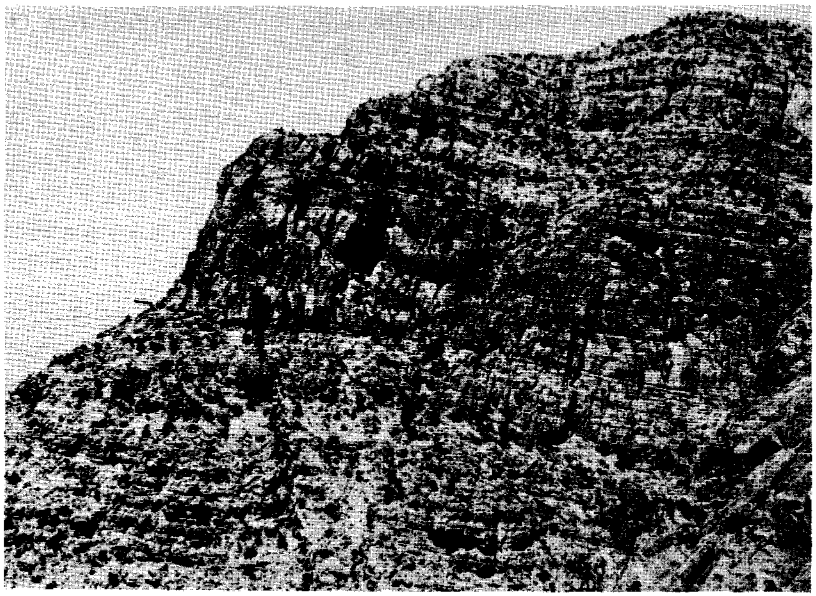


**Figure 9**

**TYPICAL OUTCROP PROFILE OF UPPER EL PASO, MONTOYA, AND VALMONT FORMATIONS, ARROW** CANYON

Basal contact of the Montoya is marked at left; dark massive cliff is lower member of the Montoya, overlying lighter ledges are the upper member; skyline slopes are cut on lower beds of Valmont dolomite.

The Bliss sandstone may be transitional with the El Paso formation in the Sacramento Mountains, although a disconformity could exist at the base of several clastic units in the Bliss—El Paso transition zone. Undoubtedly, the El Paso formation contained many fossils, but many have been obscured and obliterated by dolomitization. The El Paso formation is dated as Lower Ordovician (Canadian). The fossils that have been collected suggest .a correlation with the lower part of the type El Paso section of the Franklin Mountains. Flower (1959) indicated that the youngest part here belongs to the "second piloceroid" zone, a faunal zone common in the upper El Paso in southern New Mexico. Comparison of the Sacramento Mountains section with the type section suggests the same northeastward changes as those existing, south to north, in the San Andres range (Kottlowski et al., 1956). The El Paso formation becomes thinner, in part at least by erosional truncation; and the formation becomes more dominantly dolomite as compared to the mixed limestone-dolomite sequence of the type locality.

The thickest section of the El Paso formation that was measured was in Agua Chiquita Canyon (fig. 10), and is described as follows:

## STRATIGRAPHIC SECTION OF THE EL PASO FORMATION IN THE SOUTHERN SACRAMENTO MOUNTAINS

Section measured in Agua Chiquita Canyon. Base of section at 4,500 feet altitude, and 200 feet east and 1,400 feet south of the northwest corner of sec. I, T. 19 S., R. 10 E.; top of section is 1,000 feet east of base.

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| | *Montoya formation* | |
| | Quartz sandstone and conglomerate, coarse-grained to granule size (1-4 mm); subrounded and frosted grains; dolomitic, massive; grade upward in 5 feet into sandy, finely to medium-crystalline dolomite | |
| | Contact is smooth, with only a few inches of relief except for minor "dikes" of sandstone filling fractures penetrating downward into the upper 1-2 feet of the El Paso formation; disconformity | |
| | *El Paso formation*—432 feet thick | |
| 23 | Dolomite, light-gray to light olive-gray, finely to medium-crystalline; obscure laminations in essentially massive unit; minor streaks of fine-grained quartz sand; irregular 1-foot-thick silicified zone 4 feet above base | 13 |
| 22 | Dolomite, light-gray to light olive-gray, very finely to finely crystalline, obscurely laminated; contains 20 percent quartz grains 1-4 mm | 6 |
| 21 | Dolomite, light-gray to light olive-gray, finely to medium-crystalline; some obscurely crosslaminated sandy dolomite with fine-grained quartz | 13 |
| 20 | Dolomite, medium-gray, finely crystalline; even, obscure beds (2 in. to 3 ft thick); obscure lamination within beds | 4 |
| 19 | Dolomite, light olive-gray, very finely crystalline; sandy, with coarse- to very coarse-grained quartz grains | 2 |
| 18 | Dolomite, light olive-gray, very finely to finely crystalline; in lower 13 feet mostly irregular 2-inch to 2-foot-thick obscure beds; 3-6 feet above base similar to unit 17 except for absence of chert; upper 6 feet massive | 19 |
| 17 | Dolomite, medium-gray, finely crystalline; conspicuous even beds 2-6 inches thick; minor ($<1\%$) medium-gray chert nodules and seams ($<1$ in. thick) | 9 |
| 16 | Dolomite; thin, irregular, obscure beds with 2-inch-thick chert band at top; unit contains 5 to 10 percent undulating silicified streaks (1 in. long and 0.1 in. thick) that form reticulated markings on bedding plane | 10 |
| 15 | Dolomite, medium-gray to olive-gray, finely crystalline, obscurely bedded to massive; minor sandy dolomite with fine-grained quartz; scattered ($<1\%$), irregular 1-inch nodules of white chert; unit forms lower of two resistant cliffs in upper El Paso section | 22 |
| 14 | Dolomite. Rock units in this part of section are difficult to distinguish and trace, owing largely to minor faulting, poor exposures, and lenticular to obscure bedding. Lithologic units are all dolomite, very finely to finely crystalline, light olive-gray to medium-gray, with sporadic irregular zones of light- to dark-gray chert nodules, commonly 1-3 inches thick, which form up to 10 percent of rock unit | 127 |
| 13 | Dolomite, light olive-gray to medium light-gray, finely crystalline; obscure, faintly laminated beds; minor quartz sand streaks and 1- to 2-inch nodules of dark-gray chert; unit weathers yellowish brown | 26 |
| 12 | Dolomite, light olive-gray to light-gray, finely crystalline, obscurely bedded to massive; 1- to 2-inch nodules of dark-gray chert sporadic in lower 4 feet, more abundant in upper 3 feet | 13 |

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| 11 | Dolomite, light-gray to olive-gray, finely crystalline; minor quartz grains; even beds 6 inches to 1 foot thick alternate with 6-inch to 1-foot zones of irregular, nodular (1 in.) bedding | 10 |
| 10 | Dolomite, sandy, medium- to medium dark-gray, finely crystalline; 6-inch- to 2-foot-thick, essentially massive beds, locally crosslaminated; weathers dark brown; fine- to medium-grained quartz throughout, less abundant in middle portion | 18 |
| 9 | Poorly exposed; mostly thin-bedded dolomite, locally sandy | 8 |
| 8 | Quartz sandstone, very light-gray, fine- to medium-grained, dolomitic; grades upward into light olive-gray, finely crystalline, massive, sandy dolomite; forms resistant unit; lower contact sharp and irregular, with 6-inch relief in 2 feet | 22 |
| 7 | Quartz sandstone, fine-grained, very light-gray, siliceous; few worm(?) borings; sharp, irregular lower contact | 1 |
| 6 | Dolomite, light-gray, very finely to finely crystalline; obscure bedding, locally massive; fine- to medium-grained quartz grains in obscure laminations; minor small chert particles | 11 |
| 5 | Dolomite, light-gray to light olive-gray, finely crystalline; obscure bedding; minor fault breaks and shearing complicate this rock unit | 13 |
| 4 | Dolomite, light olive-gray, finely crystalline; even to undulating beds 4 inches to 2 feet thick | 11 |
| 3 | Chert, light-gray, cryptocrystalline; in seams and nodules 1-6 inches thick; partially silicified dolomite; minor interbedded dolomite | 1 |
| 2 | Dolomite, light brownish-gray to olive-gray, finely to medium-crystalline; irregular to undulating bedding planes 4 inches to 2 feet apart, locally obscure; beds massive to faintly laminated; minor streaks of fine- to medium-grained quartz grains; locally, in upper part, minor, wavy siliceous streaks, commonly $< 1/4$ inch x 1/16 inch, weather in relief to reticulated pattern on bedding-plane surfaces | 72 |
| 1 | Quartz sandstone, light-brown, coarse- to very coarse-grained, siliceous; minor glauconite grains and few quartz pebbles near base | 1 |
| | Contact, sharp erosional surface of low relief; disconformity(?) | |
| | *Bliss sandstone* | |
| | Quartz sandstone, medium- to coarse-grained, siliceous, crosslaminated; abundant worm(?) borings | |

Although the general lithology of the El Paso formation contrasts with that of the underlying Bliss sandstone, the selection of a specific contact between these formations is somewhat arbitrary; over a distance of a few feet, several interruptions in the sequence of strata might be interpreted as disconformities. Unfortunately, diagnostic fossils have not been obtained from this critical interval, and the overlying and underlying beds appear to be essentially parallel. The basal contact of the El Paso formation is placed arbitrarily at the bottom of a 1-foot bed of coarse-grained, locally pebbly quartz sandstone that underlies the lowest thick unit of dolomite and that overlies "wormy" quartz sandstone, glauconitic sandstone, and clastic dolomites typical of most of the Bliss. The pertinent question whether this contact represents a disconformity or a diastem remains unanswered. The upper boundary of the El Paso formation, in contrast, is at one of the sharpest and most easily recognized disconformities of the Lower Paleozoic section.

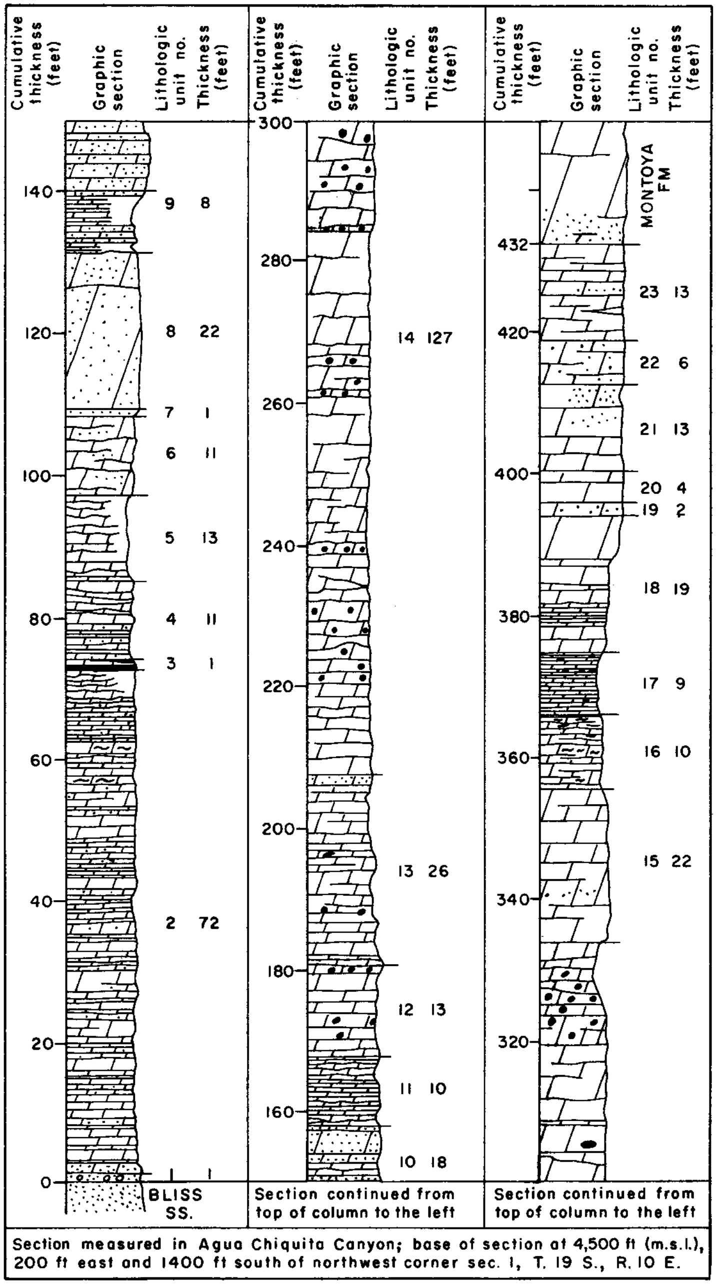



**Figure 10**

GRAPHIC SECTION OF EL PASO FORMATION, AGUA CHIQUITA CANYON

## MONTOYA, VALMONT, AND FUSSELMAN FORMATIONS

Strata in the Franklin Mountains between the El Paso formation and the Devonian rocks were designated originally as the Montoya and Fusselman limestones by Richardson (1909). These units were recognized in New Mexico by Darton (1928), who noted that each formation was composed of two major distinctive lithologic units, which he referred to as upper and lower members of each formation. These four units, as well as a thinner unit of sandstone at the base of the Montoya, have been shuffled and reshuffled in subsequent reports, such as those by Entwistle (1944), Kelley and Silver (1952), Pray (1953, 1958b), and Flower (1957, 1959). The end may not yet be in sight!

Most discussion relates to the specific names given these five rock units, and to their age and correlation. Current consensus favors raising the Montoya to group status, even though this requires redefining the Montoya-Fusselman contact at a position permitting inclusion of the lower part of the original Fusselman sequence in the Montoya group. By this redefinition, the rock unit variously termed the lower member of the Fusselman by Darton (1928), the Raven by Entwistle (1944), the Cutter by Kelley and Silver (1952), and the Valmont by Pray (1953) is included as the uppermost unit of the Montoya group. Much of the confusion regarding the nomenclature and correlation of these rock units could have been prevented had specific type sections been designated and described in detail for the Montoya and Fusselman formations in the original work by Richardson (1909) (whose work, however, was in accordance with customary stratigraphic standards at that time), and if later geologists doing more detailed work in the different parts of New Mexico had studied the Montoya and Fusselman sequences in the type area. Specific type sections of the Montoya and Fusselman formations were proposed and described in the northern Franklin Mountains (Pray, 1958b) 50 years after the names were introduced into geological literature.

The writer accepts, albeit reluctantly, the current majority decision to redefine the upper limit to include the rock unit variously termed the Raven, Cutter, or Valmont. The usage in this report, however, is that of earlier articles by the writer regarding the sequence in the Sacramento Mountains (Pray, 1953, 1954). Thus, the strata between the Devonian and the El Paso formation of the Sacramento Mountains are subdivided in descending order into the following: Fusselman formation, Valmont dolomite (upper and lower members), and Montoya formation (upper and lower members). By this usage, the Montoya formation corresponds to the original limits of the formation in the type area. It includes the rock units termed the Second Value and Par Value by Entwistle (1944), and the units of Kelley and Silver (1952) termed the Cable Canyon, the Upham, and the Aleman. The Valmont dolomite is the lower part of the originally defined Fusselman limestone, and corresponds to the lower member of the Fusselman of Darton (1928), the Raven of Entwistle (1944), and the Cutter of Kelley and Silver (1952). As formal names, both the Raven and the Cutter have priority over the Valmont. The term Valmont, however, is useful here, as its type section is in the Sacramento Mountains, and the limits of this formation used for the geologic maps and sections accompanying this report are more precisely defined than those of its equivalents.

Part of the interpretive problem of the Montoya, Valmont, and Fusselman formations concerns the location of disconformities within this sequence in the region. There is no question regarding the existence of disconformities or unconformities of low angular discordance at the base of the Montoya and at the base of the Devonian strata that overlie the Fusselman in most of the area, but which locally directly overlie the Valmont. Richardson (1909) and Darton (1928) state or imply an erosional break between the Montoya and the Fusselman. This would be between the Montoya and Valmont in the usage of this report, or between the Par Value and Raven of Entwistle (1944) and the Aleman and Cutter of Kelley and Silver (1952). Entwistle (1944) did not discuss possible erosional breaks. Kelley and Silver (1952) specifically stated the absence of an erosional break between the Aleman and Cutter units, and indicated the possibility of post-Cutter—pre-Fusselman erosion. As neither Entwistle nor Kelley and Silver appear to have been aware that their usage of the Montoya group to include the Raven or Cutter unit involved an upward revision of the contact between the Montoya and Fusselman at the type area, it is not known if they accepted or rejected Richardson's and Darton's interpretations. The writer (Pray and Bowsher, 1952; Pray, 1953) indicated that the major break within the Montoya-Fusselman sequence occurs at the top of the Valmont dolomite, rather than within the Montoya-Valmont units, and interpreted this as a disconformity. Evidence in support of this interpretation in the Franklin Mountains was published recently (Pray, 1958b).

Based on studies of the lithology and interpretations of the age of the faunas, Flower (1957, 1959) has indicated the occurrence of a major erosional break (disconformity) between the Upham and Aleman, and a minor erosional interval between the Aleman and Cutter. Although minor breaks or diastems occur locally, the writer here reaffirms his belief that physical breaks representing disconformities within the Montoya-Valmont sequence have not been proved, and feels that the faunas are still too little known to apply significant leverage to the problem.

The Montoya, Valmont, and Fusselman formations of the Sacramento Mountains have been discussed previously in more detail than is possible in this brief report (Pray, 1953), and are merely summarized here. The stratigraphic sequence of the Montoya, Valmont, and Fusselman formations ranges from 350 to 500 feet in thickness, and consists almost entirely of dolomite. The Montoya and

Valmont strata are relatively constant in thickness and lithologic characteristics throughout the area. The Fusselman formation has relatively constant lithology, but the thickness varies from a maximum of slightly more than 100 feet to areas in which the entire formation has been removed by pre-Devonian erosion. The Montoya, Valmont, and Fusselman formations of the Sacramento Mountains are similar in overall aspects to equivalent rock units in other mountain ranges in southern New Mexico, such as the San Andres Mountains (Kottlowski et al., 1956).

For the purposes of this report, a single detailed section of the Montoya, Valmont, and Fusselman formations is given below. This section, excellently exposed in upper Alamo Canyon, includes the type section of the Valmont formation. The graphic section is shown in Figure 11, and the lithologic description of the rock units is given below.

## STRATIGRAPHIC SECTION OF UPPER ORDOVICIAN AND SILURIAN STRATA IN THE SACRAMENTO MOUNTAINS

Section measured in the SE1/4SW1/4SW1/4 sec. 6, T. 17 S., R. 11 E. Top of section is about one-half mile S. 72° E. of conspicuous conical hill (elevation 6,100 feet) that rises above the flat area between Alamo and Caballero Canyons in the west part of sec. 1, T. 17 S., R. 10 E.

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| | *Onate formation*—about 30 feet thick | |
| | Dolomite, silty, olive-gray, thinly bedded; shaly near base; lower 2 feet covered | |
| | Disconformity; contact not observable. Top surface of Fusselman formation smooth, locally dark red brown, silicified | |
| | *Fusselman formation*—42 feet thick | |
| 4 | Dolomite, medium-gray to light olive-gray, finely crystalline, massive; irregular nodules of gray chert form nearly one-third of lower 5 feet | 20 |
| 3 | Dolomite, medium-gray, finely crystalline | 5 |
| 2 | Dolomite, light brown-gray to brown-gray, finely crystalline, massive; weathers dark brown gray; very irregular gray chert masses up to 3 inches thick parallel with bedding | 15 |
| 1 | Dolomite; top 1 foot dolomite-pebble conglomerate, with grains of quartz and glauconite; lower 1 foot fine-grained quartz sand, glauconitic medium-crystalline dolomite, this basal clastic zone being absent in adjacent gullies north and south | 2 |
| | Disconformity; contact, smooth and sharp; observable relief about 4 inches | |
| | *Valmont dolomite*—179 feet thick | |
| | *Upper member*—114 feet thick | |
| 16 | Dolomite, very light-gray, sublithographic; most beds less than 1 foot thick; minor nodules and seams of gray chert | 16 |
| 15 | Dolomite, very light-gray, sublithographic; even beds; conspicuous, brown-weathering nodules and layers up to 1 foot thick of siliceous dolomite containing some small masses of solid chert | 10 |
| 14 | Dolomite, very light-gray, sublithographic; even beds 6 inches to 1 foot thick, some slightly nodular bedding; 10 feet above base, brown-weathering nodules of siliceous dolomite; 1- to 2-inch seam of gray chert at top | 17 |

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| 13 | Covered; probably similar to underlying unit | 4 |
| 12 | Dolomite, medium light-gray, sublithographic; beds less than 2 inches thick | 2 |
| 11 | Dolomite, medium- to light-gray, sublithographic; even to undulating bedding planes 6 inches to 2 feet apart; minor partings of argillaceous dolomite near base; minor chert nodules 11 and 31 feet above base; 8 feet from top, 1-foot zone contains irregular silicified masses of corals (*Favosites ?-Foerstephyllum* ? sp.) | 49 |
| 10 | Poorly exposed; probably argillaceous, thin-bedded dolomite | 3 |
| 9 | Dolomite, medium-gray; sublithographic; basal 3 feet argillaceous; beds 3 inches to 1 foot thick; minor dark-gray, round chert nodules 1-4 inches across | 9 |
| 8 | Dolomite, medium-gray, argillaceous; 1- to 4-inch laminated beds; appears gradational with underlying strata; lower 2 feet poorly exposed; this forms persistent white-weathering, nonresistant zone in Valmont formation | 4 |
| | *Lower member*—65 feet thick | |
| 7 | Dolomite, medium- to medium light-gray, sublithographic; beds 2 inches to 1 foot thick, upper part argillaceous; minor gray-brown chert nodules and some silicified brachiopods in upper 3 feet | 8 |
| 6 | Dolomite, light olive-gray, sublithographic; even beds 6 inches to 2 feet thick; conspicuous conchoidal fracture; brown-weathering silicified dolomite seam 2-4 inches thick at top | 7 |
| 5 | Dolomite, light olive-gray, sublithographic; obscure, undulatory bedding planes 1 inch to 2 feet apart; upper beds more massive | 15 |
| 4 | Dolomite, very light-gray, sublithographic; obscure beds 2 inches to 1 foot thick; medium-gray, smooth chert nodules 2 inches thick, 2-3 feet across, 4 feet above base | 20 |
| 3 | Dolomite, very light-gray, sublithographic; massive to obscurely bedded | 7 |
| 2 | Dolomite, medium light-gray, sublithographic, thin-bedded; irregular chert layer at base; top 1 foot, irregular nodules form discontinuous band of light-gray chert; top contact of chert with dolomite is smooth, mammillary surface | 2 |
| 1 | Dolomite, medium light-gray, very finely crystalline, massive to obscurely bedded | 6 |
| | Contact. No evidence observed of erosional break. Possibly represents only a change in the type of deposition | |
| | *Montoya formation*—209 feet thick | |
| | *Upper member*—113 feet thick | |
| 11 | Dolomite, mottled olive-gray and white, very finely crystalline; white bands and layers of partly silicified dolomite, locally with centers of white chert; chert nodules form 30 percent of top half | 5 |
| 10 | Dolomite, light olive-gray to olive-gray, finely crystalline; obscure irregular nodules 2-10 inches thick; white porcelaneous chert (20%) in irregular nodules 1-2 inches thick, and also scattered in distinctive irregular, angular particles as small as 1-2 mm; chert shows molds of brachiopods, crinoid stems, and bryozoa; lower contact gradational | 23 |
| 9 | Dolomite, olive-gray, finely crystalline; obscure beds 2 inches to 2 feet thick; 5 percent chert in lower half, less above; weathers to resistant ledge | 12 |
| 8 | Dolomite, olive-gray, very finely crystalline; obscure irregular beds 2 inches to 6 inches thick; about 5 percent chert, white to dark-gray, in 1- to 2-inch nodules and seams; gradational contacts above and below | 14 |

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| 7 | Dolomite, light olive-gray to olive-gray, finely crystalline; obscure beds 2 inches to 2 feet thick; chert, light- to dark-gray, in sporadic nodules and thin seams, about 5 percent of basal half, less above | 10 |
| 6 | Dolomite, light olive-gray, very finely crystalline, thick-bedded; minor (<2%) light- to dark-gray chert nodules; weathers to olive-gray resistant ledge | 12 |
| 5 | Dolomite, light brown-gray to light olive-gray, very finely crystalline; obscure irregular 1- to 4-inch beds; chert, light- to dark-gray, forms 10-20 percent of unit in nodules 1-3 inches thick | 32 |
| 4 | Dolomite, light olive-gray, very finely crystalline; irregular, thin 1- to 4-inch beds; minor (<5%) chert in light-gray nodules; gradational with underlying more coarsely crystalline, darker unit over thickness of 1-2 feet | 5 |
| | *Lower member*—96 feet thick | |
| 3 | Dolomite, olive-gray to medium dark-gray, finely to medium-crystalline, massive to thick-bedded; dark-gray chert nodules and layers more abundant toward the top (5%-10%); forms the top of the resistant dark cliff of the lower member | 30 |
| 2 | Dolomite, olive-gray to medium dark-gray, finely to medium-crystalline; few dark-gray chert nodules 1-2 inches thick; scattered corals | 45 |
| 1 | Dolomite, olive-gray to medium dark-gray, finely to medium-crystalline, massive, chert-free; basal 10 inches dolomitic quartz sandstone, subangular quartz grains up to 2 mm; grades upward into quartz-free dolomite 6 feet above basal contact | 21 |
| | Disconformity. Clean, knife-edge contact, parallel with underlying El Paso beds; less than 1 inch of channeling noted over 100 feet of exposed contact; scattered pseudomorphs of limonite after pyrite up to half-inch size along top surface of El Paso formation | |
| | *El Paso formation*—88 feet exposed above canyon base; section incomplete | |
| | Dolomite, light- to medium-gray, finely crystalline; beds 1 inch to 5 feet thick; minor gray chert nodules and seams; locally scattered fine-grained quartz | |

## MONTOYA FORMATION

The Montoya formation, as the term is used in this report, ranges in thickness from 190 to 225 feet in the Sacramento Mountains. It consists almost entirely of dolomite, or cherty dolomite, except for a thin interval of dolomitic quartz sandstone or sandy dolomite near the base. Outcrops of the Montoya formation are nearly continuous along the base of the western escarpment and extend into the major canyon areas in the central and southern parts of the area. Several isolated exposures occur east of the mountain front in the north-central part of the area, as well as in Grapevine Canyon, near the southern edge of the mapped area.

The lithologic details of the Montoya formation shown in Figure 11 are representative of the formation in the Sacramento Mountains.

The lower member of the Montoya formation (Cable Canyon and Upham) forms a (lark-colored steep cliff in most of the outcrop (fig. 9) and in most places is about 100 feet in thickness. The lower contact is at a distinct, remarkably even surface of disconformity. In most of the outcrop area, the basal part of the Montoya formation consists of quartz

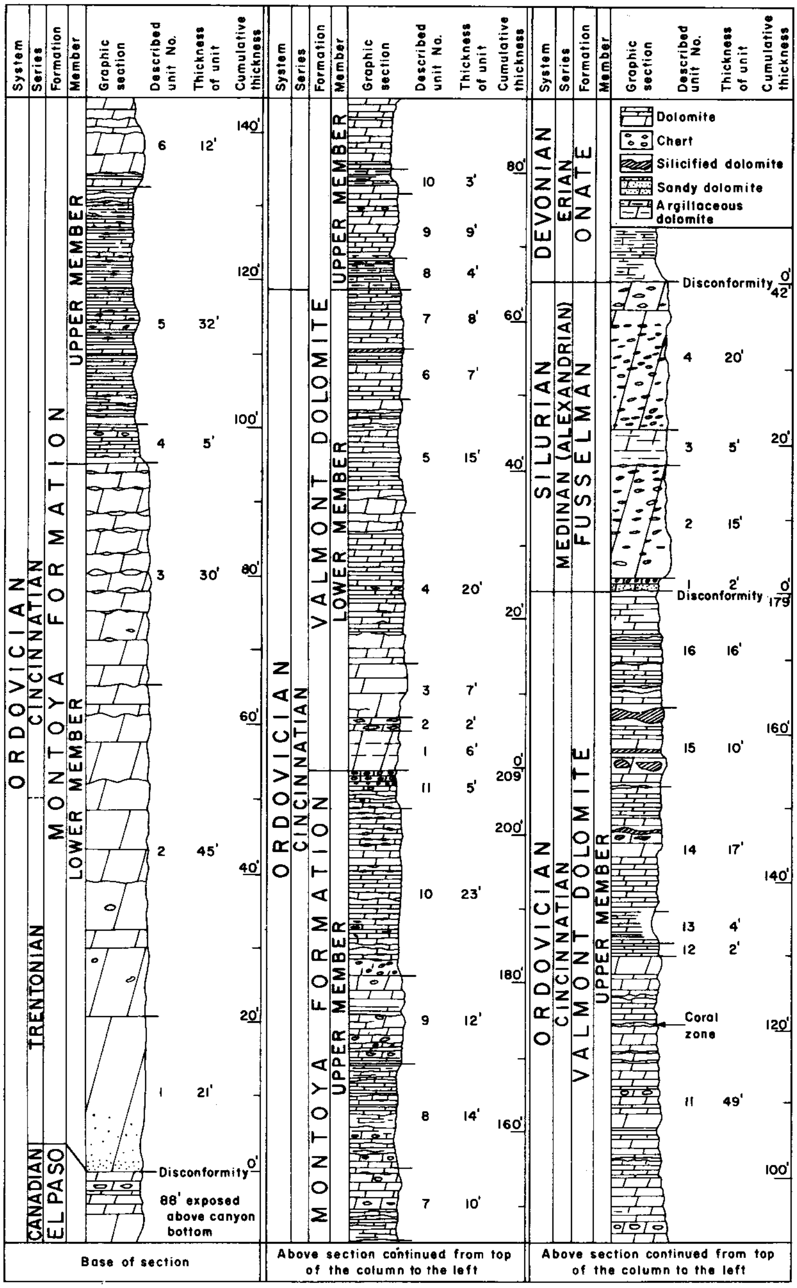



**Figure 11**

Graphic section of Montoya, Valmont, and Fusselman fo tions. upper Alamo Canyon sandstone and sandy dolomite. This sandy interval ranges from a few inches to 12 feet in thickness. Whereas locally, as at the mouth of Alamo Canyon, the upper limit of the quartz sandstone is sharp, in most places the sandy zone is transitional into quartz-sand-bearing dolomite and thence upward into sand-free dolomite. The detrital particles in the basal sandstone are composed largely of quartz of medium-grained to granule size. The coarser fragments are subangular, whereas many of those of medium- and coarse-grained sand size are subrounded. Some grains are frosted.

The dolomite that forms the bulk of the lower member is coarser in texture than that of other dolomitic rock units in the Sacramento Mountains. Most of the dolomite crystals are about one-quarter mm in diameter, but some as large as 1 mm give the rock a more coarsely crystalline aspect. The color of the dolomite ranges from medium dark gray to olive gray. The most distinctive feature of the lower member is the thick bedding of the dolomite and the massive character of the beds. The thickness of bedding and the massiveness diminish upward in the lower member. Chert, which is almost absent in the lower half of the lower member, increases in amount toward the upper part. The upper contact of the lower member is somewhat arbitrary, as no distinct and persistent erosional break occurs, and the change in overall lithology from the lower to the upper member appears in many sections to be transitional over a thickness of 10 to 20 feet. The lower member of the Montoya contains many poorly preserved fossils, among which corals and sponges are conspicuous, especially in the lower part of the member. Detailed paleontologic study of the faunas from this rock unit throughout the region (Flower, 1957, 1959) indicates an age of Middle Ordovician (Trenton age) for the lower part of the member and of lower (Eden age) Upper Ordovician for the upper part.

The upper member of the Montoya formation (Aleman) forms a lithologically distinctive unit throughout the area. It consists largely of cherty dolomite and weathers to a slope, in contrast to the cliff of the underlying member. The thickness ranges from 85 to 125 feet within the area and commonly is about 110 feet. Most of the dolomite is light olive gray to olive gray, and its texture is very finely to finely crystalline. The more coarsely crystalline strata appear to be darker in color. Bedding is rather obscure, but where discernible is thin to medium. At many places, bedding is defined by the occurrence of chert seams and nodules. The abundance of zones of chert, as shown in Figure 12A, is diagnostic of the upper member of the Montoya in the Sacramento Mountains and in much of the region. Zones of abundant chert alternate with chert-free dolomitic strata, or with zones containing only sporadic nodules. In the western part of Alamo Canyon and along the west front of the range in T. 17 S., the upper 1 to 3 feet of the upper member consists of solid chert. Chert ranges in color from nearly black to very light gray.

Fossils are common in some layers in the upper member of the Montoya formation. Some are well preserved, but fragmentation and silicification are common. Paleontologic studies by Bowsher (in Pray, 1953), Flower (1957, 1959), and Howe (1959) indicate an Upper Ordovician age.

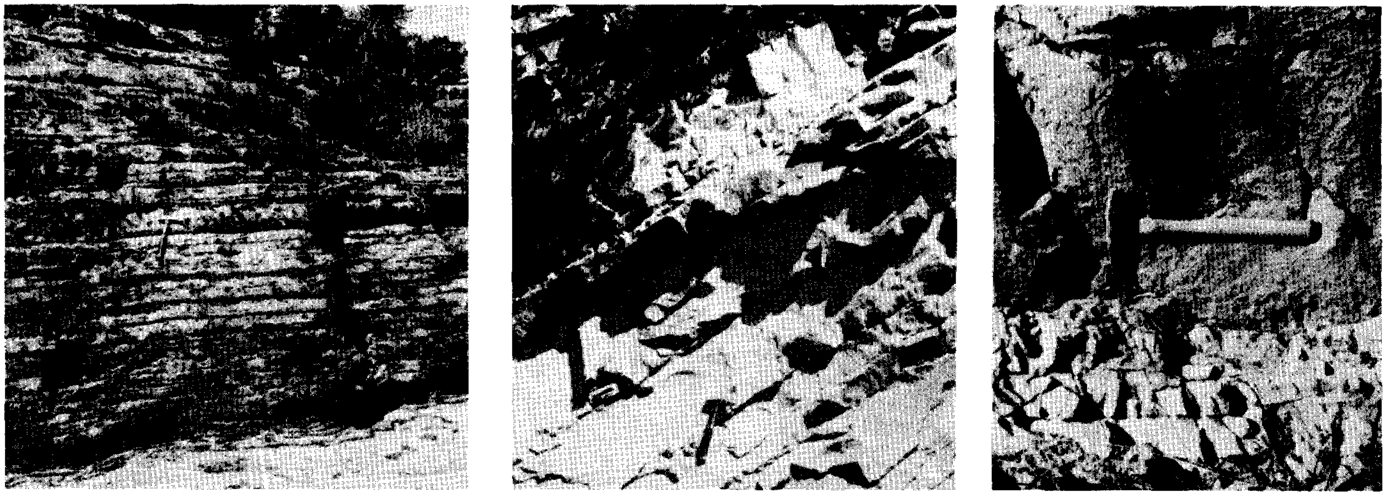
The basal surface of deposition of the Montoya formation is a sharp, remarkably even surface of erosional truncation. At one exposure, less than an inch of relief was detectable in a lateral distance of 100 feet. Locally some undulation occurs, however, and the few localities where the basal sandy zone is absent probably represent local highs on this disconformity. Regionally, Darton (1928, fig. 75), Flower (1957, 1959), and others have demonstrated the truncation of the El Paso formation along the disconformity. The upper contact of the Montoya formation with the overlying Valmont, though locally sharp, appears gradational in many places over a thickness of several feet.

## VALMONT DOLOMITE

The Valmont dolomite is one of the most distinctive rock units in the Paleozoic section of southern New Mexico, and is remarkably constant in both lithologic characteristics and thickness throughout the region. The term "Valmont" is used in this report in the sense of the original definition (Pray, 1953), and the rock unit to which it is applied corresponds closely or is equivalent to the lower member of the Fusselman of Darton (1928), the Raven member of the Montoya of Entwistle (1944), and the Cutter formation of the Montoya group of Kelley and Silver (1952). In the Sacramento Mountains, outcrops of the Valmont dolomite are nearly continuous along much of the western escarpment and in the major canyons southward from the vicinity of Alamogordo. Several isolated outcrops occur east of the mountain front in upper Dry Canyon, Arcente Canyon, and Grapevine Canyon.

The type section of the Valmont dolomite occurs in upper Alamo Canyon, in the SE1/4SW1/4SW1/4 sec. 6, T. 17 S., R. 11 E. (fig. 11). The formation consists largely of light- to very light-gray, sublithographic dolomite. Chert is scarce, except in a few local zones. Bedding planes are sharply defined, and commonly the beds are a few inches to 1 to 2 feet in thickness. The formation weathers to a distinctive light-gray slope. The color, the fineness of grain, and the thin to medium bedding are the principal diagnostic features of the Valmont. A typical outcrop is shown in Figure 12B. The formation is divided into two members on the basis of a thin argillaceous zone about a third of the distance above the base.

The lower member of the Valmont formation consists of 40 to 70 feet of dolomite and minor chert. The strata in the lower part are somewhat transitional in lithologic characteristics with the underlying cherty member of the Montoya formation, as some of these strata are darker in color (medium to medium light gray), are coarser in texture



a. b. c.

Figure 12

LITHIC FEATURES OF MONTOYA, VALMONT, AND FUSSELMAN FORMATIONS

A, cherty upper member of Montoya formation; **B,** typical light-colored dolomites of Valmont dolomite; C, sharp contact between overlying dark Fusselman dolomite and underlying Valmont dolomite.

(very finely to finely crystalline), and have bedding planes less regular and more obscure than is characteristic of most of the Valmont dolomite. Chert forms a minor part of the lower member. Most of the chert is light gray and occurs as large, smooth nodules resembling pillows in size and shape. Lateral variation and lenticularity are more common in the lower member of the Valmont dolomite than in the upper member. Some of the more obvious lenticular units consist of poorly preserved, silicified internal molds of gastropods.

Two thin zones of argillaceous dolomite and dolomitic shale occur 40 to 70 feet above the base of the Valmont dolomite. These clayey zones, each 2 to 5 feet thick and spaced 5 to 10 feet apart, can be traced throughout the Sacramento Mountains and form the basal part of the upper member of the Valmont. The argillaceous dolomite is an excellent stratigraphic marker throughout the region of southern New Mexico and western Texas. It forms a distinctive niche on the Valmont slope in outcrop areas and a light-colored band on aerial photographs, and can be recognized in the subsurface by the response of the gamma-ray curve to the clay content.

The upper member of the Valmont dolomite is 90 to 120 feet thick in most places in the Sacramento Mountains. Above the basal argillaceous zone, the section consists of relatively pure, light- to very light-gray dolomite. The average crystal size is about 0.02 mm. Most bedding planes are sharply defined, are very persistent laterally, and are 2 inches to 2 feet apart. Although pure chert nodules and seams are only minor constituents of the upper member, layers and nodules of partially silicified dolomite are abundant and conspicuous in sonie beds, especially in the uppermost 50 feet of the member. These masses, generally 2 to 6 inches thick, weather to a light brown and form local marker units in the section.

The Valmont formation is relatively barren of fossils except in local zones. Many of the fossil zones that do occur contain a single species or only a few types of organisms. Fossils are locally common in the upper part of the lower member, and one or two thin zones (see fig. 11) of silicified favositid corals occur in the upper member. The Ordovician age (rather than Silurian) of the rock unit in the Sacramento Mountains here referred to as the Valmont was first determined by A. L. Bowsher (Pray and Bowsher, 1952) on the basis of a fauna from the upper part of the lower member in the Alamo Canyon area. From detailed studies of the fauna of the Valmont dolomite and its regional equivalents in southern New Mexico and western Texas made by Flower (1959), the age has been determined as Late Ordovician (Richmond).

The contact between the Valmont and the Montoya formations does not appear to represent a disconformity. Locally, as in parts of Alamo Canyon and along the western front of the range in T. 17 S., a sharp discontinuity occurs, but this could not be traced throughout the area. The lower contact of the Valmont dolomite is picked at the top of the highest zone that is rich in chert nodules of the type characteristic of the Montoya (fig. 12A), or at the top of a 1- to 3-foot-thick zone of solid chert. The upper contact of the Valmont dolomite is sharp (fig. 12C), and is interpreted by the writer as a disconformity throughout the region. Thickness variation within the Valmont dolomite in the Sacramento Mountains is believed to be largely caused by the somewhat indeterminate lower contact and varying amounts of erosion along the upper contact.

The overall characteristics of the Valmont dolomite in the Sacramento Mountains and environs suggest deposition of chemically precipitated carbonate mud in relatively shallow, well-aerated waters of low turbulence. During much of the Valmont deposition, salinity conditions may have been too high for normal marine faunas.

## FUSSELMAN FORMATION

The Fusselman formation is a thin and distinctive rock unit in the Sacramento Mountains, consisting largely of dark-weathering cherty dolomite. The formation is resistant to erosion, and forms conspicuous dip slopes, ledges, and cliffs in the outcrop areas. The Fusselman formation is distinctly darker and more resistant than the underlying Valmont dolomite; these contrasts create one of the most easily recognizable and readily traceable contacts of the Paleozoic section of the Sacramento Mountains, and indeed, in much of southern New Mexico. The Fusselman formation crops out along the western escarpment and within the major canyons over a north-south distance of 18 miles. In addition, it crops out in two structurally high, isolated areas well east of the mountain front, namely, on both sides of the Bug Scuffle fault in Grapevine Canyon, in T. 19 S., R. 11 E., and near the Arcente fault in upper Arcente Canyon, in T. 16 S., R. 11 E. Owing, however, to pre-Devonian erosion, the formation is absent at the northernmost outcrop of the lower Paleozoic section in the Sacramento Mountains in the NW1/4 SW1/4 sec. 7, T. 16 S., R. 11 E. In most of the outcrop area in the Sacramento Mountains, the Fusselman formation is about 75 feet thick. The maximum thickness is 'about 100 feet, and near the northern limits of the outcrop area thicknesses of 20 to 50 feet are common. The upper and lower contacts of the formation are sharp disconformities. The broadly undulating surfaces of these two unconformities account for the rather abrupt thickness variations of the formation in the area.

Although the .Fusselman formation is lithologically distinctive from other rock units, many minor variations exist within the dolomite. In many places, the variation is abrupt, both vertically and laterally. With the exception of the abundant chert, and minor detrital material, such as isolated grains of quartz sand, the Fusselman formation is entirely dolomitic. Clay and silt impurities are very minor. The color of the dolomite ranges from very light gray, for a unit at the base in the

Alamo Canyon area, to the more common, darker shades of gray, or to darker hues of olive or brown gray. The weathered surface is darker than the fresh rock. The texture of the dolomite ranges from very finely crystalline to medium crystalline; most is finely crystalline and somewhat sugary in appearance. The nature of the bedding varies widely, and in many places, abruptly. In some sections, the formation is essentially massive, or composed of thick-bedded units; in other sections, beds a foot or less in thickness are the rule, or thin beds are interlayered with thick beds. The bedding is commonly an obscure feature.

Chert is abundant in the Fusselman formation and locally may form as much as one-third of the total section. The distribution appears erratic, however, and locally chert either is a very minor constituent, or is absent from the entire Fusselman section. Most of the chert ranges from gray to gray brown and tends to weather to a yellow brown. Porcelaneous textures predominate. The chert masses rarely form in smooth, even layers or nodules, as in the Montoya or Valmont formations, but are extremely irregular in form. Within the irregular outlines of the chert masses are scattered patches or single rhombs of dolomite. Selective leaching during weathering of these carbonate areas produces a hackly, punctate, or somewhat spongy aspect. Most chert masses are oriented parallel with the bedding. Where chert is abundant, the irregular masses and nodules may occur somewhat rhythmically in zones spaced one-half to 1 foot apart in obscurely bedded or massive dolomite.

Locally, especially in the lower part along the somewhat undulose basal contact of the formation, sandy to conglomeratic units occur in thicknesses of a few inches to a few feet. These consist largely of quartz grains of sand to granule size, and contain granule to fine-pebble sizes of phosphatic nodules, dolomite, and minor chert. Scattered glauconite grains have been noted locally. In most areas, the detrital material in the Fusselman formation consists of isolated sand-sized grains of quartz within the basal few inches of the dolomite.

Massive, very light-gray, noncherty, finely to medium-crystalline dolomite forms a distinctive basal unit of the Fusselman formation in many parts of the Sacramento Mountains outcrop area, although it is absent in both the northeasternmost and the southernmost exposures. Where this unit occurs, reliance cannot be placed solely on the color change for the precise position of the Valmont-Fusselman contact. The Valmont-Fusselman contact is still easy to recognize on the basis of the massiveness and coarser texture of the Fusselman dolomite as compared to the Valmont dolomite. The basal unit overlies beveled edges of the Valmont strata, and the thickness of the unit changes rapidly along the outcrop. The relationships suggest that this unit, the first major phase of Fusselman deposition, largely eliminated the initial irregularities of the disconformity on the sea floor, and that the dark cherty dolomites of the Fusselman were deposited on a more even surface that was essentially parallel to the bedding planes of the underlying Valmont formation.

Fossils are present, though in general neither abundant nor well preserved. A faunal collection from several localities in the Sacramento Mountains (Pray, 1953) was studied by Arthur L. Bowsher and dated as early Silurian (Alexandrian). The precise age of this fauna is unknown, but it appears to be older than faunas from the Fusselman formation generally known in areas farther to the south and west (Flower, 1959). Definitive fossils of later Silurian age common in the Fusselman formation in other parts of the region have not yet been reported from the thin Fusselman formation of the Sacramento Mountains. The faunas from the Fusselman formation in the Sacramento Mountains have been collected largely from the lower part of the formation. Moreover, the entire thickness of the Fusselman formation in this area is less than the thickness between the base of the Fusselman formation and the lowest known occurrence of pentamerid brachiopods, reportedly of Middle Silurian age, in the type section of the Franklin Mountains (Pray, 1958b). Thus the lower part of the Fusselman of the region may be of Early Silurian age.

The lithology and the fauna of the Fusselman formation in the Sacramento Mountains suggest deposition in a normal marine environment on a stable shelf with the virtual absence of terrigenous detritus. The minor amount of silt and clay, together with the lateral variability of the formation, suggests more turbulent water than prevailed during Valmont deposition.

The upper and lower contacts of the formation are interpreted as disconformities of regional extent. The basal contact is the most persistent physical break in the Montoya-Valmont-Fusselman sequence. Evidence of disconformity consists of truncation and channeling of the underlying strata; basal lenses of phosphatic nodules, dolomite, quartz, and other detrital material; and a sharp, persistent change in lithology (fig. 12C). These evidences of a disconformity in the Sacramento Mountains are similar to those observed in the Franklin Mountains (Pray, 1958b). The disconformity at the top of the Fusselman formation is a distinct physical break, but the precise contact is almost everywhere concealed. However, the extreme resistance of the Fusselman formation affords many exposures of its uppermost few inches. The surface is essentially smooth. Siliceous, iron-rich masses in fractures and along the upper surface are common and can be used to determine proximity to the pre-Devonian surface. Locally, the upper few feet of the Fusselman is completely silicified.

The Fusselman formation of the Sacramento Mountains appears similar to the Fusselman of the San Andres Mountains. It thins northward to a pinchout owing to post-Fusselman truncation rather than to depositional differences. The original northward **limit of Fusselman deposition is unknown.**

## DEVONIAN FORMATIONS

Strata of Devonian age form a thin, but rather complex part of the Paleozoic section of the Sacramento Mountains. Three main rock units, the Onate, Sly Gap, and Percha, are recognized in the area. The total thickness of the Devonian strata in the Sacramento Mountains is everywhere less than 100 feet, and in many localities is 60 feet or less. The Devonian formations are less resistant than most of their associated rock units, and commonly are covered with slope wash or only poorly exposed. Local well-exposed sections occur sporadically. In general, the Devonian rock units must be correlated by comparison of the intermittent sections, rather than by tracing of the individual strata. The variable nature of these Devonian strata, the lithologic similarity of shaly strata in each of the formations, and the discontinuous nature of the outcrops render the correlations more hazardous than for most other rock units in the Sacramento Mountains.

Devonian strata occur along the western escarpment and within the major canyons over a north-south distance of 18 miles. In the vicinity of Alamogordo, the Devonian formations extend eastward from the front of the range for distances of 3 to 4 miles, and occur farther east as isolated exposures on several structural highs in Tps. 16 and 17 S., R. 11 E. A thin Devonian section occurs near the Bug Scuffle fault in Grapevine Canyon, in T. 19 S., R. 11 E. The writer believes that the Onate formation persists throughout the area of Devonian outcrops, that the Sly Gap formation is largely restricted to the northern and central parts of the escarpment, and that the Percha shale is largely in the southern part, with only minor occurrences farther north. The thickness and distribution of the three Devonian formations are shown in Figure 13.

The first detailed work on the Devonian strata in the Sacramento Mountains was by Stainbrook (1935), who described a 40-foot-thick section of strata (now considered the Sly Gap) in upper Alamo Canyon and dated it as equivalent to the Independence shale of Iowa (Upper Devonian age). Based on lithologic and faunal studies of the early 1940's, Stevenson (1945) published a summary of the Devonian of southern New Mexico. He established type sections of the Onate and Sly Gap formations in the San Andres Mountains, and recognized these units, together with the Percha shale, in the Sacramento Mountains. Further published work on the Devonian of the Sacramento Mountains is by Stainbrook (1948); Laudon and Bowsher (1941, 1949), as a part of their studies of the overlying Mississippian; and Flower (1957, 1959), as a part of a regional review. The writer's interpretation of the physical stratigraphy of the Devonian of the Sacramento Mountains differs in some details from interpretations of these other workers. Bowsher's studies of fossils collected during the mapping of the escarpment have contributed to the writer's conclusions.

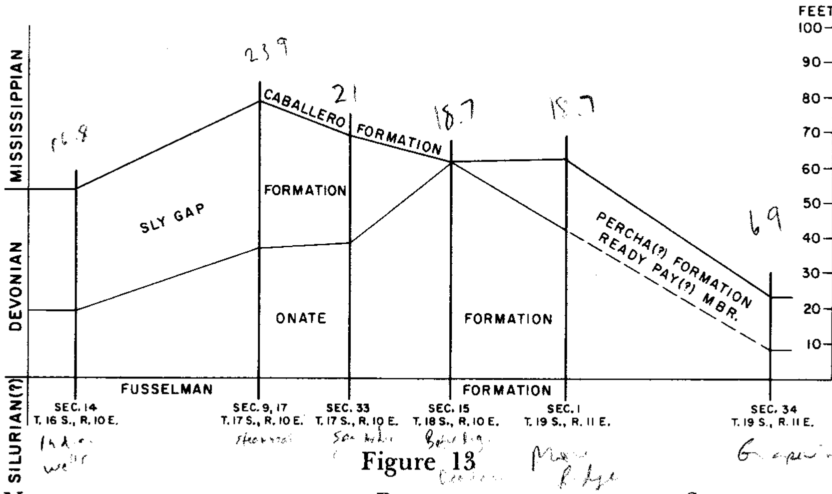



Figure 13

**North-south cross-section of Devonian formations in Sacramento Mountains**

Interpretations of the depositional conditions of the complex of Devonian strata in the 'Sacramento Mountains await more detailed study. The entire sequence is believed to have been deposited under marine conditions. The Devonian represents the first record of shale deposition during Paleozoic time in the Sacramento Mountains area, and the carbonate units of the Devonian are somewhat transitional between the dolomitic strata of the earlier Paleozoic and the calcitic strata of the later Paleozoic periods.

## ONATE FORMATION

The Onate formation is the basal and most persistent of the Devonian formations of the Sacramento Mountains. It consists largely of silty dolomite, and dolomitic quartz siltstone or very fine-grained quartz sandstone. The silty dolomite and dolomitic siltstone or sandstone is generally medium gray to brownish gray or olive gray. Most of the dolomite is very finely crystalline, or about the same size as the intimately admixed grains of quartz silt and sand. Most of the detrital grains are subangular quartz grains of coarse silt size, but some are as coarse as fine-grained sand. Coarser detrital grains are absent, except in the western part of Alamo and Marble Canyons (T. 16 S., R. 10 E.), where 2 to 6 feet of quartz sandstone containing minor pebbly zones occurs. In most places in the escarpment area, however, the basal part of the formation is dolomitic siltstone, and is more argillaceous than the upper part. The beds rarely are thicker than 2 feet, and are generally less than 1 foot. Most strata have little resistance to erosion, but the more massive beds of silty dolomite or dolomitic siltstone that occur in the section locally form traceable ledges.

Small, highly irregular nodules, about an inch in diameter and several inches long, are a distinctive lithologic feature of the upper part of the Onate formation in the central and northern parts of the escarpment. These nodules are composed of chert or of partially silicified dolomite, and are found only in silty dolomite or dolomitic siltstone that the writer interprets as belonging to the Onate formation. The presence of zones of these siliceous nodules and of several relatively massive silty dolomite layers that weather a distinctive pale red to brown, and the local presence of the ribbon bryozoan *Sulcoretopora anomalotruncata* are the primary basis for the writer's interpretation that the entire Devonian section in the vicinity of Dog and Escondido Canyons (T. 18 S., R. 10 E.), as shown on Figure 13, is Onate. Relationships in the Sacramento Mountains indicate the desirability of revising upward by 10 feet the Onate-Sly Gap contact at the type section, a conclusion also reached by Kottlowski et al. (1956). This revision permits inclusion within the Onate formation of all the strata that are dolomitic, and that weather to the pale-red to brown color. Details of a section typical of the Onate formation in the northern and central parts of the Sacramento Mountains are given by the graphic section of Figure 14, and the lithologic description of this section follows.

## STRATIGRAPHIC SECTION OF THE ONATE FORMATION IN THE NORTH-CENTRAL SACRAMENTO MOUNTAINS

Section was measured at the junction of Alamo Canyon and a northern tributary canyon in the SE1/4 N1/4NW1/4 sec. 7, T. 17 S., R. 11 E. (fig. 14).

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| | Top of section | |
| | *Sly Gap formation* | |
| | Calcareous shale; weathers light yellow gray with minor dark-gray beds; basal 1 to 2 inches contains a few fragments of olive-gray shale | 6 |
| | Contact is sharp, with no relief noted. Disconformity? | |
| | *Onate formation*—34 feet thick | |
| 5 | Dolomitic limestone and calcareous dolomite; silty, argillaceous, nodular; interbedded with calcareous and dolomitic shale; irregular tubular calcareous nodules in the carbonate-rich beds increase in size and abundance to the top of the unit, where they form 10 to 20 percent of the bed and are 1 inch thick and 6 to 10 inches in length | 13 |
| 4 | Dolomite, olive-gray, very fine-grained, silty; some very fine-grained quartz sand; resistant, obscurely laminated beds with thin argillaceous partings; beds weather moderate to pale yellow brown; abundant brachiopods | 8 |
| 3 | Shale, dolomitic, silty, light olive-gray to olive-gray, thin-bedded; fossils abundant in upper foot; unit is gradational with overlying and underlying dolomitic units | 3 |
| 2 | Dolomite, medium dark-gray, silty, argillaceous; resistant, obscurely laminated beds as much as 2½ feet thick, interbedded with less-resistant, more-argillaceous beds; local pyrite concretions; fossils sparse | 7 |

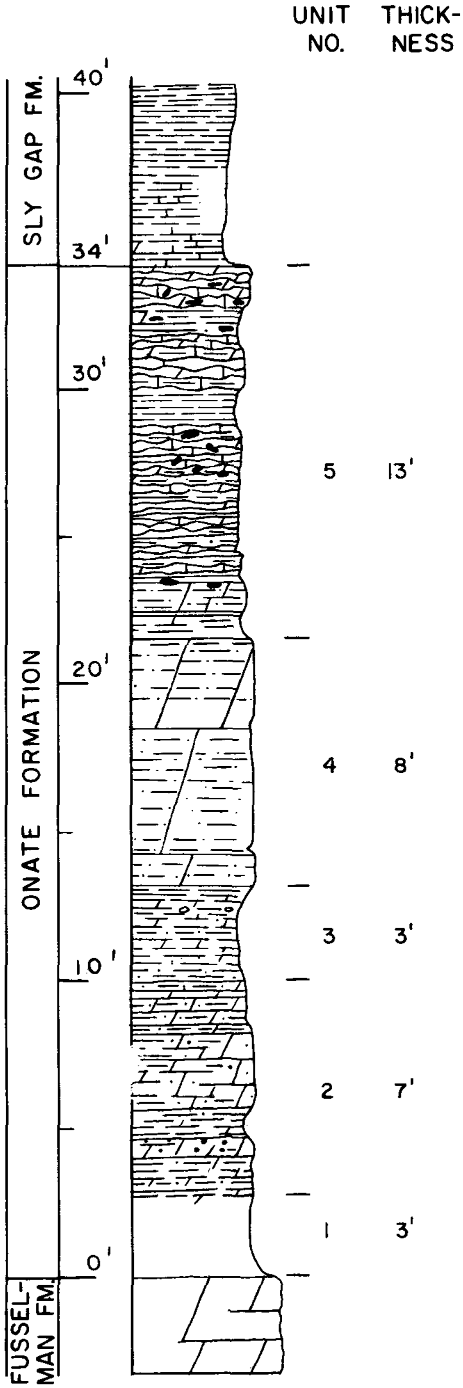



Figure 14

GRAPHIC SECTION OF ONATE FORMATION IN ALAMO CANYON

| UNIT No. | DESCRIPTION | THICKNESS (feet) |
|---|---|---|
| 1 | **Covered; probably medium dark-gray dolomitic shale** | 3 |
| | **Contact not exposed; disconformity** | |
| | ***Fusselman formation*** | |
| | **Dolomite, light olive-gray, very finely crystalline, obscurely bedded; irregular nodules of yellow and gray chert; forms persistent cliff; upper surface silicified, locally ferruginous, with 1 to 2 feet of relief** | |

Correlations of the Devonian formations are uncertain in the southern part of the Sacramento Mountains escarpment. In this area, especially the part south of Escondido Canyon, the lithology changes rapidly into a shaly sequence that is dolomitic at the base. The lower 8 to 15 feet of the Devonian strata of Grapevine and Negro Ed Canyons (T. 19 S., R. 11 E.) is light gray-brown, silty dolomite and is overlain by (lark-gray, noncalcareous, fissile shale. The writer considers the dolomitic part to be Onate. The overlying shale may be Onate, but probably is younger. It is here correlated with the Percha shale, although others interpret it as a Sly Gap equivalent (Laudon and Bowsher, 1949; Kottlowski et al., 1956).

Much of the Onate formation is unfossiliferous, though fossils are abundant locally. The most common forms are the ribbon bryozoa *Sulcoretopora anomalotruncata* and various types of brachiopods, such as *Leiorhynchus, Atrypa,* and *Stropheodonta.* The Onate fauna from the Sacramento Mountains and elsewhere in the State appears to date the Onate as either latest Middle Devonian or earliest Upper Devonian (Stevenson, 1945; Flower, 1957, 1959).

The basal contact of the Onate formation is a well-marked disconformity in the Sacramento Mountains and the surrounding region. The contact zone is rarely exposed, but outcrops of the underlying few inches to a foot of strata indicate proximity to the pre-Onate erosion surface by siliceous and ferruginous zones. The surface of erosion appears to be generally even locally, but may undulate over distances of a mile or more. The upper contact of the Onate is with the Sly Gap, the Percha, or the Caballero formations within the Sacramento Mountains area and probably is disconformable.

## SLY GAP FORMATION

The Sly Gap formation consists of interbedded gray calcareous shale; thin, somewhat nodular gray limestone; and minor "black" shale. The Sly Gap strata weather to a light yellowish brown, distinctly lighter and more yellowish than the underlying Onate formation. Few of the rock units of the Sly Gap are resistant to weathering, and the formation normally forms a uniform slope veneered by slope wash from overlying formations. The intermittent exposures are either restricted to gully bottoms, or to areas where erosion has stripped off the bulk of the overlying section. The Sly Gap formation contains an abundant marine fauna, dated as Upper Devonian. It is 30 to 40 feet thick in most of the northern and central parts of the escarpment, and is interpreted to be absent in the southern part of the escarpment. General relationships are shown in Figure 13.

Shale is the predominant lithology of the Sly Gap formation. In the lower half to two-thirds of the formation, the shale is calcareous and largely light gray to olive gray; minor amounts of (lark-gray shale are interbedded. The shale in the upper part of the formation is of the same types as in the lower, but the interbeds of dark-gray, noncalcareous shale are more common and locally form units several feet in thickness. Limestone layers, rarely more than 6 inches in thickness, increase in abundance in the upper part of the formation. These are mostly medium-to light-gray, fossiliferous calcilutites. Minor amounts of pyrite are the source of the characteristic yellow weathering of the Sly Gap. Limestone nodules, 1 to 2 inches in thickness, form thin layers in most sections of the Sly Gap formation and are easily confused with the overlying nodular limestones of the Caballero formation, unless the fauna or the strati-graphic position is carefully ascertained.

The "black" shale of the Sly Gap formation is noncalcareous, and the precise color is grayish or brownish black. Rounded iron sulfide concretions up to an inch in diameter are common in these shale beds. Lithologically, the Sly Gap "black" shales are difficult, if not impossible, to distinguish from the "black" shale of later Devonian rock units. Where these shales occur near the top of the Sly Gap and are overlain by a few feet of Sly Gap nodular limestones, as is common in the northern part of the escarpment, frequently the shales have been considered erroneously as Percha or Caballero, and the nodular limestones have been included in the Caballero formation (Stevenson, 1945; Laudon and Bowsher, 1941, 1949). Independent observations by A. L. Bowsher and the writer indicate that most "black" shale in this area is within the Sly Gap formation and that the Percha is generally absent. The basal Caballero contact is best determined by location of the ubiquitous basal zone, one-half to 2 inches thick, containing dark siliceous concretions, and occasional fish teeth and bones.

The Sly Gap formation contains abundant fossils in the Sacramento and San Andres Mountains. The fauna from the Sacramento Mountains, collected mostly in T. 16 S., R. 10 E., has been studied in detail by Stainbrook (1935, 1948), who considered it to be of early Upper Devonian age and equivalent to the Independence shale of Iowa. Stevenson (1945) likewise concluded that the formation was of Upper Devonian age, although somewhat younger than indicated by Stainbrook. The age of the Sly Gap, based largely on studies at the type section, has most recently been stated as early Upper Devonian (Independence equivalent) and somewhat younger than any known Onate faunas (Kottlowski et al., 1956; Flower, 1959).

Correlation of the Sly Gap formation southward in the Sacramento Mountains from the better exposed areas in T. 16 S. and the northern part of T. 17 S. is somewhat uncertain. Thus, in the vicinity of San Andres Canyon, a local section correlated as upper Sly Gap contains about 10 feet of thin- to medium-bedded, dark, argillaceous limestone and some 1- to 3-foot pods of replacement dolomite. Perhaps this part of the section is equivalent to the Contadero formation or even younger strata of pre-Percha, Upper Devonian age in the San Andres Mountains. Kottlowski et al. (1956) and Flower (1959) indicate that the Sly Gap becomes more shaly to the south in the Sacramento Mountains, similar to the change observed in the San Andres Mountains. The writer cannot disprove this, but prefers to interpret the shaly facies of the southern Sacramento Mountains as Percha shale, and to limit the Sly Gap in the Sacramento Mountains to the area north of Dog Canyon. The Sly Gap strata described by Stevenson in the Dog Canyon area are considered part of the Onate by the writer. More detailed stratigraphic and paleontologic studies are needed to resolve these questions.

The basal contact of the Sly Gap formation is everywhere with the Onate in the Sacramento Mountains. It is interpreted as a disconformity, though evidence is meager and the contact is rarely exposed. Some evidence suggests that part of the Onate is locally absent and may have been removed by erosion. Additional support for a disconformity is the occurrence in the SE1/4 NW1/4 sec. 14, T. 16 S., R. 10 E., of reddish (ferruginous) stains and siliceous masses scattered along the top surface of the Onate, an occurrence similar to that along the basal Devonian disconformity. Where the contact is well exposed, the lithologic change is abrupt between the Onate and the Sly Gap, and the contact is smooth.

## PERCHA SHALE

Within the escarpment of the Sacramento Mountains, certain sections of "black," noncalcareous shale in the upper part of the local Devonian sequence have been correlated with the Percha shale of western New Mexico. The writer follows the lead of Stevenson (1945) and of Laudon and Bowsher (1941, 1949) in this practice, although differing somewhat with these geologists regarding which of the "black" shales should be assigned to the Percha. To date, paleontologic data have not established the age of these shales; hence the correlation of any of these local "black" shale sections with the Percha farther west in New Mexico is hazardous. Use of a color chart indicates that few or none of these "black" shales are a true black, but range from dark gray to the darker shades of gray brown or olive gray.

Lithologic correlation of the units interpreted as Percha shale in the Sacramento Mountains would place them in the lower part of the

Percha type section, the Ready Pay member (Stevenson, 1945). Green to gray calcareous shale resembling that of the upper or Box member of the Percha shale has not been recognized in the Sacramento Mountains.

According to the writer's interpretations, all but one of the known outcrops of "black" shale in the Devonian sequence in the northern and central parts of the escarpment are a part of the Sly Gap formation, rather than a part of the Percha or a part of the basal Caballero formation. The one exception merits some discussion, as it has been reported upon in detail by Stevenson (1945) and may represent an unusual phenomenon in the Devonian of New Mexico.

Stevenson (1945) discovered a distinct angular relationship between truncated Sly Gap strata and overlying "black" shale and minor silt-stone at a small outcrop in the NE1/4 NW1/4 sec. 26, T. 16 S., R. 10 E., in the Marble Canyon area. In a short distance nearly the entire Sly Gap section is cut out, although the Silurian, the Onate and Sly Gap, and the overlying Mississippian strata are essentially parallel. Stevenson considered various hypotheses to account for the structural relationships, including the hypothesis that the dark shale and siltstone represented a channel fill. He concluded that an interpretation of faulting best fits the available evidence. The writer's observations at this locality generally verify the data observed by Stevenson, the major exception being that the rock unit of Mississippian age overlying the anomalous shales is the Caballero, rather than the basal unit of the Lake Valley formation. However, examination of the outcrops at the end of a low ridge about 500 feet south of the angular discordance observed by Stevenson revealed some pertinent data. This adjacent locality may not have been so clearly exposed at the time of Stevenson's examinations. At this locality, dark shale and siltstone are discordant with the attitude of the overlying Caballero formation and, significantly, dip toward the north. This is the reverse of the shale dips observed by Stevenson to the north. This evidence appears to rule out a faulting interpretation, and greatly strengthens the interpretation that the dark shale and minor siltstone represent a 40-foot-thick fill of a channel cut into the Sly Gap. If this interpretation is correct, more such dark shales and minor siltstones are likely to exist in the region. The dark shales are clearly younger than Sly Gap and older than the overlying Caballero. Stevenson correlated these dark shales and minor siltstones with the Percha formation (Ready Pay member), an interpretation followed here.

Southward from the vicinity of Escondido Canyon, in T. 19 S., in the southern part of the escarpment, a sequence of fissile, noncalcareous, dark-gray shale, from 10 to 20 feet thick, is tentatively correlated by the writer with the Percha shale, although Stevenson (1945), Laudon and Bowsher (1941, 1949), and Flower (1957, 1959) apparently consider this a shaly facies of the Sly Gap formation. On the basis of the present data, this unit could be a shaly lateral equivalent of either, or both, the Onate or Sly Gap, or could be a rather normal section of Percha shale. The dark shales of the Devonian of southern New Mexico are correlated into the subsurface as Woodford (Lloyd, 1949; Ellison, 1950).

## MISSISSIPPIAN FORMATIONS

The Mississippian strata of this area and in much of southern New Mexico were little known until the excellent work of Laudon and Bowsher (1941, 1949). These writers established most of the present stratigraphic framework of the Mississippian beds of this region, measured and described many Mississippian sections in southern New Mexico, and were the first to recognize and study the fascinating bioherms of the Lake Valley formation.

Laudon and Bowsher (1941) divided the lower Mississippian strata into two formations, the Caballero formation, of Kinderhookian age, and The Lake Valley formation (restricted), of Osagian age. The latter was subdivided into three members, the Alamogordo, the Arcente, and the Dona Ana, the type section for each of these units being established in the NW1/4 SE1/4 sec. 3, T. 17 S., R. 10 E., in the Alamo Canyon area (pl. 1). On the basis of further studies throughout southern New Mexico, Laudon and Bowsher (1949) subdivided the Alamogordo member into four additional members; from base to top, the Andrecito, Alamogordo (restricted), Nunn, and Tierra Blanca. Of these the type section of only the Alamogordo member is in the Sacramento Mountains. In their later work, Laudon and Bowsher (1949) recognized a series of Mississippian strata in the southern Sacramento Mountains that were younger than the Lake Valley formation, and correlated them with the Rancheria formation (Meramecian) of the Franklin Mountains.

The detailed mapping of the Mississippian in the Sacramento Mountains has required some, but relatively little, modification of the results published earlier by Laudon and Bowsher, and has shown the adequacy of their stratigraphic framework for this area. The principal changes have been in the areal extent of the Rancheria formation (now mapped as far north as Mule Canyon in the northern part of T. 17 S.; possibly a feather edge occurs also in the Alamo Canyon area), and the recognition of the Helms formation in the southern part of the escarpment (T. 19 S.).

The general characteristics of the Mississippian rock units of the Sacramento Mountains are shown in Figure 3, and the north-south variation of these units is given in Figure 15. Type sections (fig. 16) of four of the currently recognized rock units of the Mississippian system (the Caballero formation, and the Alamogordo, Arcente, and Dona Ana members of the Lake Valley formation) occur in Deadman Canyon (sec. 3, T. 17 S., R. 11 E.) and have been visited during many formal and informal field conferences.

Mississippian strata are everywhere present between the Devonian and Pennsylvanian strata in the Sacramento Mountains outcrops, and their total thickness is generally 300 to 400 feet. The basal formation, the Caballero, is everywhere present, but thins to the south. The Lake Valley formation and the later Mississippian strata comprising the

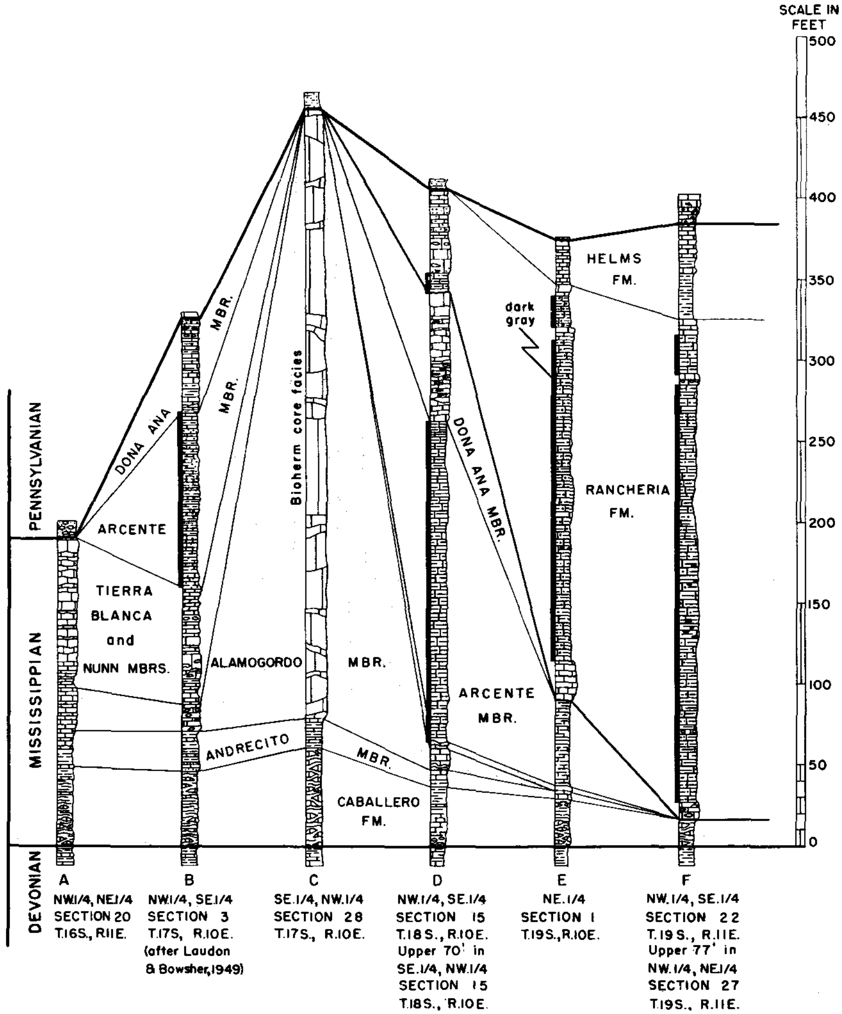



Figure 15

NORTH-SOUTH CROSS-SECTION OF GRAPHIC SECTIONS, MISSISSIPPIAN STRATA, SACRAMENTO MOUNTAINS

Rancheria and Helms formations form mutually compensating wedges that taper out toward the southeast and northwest respectively. The north-south changes in lithology and thickness of the Mississippian units in the area are shown on Figure 15.

## CABALLERO FORMATION

This distinctive lithologic unit consists largely of interbedded, gray, very nodular argillaceous limestone and gray calcareous shale in about equal proportions. In the upper part of the section, some evenly bedded crinoidal calcarenites and calcirudites occur and may form a low scarp at the top of the otherwise uniform slope. The formation is commonly covered by slope wash from overlying, more resistant strata. The distinctive limestone nodules are ellipsoidal, commonly 1 to 2 inches in diameter, and twice as long. Fossils are abundant, though commonly of small forms. Many marine invertebrate types are present.

The Caballero formation occurs throughout the Sacramento Mountains escarpment, ranging in thickness from a maximum of about 60 feet in the north to 15 feet where exposed farthest south.

The basal contact of the Caballero is sharply defined and interpreted as a disconformity. It is marked by a zone about an inch thick containing abundant small, irregularly shaped, black siliceous nodules and occasional bone fragments and fish teeth.

Dark-gray or "black" shales are not a part of the formation, although commonly occurring directly below the Caballero and above nodular limestones of the Sly Gap that locally are differentiated from the Caballero only by faunal content, or by properly identifying the nodular strata as occurring above or below the basal unconformity of the Caballero formation. The Caballero has been tentatively identified in the subsurface of eastern Lea County.

## LAKE VALLEY FORMATION

The Lake Valley formation is well developed in the central Sacramento Mountains, reaching a thickness of about 400 feet and consisting largely of crinoidal limestones, with minor calcareous siltstones and shales. The stratigraphic relationships of this formation are complex, owing to lateral and vertical variations in lithology and thickness. The thickness changes are caused both by variation of depositional thickness and by subsequent erosion along unconformities either during or subsequent to Mississippian time. The Lake Valley formation has been divided into six members by Laudon and Bowsher (1949), the Andrecito, Alamogordo, Nunn, Tierra Blanca, Arcente, and Dona Ana members in ascending order. As biohermal growth has so profoundly affected the Lake Valley stratigraphy of this area, the six members can be conveniently discussed on the basis of prebiohermal, biohermal, and postbiohermal members. On the geologic maps (pls. 1, 2), the prebiohermal and biohermal beds, together with the Caballero formation, were mapped as a unit (M1), whereas the Arcente (Ma) and Dona Ana (Md) members were mapped separately.

The bioherms in the Lake Valley formation of the Sacramento Mountains are among the best exposures of Mississippian bioherms known in North America, if not in the world. Generalized descriptions regarding the occurrence and nature of these bioherms, and detailed study of certain facies, particularly the flank facies, which yielded a prolific crinoid assemblage, have been provided by Laudon and Bowsher (1911, 1949) and Bowsher (1948); however, many important aspects regarding the genesis of these spectacular bioherms remained unanswered. Detailed field and laboratory studies, the latter largely petrographic, directed toward a more adequate understanding of these bioherms are currently being undertaken by Alan S. Horowitz and the writer. Preliminary results have been published (Pray, 1958a; Pray and Horowitz, 1959). The recognition of fenestrate bryozoans and their genetic significance in the core facies of these bioherms has been of major interest. The Lake Valley bioherms have many similarities with the heretofore little known Mississippian bioherms of Montana, northeastern Oklahoma, and north-central Texas. Literature surveys and field reconnaissance studies indicate that they are similar to many of the Lower Carboniferous "reef knolls" of Great Britain and western Europe, but are dissimilar to the crinoidal bioherms in the Borden group of Indiana, with which they have often been classified. Photographs of two of the biohermal complexes are shown in Figures 18 and 33. In the Sacramento Mountains, the bioherms are most numerous in the northern part of the area, in T. 16 S. and the northern part of 1' 17 S. In this area many have a distinct linear trend, oriented roughly north-south. The largest bioherms occur in the central part of the area, to the north and south of San Andres Canyon, where they are about 350 feet thick and are domical in shape.

## Prebiohermal Strata

The only member of the Lake Valley not influenced by biohermal growth is the basal Andrecito member. The Andrecito member consists largely of calcareous shale, marl, thin-bedded argillaceous limestone, some well-sorted crinoidal calcarenites, and minor quartzose siltstone. The unit is 20 to 35 feet thick in the northern Sacramento Mountains and thins southward. Swirllike or branching patterns of the problematic fossil *Taonurus* are abundant and serve as an index fossil for this member in the area. The base of the Andrecito formation is a clearly marked disconformity, commonly with observable low angular discordance. The relatively even bedding, the quartz silt or very fine-grained sand, and *Taonurus* are distinguishing characteristics of this member.

The lithology of the Andrecito in the northern part of the area is shown in Figure 16. In this area, the basal few feet (in particular, the basal 1 foot, a relatively massive bed) contains abundant quartz silt and

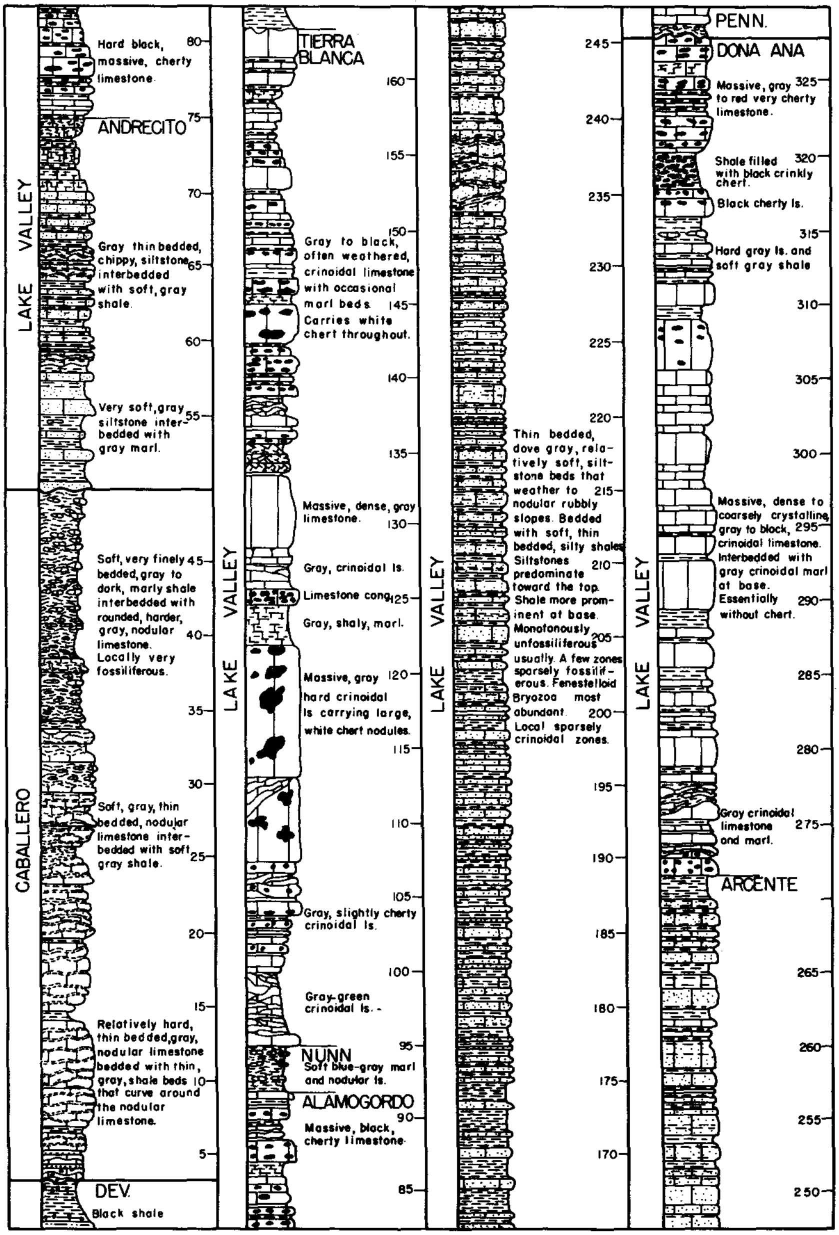



Figure 16

STRATIGRAPHIC SECTION OF MISSISSIPPIAN STRATA IN DEADMAN CANYON

(From Laudon and Bowsher, 1949, fig. 12.)

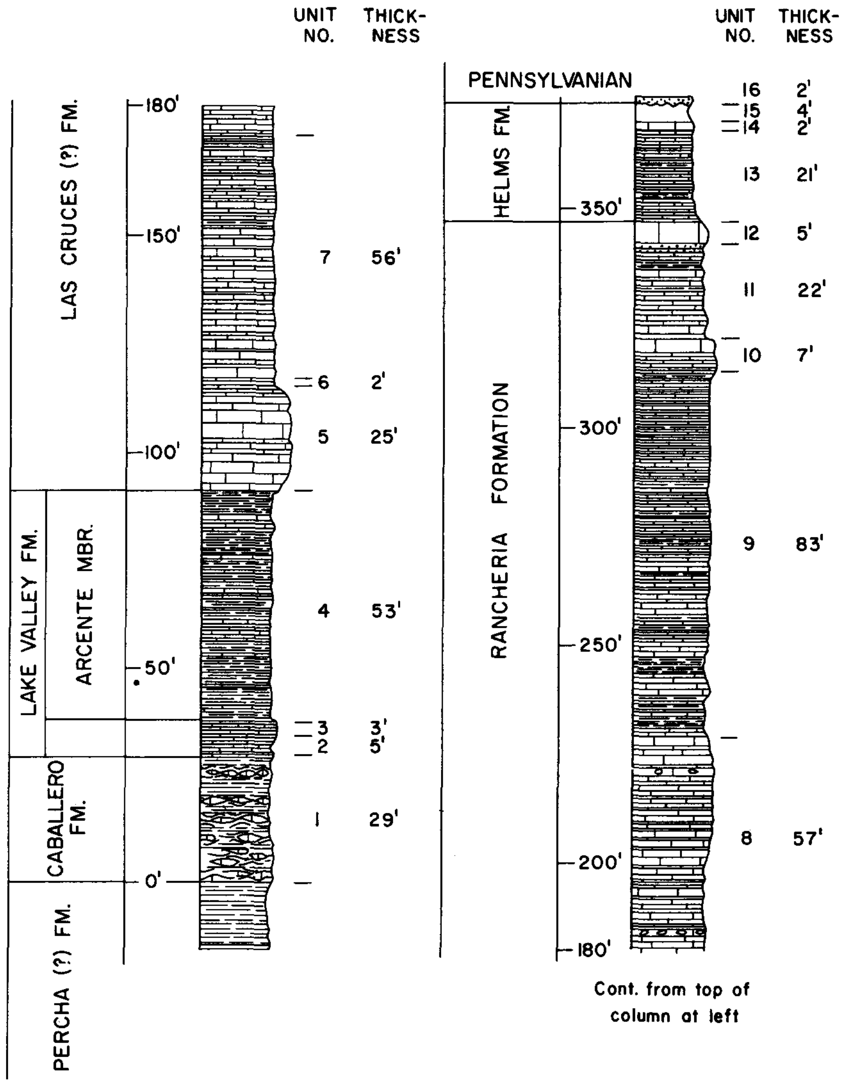



Figure 17

GRAPHIC SECTION OF MISSISSIPPIAN FORMATIONS IN SOUTHERN SACRAMENTO MOUNTAINS, AGUA CHIQUITA CANYON

(NE. corner, sec. 1, T. 19 S., R. 10 E.)

some sand grains Toward the south in the Sacramento Mountains, the Andrecito member not only thins (fig. 17), but also loses some of its distinctive characteristics, and locally cannot be differentiated with assurance from the Caballero formation. As the underlying Caballero formation is thin and is present throughout the escarpment, the angular discordances at the base of the Andrecito member must be local in nature.

## Biohermal Strata

Nearly all the bioherms occur in the Alamogordo, Nunn, and Tierra Blanca members of the Lake Valley formation. The typical lithology of these members in the Sacramento Mountains was developed away from the influence of the growing bioherms; that is, an "interreef" facies. Recognition of these three members serves a useful purpose for a regional correlation in New Mexico. Difficulties arise, however, in attempting to apply this terminology near the bioherms. A threefold classification of lateral facies within the biohermal sequences appears more useful than the vertically segregated-member terminology. These lateral facies are the core facies, the flank facies, and the "interreef" facies. The core and flank facies are both considered parts of the biohermal complexes, and the interreef facies is the enclosing rock within which the biohermal complexes developed. The interreef facies is thus the normal regionally developed fades.

The typical or interreef facies of the Alamogordo member is that of medium-gray cherry calcilutite developed in massive beds a few inches to several feet in thickness. These beds are hard and resistant to weathering, and in most places form a ledge or scarp. The thickness of the Alamogordo member (interreef facies) ranges from 15 to about 40 feet in most places. It thins to less than 5 feet in the southern part of the escarpment and is absent in the Grapevine Canyon area.

The Nunn member in the Sacramento Mountains consists largely of interbedded friable or poorly cemented crinoidal limestone, and minor amounts of crinoidal marl. Regionally, and in the Sacramento Mountains, this member is the "Happy Hunting Ground" for crinoid collectors, as the crinoids are well preserved and easily collected. The Nunn member is represented by both interreef and flank facies and is rarely well exposed, being less resistant to weathering than the enclosing rock units. The thickness is variable over a wide range, depending on position with respect to a bioherm, and (or) later erosion. The Nunn is the least satisfactory of the various members of the Lake Valley to attempt to trace laterally.

The upper member of the biohermal strata is the Tierra Blanca member, composed largely of crinoidal calcarenites and calcirudites. Large nodules of light-colored chest are abundant. The limestone is normally well cemented, with sparry calcite growing in optical continuity with the crinoidal host grains. Some of the Tierra Blanca contains a calcilutite (lime-mud) matrix, especially in areas farthest removed from sites of the growing bioherms. The Tierra Blanca member characteristically forms a resistant cliff. It ranges in thickness from a maximum of nearly 200 feet to a more prevalent 100 feet in areas where it is near large bioherms, as in western Alamo Canyon. The member becomes progressively thinner away from these areas. The Tierra Blanca forms both flank and interreef facies. Part of the Tierra Blanca member may represent deposition that was later than active biohermal growth. The member is absent south of Dog Canyon, in T. 18 S., probably because of pre-Arcente erosion of an originally thin section of Tierra Blanca strata (fig. 17).

The core facies, of light- to very light-gray massive limestone, consists largely of aphanitic and sparry calcite, with a subordinate amount of skeletal fossil constituents, of which fenestrate bryozoans are the dominant indigenous faunal component. Crinoidal columnals are common, and many other types of fossils are recognized, though in very subordinate amounts. The aphanitic calcite is predominant in most core rocks, but locally sparry calcite is most abundant. The flank facies is simpler in lithology, being composed largely of relatively pure crinoidal calcarenites and calcirudites. It may dip away from the core facies at angles in excess of 30 degrees. The flank facies thins markedly and becomes more distinctly bedded away from the core facies, grading then into the "interreef" strata described above. Within the flank facies, the amount of calcilutite (primary lime-mud) ranges from almost none to forming a predominant matrix for crinoidal debris. The lateral transition from core to flank facies is exceedingly abrupt, whereas that between the flank and interreef facies is more gradual. Where the interreef facies consist of the Nunn or Tierra Blanca members, the differentiation of flank and interreef is arbitrary, and the amount of primary dip of the beds is an important factor.

Most of the bioherms apparently began growth early in Alamogordo time, and some continued to grow into or perhaps through Tierra Blanca time. Small bioherms locally occur within all three members of the biohermal strata.

The formation of the bioherms is difficult to interpret. Two of the many problems are the growth mechanism of the core facies, and the source of the abundant aphanitic calcite (lime-mud) of the core facies. Depositional relief in excess of 200 feet occurred on the larger bioherms, and angles of primary dip of both the core facies and the adjacent part of the flank facies locally are nearly 35 degrees. Of the faunal components, fenestrate bryozoa have undoubtedly assisted or permitted local buildup of the core facies. In some bioherms, however, bryozoans appear to form simply a coarse-grained accessory component of an aphanitic core facies, and another buildup mechanism seems necessary.

Neither algal frame builders nor stromatolitic algae have been recognized. Filamentous algae could have played a role in these bioherms, but direct evidence of this has not been found; moreover, the depth of water in which some of the bioherms must have formed is below the range now known for such organisms.

The bioherms are interpreted to have grown below the zone of appreciable wave abrasion. Many probably formed initially in relatively deep waters, and appear to have been capable of growth into somewhat turbulent water.

### Postbiohermal Strata

The Arcente and overlying Dona Ana members (each mapped separately; pls. 1, 2) are later than the period of major biohermal growth. The Arcente consists largely of dark calcareous shale and thin-bedded, medium-gray argillaceous limestone. The conditions that prevailed during deposition of this member probably were distinctly unfavorable for the growth of bioherms, if prior conditions, such as emergence or submergence, had not already stopped their growth. The Arcente appears to level out some of the topographic relief caused by biohermal growth.

The Arcente member consists of about equal quantities of dark-gray calcareous shale and argillaceous silty limestone, which alternate monotonously throughout much of the section in layers rarely thicker than 1 foot, and more commonly about 6 inches thick. In the upper half of the member, a zone 10 to 30 feet thick is composed largely of argillaceous dark limestone, forming a scarp on the otherwise uniform slope of the Arcente member. Dark-gray chert nodules, 1 to 2 inches thick, are common in this zone, but are lacking elsewhere in the member. The Arcente attains a maximum thickness of about 200 feet in the central part of the escarpment. It thins and becomes more shaly and lighter in color toward the southern part of the escarpment (fig. 17). Approaching a major bioherm, the Arcente shows abrupt thinning and local pinch-out. The basal contact of the Arcente is not well exposed. It appears to be disconformable in the southern area of outcrop, but may be gradational with the underlying Tierra Blanca in the northern area.

The Dona Ana member is gradational with the Arcente, marking a return to clear seas and profuse growth of crinoids. The Dona Ana is a cherty, light-gray, irregularly bedded crinoidal limestone very similar to the Tierra Blanca member. It reaches a maximum thickness of about 150 feet and thins abruptly or pinches out at the edges of major biohermal cores. The Arcente and Dona Ana are absent in the northernmost outcrops, where they probably were removed by pre-Pennsylvanian erosion. They are largely absent from the southern part of the Sacramento Mountains, where they may initially have been but thinly developed, and from which they were stripped by erosion prior to the deposition of the Rancheria formation.

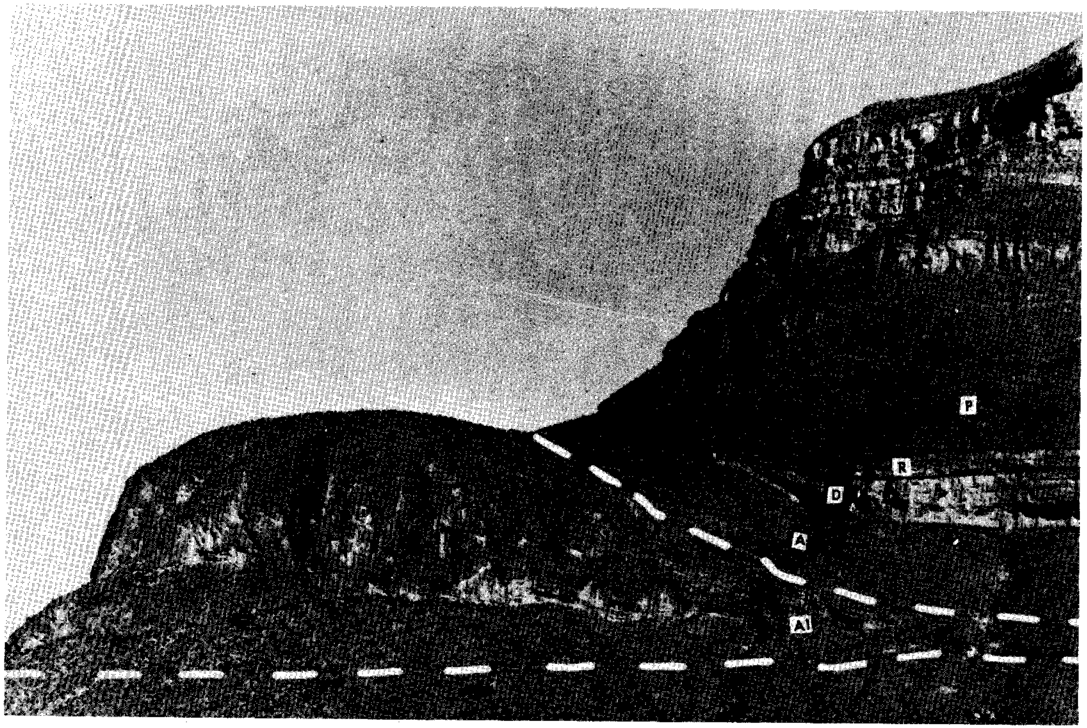



Figure 18

MULESHOE CANYON MISSISSIPPIAN ISIOHERM

The biohermal facies (Al) is about 350 feet thick at center of buildup, and thins in about 1,000 feet to right to about 65 feet. Other units designated are: A, Arcente member, and I), Dona Ana member of Lake Valley formation; R, the Rancheria formation; and P, Pennsylvanian rocks.

## RANCHERIA FORMATION

In the southern part of the Sacramento Mountains escarpment a sequence composed largely of dark, relatively thin-bedded, argillaceous and silty limestones was identified by Laudon and Bowsher (1949) as the Rancheria formation and is considered to be of Meramecian age. Lithologically, the formation is dissimilar to any of the underlying rock sequences.

The Rancheria formation (fig. 17) consists of a rather monotonous repetition of a few basic rock types. A common type is dark-gray, thin-bedded, argillaceous and silty limestone, or similar calcareous siltstone, that contains abundant streaks and laminae of porous chert which weather a distinctive yellow brown. A related abundant rock type is similar to the above, but lacks the chert and weathers a light gray. A minor, though significant and conspicuous, rock type is medium-gray, silty or sandy, crinoidal calcarenite containing brachiopods, shark teeth, and other fossils. These strata form several resistant ledges in most of the Rancheria sections. Calcareous gray and brown shale is a fourth rock type, most common as thin interbeds between the dark limestones.

Numerous erosional discontinuities, some of which have angular discordances as high as 10 degrees, are of unusual interest. Almost invariably these occur at the base of the resistant calcarenites. In some sections two or more of these discontinuities occur between the Lake Valley formation and the Helms formation. The lithologic character of the Rancheria sequence does not appear to change despite these discontinuities. The multiplicity of the small angular discordances, and the overall constancy of the rock types, suggest that these breaks are of intraformational origin and may not be the obvious angular unconformities they appear to be on first inspection. A similar discontinuity reported by Laudon and Bowsher (1949) in the Franklin Mountains formed the primary basis for establishing the Las Cruces formation as a separate unit below the Rancheria. Until the lateral persistence of these discontinuities can be better established or other means of correlation found, the writer prefers to consider as the Rancheria formation all the strata having these characteristics in the Sacramento Mountains.

The Rancheria formation is about 300 feet thick in the southern Sacramento Mountains escarpment (fig. 17), and has been traced northward as a thinning wedge to the northern part of T. 17 S., in Mule Canyon. A thin remnant may occur locally in Alamo Canyon. The northernmost onlapping part of the Rancheria is more massive, lighter colored limestone than prevails to the south, and has characteristics of deposition in shallower or more turbulent water than farther to the south. The sparse fauna of the Rancheria formation is considered to be Meramecian by Laudon and Bowsher (1949), but Weller and others apparently consider the same fauna to be uppermost Osagian (Jones, 1953).

The basal contact of the Rancheria is a clearly marked unconformity of low angular discordance that progressively cuts out the underlying Lake Valley and Caballero formations from northwest to southeast. Locally, angular discordances of 5 to 10 degrees occur, as may be seen in Figure 18.

## STRATIGRAPHIC SECTION OF MISSISSIPPIAN FORMATIONS IN THE SOUTHERN SACRAMENTO MOUNTAINS

Section measured in Agua Chiquita Canyon; base of section is 2,300 feet west and 1,600 feet south of the northeast corner of T. 19 S., R. 10 E. (fig. 17).

| UNIT No. | DESCRIPTION | THICKNESS (feet) |
|---|---|---|
| | Top of section | |
| | PENNSYLVANIAN SYSTEM | |
| | *Gobbler formation* | |
| 16 | Quartz sandstone, greenish-gray, fine-grained | 2 |
| | MISSISSIPPIAN SYSTEM | |
| | *Helms formation*—27 feet thick | |
| 15 | Covered slope | 4 |
| 14 | Limestone, brown-gray, oolitic, massive; weathers yellow brown | 2 |
| 13 | Limestone, medium-gray, argillaceous; thin beds less than 1 foot thick; weathers light gray; some interbedded gray shale | 21 |
| | *Rancheria formation*—257 feet thick | |
| 12 | Limestone, medium-gray, granular, massive; much lateral variation in thickness; silicified brachiopods and fish teeth present | 5 |
| 11 | Limestone, medium-gray, silty; conspicuous brown-weathering silicified nodules, bands, and laminae; 2 feet of gray calcareous shale at base; locally unit is nearly 40 feet thick | 22 |
| 10 | Limestone, medium-gray, granular, fossiliferous; upper part massive and grading downward into laminated medium dark-gray silty limestone | 7 |
| 9 | Limestone, medium-gray, silty, argillaceous; beds less than 1 foot thick; interbedded with dark-gray argillaceous limestone and calcareous shale; weathers light gray except for brown siliceous beds in upper part | 83 |
| 8 | Limestone, medium dark-gray to olive-gray, sublithographic, silty; beds 3 inches to 2 feet thick; minor shale partings; gray chert nodules 11 feet above base, 1-foot dark-gray chert layer at top; basal 50 feet weathers very light gray and is capped by thin dark zone | 57 |
| | Units 5, 6, and 7 may represent the *Las Cruces formation* | |
| 7 | Limestone, medium dark-gray, sublithographic, silty; evenly laminated beds, 2 inches to 1 foot thick, interbedded with minor dark calcareous shale; siliceous laminae weather brown; forms distinctive brown-weathering slope | 56 |
| 6 | Shale, brown-gray, calcareous | 2 |
| 5 | Limestone, gray, granular, petroliferous; basal 4 feet argillaceous; forms first resistant cliff above Fusselman formation | 25 |
| | *Lake Valley formation, Arcente member*—53 feet thick | |
| 4 | Shale, light-gray, calcareous (60 percent), interbedded with 1- to 3-inch beds of sublithographic, medium light-gray limestone; more argillaceous toward top; 2-inch-thick crinoidal limestone 28 feet above base | 53 |
| | *Lake Valley formation, Alamogordo member*—8 feet thick | |

| UNIT No. | DESCRIPTION | THICKNESS (feet) |
|---|---|---|
| 3 | Limestone, medium light-gray, sublithographic, thin-bedded, resistant | 3 |
| 2 | Limestone, yellow-gray, very argillaceous; 1 foot of resistant reddish argillaceous limestone at base; possibly *Andrecito* or *Caballero* | 5 |
| | *Caballero formation*—29 feet thick | |
| 1 | Upper shale, yellow-gray, calcareous, with minor, somewhat nodular limestone; middle shale, light gray-green, calcareous, with nodular limestone; basal limestone, light-gray, argillaceous, nodular, with calcareous shale partings | 29 |
| | DEVONIAN SYSTEM | |
| | *Percha(?) shale* | |
| | Shale, olive-gray to dark-gray; poorly exposed | |

## HELMS FORMATION

The Helms formation occurs in the southern part of the area and extends northward to near Dog Canyon. The unit is a maximum of 60 feet in thickness, consisting of thin-bedded argillaceous 'limestone and yellow and gray interbedded shale. Several thin beds of oolitic limestone occur near the top of the formation. It is similar in lithology and fauna to the thicker Helms sections of the Hueco and Franklin Mountains, except that sandstone is almost absent in the unit in the Sacramento Mountains area. The Helms formation contains Chesterian fossils. The basal contact is probably a disconformity, but little physical evidence of this relationship has been observed in the mapped area.

The precise northern pinchout of the Helms formation is not known, but the unit has been traced to Escondido Canyon, and probably persists as far north as Dog Canyon, in T. 18 S. Where it is best exposed and thickest, along the bottom of Grapevine Canyon, in the SW1/4 NE1/4 NW1/4 sec. 27, T. 19 S., R. 11 E., the section is as follows:

### STRATIGRAPHIC SECTION OF THE HELMS FORMATION IN THE SOUTHERN SACRAMENTO MOUNTAINS

| UNIT No. | DESCRIPTION | THICKNESS (feet) |
|---|---|---|
| | Top of section | |
| | PENNSYLVANIAN SYSTEM | |
| | *Gobbler formation* | |
| | Shale, red-brown; minor quartz sandstone with 2-inch chert-pebble conglomerate at base | 2 |
| | Unconformity; irregular surface that truncates the underlying beds | |
| | MISSISSIPPIAN SYSTEM | |
| | *Helms formation*—58½ feet thick | |
| 6 | Limestone, medium-gray, sublithographic, argillaceous; even beds 2 inches to 1 foot thick; interbedded with olive-gray calcareous shale | 11 |
| 5 | Limestone, gray, oolitic | 2 |
| 4 | Limestone, medium-gray, sublithographic, argillaceous; interbedded with light olive-gray calcareous shale; 2 feet of dark-gray granular fossiliferous limestone 2 feet above the base | 8 |

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| 3 | Shale, light olive-gray, calcareous | 7 |
| 2 | Limestone, medium-gray, medium-granular; top is fossiliferous (*Archimedes* sp.) | 1½ |
| 1 | Shale, light olive-gray, calcareous; interbedded with thin argillaceous limestone; minor siltstone | 29 |
| | *Rancheria formation* | |
| | Limestone, dark-gray, medium-granular, silty, fossiliferous (brachiopods, crinoids); upper surface locally iron stained | |

## PENNSYLVANIAN FORMATIONS

The Pennsylvanian strata of the Sacramento Mountains escarpment form more than a third of the total Paleozoic section, are the surface strata of more than a third of the total mapped area of the mountain block, and present at least an equivalent amount of the geologic problems in the area. The brief summary of the Pennsylvanian strata given in this report affords only an introduction to this interesting and complex part of the stratigraphic section. Broader investigations of the Pennsylvanian system that provide regional perspective for the more local data of this report are largely those of Thompson (1942), Read and Wood (1947), Lloyd (1949), and Kottlowski (1960). The latter is an excellent compilation and synthesis of data pertaining to the Pennsylvanian system in southeastern Arizona and southwestern New Mexico, and includes the area of the Sacramento Mountains.

The Pennsylvanian strata (fig. 19) of the Sacramento Mountains area stand in sharp contrast to the older Paleozoic rocks. The sequence is as thick as, or thicker than, the entire underlying Paleozoic section. Pennsylvanian beds contain large amounts of terrigenous clastics, and lithologic changes (laterally as well as vertically) occur with a rapidity that leads to despair if one attempts to subdivide the Pennsylvanian section on the basis of rock units that will prove recognizable over the entire escarpment area. The Pennsylvanian deposits clearly reflect the increasing degree of tectonic instability that occurred during this period in the region, an instability that resulted in the formation of basins and source areas of more localized extent than previously had existed in earlier Paleozoic time. This more localized aspect of Pennsylvanian sedimentation, combined with probably frequent eustatic changes in sea level, resulted in the complexity of Pennsylvanian deposits found in the escarpment area of the Sacramento Mountains.

The tectonic setting is important for an understanding of the Pennsylvanian deposits of the Sacramento Mountains. In late-Paleozoic time, the area of the escarpment appears to have been between a relatively positive area that occurred to the east and northeast, and a relatively negative area that lay to the west. The positive area is the southern part of the Pedernal landmass (Thompson, 1942). The negative area to the west has been termed the Orogrande basin by the writer. Though this


Figure 19

PENNSYLVANIAN AND OLDER STRATA ON SOUTH SIDE OF NEGRO Ell CANYON

V, Valmont dolomite; F, Fusselman formation; M, Mississippian strata; Pg, Gobbler formation; Pb, Beeman formation; and Ph, Holder formation. Most of the Gobbler formation at this locality is in the cliff-forming Bug Scuffle limestone member.

general pattern may have existed throughout Pennsylvanian time, the degree of tectonic differentiation ranged from slight, in the earlier part of Pennsylvanian time, to a role of major significance by the end of Pennsylvanian time.

The older Pennsylvanian strata (Morrowan?, Atokan, and Desmoinesian) appear to have been deposited largely on a broad marine shelf area subject to local invasion by tongues of detrital facies, presumably deltaic, that were introduced from the more positive, but perhaps not emergent, area to the east and northeast. In Missourian time, a sharper tectonic differentiation existed, and in the area of the escarpment there is evidence for a north-south boundary or "hinge line" between a more shallow marine shelf area to the east and a more basinal area to the west. In latest Pennsylvanian time, the evidence clearly indicates a shallow shelf in most of the escarpment area, with cyclic sedimentation that shifted progressively from cycles entirely marine in origin to those with some terrestrial or transitional environments represented. Moreover, in the northeasternmost part of the escarpment, the latest tectonic activity of Pennsylvanian time shows deformation, uplift, and presence of an emergent source area. The interpreted tectonic record of the area immediately west of the escarpment area is of a subsiding basin receiving a thick sedimentary fill compared to the escarpment area.

The Pennsylvanian section of the Sacramento Mountains has a maximum thickness of about 3,000 feet, and the deposits span a time range from possible Morrowan, at the base, to the end of the period. Field evidence to date indicates that deposition was essentially continuous throughout this time; at least, no persistent erosional surfaces have been recognized that are interpreted as significant time breaks. The boundaries of most of the series (based on fusulinids) do not appear to have a physical basis.

Along most of the western edge of the mountains, the Pennsylvanian section is nearly complete, ranging commonly from 2,000 to 2,500 feet in thickness and including Virgilian strata at the top. Pre-Abo erosion is more pronounced to the east, where the Abo in many places overlies strata of Desmoinesian and Missourian age. Locally, pre-Abo erosion has removed all of the Pennsylvanian section.

A multiplicity of terms for time-rock units and for rock units have been applied to the Pennsylvanian of southern New Mexico. In this report, the terminology used for the major series represented within the Sacramento Mountains escarpment is the following, in order of decreasing age: Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian. This terminology for the time-rock units is better established than that of the rock units of the New Mexico area. The term Magdalena (formation or group) has been used to include all the strata between the Mississippian and the Abo formation (Dane and Bachman, 1958). As such, the term applies to the entire Pennsylvanian system and

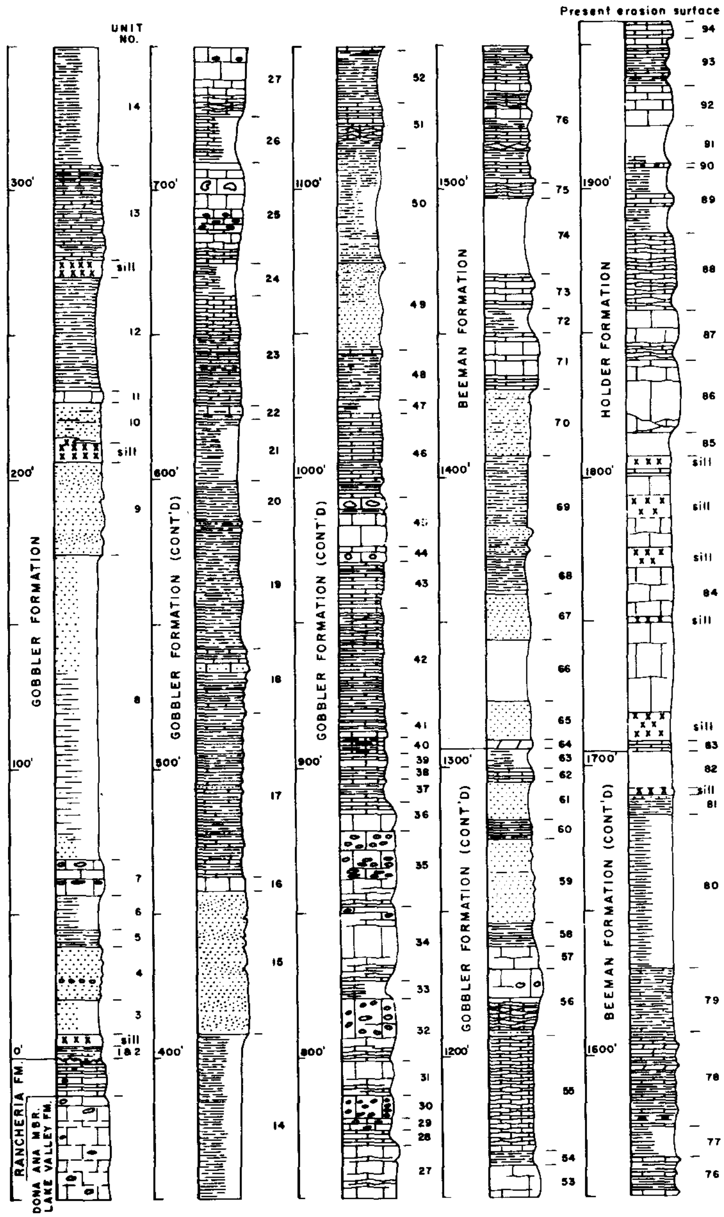


Figure 20

GRAPHIC SECTION OF TYPE SECTION OF HOLDER, BEEMAN, AND GOBBLER FORMATIONS

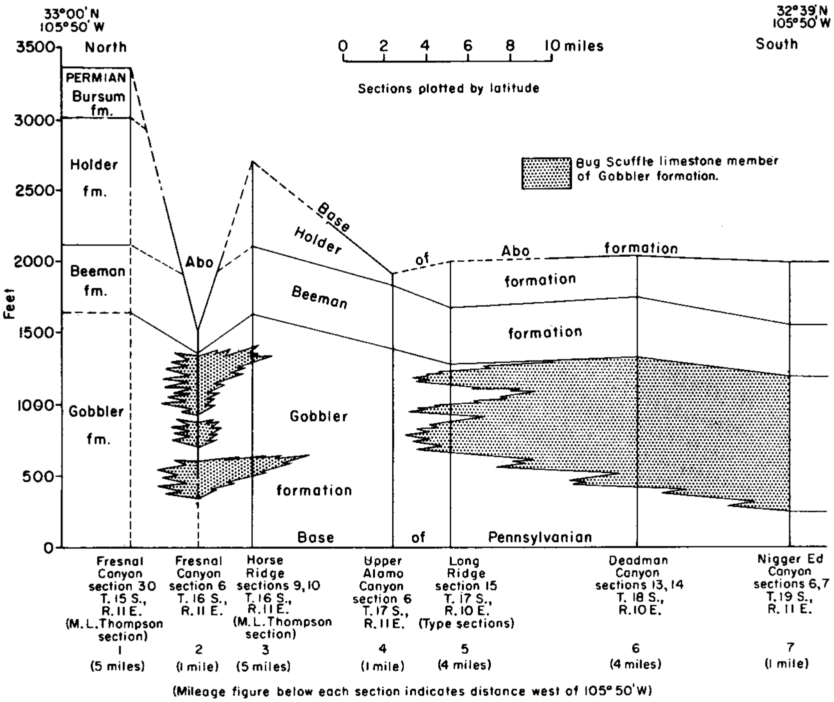



Figure 21

NORTH-SOUTH VARIATION DIAGRAM OF PENNSYLVANIAN UNITS IN SACRAMENTO MOUNTAINS

to part of the Permian as well. It is shown in this sense, as Magdalena group, on Plate 1. The term is so broad, however, and the sections to which it has been applied are so varied in New Mexico, that it serves little practical purpose.

Pre-existing terminology for subdivisions of the Pennsylvanian system in New Mexico was found to be inadequate for the Pennsylvanian strata of the Sacramento Mountains escarpment. In this report, the writer formally proposes three new formations and a member of one of the formations as the subdivision of the Pennsylvanian system in the Sacramento Mountains escarpment. This classification has been used in previous short articles by the writer (1954, 1959) and others, but the type sections necessary for formally establishing the classification have not been published previously. The subdivision given here is introduced specifically for this area, where it has been found to be of practical value. Some of the units may be recognizable in other areas of southern New Mexico, but this is incidental.

The Pennsylvanian strata are here subdivided into three major rock units, the Gobbler, Beeman, and Holder formations. A distinctive facies termed the Bug Scuffle limestone is recognized as a member of the

Gobbler formation. The type section for these rock units is a single, nearly continuous, stratigraphic section (sec. 5, fig. 21) located on Long Ridge, near the west front of the mountains southeast of Alamogordo (see fig. 2). The main features of these rock units are discussed below. Figures 19 to 23 present the major aspects of these rock units in the escarpment area.

The type section of the formations named in this report from the Pennsylvanian system of the Sacramento Mountains 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 1,950-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 the lithologic types and many of the marker beds used 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 the type section.

The greatest disadvantage in the use of this single stratigraphic section (fig. 20) is that the strata of the Holder formation are better exposed, and the section is more complete, farther north in the escarpment area. Much stratigraphic detail of this northernmost area is available, however, to supplement the lithologic details of the Holder formation. This includes the description by Thompson (1942) of the upper two-thirds of the Virgilian section as the Fresnal group, recent detailed description and interpretation of the same part of the section by Cline (1959), and further details on the uppermost Pennsylvanian of the same area by Otte (1959) and Oppel (1959).

The names Gobbler, Beeman, and Holder were derived from geographic localities shown on the U. S. Forest Service base map of the escarpment area. Gobbler is the name of a conspicuous dome (and triangulation station) in sec. 19, T. 18 S., R. 11 E., which is largely composed of limestones of the Gobbler formation. Beeman is the name of a major canyon in T. 16 S., R. 10 E., which is cut into the Beeman formation, and Holder is the name of a ridge composed of Holder formation strata in sec. 36, T. 17 S., R. 11 E.

Field mapping, based on physical attributes of the strata, has been the primary basis for extending the formational limits from the type section to the rest of the escarpment area. In most of this area, the boundaries are believed to be at or near the same horizon as at the type section. In a few localities where the Pennsylvanian exposures are isolated, and especially where facies changes are abrupt, the correlations are less certain. The series boundaries were determined by M. L. Thompson from the study of fusulinids collected from the Pennsylvanian section exposed in the area extending northward from sec. 11, T. 16 S., R. 10 E., to the Fresnal group type section (Thompson, 1942) in sec. 30, T. 15 S., R. 11 E. M. L. Thompson, R. C. Spivey, and G. E. Marrall have dated numerous collections of fusulinids from sections throughout the escarpment area, providing additional control.

## DESCRIPTION OF THE TYPE SECTION OF THE HOLDER. BEEMAN, AND GOBBLER FORMATIONS

Measured in Mule Canyon and Long Ridge area, NW1/4 NW1/4 sec. 14,10 E and NE1/4 NW1/4 and NW 1/4 NE1/4 sec. 15, T. 17 S., R. . (fig. 20).

| UNIT No. | DESCRIPTION | THICKNESS (feet) |
|---|---|---|
| | Top of section | |
| | *Holder formation* | |
| | Incomplete. Measured thickness 215 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 section | |
| 94 | Limestone, very light-gray, dense | 6 |
| 93 | Limestone, medium dark-gray to brown-gray, argillaceous, thin-bedded; interbedded with red, very calcareous shale; fusulinids at top | 16 |
| 92 | Limestone, very light-gray to white, massive | 14 |
| 91 | Covered; red calcareous shale near base | 13 |
| 90 | Conglomerate, dark limestone pebbles and cobbles, and limy matrix; intraformational | 1 |
| 89 | Partly covered; light-gray limestone in middle | 23 |
| 88 | Limestone, pale-red, thin-bedded, argillaceous at base; grades up into very light-gray limestone with obscure nodular bedding; fusulinids abundant | 27 |
| 87 | Limestone, light brown-gray; thin irregular beds at base; grades up into light-gray massive limestone | 17 |
| 86 | Limestone, very light-gray, massive; some irregular obscure bedding; fusulinids 5 feet above base | 25 |
| 85 | Covered | 8 |
| | Igneous sill | (5) |
| 84 | 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 thick at 50 feet, 8 feet thick at 68 feet, and 2 feet thick at 82 feet above the base of the unit | 65 (84) |
| | Igneous sill | (10) |
| | *Beeman formation*—395 feet thick | |
| 83 | Limestone, medium-gray, argillaceous, thin-bedded; algal(?); probably grades into overlying limestone | 3 |
| 82 | Covered; probably argillaceous limestone | 13 |
| | Igneous sill | (2) |
| 81 | Shale, light olive-gray, calcareous; top 1 foot fine-grained, micaceous, dark green-gray calcareous sandstone | 7 |
| 80 | Covered; probably same as unit 79 | 53 |
| 79 | Shale, light olive-gray, calcareous, poorly exposed | 22 |
| 78 | Limestone and dolomitic limestone, light- to medium dark-gray, argillaceous; thin beds 2 inches to 2 feet thick; interbedded with gray, green, and pale-red silty shale. The top 7 feet of dolomitic limestone weathers to brown band on hillside just below level of major slumped masses | 33 |
| 77 | Covered | 11 |

| UNIT No. | DESCRIPTION | THICKNESS (feet) |
|---|---|---|
| 76 | 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 | 61 |
| 75 | Limestone, dusky yellow-gray, argillaceous, silty, thin-bedded; 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 Mountains escarpment | 5 |
| 74 | Covered | 24 |
| 73 | 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 | 12 |
| 72 | Covered, probably shale. Section above unit No. 71 measured in E½ NW¼NW¼ sec. 14, T. 17 S., R. 10 E. | 8 |
| 71 | Limestone, medium light-gray, thick-bedded; basal 3 feet argillaceous, thin bedded; fusulinids near top and at base; 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 | 20 |
| 70 | Feldspathic sandstone, light olive-gray to green-gray, silty, medium-grained; minor siltstone beds | 23 |
| 69 | Siltstone and fine- to medium-grained feldspathic sandstone, dark gray-green to olive-gray, thin-bedded | 35 |
| 68 | Shale, olive-gray, calcareous; siltstone near top; 6-inch bed of dense, laminated brown limestone near base | 13 |
| 67 | Sandstone, green-gray, silty, micaceous, feldspathic(?); medium- to coarse-grained, massive | 15 |
| 66 | Covered | 21 |
| 65 | Feldspathic sandstone, green-gray, fine- to coarse-grained; poorly exposed | 13 |
| 64 | Dolomite, medium-gray, finely crystalline; weathers moderate yellow brown | 3 |
| | *Gobbler formation*—1,287 feet thick | |
| | Top of section at 6,800 feet, in the NW¼NE¼ sec. 15, T. 17 S., R. 10 E. | |
| 63 | Largely covered; green-gray calcareous shale | 7 |
| 62 | Limestone, medium dark-gray, argillaceous; beds 6 to 12 inches thick; fossiliferous (brachiopods) | 5 |
| 61 | Quartz sandstone, gray to olive-green, micaceous, fine- to medium-grained, slightly feldspathic | 13 |
| 60 | Shale, olive-gray, micaceous; minor interbedded dense, argillaceous, medium light-gray limestone; beds 6 to 12 inches thick | 7 |
| 59 | Quartz sandstone, green-gray, micaceous, medium- to coarse-grained, slightly feldspathic; minor granules and interbedded siltstone; petrified wood | 29 |
| 58 | Shale, silty, olive-gray to olive-brown, micaceous; minor interbedded dark-gray fossiliferous limestone | 8 |
| 57 | Limestone, medium light- to light-gray, massive; minor gray chert in center; limestone forms the conspicuous ledge that caps Steamboat to the northwest | 21 |
| 56 | Limestone, dark-gray, argillaceous, nodular, shaly; grades up into unit 57; basal 2 inches silty | 10 |
| 55 | Limestone, dark-gray, silty, slightly nodular; beds 4 to 12 inches thick; thicker at top; brown-weathering silicified streaks; forms distinctive marker in Gobbler formation | 41 |

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| 54 | Largely covered; olive-gray calcareous shale and minor thin crinoidal limestone | 5 |
| 53 | Limestone, medium dark-gray, massive, fossiliferous, algal(?) | 12 |
| 52 | Shale, olive-gray, calcareous; minor argillaceous limestone near base and top | 19 |
| 51 | Limestone, light olive-gray, silty, argillaceous, thin-bedded, slightly nodular | 16 |
| 50 | Quartz sandstone, silty, micaceous, fine- to medium-grained; thin-bedded; interbedded with green-gray micaceous siltstone | 40 |
| 49 | Quartz sandstone, green-gray, silty, fine- to medium-grained; interbedded siltstone, crosslaminated | 30 |
| 48 | Shale, olive-gray, calcareous, fossiliferous; 2 inches of argillaceous crinoidal limestone at top | 18 |
| 47 | Covered | 4 |
| 46 | Limestone, dark-gray, silty; interbedded with calcareous brown-gray to olive-black shale; very fossiliferous (brachiopods, bryozoa, crinoids); beds 2 to 18 inches thick | 28 |
| 45 | 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 | 17 |
| 44 | Limestone, medium-gray, granular; minor dark chert nodules | 5 |
| 43 | Limestone, medium dark-gray, thin-bedded; shaly partings; scattered fusulinids, abundant horn corals | 16 |
| 42 | Limestone, medium dark-gray, argillaceous; thin irregular beds 6 to 12 inches thick; minor thin crinoidal limestone; interbedded brown-black calcareous shale | 35 |
| 41 | Limestone, crinoidal; interbedded with dark-gray calcareous shale; brown-gray chert near base | 9 |
| 40 | Limestone, medium dark-gray, argillaceous | 5 |
| 39 | Limestone, medium dark-gray, granular | 5 |
| 38 | Limestone, dark-gray, argillaceous and silty; interbedded brown-black calcareous shale | 5 |
| 37 | Limestone, dark-gray, argillaceous; 6-inch beds | 7 |
| 36 | Limestone, medium light-gray; lower 6 feet massive; minor chert | 10 |
| 35 | Limestone, light-gray to medium-gray, obscurely bedded; gray chert nodules abundant; 1 to 2 feet of very argillaceous limestone at base | 26 |
| 34 | Limestone, light-gray to medium-gray; obscurely bedded; minor light-gray chert; forms lower half of resistant cliff | 26 |
| 33 | Covered | 6 |
| 32 | Limestone, light-gray, massive and cherty in upper part | 22 |
| 31 | Limestone, light-gray, obscurely bedded; argillaceous limestone near base | 12 |
| 30 | Limestone, light-gray, cherty | 8 |
| 29 | Limestone, coarsely crystalline, cherty | 4 |
| 28 | Limestone, medium light-gray, argillaceous, thin-bedded | 5 |
| 27 | Limestone, medium-gray; obscure beds 2 to 4 inches thick at base, more massive above; forms distinct cliff | 43 |
| 26 | Covered; probably thin-bedded limestone. Above this point, section measured up canyon N. 38° E., which is eroded along igneous dike | 16 |
| 25 | 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) | 35 |
| 24 | Covered. Top is at base of cliff N. 76° E. from head of Mississippian outcrops in Mule Canyon | 11 |

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| 23 | Limestone, medium dark-gray, argillaceous and silty; interbedded with dark-gray calcareous shale; beds 2 to 12 inches thick; fossiliferous (productids) | 38 |
| 22 | Limestone, medium dark-gray, dense, argillaceous; fusulinids in center of 2-foot bed | 4 |
| 21 | Largely covered; probably largely dark-gray calcareous shale and argillaceous limestone | 22 |
| 20 | Shale, olive-gray to olive-black, silty, calcareous | 14 |
| 19 | Shale, olive-gray, calcareous, micaceous; interbedded with thin ½-inch to 6-inch beds of medium dark-gray calcareous siltstone | 44 |
| 18 | Shale, medium dark-gray, calcareous, silty; interbedded with 2-inch to 2-foot beds of dark-gray silty limestone | 22 |
| 17 | Shale, medium dark-gray to dark-gray, calcareous, silty; interbedded with 1- to 6-inch beds of calcareous siltstone and silty limestone | 57 |
| 16 | Limestone, brown-gray, dense, fossiliferous; weathers moderate yellow brown | 5 |
| 15 | Quartz sandstone; coarse to granule-size grains; crosslaminated; forms upper of two prominent sandstone ledges | 49 |
| 14 | Covered; probably largely soft gray shale | 99 |
| 13 | Limestone, dark-gray, silty, platy to laminated; interbedded with gray shale in 6-inch layers | 33 |
| | Igneous sill | (6) |
| 12 | Shale, medium dark-gray, fissile; interbedded with minor thin dark-gray calcareous micaceous siltstone | 39 |
| 11 | Limestone, medium-crystalline, olive-gray, silty | 4 |
| 10 | Quartz sandstone, green to brown, micaceous, silty; minor interbedded shale | 14 |
| | Igneous sill | (7) |
| 9 | Quartz sandstone, yellow-gray; coarse to granule-size grains; minor crosslamination; forms lower of two prominent sandstone ledges | 32 |
| 8 | Covered; upper 40 feet probably soft medium- to coarse-grained quartz sandstone | 105 |
| 7 | Limestone, medium dark-gray, massive, argillaceous near base; 1- to 3-inch black chert seam in center; gray chert near top | 12 |
| 6 | Largely covered; probably as below | 12 |
| 5 | Shale, medium dark-gray, silty, calcareous, and siltstone | 6 |
| 4 | Quartz sandstone, tan, medium- to coarse-grained; minor pebble conglomerate | 18 |
| 3 | Covered; probably soft medium-grained quartz sandstone | 12 |
| | Igneous sill | (4) |
| 2 | Shale, dark-gray, carbonaceous, fissile; 2 inches dark-gray micaceous siltstone; some chert pebbles | 4 |
| 1 | Shale, silty | 1 |
| | Base of Pennsylvanian—unconformity | |
| | MISSISSIPPIAN SYSTEM | |
| | *Rancheria formation* | |
| | Limestone, medium-gray, silty; beds 6 to 18 inches; cherty; abundant fossils near base | 13 |
| | *Lake Valley formation, Dona Ana member* | |
| | Limestone, very light-gray, crinoidal; light-gray chert nodules | 20 |
| | Base of section at 5,650 feet, in the NW¼NE¼NW¼ sec. 15, T. 17 S., R. 10 E., at junction of Mule Canyon with valley from NE. | |

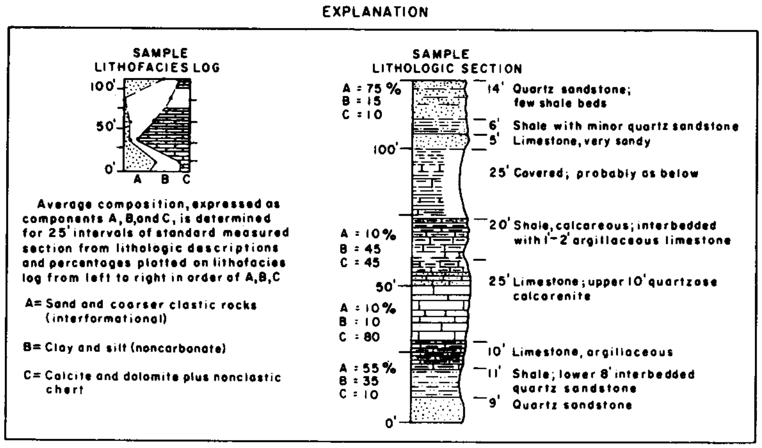



Figure 22

EXPLANATION OF DERIVATION OF LITHOFACIES LOG ON LEFT FROM STANDARD LITHOLOGIC SECTION ON RIGHT

Used to produce lithofacies logs of Figure 23.

## GOBBLER FORMATION

The Gobbler formation forms the lower 1,200 to 1,600 feet of the Pennsylvanian strata of the area, and consists of a wide variety of lithologies that represent environments of deposition ranging from terrestrial to open marine. The Gobbler strata range in age from Morrowan(?) at the base to middle Missourian. The basal Gobbler beds were deposited on a surface of subaerial erosion, which in the northern part of the area was, channeled locally to a depth of about 100 feet. These local channels and lower parts of this surface are in most places filled with coarse-grained to granule-size quartz sandstones, or with chert-cobble conglomerate having a sandstone matrix. An accessible locality where channel fills are conspicuous occurs 11/4 miles east of the entrance of Alamo Canyon, where the. Dona Ana and part of the Arcente members of the Lake Valley formation are abruptly cut out of the section on both sides of the canyon (pl. 1). The relief of the pre-Pennsylvanian erosion surface decreases toward the south in the escarpment area, and the amount and coarseness of the detrital material in the lower part of the Gobbler formation decreases correspondingly.

The lower 200 to 500 feet of the Gobbler formation weathers to a slope in most of the area, is host for numerous intrusive sills of Tertiary(?) age, and is somewhat different lithologically from the overlying section. Two rock types that are common and diagnostic are well-sorted quartz sandstone composed of angular, coarse-grained to granule-size quartz grains, and dark limestone with conspicuous black chert masses.

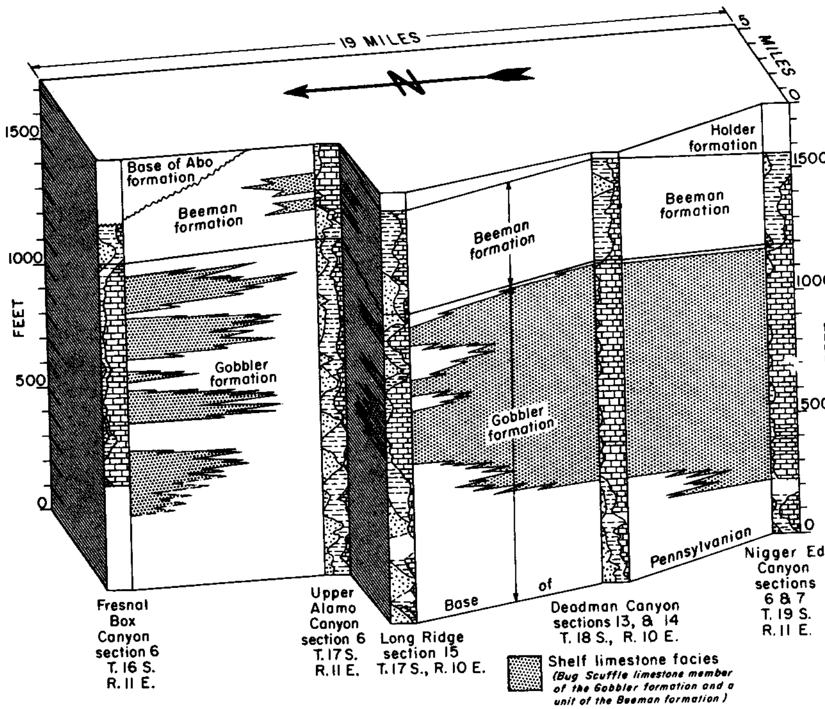



Figure 23

**ISOMETRIC DIAGRAM OF LITHOFACIES LOGS OF GOBBLER AND BEEMAN FORMATIONS IN SACRAMENTO MOUNTAINS**

The sandstone forms resistant ledges several tens of feet thick, such as units 9 and 15 of the type section, which commonly are crosslaminated and locally contain plant fossils. These may be nonmarine deposits. The dark limestone is argillaceous and silty. It forms massive, resistant ledges and is most abundant in the lower 100 to 200 feet of the Gobbler formation. Locally it directly overlies the basal unconformity. Gray to "black" shale forms an important part of the lower Gobbler formation and probably is mostly of marine origin.

## Bug Scuffle Limestone Member

Above the lower 200 to 500 feet (fig. 21, 23), the Gobbler formation has two major facies. One consists almost entirely of limestone and is termed the Bug Scuffle[2] limestone member of the Gobbler formation. This member is as much as 1,000 feet thick, with layers of both calcarenite and calcilutite, and is commonly cherty. The other facies is composed almost entirely of shales and quartz sandstones, with only a minor amount of limestone (and that dissimilar to the limestones of the Bug Scuffle limestone member). This facies is referred to as the detrital facies, but has not been given a more formal name. The two facies are contemporaneous, involve 1,000 feet of strata, interfinger layer by layer, and appear to have been deposited in essentially the same lateral position throughout Desmoinesian time and during part of Missourian time. The relationships between these two facies were studied by R. W. Graves, of the California Research Corp., shortly after the writer completed his field work in the area, and presentation was made of a joint oral paper and abstract (Pray and Graves, 1954) summarizing these independent studies. In an attempt to show the nature of this facies variation in cross-sections, a technique described in Figure 22 was devised to produce a "lithofacies log" on the basis of three major components, A and B of terrigenous origin, and C of intraformational origin. This technique was applied to five of the detailed strati-graphic sections measured in the area, and the results are given in Figure 23 for both the Gobbler and Beeman formations.

At the type section of the Gobbler formation, both the Bug Scuffle limestone and the detrital facies occur. The limestone is predominant in the interval from about 700 to 1,000 feet above the base of the formation, and the detrital facies predominates above this interval (fig. 20). Many of the lithologies of the type section are somewhat intermediate between the two "end member" facies. This same situation prevails at the section in upper Fresnal Canyon farther to the north. The "end member" section of the detrital facies occurs in upper Alamo Canyon (fig. 23), and the better sections for optimum development of the Bug Scuffle limestone are those farther to the southwest, such as the sections in Deadman or Negro Ed Canyons.

2. Bug Scuffle is a bona fide name of a canyon, a hill, and a quadrangle in the southern escarpment area.

The Bug Scuffle limestone member forms the conspicuous, sheer cliffs from 500 to 700 feet or more in height along the central and southern parts of the west front of the Sacramento Mountains (see frontispiece and figs. 5, 19). As a topographic and mappable unit, the essential feature of the Bug Scuffle is the presence of limestone to the virtual exclusion of other rock types. Most of the limestones of the fades contain, or consist largely of, lime-mud. Medium- to light-gray calcilutite is abundant. Although calcarenites occur, well-sorted, matrix-free types of limestones form a smaller proportion of the Bug Scuffle limestone than in the limestones of the detrital facies. Many of the layers of the Bug Scuffle limestone are thick bedded to massive. Terrigenous detritus either is absent or is present in very minor quantities, and is mostly clay. The argillaceous limestone noted occurs largely in the lower part of thick limestone units; it is generally darker in color and less massive than the upper part. This type of cyclic variation occurs throughout the Bug Scuffle section. Chert nodules, generally light-gray, occurs in many of the limestone layers, but rarely form more than 10 to 20 percent of the rock. Fossils of many types (principally brachiopods, crinoids, bryozoans, corals, calcareous algae, and foraminifera) occur throughout the limestones of the unit, but only locally are abundant. Most of the section appears to have formed in relatively shallow marine water of low turbulence. Occasional small channels and the sorted calcarenites indicate higher energy conditions.

The detrital facies consists of a wide variety of rock types. Shale, siltstone, and sandstone form most of the section, and the amount of limestone is relatively minor. The sandstones are generally calcareous and composed largely of quartz, with minor muscovite, and locally with minor feldspar. Many of the sandstones would be classed as subgraywackes (Pettijohn, 1949). The limestones that occur show much diversity, from relatively unfossiliferous calcilutites to well-sorted calcarenites and calcirudites. However, light-colored, cherty calcilutites, abundant in the Bug Scuffle limestone facies, are relatively uncommon. Mixed rock types, such as calcarenaceous sandstone, or limestones with admixtures of coarse-grained terrigenous material, are common. Fossils are abundant in the limestone, and their sorting, abrasion, and fragmentation suggest transportation prior to deposition.

Along the west front of the range in the central and southern parts of the escarpment, the top of the Bug Scuffle limestone is near the top of the Gobbler formation, and the major changes in thickness of the Bug Scuffle limestone occur at the base, which comes closer to the base of the Gobbler formation toward the south (fig. 23).

The field evidence proves that the detrital facies and the limestone facies are contemporaneous, as the interfingering can be traced along many discrete beds. The rate of facies change as shown in Figure 23 is more abrupt than is indicated by the isometric cross-section, for the direction of maximum change is believed to be northeast-southwest rather than north-south. In a lateral distance of only 3 to 4 miles, nearly 1,000 feet of essentially pure limestone changes to a section largely composed of terrigenous detritus. There is no suggestion that this facies change involves a reef to off-reef transition, a common cause of such abrupt and persistent facies changes.

The northward change in the Gobbler formation along the west front of the Sacramento Mountains, and the occurrence of the detrital facies of the Gobbler and Beeman formations led Thompson (1942) to the conclusion that the Pennsylvanian section becomes deltaic to the north in the Sacramento Mountains. However, the Bug Scuffle limestone facies reappears in the outcrops in the northwestern part of T. 16 S., R. 11 E., as is shown by Figure 23. In San Andres Canyon, and to a somewhat lesser degree farther to the south, a distinct facies change occurs from the purer, more massive limestones of the Bug Scuffle type on the west to sections farther east containing more detrital material in the limestones, and discrete layers of sandstone, siltstone, and shale. The Bug Scuffle limestone was encountered in the two subsurface tests drilled west of the southern Sacramento Mountains escarpment (see fig. 24), but in the test drilled near the crest of the range in sec. 5, T. 18 S., R. 12 E., the Desmoinesian section was composed of a mixture of sandstone, shale, and limestone units resembling the Gobbler formation detrital facies.

The present interpretation is that the Bug Scuffle limestone represents a facies deposited over a broad area, possibly of regional extent, on the west side of the crest of the present Sacramento Mountains. The detrital facies is interpreted to have been deposited on the shoreward side of the limestone facies in the area along the present crest of the mountains; it protruded abruptly into the general area of the carbonate facies along an axis trending west or northwest and passing through upper Alamo Canyon. This axis may indicate the location of a major distributary carrying detrital material from the east or northeast.

## BEEMAN FORMATION

The Beeman formation at the type section, and in most of the area, consists largely of thin-bedded argillaceous limestone interbedded with calcareous shale. Green-gray feldspathic sandstone and a variety of light-colored, relatively pure limestone occur locally. The formation ranges in thickness from 350 to 500 feet. Fusulinid dating indicates that the age is from middle to upper Missourian.

Several distinct facies changes occur within the Beeman formation in the escarpment area, some of which can be seen on the diagram of lithofacies logs (fig. 23). Changes in fades are rather abrupt from east to west, and are interpreted to indicate the existence of a "hinge line," extending north-south through the center of the Pennsylvanian outcrops, which served to separate shallower water or shelf types of deposits

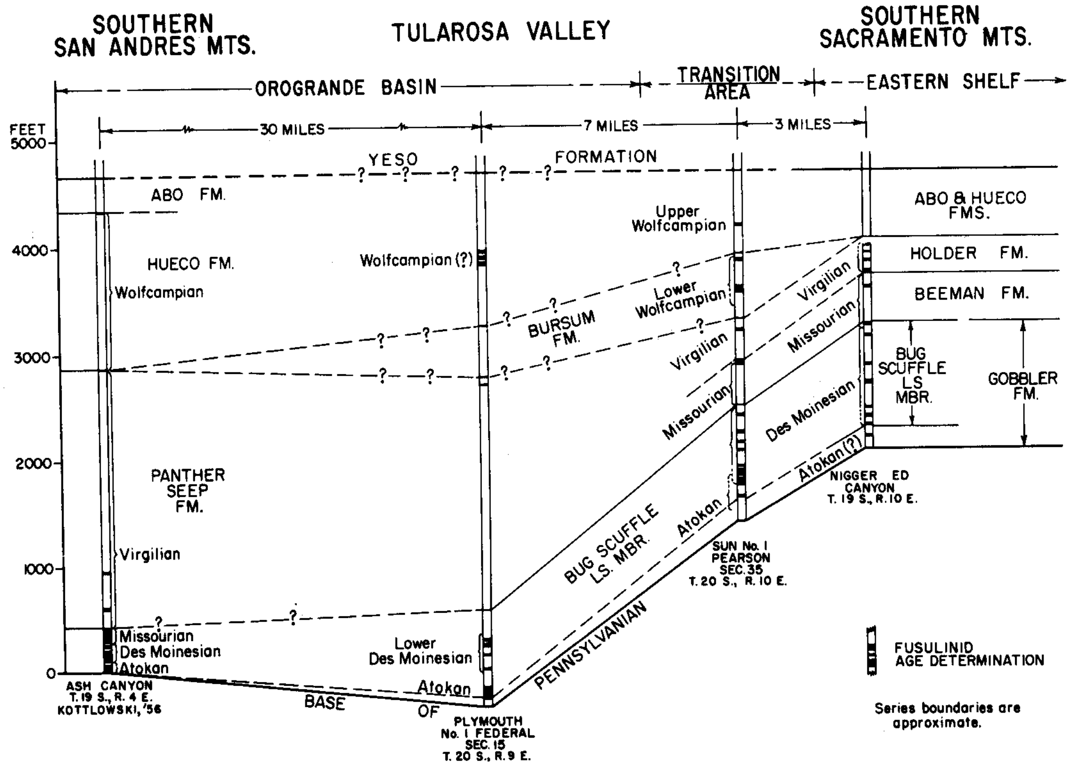



Figure 24

**EAST-WEST CROSS-SECTION OF PENNSYLVANIAN AND LOWER PERMIAN STRATA FROM SOUTHERN**

**SACRAMENTO MOUNTAINS TO SAN ANDRES MOUNTAINS**

Showing interpretation of position of Orogrande basin and its eastern shelf.

on the east from somewhat thicker strata of a more basinal aspect farther to the west.

At the type section, as along most of the western edge of the mountains and in the major canyons, the Beeman formation has the litho-logic characteristics of the basinal facies. This facies forms the rather uniform slopes between the underlying cliffs of the Bug Scuffle limestone and the overlying cliffs of the Holder formation (fig. 19). In these western areas, the Beeman formation typically consists of brown-gray to dark-gray, very argillaceous or silty limestone in even beds a few inches to 2 feet thick. Interbedded with the limestones are thin beds of brown, gray, and green calcareous shale.

In the lower third of the Beeman formation, a marked increase occurs in the thickness and number of sandstone strata from west to east throughout the area. In many instances, the thickness of a sandstone bed changes from a foot to 20 to 30 feet within the distance of a mile. In the southernmost part of the mapped area, petrified' wood is locally abundant in this lower part of the Beeman formation. Logs up to a foot thick and 10 to 20 feet long were noted in a shale and sandstone section in the NW1/4 sec. 5, T. 20 S., R. 11 E.

In the central part of the escarpment, particularly in the vicinity of Alamo Canyon, the argillaceous limestone and shale of the upper two-thirds of the Beeman formation grade eastward, in a distance of only 2 to 3 miles, into a sequence of massive, relatively pure limestones that are cyclically interbedded with gray and reddish marls, and limestone conglomerates. The section here resembles that of the Holder formation, and is interpreted as a shoal-water, marine sequence. This section forms cliffs in the eastern area that easily can be confused on first inspection either with those of the Gobbler formation to the west or those of the overlying Holder formation.

Several excellent marker beds occur within the Beeman formation, which greatly assist field correlation. The best of these is the thin bed of limestone teeming with fusulinids in the basal part of unit 71 of the Beeman type section. Another valuable marker bed is a resistant, silty, nodular limestone that characteristically weathers to a low greenish scarp on the Beeman slope (unit 75 of the type section).

The basal contact of the Beeman formation is determined by two features. Along much of the western escarpment, a thin bed of yellowbrown-weathering dolomite or dolomitic limestone, one of the few dolomitic layers of the Pennsylvanian section, is picked as the basal unit of the Beeman. The second feature is a change in the composition of the sandstones. In the upper part of the Gobbler formation, the sandstones are silty quartz sandstones or subgraywackes (Pettijohn, 1949). The sandstone above the base of the Beeman contains appreciably more feldspar, and the rocks are feldspathic sandstone (10-25 percent feldspar) or arkose (over 25 percent feldspar). The change is not abrupt, but commonly occurs within 50 feet valuable, this criterion should be used with caution, as some beds of feldspathic sandstone were found several hundred feet below the top of the Gobbler in the Arcente Canyon area of T. 16N., R. 11 E.

The Beeman formation is interpreted to indicate an increasing degree of tectonic activity in the area and the relative emergence of an area to the east compared with one to the west. Some of the sedimentary cycles include transitional or nonmarine strata, the first red beds in the local Pennsylvanian system occurring within the Beeman formation.

## HOLDER FORMATION

The uppermost unit of the Pennsylvanian is the Holder formation, which includes the strata between the top of the Beeman formation and the base of the Bursum (Laborcita) or Abo formation. It appears to represent essentially the Virgilian series. The formation contains a wide variety of rock types, nearly all of which were deposited on a relatively shallow-shelf, dominantly marine area. Some nonmarine strata occur in cyclic deposits in the upper part of the unit in the northeasternmost part of the area. Cyclic deposition characterizes much of the Holder formation throughout its entire outcrop, and has been studied in detail by Cline (1959) and his students in the northernmost outcrop areas.

The Holder formation is the most widespread of the Pennsylvanian formations of the Sacramento Mountains escarpment. It occurs throughout the length of the mapped area, forming the resistant series of cliffs on the top of the high, western ridges along much of the front of the range. The formation is absent in most of the eastern outcrops of the Pennsylvanian strata, owing to pre-Abo erosion (pl. 3). The evidence in the Sacramento Mountains escarpment, particularly in the northernmost part of the area, clearly shows the increasing significance of tectonic uplift of the eastern part of the escarpment area in late Pennsylvanian time.

The Holder formation is as much as 900 feet thick in the northwesternmost part of the mapped area and thins to the east and south. Some of these changes in thickness are caused by erosion of the upper part of the strata, but depositional thinning is at least equally important.

The type sections of the Pennsylvanian formations are in an area where the Holder formation is thinner, less complete, and less well exposed than near Dry and Fresnal Canyons, 10 miles to the north. The term Holder formation applies to all the Pennsylvanian strata between the Beeman formation and the overlying Permian strata. In the entire mapped area, except the northwesternmost 2 to 3 miles, this upper contact is an unconformity. The writer would have preferred to retain the previously defined rock unit, the Fresnal group of Thompson (1942), whose type section occurs in the mapped area (sec. 30, T. 15 S., R. 11 E.), but the basal contact of the Fresnal group is not mappable outside of the northern part of the area. This sequence of strata (which forms about the upper two-thirds of the Holder formation) could be considered a local member of the Holder formation. The upper contact of the Fresnal group is the upper contact of the Holder formation. It appears to be at or very close to (within 30 feet) the horizon of the unconformity separating Permian and Pennsylvanian strata a mile farther to the south; on the basis of fusulinids identified by M. L. Thompson (Otte, 1959b), it is about 60 feet below the Pennsylvanian-Permian paleontologic boundary. Detailed discussion of the strata near this boundary in the Fresnal and Dry Canyons area is given by Otte (1959b) and Oppel (1959).

The Holder formation of the Sacramento Mountains escarpment consists of a wide variety of sedimentary rocks. The lower part of the sequence is believed to be almost entirely marine in origin. Toward the upper contact, the cyclic sequences contain an increasing proportion of brackish to nonmarine strata. Corresponding to this change is an increase in the amount of reddish shales, mudstones, and marls, of nodular limestone, and of limestone conglomerate. Many, but probably not all, the reddish strata are of marine origin. Calcareous algae of many different types are important contributors to the limestone strata. Chert and quartzite pebble conglomerates, and a variety of sandstones (quartz sandstone, subgraywacke, and feldspathic sandstone), occur intermittently in the Holder formation.

Algal bioherms and biostromal limestones form massive cliffs in the basal Holder formation. The bioherms in most places are 50-75 feet thick and are the predominant basal deposit in the northern part of the escarpment area. To the south, bioherms and biostromal layers form the basal strata. The bioherms are essentially flat across the base, thickening abruptly along bounding upper surfaces with dips of 10 to 30 degrees. A bioherm (shown in fig. 25) that is a part of a broader biohermal and biostromal complex is well exposed on the north side of Dry Canyon, in T. 16 S., R. 10 E. This bioherm and the associated facies have been the subject of many detailed studies, such as those by Plumley and Graves (1953) and a recent summary by Wray (1959; also Pray, 1959).

The writer's present knowledge of these bioherms has come principally through the work of Wray. The bioherms are composed largely of light- to very light-gray, massive limestone. They were interpreted by Plumley and Graves (1953) to be of algal origin, formed largely by stromatolitic types of algae, such as *Collenia* and *Cryptozoon*. Although these forms occur in the bioherms and adjacent strata, Wray (1959) has demonstrated that a variety *(Anchicodium)* of calcareous green algae is by far the most abundant biotic constituent. Similar algae form many of the resistant limestone strata of the Holder formation. These algae were observed by the writer during the field work, but were not identi-

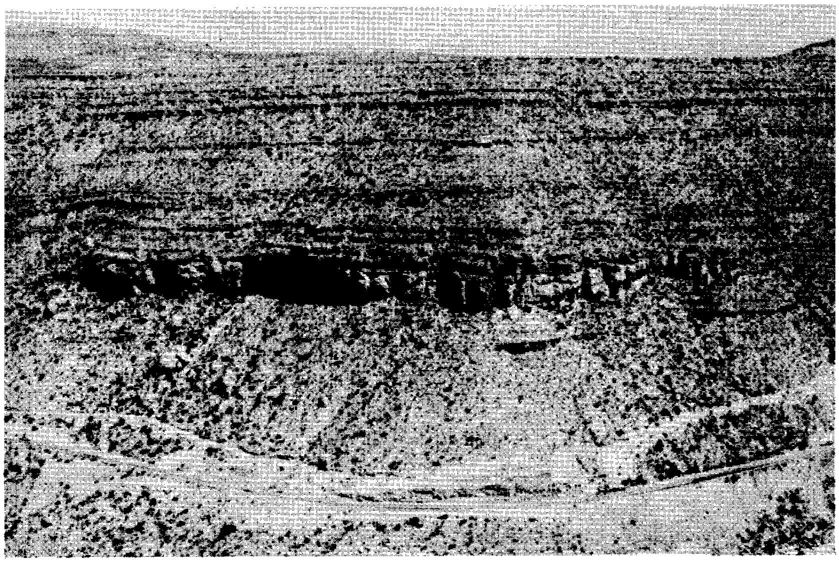


Figure 25

BIOHERM IN BASAL HOLDER FORMATION ON NORTH SIDE OF DRY CANYON AND N. MEX. HIGHWAY 83

(Photograph by John L. Wray.)

fied, nor was their significance appreciated. These algae and a variety of other types occur in the type section of the Holder formation.

Nearly all the bioherms of the Holder formation appear to have grown from essentially the same horizon, the contact between the Beeman and Holder formations. Locally, as in Dry Canyon, several bioherms are developed at higher horizons. Selection of the base of the discontinuous bioherms resulted in an easily traceable contact that separates nonresistant slope-forming strata below the contact from resistant cliff-forming strata above the contact along most of the escarpment. Locally, where the somewhat similar, light-colored limestones of the shoal-water facies of the Beeman formation underlie the Holder, the contact is more difficult to identify. The basal contact of the Holder formation is not interpreted as a disconformity in the area. It appears to represent a change in sedimentation over a broad area, perhaps extending south to the Hueco Mountains, where similar features in the basal Virgilian strata have been described (King and Knight, 1945). Bioherms similar to those of the Sacramento Mountains also occur in the San Andres Mountains (Kottlowski et al., 1956; Kottlowski, 1960).

Evidence based primarily on fusulinid identifications from subsurface samples indicates an abrupt thickening and facies change of the

Virgilian strata west of the southern Sacramento Mountains. The facies change, from a marine-shelf sequence of cyclic carbonate rocks and shales on the east into a dark-shale and sandstone sequence on the west, occurs in a few miles. The interpreted relationships are shown in Figure 24, and the basinal section is correlated to the southern San Andres Mountains, where a similar, thick, late Pennsylvanian sequence was termed the Panther Seep formation (Kottlowski et al., 1956). The correlations and ages shown in Figure 24 are only tentative, but the overall relationships seem clearly to indicate an abrupt facies change in late Pennsylvanian time from an eastern shelf to the basinal realm of the Orogrande basin.

## PERMIAN FORMATIONS

### BURSUM (LABORCITA) FORMATION

In the escarpment area, the oldest Permian strata, dated on the basis of fusulinids, are of lower Wolfcampian age and occur in the northernmost Sacramento Mountains west and northwest of the Fresnal fault, near High Rolls. These oldest Permian strata represent both marine and nonmarine facies.

The evidence in the Wolfcampian strata clearly indicates uplift of the northeastern part of the Sacramento Mountains area, and accumulation of a thick sequence of both marine and nonmarine strata west of this positive area. In the subsiding area, or basin (probably continuous to the south as the Orogrande basin), deposition was essentially continuous from Pennsylvanian through Permian time. The exposed sections north of La Luz Canyon show a largely marine, lower Wolfcampian sequence that grades upward and laterally toward the positive area into a red-bed nonmarine facies. The overlying nonmarine facies are correlated with the Abo formation, and the lateral nonmarine equivalents are classed as both the Abo and the Laborcita (or Bursum) formations.

The precise terminology of rock units in the area is somewhat confusing. Work in several areas of central New Mexico during the 1940's, including that of Thompson (1942) in the northern Sacramento Mountains, resulted in the recognition of stratigraphic sections between the Pennsylvanian and the Abo formation which consisted largely of red beds, but which locally contain some marine fossils, such as fusulinids, of Permian age. Of several terms introduced for these local sequences, the the term Bursum formation (Wilpolt et al., 1946) became most widely used. The writer applied it to the sequence of about 350 feet of strata directly overlying the type section of the Fresnal group (Thompson, 1942) in sec. 30, T. 15 S., R. 11 E., as it contained marine Permian fossils in the upper portion. A ledge of quartzite-cobble conglomerate directly overlying this section was interpreted by the writer as the base of the Abo formation, and was believed to be approximately at the stratigraphic position represented by the major angular unconformity at the base of the Abo 3 to 4 miles to the east and southeast. The subsequent, more detailed, study of this northernmost part of the Sacramento Mountains escarpment by Otte (1959b) resulted in the discovery of a post-Pennsylvanian section containing a much higher proportion of marine strata, in sec. 13, T. 15 S., R. 10 E., a few miles north of the area mapped by the writer. This sequence extends about 200 feet higher in the section than the horizon of the quartzite-cobble conglomerate selected by the writer as the Bursum-Abo contact. Moreover, Otte's more detailed stratigraphic work and mapping indicated that this higher contact for the base of the Abo formation (also at the base of a quartzite-cobble conglomerate) was the horizon that correlated laterally with the horizon of the major pre-Abo unconformity to the southeast. Otte (1959b) named the section between the top of the Fresnal group and his Abo contact the Laborcita formation. This term is clearly preferable to the use of Bursum in the Sacramento Mountains area; however, as the lower horizon was used as the base of the Abo in preparing the writer's geologic map and sections of the area, the term Bursum is used in this report. The difference in the position of the basal Abo contact affects only the area west of the Fresnal fault (pl. 1), and there it does not appreciably affect the interpretations (see fig. 26).

The writer's work in the complex area north and west of the Fresnal fault indicated the need for more detailed studies. Subsequent work by Otte now permits adequate interpretation and ably documents the relationships in this area. The section on the Bursum formation of this report is abbreviated in view of Otte's published work (1959b).

Strata mapped as the Bursum formation in the area of the Sacramento Mountains escarpment occur only in the northernmost 5 miles of the area, and all lie west of the Fresnal fault or its probable northward continuation in R. 11 E. The Bursum formation in the section overlying the Fresnal group type section (sec. 30, T. 15 S., R. 11 E.) is 342 feet thick, and here consists largely of drab calcareous shales, thin argillaceous limestones, quartz sandstones, and limestone conglomerate. About 10 percent of the beds are reddish. Details of the section are shown in the graphic section and the accompanying lithologic descriptions (fig. 27). The upper part of this Bursum section contains thin limestone layers from which lower Wolfcampian fusulinids have been identified.

## STRATIGRAPHIC SECTION OF BURSUM FORMATION NORTH OF FRESNAL CANYON

Base of section (fig. 27) is near the center of sec. 30, T. 15 S., R. 11 E., 20 feet northeast of road, in second arroyo northwest of junction of roads from La Luz and Fresnal Canyons. Section measured up the arroyo toward the northeast.

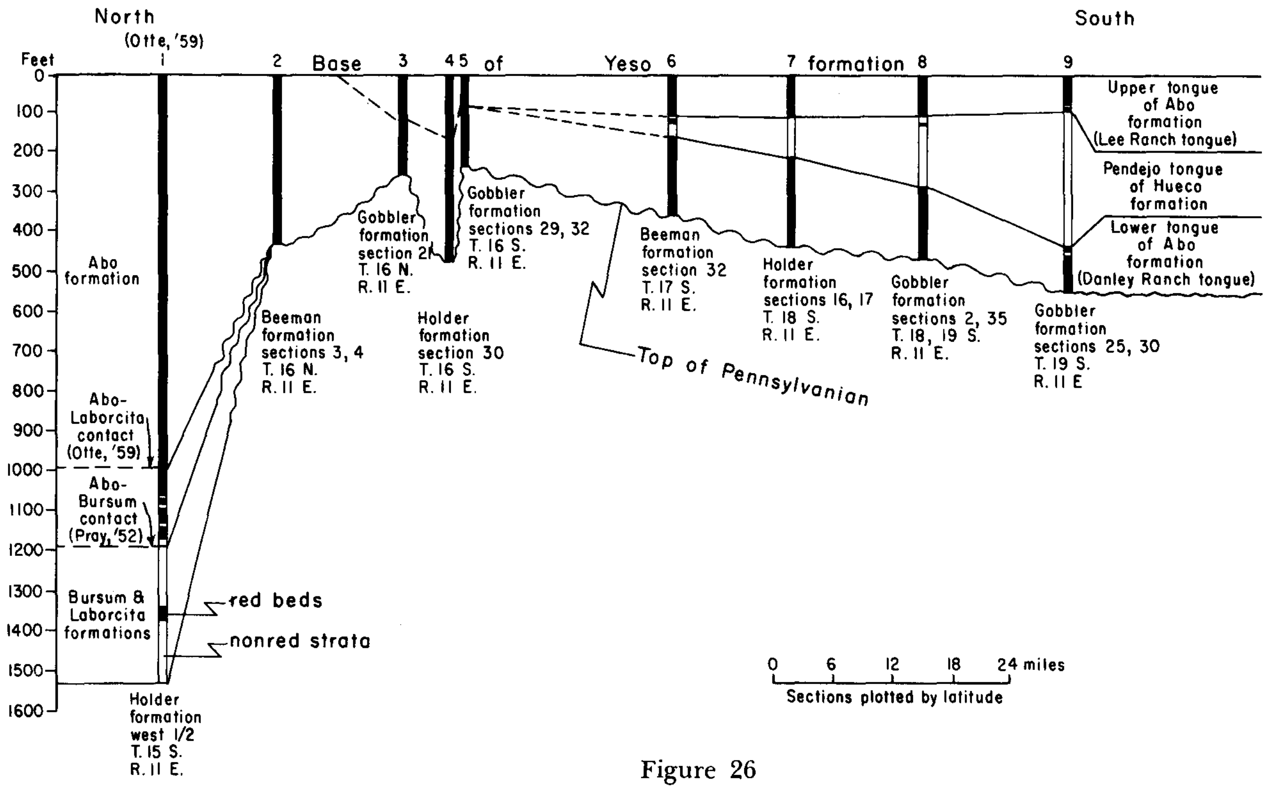



Figure 26

NORTH-SOUTH CROSS-SECTION OF WOLFCAMPIAN STRATA IN SACRAMENTO MOUNTAINS Showing thickening of sequence to northwest and south, and major facies relationships.

| UNIT No. | DESCRIPTION | THICKNESS (feet) |
|---|---|---|
| | Top of section | |
| | *Abo formation* | |
| | Conglomerate, sandy; pebbles and cobbles of limestone, quartzite, and chert; unit forms local cap and eastern dip slope of hill | 2 |
| | Covered | 2 |
| | *Bursum formation*—342 feet thick | |
| 30 | Quartz sandstone, fine-grained, calcareous; light-gray silty limestone at base grades upward into the sandstone; unit forms resistant rim of hill and thickens to northwest | 10 |
| 29 | Shale, olive-gray, calcareous; 6 feet above base is a 6-inch bed of gray, argillaceous, fossiliferous limestone | 17 |
| 28 | Shale, medium-gray, calcareous, fossiliferous (brachiopods) | 7 |
| 27 | Limestone, medium dark-gray, silty; interbedded with shale, medium-gray, calcareous, silty; abundant fusulinids *(Schwagerina)* | 9 |
| 26 | Poorly exposed; largely nonresistant olive-gray calcareous shale | 15 |
| 25 | Shale, olive-gray, calcareous; capped by 6-inch argillaceous limestone; abundant brachiopods, gastropods, and pelecypods | 5 |
| 24 | Shale, olive-gray, calcareous; interbedded feldspathic quartz sandstone and siltstone; carbonaceous | 17 |
| 23 | Limestone, pale red-brown, very argillaceous, massive | 1 |
| 22 | Poorly exposed; largely nonresistant, olive-gray, very calcareous shale | 21 |
| 21 | Limestone, medium-gray; grades upward into sandy limestone conglomerate | 3 |
| 20 | Poorly exposed; largely greenish-yellow claystone with minor interbedded dark, silty, fossiliferous limestone | 16 |
| 19 | Conglomerate, sandy; pebbles and cobbles of limestone and chert; overlying section measured N. 20° E. of base of Bursum section | 14 |
| 18 | Limestone, medium-gray, argillaceous | 1 |
| 17 | Covered; probably gray shale | 11 |
| 16 | Claystone, red, very calcareous | 25 |
| 15 | Quartz sandstone, calcareous, brown-weathering; a few chert pebbles | 2 |
| 14 | Largely covered; probably gray calcareous claystone | 30 |
| 13 | Limestone, olive-gray, argillaceous, thin-bedded; probably interbedded shale | 12 |
| 12 | Covered; nonred material | 8 |
| 11 | Conglomerate; granules and pebbles of limestone; grades upward into calcareous medium-grained quartz sandstone | 4 |
| 10 | Largely covered; probably yellowish claystone | 18 |
| 9 | Quartz sandstone, medium-grained, calcareous; argillaceous limestone at base | 6 |
| 8 | Conglomerate, sandy, calcareous; pebbles of limestone and chert; overlying section measured along strike of beds about 500 feet to the north | 3 |
| 7 | Claystone and siltstone, dusky-yellow, calcareous; a few 1- to 2-inch beds of argillaceous limestone | 5 |
| 6 | Covered; probably similar to underlying unit | 18 |
| 5 | Poorly exposed; light yellowish-gray, calcareous claystone; minor argillaceous limestone | 6 |
| 4 | Limestone, medium dark-gray, silty, thin-bedded; upper 5 feet weathers yellowish gray, carbonaceous; streaks of chert pebbles and quartz sand in middle part | 15 |
| 3 | Shale and siltstone, dark-gray, calcareous, carbonaceous; grades into overlying limestone | 19 |
| 2 | Covered; probably dark-gray shale | 20 |

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| 1 | **Quartz sandstone and pebble conglomerate; pebbles largely limestone and chert** | 4 |
| | **Contact is a sharp lithologic break from underlying limestone and shale up into sandstone and pebble conglomerate; traced laterally, lithologic distinctions between the underlying and overlying strata are not sharp; contact, therefore, is interpreted as a diastem, rather than a major surface of unconformity** | |
| | **PENNSYLVANIAN SYSTEM** | |
| | ***Holder formation*** | |
| | **Limestone, medium-gray, partly nodular; overlies greenish-gray and reddish shale; top of the type section of the Fresnal group (Thompson, 1942)** | |

Traced to the southeast along the strike, the Bursum section thins and changes facies abruptly. Within a distance of 2 miles, more than half of the section is composed of red beds, and in a distance of about 3 miles, the section consists almost exclusively of red mudstones and less abundant, but conspicuous, layers of limestone-pebble and limestone-cobble conglomerate. These changes are discussed in detail by Otte (1959b). The same changes probably occur in an eastward direction, but are not so well documented. Whereas many of the conglomerates containing limestone clasts in the northwestern part of the area are interpreted as of intraformational origin, those occurring farther to the southeast contain clasts that have been derived from Pennsylvanian strata that presumably were undergoing erosion from the area directly east of the Fresnal fault during Bursum time.

The basal contact of the Bursum and Laborcita formations has been studied by Otte (1959b) and Oppel (1959). Although there is minor disagreement on the precise position of the contact in the northwestern part of the area (sec. 30, T. 15 S., R. 11 E.), both interpret the basal contact as an unconformity in the southern part of the Bursum exposures, and believe that this unconformity disappears as traced to the northwest, so that deposition in that area was essentially continuous from Pennsylvanian into Permian time. Oppel demonstrated that the upper 160 feet of the Holder formation in sec. 30, T. 15 S., R. 11 E., is truncated below the basal contact of the Bursum formation within a distance of 2.3 miles to the southeast. In this southeast area, the contact is an angular unconformity. Otte (1959b) established that movement along the Fresnal fault occurred at the end of Pennsylvanian and prior to Bursum deposition, as well as between the deposition of the Bursum and Abo formations.

Based on fusulinids collected from the Bursum formation of the mapped area, the age of the Bursum here is lower Wolfcampian. However, based again on fusulinids, the Pennsylvanian-Permian contact of the adjacent Laborcita section is not at the base of the Bursum, but about 60 feet above the base (Otte, 1959b). This corroborates earlier

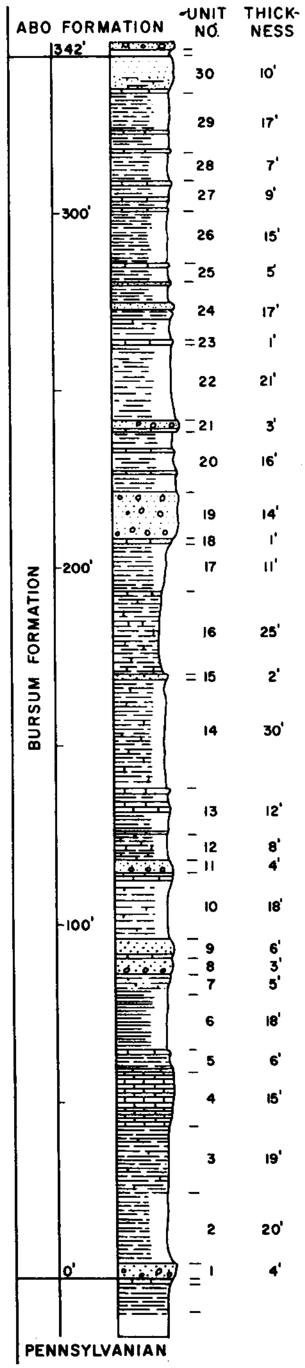



Figure 27

**GRAPHIC SECTION OF BURSUM FORMATION NORTH OF FRESNAL CANYON**

evidence of fusulinids found by J. Covington and the writer in a horizon about 20 feet above the base of the Bursum formation only a few hundred feet north of the section shown in Figure 27. Fusulinids collected in the uppermost part of the Laborcita formation in the area to the north are interpreted (Otte, 1959b) as younger than others known in the Bursum of New Mexico, and as somewhat older than the basal Hueco limestone. Perhaps they are as young as middle Wolfcampian.

All the strata above an unconformity that truncates Pennsylvanian strata in the area south of the northernmost part of T. 16 S. have been mapped as the Abo formation. It is possible that locally some of the basal deposits of limestone conglomerate are Bursum equivalents, although most of these are believed to occur above the basal unconformity of the Abo formation. The area where Bursum equivalents are most likely to be present is in the bottom of the Dry Canyon syncline between Arcente and Alamo Canyons, particularly on the south side of Caballero Canyon, where an abnormally thick section of limestone conglomerate occurs.

## ABO FORMATION

The Abo formation was deposited throughout the area of the Sacramento Mountains escarpment. It is largely a sequence of dark, reddish-brown mudstone and arkose, with local basal units of conglomerate, and contains a tongue (Pendejo tongue) of southward-thickening gray shales, limestones, and dolomites in the southern half of the area. The color of the mudstones and shales is the most useful single criterion for identification of the Abo formation in much of the Sacramento Mountains, as well as central New Mexico, where the type section is located. The Abo mudstones and shales are characteristically reddish brown to dark or very dark reddish brown, distinctly darker than the "red beds" of the overlying Yeso formation. Unfortunately, color is not a safe criterion by which to distinguish the red beds of the Bursum or Laborcita formations from those of the Abo formation.

In much of the outcrop area of the Sacramento Mountains escarpment (fig. 26), the Abo formation ranges from about 200 to 500 feet in thickness. It thickens markedly toward the northwest, where a section measured east of Tularosa by Otte (l959b) and the writer is 1,400 feet thick. From the central part of the escarpment area, the Abo thickens gradually southward, reaching a thickness of about 550 feet near the southern part of the mapped area. Farther to the south, the thickness between the formational limits continues to increase as the facies change and the section becomes dominantly marine. The variation in thickness and general facies relationships of the Abo formation along much of the escarpment are shown in Figure 26; the thickness of the Abo formation, it should be noted, varies with respect to the age of the underlying strata. The greater the pre-Abo erosion, the thinner the Abo sequence—a direct reflection of the structure. The thickness variation can be exceedingly abrupt from a synclinal to an adjacent anticlinal area, as shown by sections 4 and 5 in Figure 26, where the thickness increases from about 250 feet to above 500 feet from the thin section overlying the axis of the Caballero anticline to the thick section in the axial part of the Dry Canyon syncline, only three-fourths of a mile to the west. The relationship of thickness of the Abo formation to the underlying structure or to the age of the underlying formation also applies on a broader scale, as shown by the thickness increase northwestward from the central part of the Sacramento Mountains escarpment.

The lithology of the Abo formation in the northern part (fig. 28) of the Sacramento Mountains is relatively uniform, the section being composed almost entirely of reddish-brown to dark reddish-brown mud-stones with lenses of arkose. The basal part of the Abo formation in T. 15 S. and the northernmost part of T. 16 S. consists largely of quartzite-cobble conglomerates (see fig. 28) that directly overlie the truncated edges of Pennsylvanian strata. To the northwest of the Fresnal fault, quartzit. conglomerates occur at many levels in both the Bursum and Abo formations, as well as in the Holder formation. Southward from the northernmost part of T. 16 S., quartzite conglomerates are uncommon, and where conglomerates occur in the basal part of the Abo formation, they usually are composed of limestone and chert. The coarseness and the abrupt variation in composition of the basal conglomerates of the Abo formation in this area suggest proximity to the source areas.

Above the basal zone in the northern part of the Sacramento Mountains escarpment, the Abo section consists almost entirely of reddish-brown mudstone and minor, though conspicuous, coarse-grained to conglomeratic arkose that is normally crosslaminated and well sorted. Feldspar locally forms as much as one-half of the arkose, consisting of pink orthoclase and microcline. Most grains of quartz and feldspar of the arkose are 1 to 3 mm in diameter and are angular to subangular. Individual layers of arkose are lenticular; locally, abrupt channel fillings of arkose occur. Coarse arkose is more common in the lower part of the section than in the upper part.

## STRATIGRAPHIC SECTION OF ABO FORMATION IN NORTHERN SACRAMENTO MOUNTAINS NEAR HIGH ROLLS

Base of measured section (fig. 28) is in canyon bottom 700 feet south of the northeast corner of sec. 5, T. 16 S., R. 11 E. Section measured northeastward to road.

| UNIT No. | DESCRIPTION | THICKNESS (feet) |
|---|---|---|
| | **Top of section** | |
| | **Recent travertine spring deposits cap the local section** | |
| | ***Yeso formation*** | |

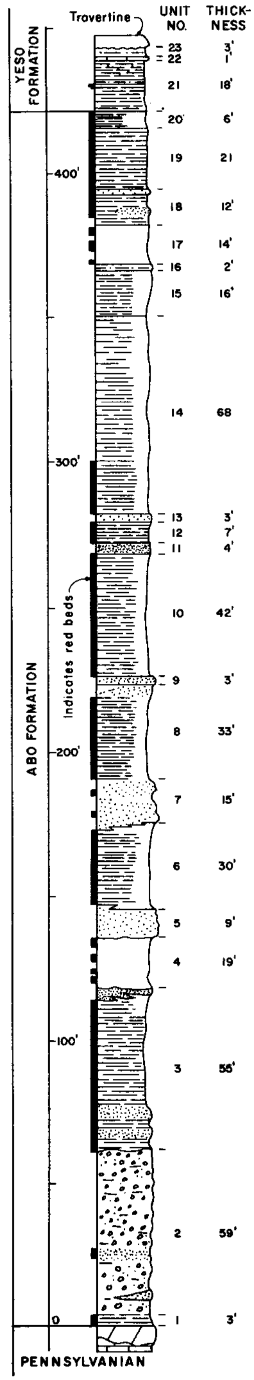



Figure 28

GRAPHIC SECTION OF ABO FORMATION IN NORTHERN SACRAMENTO MOUNTAINS NEAR HIGH ROLLS

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| 23 | Shale, silty, calcareous, yellowish-gray; 1,000 feet to east overlain by pale reddish-brown mudstone and gypsum | 3 |
| 22 | Limestone, silty, yellowish-gray, thin-bedded | 1 |
| 21 | Mudstone, yellowish-gray to gray; calcareous in upper part; 1 foot of red-brown mudstone 11 feet above the base | 18 |
| | *Abo formation*—421 feet thick | |
| 20 | Poorly exposed; mudstone, dark reddish-brown; gray at base | 6 |
| 19 | Mudstone, reddish-brown; minor gray beds | 21 |
| 18 | Mudstone, dark reddish-brown; minor interbedded shaly coarse-grained arkose | 12 |
| 17 | Covered; probably reddish-brown mudstone; overlying section measured 500 feet east of road | 14 |
| 16 | Siltstone, dolomitic | 2 |
| 15 | Poorly exposed; largely dark reddish-brown mudstone | 33 |
| 14 | Poorly exposed; largely mudstone, very dark reddish-brown; minor 2- to 3-foot-thick beds of coarse-grained arkose | 51 |
| 13 | Arkose, coarse-grained; base shaly | 3 |
| 12 | Mudstone, dark reddish-brown | 7 |
| 11 | Arkose, fine-grained | 4 |
| 10 | Poorly exposed; largely reddish-brown mudstone and interbedded coarse-grained arkose | 42 |
| 9 | Arkose, coarse-grained, crosslaminated; resistant ledge | 3 |
| 8 | Poorly exposed; largely reddish-brown mudstone; minor coarse-grained arkose | 33 |
| 7 | Arkose, coarse-grained, crosslaminated; resistant ledges; minor interbedded reddish-brown mudstone | 15 |
| 6 | Poorly exposed; largely reddish-brown mudstone | 30 |
| 5 | Arkose, coarse-grained, crosslaminated; resistant ledge; a few pebbles of quartzite and microcline granite | 9 |
| 4 | Covered; probably reddish-brown mudstone | 19 |
| 3 | Mudstone, dark reddish-brown; minor interbedded lenticular fine- to medium-grained sandstone near top and base | 55 |
| 2 | Conglomerate; quartzite cobbles predominate and are subrounded; interbedded minor dark reddish-brown sandstone and mudstone | 59 |
| 1 | Poorly exposed; largely reddish-brown mudstone | 3 |
| | Contact is an angular unconformity; underlying 1 to 5 feet of gray nodular limestone is locally replaced by dolomite; angular discordance is slight; about 60 feet of underlying Pennsylvanian Beeman formation, largely thin-bedded limestone and shale, truncated by angular unconformity along stream bottom to northwest within 400 yards | |

Traced southward, a unit of reddish-brown mudstone, very fine-grained sandstones, and coarse-grained siltstones occurs in the upper part of the formation. This is the upper tongue of the Abo formation, which can be traced continuously southward to Culp Canyon at the southern end of the Sacramento Mountains. This upper red-bed tongue recently has been formally named the Lee Ranch tongue of the Abo formation by Bachman and Hayes (1958), the lower red-bed tongue being designated by them as the Danley Ranch tongue. A tongue of the Hueco limestone penetrates northward between the upper and lower red-bed tongues of the Abo formation to the central Sacramento Mountains and is formally termed the Pendejo tongue of the Hueco limestone. It consists largely of brackish-water deposits to the north and becomes marine as traced southward. A feather edge of the Pendejo tongue, consisting largely of thin, nodular, argillaceous dolomite and gray shale, can be recognized as far north as the southern part of T. 16 S., and the dolomitic strata may persist even farther to the north.

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 (pl. 1, 2). The upper and lower units are largely of red beds and are representative of the more typical Abo formation to the north. The middle unit of gray limestone and shale is herein termed the Pendejo tongue of the Hueco formation. The name is derived from Pendejo Wash, which drains the northwest edge of Otero Mesa about 4 miles south of the mapped area and exposes a large area of outcrops of the Hueco limestone. The type section of the Pendejo tongue is in sec. 25, T. 19 S., R. 11 E., and sec. 30, T. 19 S., R. 12 E.; the lithologic description of the section, including the upper and lower tongues of the Abo red beds, is given below (fig. 29).

## STRATIGRAPHIC SECTION OF THE ABO FORMATION IN THE SOUTHERN SACRAMENTO MOUNTAINS

Top of section is at the south edge of SW1/4NW1/4 S1/4 sec. 30, T. 19 S., R. 12 E., and is continuous with base of measured section of the Yeso and San Andres formations. Measured by R. C. Northup and L. C. Pray.

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| | Top of section | |
| | *Yeso formation* | |
| | 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 | |
| | Covered | 2 |
| | *Upper tongue of Abo formation (Lee Ranch tongue)*—89 feet thick | |
| 33 | Shale, reddish-brown and green-gray; poorly exposed | 11 |
| 32 | Shale, reddish-brown; minor green-gray shale beds; dolomitic | 9 |
| 31 | Sandstone, tan, very fine-grained; thin, delicate crosslamination and ripple marks | 3 |
| 30 | Shale, reddish-brown; thin silty dolomite at base; minor gray shale | 12 |
| 29 | Sandstone, buff, very fine-grained, dolomitic; thin, delicate crosslamination; minor reddish shale | 20 |
| 28 | Siltstone, dolomitic, gray to pale-red; some pebbles and coarse sand streaks | 4 |
| 27 | Shale, reddish-brown; silty at top | 11 |
| 26 | Limestone, dolomitic, silty, nodular | 1 |
| 25 | Sandstone, buff to brown, very fine-grained, medium-bedded, resistant | 6 |
| 24 | Shale and siltstone, reddish-brown, thin-bedded | 3 |
| 23 | Siltstone, dolomitic, mottled green-gray and red | 1 |

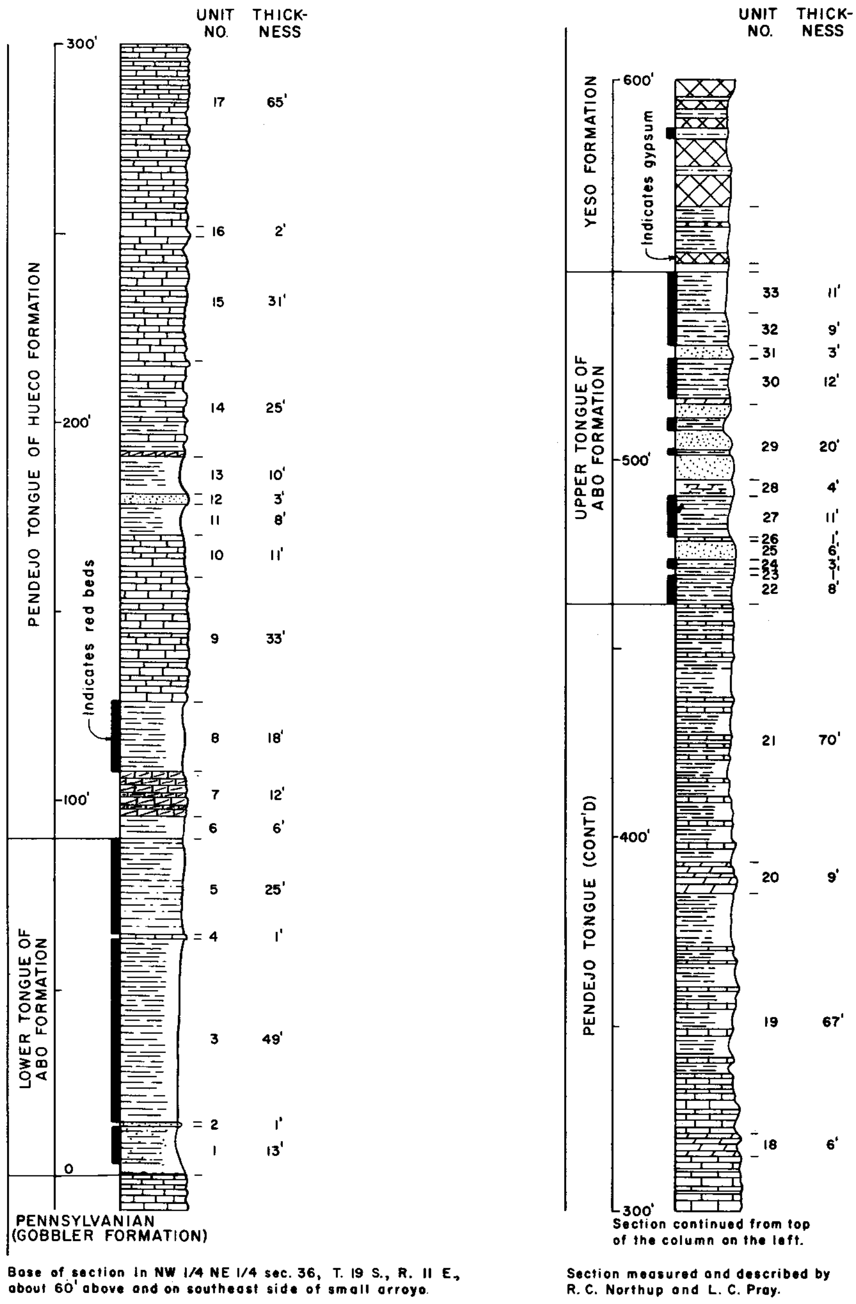



Figure 29

**GRAPHIC SECTION OF ABO FORMATION IN SOUTHERN SACRAMENTO MOUNTAINS**

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| 22 | Shale, reddish-brown | 8 |
| | *Pendejo tongue (of Hueco formation)*—376 feet thick | |
| 21 | Shale, gray, and limestone, light-gray, argillaceous, thin-bedded; minor dolomitic limestone weathering pale brown; shales poorly exposed | 70 |
| 20 | Dolomite, gray, argillaceous, and dolomitic limestone | 9 |
| 19 | Limestone, light- to dark-gray, argillaceous, thin-bedded; interbedded with poorly exposed gray shale | 67 |
| 18 | Limestone, dolomitic, dark-gray, argillaceous; weathers pale brown | 6 |
| 17 | Limestone, light- to dark-gray, argillaceous, fossiliferous; probably interbedded gray shale | 65 |
| 16 | Limestone, medium-gray; weathers dark gray; forms cap of hill; above section measured east of canyon | 2 |
| 15 | Limestone, light- to dark-gray, thin- to medium-bedded; bryozoans at base; probably interbedded gray shale | 31 |
| 14 | Shale, gray, and medium- to dark-gray, thin-bedded limestone; small fossils; basal 1 foot dolomitic limestone | 25 |
| 13 | Largely covered; silty gray shale | 10 |
| 12 | Sandstone, very fine-grained, and siltstone, micaceous, green-gray; excellent local marker bed | 3 |
| 11 | Largely covered; silty shale | 8 |
| 10 | Limestone, medium- to dark-gray, fossiliferous (gastropods) | 11 |
| 9 | Limestone, light-gray, thin-bedded, dense; small fossils; probably interbedded gray shale | 33 |
| 8 | Shale, reddish-brown; thin limestone near base | 18 |
| 7 | Limestone, dolomitic, light-gray, thin- to medium-bedded; weathers pale brown | 12 |
| 6 | Covered; probably gray shale | 6 |
| | *Lower tongue of Abo formation (Danley Ranch tongue)*—89 feet thick | |
| 5 | Shale, reddish-brown; poorly exposed; lower half fine-grained red sandstone and siltstone | 25 |
| 4 | Limestone, dolomitic, silty; weathers light gray | 1 |
| 3 | Shale, reddish-brown; minor fine-grained reddish-brown sandstone; minor gray shale near top; weathers reddish purple; poorly exposed | 49 |
| 2 | Sandstone, fine- to medium-grained, shaly | 1 |
| 1 | Covered; probably reddish-brown shale and minor sandstone | 13 |
| | *PENNSYLVANIAN SYSTEM* | |
| | *Gobbler formation* | |
| | Limestone, medium-gray, thin- to medium-bedded, very fossiliferous (brachiopods, gastropods, cephalopods). Underlain by gray limestone, and brown and green-gray silty sandstone | |
| | Base of section about 5,800 feet, located in NW¼NE¼ sec. 36, T. 19 S., R. 11 E., about 60 feet above and on southeast side of small arroyo. Section measured to east | |

In much of the escarpment area, the upper red-bed tongue contains a very distinctive type of rock, a very fine-grained sandstone and/or coarse siltstone, usually with an ankeritic cement. The rock is delicately crosslaminated, borings are locally abundant, and mud cracks occur in the unit. This lithology is illustrated by Figure 30. The writer believes that the upper tongue of the Abo formation, which contains this dis-

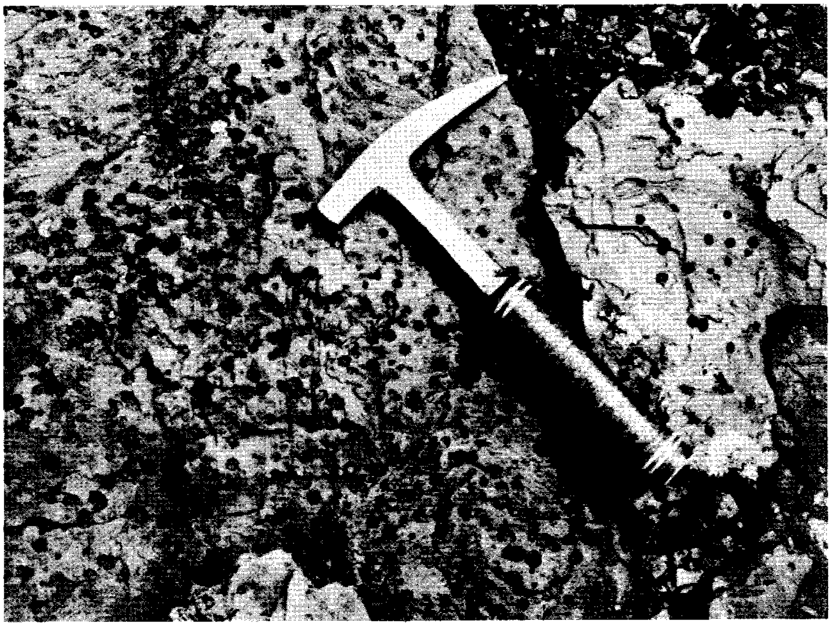


Figure 30

TYPICAL CROSSLAMINAE AND BORINGS ON FINE-GRAINED SANDSTONES OF UPPER ABO FORMATION TONGUE IN CENTRAL AND SOUTHERN SACRAMENTO MOUNTAINS

tinctive lithology, is the same rock unit that Bachman and Hayes (1958) called the Otero Mesa member of the Yeso formation. Within the central and southern parts of the Sacramento Mountains escarpment, the upper tongue of the Abo formation (Lee Ranch tongue) is relatively uniform in thickness and lithology. The major variation in thickness occurs in response to structural position rather than with respect to north-south position within the tongue, as can be noted in Figure 26. The thickness of this unit increases twofold from the crest of the Caballero anticline to the adjacent trough of the Dry Canyon syncline in the central part of the escarpment. The variation in thickness of the Abo sedimentary units in these areas indicates that some deformation, along the lines of the previous major deformation, accompanied deposition of the Abo formation. The exposures within the overlying Yeso are not adequate to prove whether or not this deformation continued later into Permian time, although the Abo-Yeso contact is gently folded.

The lower tongue of the Abo formation (Danley Ranch tongue) gradually thins toward the southern part of the escarpment, but its thickness also changes rapidly in accordance with structural position.

Traced to the south from the northern part of the area, there is a notable decrease in the coarseness of the sandstones within the lower tongue, and few units of coarse-grained arkose are recognized below 1'. 18 S.

Where coarse-grained arkose occurs in the lower Abo, and primarily in Tps. 16 and 17 S., lenses of arkose locally are mineralized. These red-bed deposits have been mined sporadically for lead, which is present as galena or various oxidized minerals, such as anglesite or cerussite. Minor amounts of copper minerals also occur in the Abo arkoses. The most productive area occurs near Caballero Canyon, such as at the Warnock (Holmes) mine, in sec. 30, T. 16 S., R. 11 E. A few details on production and the ore deposits were given by Lasky and Wootton (1933) and Fischer (1937).

The Pendejo tongue at its type section is typical of the unit in the southern part of the escarpment area. Many of the limestones are somewhat dolomitic and most are argillaceous. Beds are commonly not over a foot or two in thickness; the bedding planes generally are even. Plant fossils occur in gray shales of this thin unit in the Caballero Canyon area (southern part of T. 16 S.). Gastropods, suggestive of a specialized environment, are common in the southern part of the map area, but some normal marine fossils occur in this area as well. Fusulinids have not been found in the Pendejo tongue within the map area, but occur in this unit a few miles farther south. The fusulinids and ammonites (Miller and Parizek, 1948) collected from the Pendejo tongue in T. 22 S., R. 10 E., indicate a definite correlation with the Hueco limestone (Lloyd, 1949). Both the upper and lower contacts of the Pendejo tongue are transitional and intertonguing contacts, but the inter-tonguing is much more pronounced along the basal contact than the upper.

The Abo formation of the Sacramento Mountains indicates that a localized source area for fresh, coarse-grained feldspathic detritus, and for pebbles and cobbles of granite, granite porphyry, and quartzite, existed at the start of Abo deposition very close to the northeastern part of the escarpment area. This is a part of the positive area termed the Pedernal landmass by Thompson (1942). The source area for the limestone conglomerates of the basal Abo in the central part of the escarpment must likewise have been local, and probably was only a short distance to the east. However, the existence of a positive area east of the entire escarpment is not proved by evidence from the Abo formation, as most of the observed changes could be accounted for by increasing distance from a source to the northeast. By late Abo time, the source area of the detrital material could have been far away from the area of the Sacramento Mountains escarpment.

The Abo strata of the northern part of the escarpment are interpreted as terrestrial deposits, perhaps laid down upon a broad flood plain or piedmont area adjacent to an uplifted source area farther east that supplied the sediment. The depositional environment represented by the upper and lower tongues of the Abo formation is not established. The fossils known to the writer from these units consist of leaf impressions and petrified wood, and have not provided data on the age of the strata. C. B. Read (oral communication, July 1950) reported collecting plants of the *Supaia* assemblage from the basal strata of the Abo in Caballero Canyon. In the absence of marine or even brackish-water fossils, such as occur in the Pendejo tongue, the upper and lower tongues probably represent fresh-water deposits laid down on a broad surface of little relief.

At the north end of Otero Mesa (sec. 17, T. 21 S., R. 11 E.), Bachman and Hayes (1958) have named a well-exposed series of red beds that appear lithologically similar to the upper tongue of the Abo formation, the Otero Mesa member of the Yeso. Pray and Otte (1954) and others had previously correlated this same outcrop with the upper tongue of the Abo to the north and the Deer Mountain red shale of the Hueco to the south, despite the occurrence of a thin unit of evaporites at its base. This correlation was based on the similarity of lithology and stratigraphic position of this section with the outcrops that can be observed from a point about 4 miles north of this northern Otero Mesa section northward throughout the central and southern Sacramento Mountains escarpment. If this is not the same lithologic unit as the upper tongue of the Abo formation, it is the same facies. To regard it as a different unit seems difficult, as this appears to be a unique lithologic unit both within the section exposed at the north end of Otero Mesa and within the section to the north in the Sacramento Mountains, and it is not closely similar to other units of red beds either higher or lower in any one section. The sequence of limestones, dolomitic limestones, and shales that underlies this red-bed unit is similar to the Pendejo tongue as mapped farther to the north.

Unfortunately, the upper beds of the Abo within the critical 3 to 4 miles between the southern part of the Sacramento Mountains and the northern tip of Otero Mesa where crossed by New Mexico Road 506 are covered by alluvium, so that neither the writer's correlations nor those of Bachman and Hayes (1958) can be proved by tracing of beds.

The upper contact of the Otero Mesa member and the immediately overlying strata (interpreted by the writer as the basal part of the Yeso formation) are similar to the upper contact and overlying strata of the upper red-bed tongue (Lee Ranch tongue) as observed in the southern Sacramento Mountains. However, if the Otero Mesa member is assigned to the Abo formation, a thin sequence of gypsum and gypsiferous strata must be included as part of the Abo-Hueco intertonguing sequence. Evaporites have not been recognized farther to the north below the Yeso formation, but the writer believes that this thin section of evaporites sandwiched between the marine to brackish-water strata of the Pendejo tongue and the overlying red-bed strata is not too anomalous to occur in this part of the Abo-Hueco section. This stratigraphic variation is more acceptable than the many coincidences created by the interpretation that the Otero Mesa "red beds" are not equivalent to the upper tongue of the Abo formation traced continuously for a long distance to the north. This correlation (of the upper tongue of the Abo with the Otero Mesa member) is considered to be more certain than the correlation of the same unit with the Deer Mountain red shale of the Hueco formation in the Hueco Mountains. However, the lithologic nature of some of the silty dolomite interbeds of the Deer Mountain red shale is strongly suggestive of a correlation with the dolomitic (ankeritic) siltstones of the Otero Mesa red-beds section and the upper tongue of the Abo formation.

The variations in thickness of the Otero Mesa and Lee Ranch tongues, cited by Bachman and Hayes (1958) as evidence for the correlation of the former with the basal Yeso formation and of the latter with the upper Abo, could be allied with variations seen farther north in going from any area of pre-Abo highs to adjacent lows. The age of the Abo formation of the Sacramento Mountains is largely middle and late Wolfcampian. The early date is based on studies of fusulinids in the upper Laborcita formation east of Tularosa, and the later on fusulinids in the upper part of the Hueco limestone in the Hueco Mountains. Both ages were based on fusulinid identification determined by M. L. Thompson (Otte, 1959; Thompson, 1954).

The basal contact of the Abo formation is an angular unconformity in all but the northwesternmost part of the Sacramento Mountains. This unconformity is believed to be coextensive with the one at the base of the Hueco formation on the Diablo platform, where basal beds of the Hueco rest successively on strata ranging in age from upper Pennsylvanian to Precambrian. The surface of unconformity is relatively smooth, and there does not appear to be evidence of a karst topography developed on the underlying Pennsylvanian carbonate rocks. Over large areas, the present topographic surface is only slightly below the pre-Abo unconformity, and represents a somewhat dissected, exhumed pre-Abo contact. Many of the ridge tops west of the present limit of the Abo formation and along the projection of the basal Abo contact are smoother than would be expected from the present resistance to weathering of the units comprising the ridges.

The upper contact of the Abo formation is everywhere with the Yeso. This contact is believed to be gradational, but the lithologic change occurs in a distance of only a few feet, and appears to represent a rather sudden invasion of the Abo depositional area by the marine to super-saline seas prevailing during the deposition of the Yeso formation.

## YESO FORMATION

The Yeso formation of the escarpment area is 1,200 to 1,800 feet in thickness and is composed of a large number of rock types. These include carbonate rocks, mostly limestones and some dolomite; red, yellow, and gray shales and siltstones; evaporites, largely anhydrite (gypsum at surface exposures) and minor halite; and yellowish fine-grained sandstones. Rapid lateral and vertical variation in lithology is normal to the Yeso formation. Carbonate rocks become increasingly abundant in the Yeso formation toward the south, especially in the upper part of the formation. The Yeso "red beds" generally have a pinkish cast in contrast to the dark reddish-brown "red beds" of the Abo formation. Most of the Yeso "red beds" are in the lower and middle Yeso, but some occur at the top in the crestal part of the Sacramento Mountains. Evaporites are most abundant in the lower and middle Yeso.

The Yeso formation occurs throughout the length of the escarpment on the west side of the crest of the mountains, and also crops out in the lower parts of the major canyons that dissect the crest and eastern slope of the range. Most of the exposures of the formation are too poor to permit detailed stratigraphic work; indeed, for many miles along the higher parts of the western scarp, the exposures are inadequate for determining even the major rock types or general nature of the stratigraphic succession. Much of the area of these higher Yeso slopes is mantled with material slumped down from the overlying San Andres formation. Near the northern and southern ends of the escarpment, where the altitude is lower and mantle from overlying units is not so continuous, the stratigraphic succession and the lithologic details can be determined. The best exposures of the Yeso formation within the mapped area are on the western slope of the mountain front, in the southern part of T. 19 S. (pl. 2).

In 1948, R. C. Northup, New Mexico Bureau of Mines and Mineral Resources, and the writer measured and described two Yeso sections in the Sacramento Mountains area for the regional report by Lloyd (1949). These sections, reproduced in graphic form at a scale of 200 feet to 1 inch (Lloyd, 1949, pl. 2), were discussed briefly, together with other surface sections in central New Mexico and the subsurface Yeso of southeastern New Mexico. The discussion of the Yeso in the escarpment area is based largely on these two sections, one at the northern limit of the Sacramento Mountains (in the N1/2 sec. 27 and E1/2 sec. 22, T. 13 S., R. 11 E., 11 miles north of the mapped area), and the other (fig. 31) at the southeastern limit of the mapped area. These two surface sections are supplemented by subsurface data from the Southern Production Co. No. 1 Cloudcroft test drilled near the crest of the range in sec. 5, T. 17 S., R. 12 E., and shown on structure section DD' of Plate 3. Unfortunately, samples are absent in the interval between 320 and 940 feet below the top of the Yeso formation in this well.

The exposures of the Yeso formation south of the mapped area in the southern part of T. 19 S. and continuing southward into T. 20 S. could provide the basis for a detailed study of this complex rock unit.

The section of the Yeso and the overlying San Andres formation from the southeastern limit of the mapped area (pl. 2; pl. 3, section KK'K") is shown in graphic form as Figure 31, and the lithologic descriptions of the rock units are given below.

## STRATIGRAPHIC SECTION OF THE SAN ANDRES AND YESO FORMATIONS NEAR ORENDORF PEAK IN THE SOUTHERN SACRAMENTO MOUNTAINS

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| | Top of section is present erosion surface on Orendorf Peak | |
| | *San Andres limestone*—373 feet thick (incomplete section) | |
| 74 | Limestone, light olive-gray; many small fossil fragments; beds 1 to 6 feet thick | 42 |
| 73 | Limestone, brown-gray to medium-gray; forms conspicuous upper cliff below Orendorf Peak | 181 |
| 72 | Limestone, dolomitic, light olive-gray; small vugs lined with calcite | 27 |
| 71 | Limestone, brown-gray | 2 |
| 70 | Quartz sandstone, white, fine- to medium-grained, calcareous; top of Hondo member | 8 |
| 69 | Dolomite, light olive-gray, very finely crystalline; beds 1 foot thick | 12 |
| 68 | Limestone, argillaceous shale, and minor fine-grained quartz sandstone | 3 |
| 67 | Limestone, brown-gray to olive-gray; obscure beds 1 to 3 feet thick; some dolomite; calcite-filled vugs | 34 |
| 66 | Dolomite, light olive-gray, thin-bedded; minor dark limestone | 12 |
| 65 | Limestone, light olive-gray to brown-gray, fossiliferous; large calcite-filled vugs; forms conspicuous lower cliff below Orendorf Peak | 52 |
| | *Yeso formation*—1,239 feet thick | |
| 64 | Limestone, sandy; weathers yellowish | 2 |
| 63 | Limestone, light- to dark-gray; slumped? | 17 |
| 62 | Sandstone, buff, fine-grained, calcareous; 3 feet of gray limestone near base | 11 |
| 61 | Limestone, dark-gray; obscure beds; forms ledge | 20 |
| 60 | Covered | 7 |
| 59 | Sandstone and siltstone, buff, calcareous | 3 |
| 58 | Limestone, dark-gray, thin-bedded | 13 |
| 57 | Dolomite, gray to tan, thin-bedded; silty at base | 4 |
| 56 | Sandstone, fine-grained, calcareous; some interbedded shale; basal 4 feet coarser grained, brown spotted; good marker bed | 12 |
| 55 | Poorly exposed; silty shale and minor fine-grained brown sandstone | 24 |
| 54 | Sandstone, silty, buff to light-brown, ripple marked | 6 |
| 53 | Silty shale, light-gray; minor sandstone and sandy limestone at base | 14 |
| 52 | Sandstone, buff, silty, fine-grained, thin-bedded | 11 |
| 51 | Limestone, gray-tan, silty | 13 |
| 50 | Shale, buff, silty; sandy at top | 7 |
| 49 | Limestone, light-gray, thin-bedded; silty, especially in lower 17 feet | 50 |
| 48 | Siltstone, buff, calcareous | 3 |

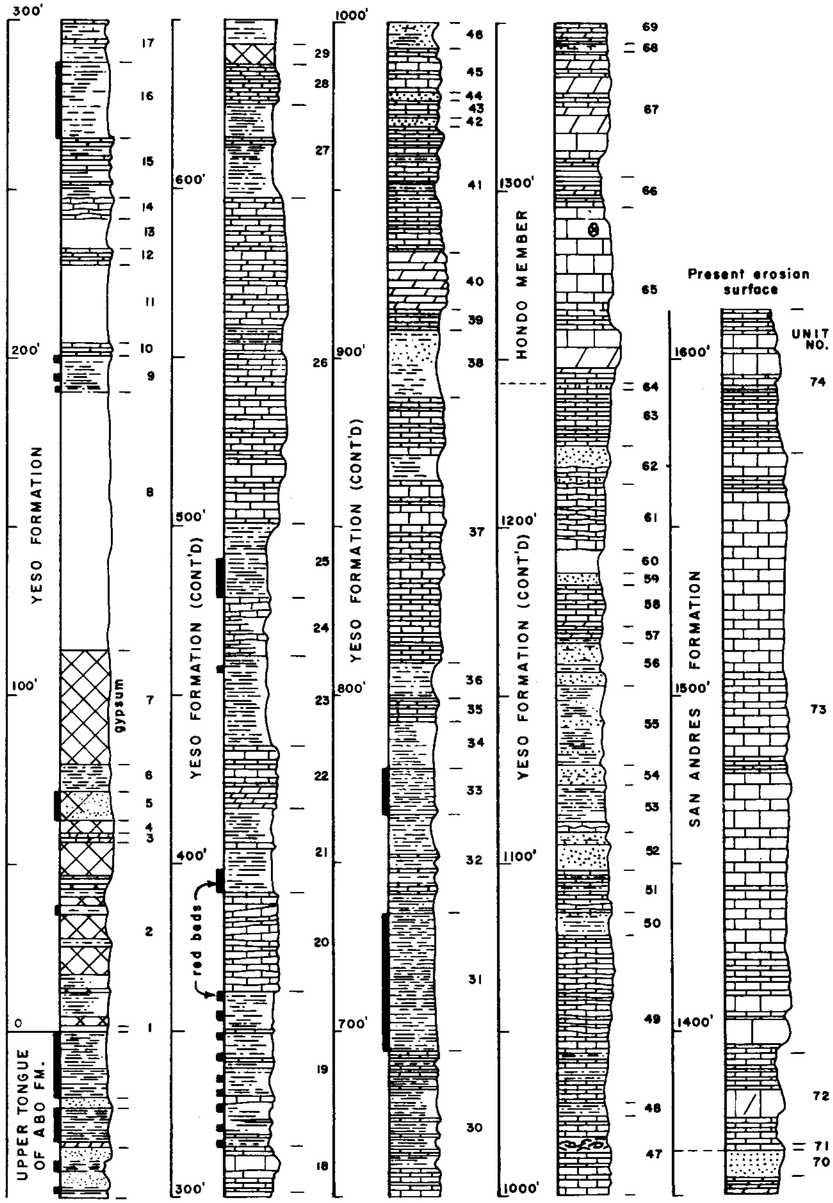



**Figure 31**

**GRAPHIC SECTION OF SAN ANDRES AND YESO FORMATIONS IN SOUTHERN SACRAMENTO MOUNTAINS**

| UNIT No. | DESCRIPTION | THICKNESS (feet) |
|---|---|---|
| 47 | Limestone, dark-gray, thin-bedded | 24 |
| 46 | Sandstone, huff, very fine-grained, silty | 8 |
| 45 | Limestone, dark-gray, thin- to medium-bedded | 13 |
| 44 | Sandstone, buff, silty to very fine-grained | 2 |
| 43 | Limestone, light-gray, thin-bedded | 5 |
| 42 | Sandstone, buff, silty to fine-grained, calcareous | 3 |
| 41 | Limestone, light- to dark-gray, thin-bedded; interbedded silty shale in middle | 38 |
| 40 | Limestone, light-gray, dense | 17 |
| 39 | Limestone, dark-gray, thin-bedded | 6 |
| 38 | Poorly exposed limestone; silty sandstone near top | 20 |
| 37 | Limestone, light- to dark-gray, silty, thin-bedded; minor silty shale | 79 |
| 36 | Shale, silty, buff | 1() |
| 35 | Limestone, light-gray, silty, thin-bedded | |
| 34 | Covered; nonred shale(?) | 13 |
| 33 | Shale, silty, pink to red | 14 |
| 32 | Shale, light-gray to buff, silty; interbedded limestone | 30 |
| 31 | Shale, silty, pink to red; interbedded minor siltstone | 41 |
| 30 | Limestone, gray to buff; thin beds; interbedded with gray silty shale; poorly exposed at base | 50 |
| 29 | Gypsum | 6 |
| 28 | Limestone, light- to dark-gray, thin-bedded | 12 |
| 27 | Largely covered; silty limestone in middle | 28 |
| 26 | Limestone, dark- to medium-gray, thin- to medium-bedded; forms conspicuous dark cliff in middle o fPeso that can be traced for miles | 97 |
| 25 | Shale, silty; lower half pink | 22 |
| 24 | Limestone, light-gray, medium-bedded, and gray shale | 17 |
| 23 | Shale, silty, buff to gray; pink 22 feet above base | 27 |
| 22 | Limestone, light- to dark-gray, silty; light-gray, dense dolomite near base | 18 |
| 21 | l'oorly exposed; gray silty shale, pink at base; minor silty limestone | 25 |
| 20 | Limestone, light- to dark-gray, thin- to medium-bedded; lighter color and more massive at top | 28 |
| 19 | Silty shale, poorly exposed, gray and pink; interbedded limestone, gray to buff, thin-bedded | 48 |
| 18 | Limestone, dark-gray, thin-bedded at base; weathers light gray; forms prominent ledge | 14 |
| 17 | Shale, silty, gray; minor buff limestone | |
| 16 | Shale, silty, pink, poorly exposed | 23 |
| 15 | Limestone, light- to dark-gray, thin-bedded; interbedded gray shale | 18 |
| 14 | Limestone, dark-gray to red; obscure bedding | 6 |
| 13 | Covered; probably gray shale | 9 |
| 12 | Limestone and dolomite, light-gray to tan, thin- to medium-bedded | |
| 11 | Covered; probably gray shale | 23 |
| 10 | Limestone, light-gray, thin- to medium-bedded | 4 |
| 9 | Shale, silty, pink and light-gray | 11 |
| 8 | Covered; base of overlying section in the E/12SW1/4SE1/4 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 | 77 |
| 7 | Gypsum; interbedded pink shale | 34 |
| 6 | Shale, silty, pink | 7 |
| 5 | Sandstone, buff, very fine-grained, and gypsum | 9 |
| 4 | Gypsum, silty, mottled | 4 |

| | |
|---|---|
| 3 Limestone, dolomitic, medium-gray, thin-bedded | 3 |

| Unit No. | Description | Thickness (feet) |
|---|---|---|
| 2 | Gypsum and minor gray silty shale; pink shale 34 feet above base; 1 foot of gray dolomitic limestone 42 feet above base; basal 15 feet poorly exposed | 54 |
| 1 | Covered | 2 |
| | *Upper tongue of Abo formation* | |
| | Partly covered; maroon and gray shale | 11 |
| | Shale, maroon; minor gray-green beds | 9 |
| | Sandstone, tan, very fine-grained, dolomitic; delicate crosslamination | 3 |
| | Shale, maroon to red; thin silty dolomite at base | 12 |
| | Sandstone, buff, very fine-grained, dolomitic(?); delicate crosslamination; minor maroon shale | 30 |
| | Base of section at south edge of the SW¼NW¼SE¼ sec. 30, T. 19 S., R. 12 E. | |

The thickness of the Yeso formation appears to range from about 1,200 feet to 1,800 feet in the Sacramento Mountains escarpment; locally, it may be thicker or thinner than this range of thickness. The southern surface section (fig. 31) is 1,239 feet thick; the depth interval of the Yeso formation in the Southern Production Co. test is from 380 to 2,180 feet, a thickness of 1,800 feet; and the northern surface section contains 1,200 feet of exposed Yeso formation. At this latter section, neither the upper nor lower contacts are exposed. The estimated total thickness is 1,300 to 1,400 feet. These three sections afford the best evidence of the Yeso thicknesses in the area, but all are approximations. Halite is known in the subsurface, and its solution would cause surface sections to be thinned. The data from the subsurface test are too incomplete to ascertain within the Yeso the effect of inclined strata (though the total thicknesses of pre-Yeso units accord with those measured in adjacent surface sections), faulting, or thickening by intrusive rocks. One igneous mass, 20 to 30 feet thick, is known in the subsurface section.

Mapping of the upper and lower contacts of the Yeso formation is unreliable in providing good estimates of the thickness of the Yeso in much of the mapped area. The upper contact in most areas is concealed, whereas the lower contact, although exposed, is in many places a mile or more west of the upper contact and somewhat folded, so that projection of the contact to the east is hazardous. Despite the uncertainties involved, the writer suspects that the Yeso formation may vary in thickness by as much as 30 percent within a few miles in the central part of the area. If such variation does exist, it is likely to reflect depositional variation of the type proved within the Abo formation (fig. 26, sections 4 and 5), thinner sections being deposited over developing anticlinal folds than those in adjacent synclinal troughs. It may be significant that the area in which folding of the Abo-Yeso contact can best be proved (the southern half of T. 16 S., R. 11 E.) is one in which the position of the upper and lower contacts of the Yeso could be interpreted as representing a section with a thickness of as little as 1,000 feet.

The various members of the Yeso formation in central New Mexico are not apparent in the Sacramento Mountains section. However, lateral variation in the Yeso within short distances can be observed locally in the escarpment area, and comparison of the Yeso sections from the northern and southern areas shows major differences. Carbonate rocks are more abundant in the southern section, and include some dolomite, a lithology almost absent in the northern section. The following table gives the approximate percentages of major rock types in the northern and southern sections. In the tabulation, some covered intervals have been assigned arbitrarily to certain lithologies, where reasonable estimates could be made.

| | *Northern section* | *Southern section* |
|---|---|---|
| **Limestone** | 25 % | 45% |
| **Dolomite** | 0.1% | 2% |
| **Sandstone** | 1 % | 5% |
| **Siltstone** | 1 % | 4% |
| **Shale, and silty shale, gray and buff** | 13 % | 20% |
| **Shale (mudstone), pink and reddish** | 13 % | 10% |
| **Mixed gypsum and shale** | 28 % | 2% |
| **Gypsum** | 19 % | 7% |

As can be noted from the above tabulation, gypsum is more abundant, both in pure layers and intermixed with clay and silt, in the northern section than in the southern section. The difference is largely compensated by the marked increase in carbonate rocks to the south. There is also a difference in distribution of the rock types. In the northern section, evaporites and "red beds" persist nearly to the top of the section, whereas to the south, most of these lithologies occur in the lower part of the section. The upper part of the southern section is largely composed of limestone, with interbeds of yellowish siltstones and quartz sandstones in the uppermost 150 feet.

The subsurface section of the Southern Production Co. test near the crest of the range (sec. 5, T. 17 S., R. 12 E.) indicates a closer similarity to the southern surface section. The uppermost 320 feet is largely limestone, with minor amounts of dolomite, reddish siltstones, and a trace of sandstone. The dolomite occurs in the uppermost 200 feet. Samples are not available from the interval from 320 to 940 feet below the top of the formation. Limestone and dolomite occur in several thick units interbedded with anhydrite, a trace of halite, and varicolored shales and siltstones in the interval from 940 to 1,260 feet below the top of the formation. The top of a distinctive unit (about 100 feet thick) of pale-reddish siltstone and very fine-grained sandstone occurs about 1,260 feet below the top of the formation. This may correlate with the Drinkard sandy zone (Fullerton or Tubb) in the subsurface to the east (Lloyd, 1949), but the apparent absence of this unit in either of the nearby surface sections throws doubt on this correlation with other subsurface sections that are even greater distances to the east. The lower 430 feet of the Yeso formation in this subsurface test consists largely of mixed anhydrite, varicolored shales, minor limestone and dolomite, and halite. The latter occurs in several zones in the lower 250 feet and may form much of the section in a 30- to 40-foot-thick interval about 200 feet above the base. The presence of halite in the Yeso formation of the Sacramento Mountains had been indicated by occasional salty water wells (Fiedler and Nye, 1933). The basal 30 feet of the Yeso is dolomitic.

Detailed studies are needed of the rock types comprising the Yeso formation in the Sacramento Mountains. A variety of carbonate rocks occur, of which medium- to dark-gray, argillaceous limestone, in relatively thin beds, is a common type. Brachiopods, molluscs, algae, and other fossils occur in these limestones and the interbedded dark shales. Some of the limestones, particularly near the base, are recrystallized, commonly weather yellow gray, and contain irregular cavities and pits probably created by solution of evaporite minerals. A limestone unit about 100 feet thick (no. 26, fig. 31) forms a conspicuous dark-gray slope in the middle part of the Yeso formation in the southern section, and can be traced in that vicinity for at least 10 miles. An 80-foot-thick limestone, only slightly higher in the section, occurs in the northern section. Possibly these units correlate and are equivalent to one of the two major zones of limestone in the middle part of the Yeso in the oil test on the crest of the range.

Sandstone forms only a few percent of the Yeso sections in the escarpment area, being most common in the upper part. The Yeso sandstones are mostly silty, very fine- to fine-grained quartz sandstone, and are a distinctive yellow to yellow brown. They contrast with the coarser grained, better sorted sandstones of the San Andres formation.

Clay and silt, locally intimately admixed with gypsum, form one-third to one-half of the Yeso section. These are of various colors. Pale-reddish or "pink" and yellowish hues are conspicuous as one of the diagnostic features of the Yeso formation. The dark reddish brown of the Abo formation is almost entirely absent in the Yeso formation.

The age of the Yeso is not known from work in the area, although undoubtedly a large fauna could be obtained. Unfortunately, fusulinids have not been observed. The Yeso is dated as Leonardian on the basis of regional evidence. The strata of the Yeso in the Sacramento Mountains escarpment are compatible with the interpretation of deposition in a regionally broad marine-shelf area that, at least intermittently, had restricted circulation, which produced the evaporitic units.

The lower contact is with the Abo formation throughout the area of the escarpment and is believed to be gradational, but the major change in rock types occurs within a thickness of only a few feet. The-change is from the characteristic dark reddish-brown shales or mudstones and interbedded calcareous siltstones and fine-grained sandstones of the Abo to any of a variety of rock types that are characteristic of the Yeso formation. These can consist of gypsum, gray shale, gray to yellowish limestone, or admixed units of evaporites with varicolored silt and clay.

The upper contact of the Yeso formation in the Sacramento Mountains is not so clearly defined as the lower and is believed to be gradational.

## SAN ANDRES LIMESTONE

The San Andres limestone forms the resistant uppermost strata of nearly all the crest and much of the eastern slope of the Sacramento Mountains. It is reported to be over 1,000 feet thick in the subsurface of the western part of the Permian Basin, but less than half this thickness occurs in most of the escarpment area of the Sacramento Mountains. Over much of the southern part of the area, only 100 to 300 feet remains. The upper contact is the present erosion surface in most of the Sacramento Mountains. Fossils are abundant in this marine section but to date have not been studied adequately; thus, they have contributed little to the problem of the age of this unit in the Sacramento Mountains area. Fusulinids have not been found in the San Andres limestone in the western escarpment area. The age and correlation of the San Andres have recently been studied in detail by Boyd (1958), in the Guadalupe Mountains to the southeast, where available evidence indicates that the Leonardian-Guadalupian boundary lies within the limestone.

The San Andres limestone consists of a rather monotonous succession of limestone layers of various shades of gray and olive gray, mostly relatively dark colored. The bedding is variable; thicknesses of 1 to 3 feet are common. Some of the strata are dolomitic, but dolomite is uncommon in the crestal part of the Sacramento Mountains. Marine fossils are common in the San Andres limestones, but have not been studied in detail. Many of the limestones are composed largely of grains of fossil material; some are oolitic. Undoubtedly, a wide variety of carbonate rock types will be found by critical study. However, with the principal exception of a unit of dolomitic limestone that commonly occurs near the base of the San Andres limestone, the writer has not attempted to differentiate the carbonate rocks of this formation. The section of the San Andres limestone measured in the southern Sacramento Mountains (fig. 31) is 373 feet thick, and is described above. The thickest occurrence of San Andres limestone noted within the map area is about 700 feet, in the southern part of T. 16 S., R. 11 E. Two sections of the San Andres formation have been measured and described by Fiedler and Nye (1933) in the area north of the Sacramento Mountains. A section near Picacho, in T. 11 S., R. 17 E., is 265 feet thick; one near Bent, in T. 13 S., R. 10 E., is 621 feet thick. Fiedler and Nye (1933) proposed the local terms of Picacho limestone and Nogal formation for the rock units termed the San Andres limestone and the Yeso formation in this report, but their names have not been generally accepted.

## Hondo Member of the San Andres Limestone

In much of central and northern New Mexico, the Glorieta sandstone forms a distinctive lithologic unit between the Yeso formation and the overlying San Andres limestone. In most of the crestal part of the Sacramento Mountains, quartz sandstone of the "Glorieta" type (clean, rounded, frosted, fine- to medium-grained orthoquartzites) does not separate typical Yeso and San Andres lithologies, but occurs instead within limestone of the San Andres type, commonly 60 to 120 feet above the highest lithology characteristic of the Yeso formation.

These thin sandstones probably correlate with the Hondo sandstone, named by Lang (1937), near Hondo, New Mexico, northeast of the escarpment area. The part of the section between the Yeso and the top of these thin sandstones is here referred to as the Hondo member of the San Andres limestone. It may correlate with part of the type Glorieta sandstone, but usage of the local name Hondo seems preferable until such time as a correlation with the Glorieta is more firmly established than at present.

More than two beds of quartz sandstone are rarely found in a given section, and the thickness of any sandstone layer is less than 10 feet almost everywhere in the crestal part of the Sacramento Mountains. A thickness of 2 to 3 feet is the most common. Similar quartz sandstone can be expected higher in the San Andres section; despite careful search, however, it was noted in only one locality in the mapped area, where it consisted of a 2-inch layer of quartz sandstone about 250 feet above the base of the San Andres limestone. For practical purposes, the quartz sandstones appear to be restricted to the lower 60 to 121 feet of the San Andres limestone and have not been found in the Yeso formation. Used with other evidence indicating proximity to the Yeso-San Andres contact, the upper limit of these quartz sandstones forms the best mappable contact above the Abo-Yeso contact in the Sacramento Mountains. If the exposures were better, it probably could be demonstrated that the top of the highest quartz sandstone is not at the same stratigraphic horizon throughout the area, but precision of a few feet or even tens of feet is unimportant.

The Hondo member consists mostly of limestone that is somewhat similar to that overlying the member, but possibly somewhat lighter in color, ranging from medium to light gray or olive gray. In much of the southern and central parts of the escarpment, 30 to 60 feet of limestone, dolomitic limestone, or, locally, dolomite occurs at or somewhat above the base of the Hondo member and may form a resistant ledge. A zone of *Dictyoclostus* brachiopods is a useful marker at the top of this ledge. Above this zone and below, the lowest of the sandstones are less resistant, light olive-gray dolomites and dolomitic limestones, which typically contain numerous small vugs.

The quartz sandstones appear to have similar characteristics throughout the area. All but 1 to 2 percent of the grains are quartz or chert; the remainder are largely potash feldspar and very minor accessory minerals. Most of the grains are in the range of fine- to medium-grained sand, rounded to well rounded, and equant in shape; frosted surfaces are common. The sandstones are well sorted, occurring in massive layers. The aggregate thickness of sandstone observed in any one section is normally less than 10 feet, and may be only a few feet. Thicker sections of similar sandstone have been reported to the north, east, and west from the crest of the Sacramento Mountains.

North and west of Cloudcroft, the sandstones are poorly developed. Only a 1-foot-thick unit could be found, which was poorly developed and may be absent locally. Thus, the contact in this northwesternmost part of the area is uncertain.

Two accessible localities where Hondo sandstones are well exposed are: (1) a few feet above and on the northeast side of the road in the northwesternmost part of sec. 30, T. 18 S., R. 12 E., and (2) the north side of a small canyon tributary to Penasco Canyon, in the N1/$_2$SW1/4 SE1/4 sec. 2, T. 17 S., R. 11 E. Other localities can be noted from the position of the solid-line contacts on the geologic maps (pl. 1, 2).

The lower contact of the San Andres limestone is somewhat arbitrary and is not believed to represent a disconformity. The writer places the contact to separate best the carbonate rocks of the San Andres type from the underlying section consisting of mixed lithologies, as based on the highest lithology of a type common to the Yeso formation, but distinctive from types occurring within the San Andres. Some of these distinctive rock types are reddish or pinkish siltstone, yellowish fine-grained silty quartz sandstone, and varicolored shale.

Springs are one of the better markers of the San Andres-Yeso contact in the Sacramento Mountains, especially in the valleys east of the crest. Springs occur at different stratigraphic levels, but the higher and most numerous are almost everywhere less than 100 feet below the quartz sandstones of the Hondo member. The ground water is believed to seep downward along joint planes in the overlying carbonate strata until it reaches the first continuous impermeable barrier, presumably a layer of clay in the uppermost Yeso, and thence to migrate downdip to the surface.

## MESOZOIC STRATA

Strata of Mesozoic age are known in the region on all sides of the uplifted Sacramento Mountains block, and at one time probably were continuous over the entire region. However, they have been completely eroded from almost all of the uplifted block. The only outcrops known to the writer occur along the Cloudcroft-Mescalero Highway (N. Mex.

24) from a point where it crosses the local Sacramento Mountains divide, about 5 miles north of the mapped area. The outcrops are of significance for their bearing on the geologic and geomorphic evolution of the Sacramento Mountains block, and thus are discussed in this report even though they occur north of the mapped area. This occurrence was discovered by J. Covington; a short discussion published by Pray and Allen (1956) is summarized below.

The outcrop belt trends north-northwest in adjacent parts of T. 14 and 15 S., R. 13 E. The southernmost outcrops are at an altitude of about 8,600 feet along the Sacramento Mountains divide where it is crossed by New Mexico Highway 24. The outcrops, as defined in reconnaissance largely on the basis of sandstone float, extend at least 3 miles north-northwest along the base and on the west side of the South Fork of Tularosa Canyon. The eastern limit of the outcrops is defined by the Mescalero fault, a fault of at least 300 feet displacement that trends north-northwest. The western limit is not known, but probably is less than a mile west of the Mescalero fault. The best exposures noted of the Cretaceous rocks occur in sec. 9, T. 15 S., R. 13 E., along and southwest of New Mexico Highway 24 at the divide. The basal contact with the underlying San Andres limestone is poorly exposed, but appears to represent a smooth surface and to be a disconformity or unconformity of low angular discordance.

The lower 150 feet of the section lies between the uppermost San Andres limestone and the Sacramento divide and consists largely of quartz sandstone of fine to coarse grain. The sandstone ranges from nearly white to reddish brown, but most of it is pale to dark yellowish orange. Some of the outcrops show crossbedding; others are essentially massive. The basal part of the section is poorly exposed, and may contain shale and siltstone, as well as quartz sandstone. Nearly all the sand grains are quartz; feldspar constitutes less than 1-2 'percent of the grains. The grains range from subangular in the finer sizes to rounded in the medium- to coarse-grained sizes.

Several feet of thin-bedded white to reddish-brown siltstones and quartz sandstones, with local thin sandy layers containing small pebbles and granules of siliceous rocks, is exposed at the divide along the south side of the road, about 150 feet above the base of the section. The pebbles and granules consist largely of quartz, cherts of various colors, and quartzite. Ferruginous concretions, commonly up to an inch in diameter, are conspicuous in these strata.

Overlying the ferruginous and pebbly strata at the top of the divide is 20 to 50 feet of dark olive-gray shale, with minor thin beds of siltstone. Fossils occur in the shale and two siltstone layers interbedded with the shale.

The fossils obtained are poorly preserved. They have been examined by David Nicol and J. B. Reeside, Jr. Nicol (personal communication, April 12, 1956) suggested that the fauna is approximately the equivalent of the Texas Woodbine (Cenomanian), although possibly it is uppermost Albian and equivalent to the Washita group. Either of these ages would place the strata near the boundary between the Upper and Lower Cretaceous, an age consistent with that generally assigned to the Dakota(?) in New Mexico.

The exposures in this locality are not adequate to prove that unconformities do not occur between the fossiliferous shale and the base of the quartz sandstone section. However, it is reasonable to infer that the fossils afford an approximate age for the entire post-San Andres section at this locality. In other New Mexico localities, the Dakota(?) sandstone is generally considered to be the basal transgressive deposit of the Upper Cretaceous sea, and overlying shales are interpreted as a conformable part of the transgressive sequence.

These outcrops provide the only occurrence of post-Permian strata (exclusive of Cenozoic alluvial formations) in either the Sacramento Mountains or the Guadalupe Mountains, a combined area of more than 5,000 square miles. As Triassic strata occur between the Paleozoic and the Dakota(?) rocks in the adjacent Sierra Blanca area, closer control is established for the zero isopach of the Triassic strata of the region. A geomorphic interpretation is that the summit peneplain of the Sacramento Mountains bevels somewhat deformed Cretaceous as well as Paleozoic strata. It thus can be interpreted as Cenozoic, and as a surface not directly controlled by the position of the unconformity at the base of the Cretaceous, an interpretation applied to a similar and probably correlative surface in the Guadalupe Mountains. The age of the formation of the surface is unknown; probably it is late Cenozoic. Pray and Allen (1959) suggested that it may coincide with Ogallala deposition in eastern New Mexico (Pliocene), but the evidence is inconclusive (Motts, 1959).

## CENOZOIC STRATA

Strata of Tertiary age are not known in the area of the Sacramento Mountains escarpment; they may be important, however, below the present surface of the Tularosa Basin. As this is a closed basin, there is no opportunity for dissection of the valley fill; consequently, the presence of Tertiary strata will be difficult to determine.

Deposits of Quaternary age occur both in the mountain block and in the Tularosa Basin. Those in the Tularosa Basin are alluvial materials of clay, silt, sand, and gravel that have been deposited as part of the alluvial apron at the base of the range. Toward the southwestern part of the mapped area, much of the Tularosa Basin surface is covered by low reddish sand dunes that rarely are more than 10 feet in height. The depth of the alluvium in the Tularosa Basin adjacent to the mountain front is unknown except for well borings in a few localities. A test well drilled near Valmont, in sec. 14, T. 18 S., R. 9 E., penetrated 1,800 feet of valley fill without reaching the base, and a well west of Alamogordo drilled 1,000 feet without leaving valley fill (Meinzer and Hare, 1915). It is probable that the valley fill is thickest near the base of the range and decreases westward toward the line of outcrops a few miles west of the mapped area (Hood, 1959).

Within the mapped area, numerous types of unconsolidated deposits of Quaternary age occur. These deposits were subdivided into three major categories for mapping purposes:

1. Alluvium, younger terrace deposits, and spring deposits.
2. Older pediment gravels and the Ranchario pediment gravels.
3. Landslides, talus, and colluvium.

Alluvium in the base of present drainage courses is of negligible volumetric significance in the mountain area, but forms the bulk of the surface deposits west of the mountain block. Several levels of terrace deposits occur along the major drainage courses, but were not differentiated in mapping. The most conspicuous area of terraces occurs on the north side of La Luz Canyon and forms Burro Flats in T. 15 S., R. 11. E., at an elevation about 100 feet above the base of the present canyon. Spring deposits are common only in the upper part of Alamo Canyon and along the Sacramento River. Those below the Permian are generally mapped, but those above the Permian contact are not differentiated on the geologic maps, as it proved impractical to map Quaternary deposits consistently in the higher parts of the mountains.

In the broad area of low relief that separates the steep slopes of the Yeso formation on the east from the western front of the range between High Rolls and Tularosa, in T. 15 S., R. 11 E., the interstream areas are capped by light-colored limestone gravels. These are interpreted as dissected pediment gravels. The level of the surface is now 200 to 300 feet above the level of the present stream bottoms. The surface formed by these gravel cappings slopes gently toward the northwest. These isolated deposits are interpreted to have been part of a broad sheet of fluviatile gravels occurring as a thin deposit on a broad erosional surface or pediment. They are termed herein the Ranchario pediment gravels. The name is derived from Ranchario Canyon, which drains part of the area in which the gravels are present. The gravels appear to have been derived from the San Andres limestone. In the southern part of the escarpment, similar isolated gravels occur in a similar position and have been differentiated on the map (pl. 2) as "older pediment gravels." They may correlate with the Ranchario gravels.

Rock debris in the form of landslides, talus accumulations, and other slumped masses locally covers areas sufficiently extensive to be differentiated on the geologic maps. Along the west front of the range, major debris accumulations occur below the Pennsylvanian cliffs. Several of the major canyons in Tps. 18 and 19 S. are clogged with this debris, which is now undergoing erosion. Landslides are most prevalent along the Yeso slopes in the higher areas of the escarpment, some including areas of a square mile or more. Only the largest of these are differentiated on the maps. In general, it was found practical to differentiate only those that occurred below the level of the Abo-Yeso contact. The landslide masses are now being eroded, and it appears that most of the mass movements occurred prior to the present erosion period. Perhaps these landslides occurred largely during a wetter period than the present, possibly during or late in the Pleistocene.

# *Tertiary (?) Igneous Rocks*

Intrusive igneous rocks are numerous within the pre-San Andres formation section of the northern and central Sacramento Mountains escarpment, and minor intrusive bodies occur farther south along the western front of the range. In this report, only the major relationships of these post-Paleozoic intrusive rocks are briefly summarized.

At the present levels of erosion, the major center of these igneous intrusive rocks is in the eastern part of T. 16 S., R. 10 E., and in the north part of T. 17 S., R. 10 E. (pls. 1, 2). Perhaps a comparable amount of such rocks occurs in the subsurface at similar stratigraphic levels over most of the northern part of the escarpment.

Most of the intrusive rocks in the Paleozoic section appear to be comagmatic. Many of the igneous rocks are greenish-gray porphyries of composition intermediate between andesite and latite, although the total range of composition includes some more-silicic rocks and a few more-basic varieties. Hornblende trachyandesite porphyry is the most common rock type. Plagioclase feldspar, commonly Ab60_65, forms one-half to two-thirds of many of the rocks, and occurs both as small phenocrysts and in the finely crystalline to aphanitic groundmass. Potash feldspar is distinctly subordinate to plagioclase in most rocks, but predominates in some. Where quartz has been noted, it rarely forms over 5 percent of the rock, and normally occurs in the groundmass. Late-stage alteration has affected many of the minerals of the rocks, forming such typical alteration products as chlorite, epidote, sericite, calcite, and clays. Normal accessory minerals are present. Contact effects within enclosing strata are very minor.

Most of the igneous bodies can be classified readily as sills or dikes. The dikes tend to be vertical or steeply inclined, and trend northeast-southwest within the area. Most of the dikes are a few feet to a few tens of feet in width. In the northernmost part of the area, several dikes can be traced as straight features of rather uniform width for 4 miles or more. The dikes appear to have been intruded along northeast-southwest joints, but locally they follow faults or other cross-cutting planes of weakness. Dikes occur throughout the sedimentary section as high as the Yeso formation. They have not been noted within the San Andres formation of the mapped area, but probably some occur in this part of the section. It is likely that there are more dikes, occurring along the steep cliffs of the pre-Permian section, than are shown on the maps, as the dikes are nonresistant compared to the carbonate rocks and rarely are exposed.

Quantitatively, most igneous rocks in the section occur in sills rather than dikes. The sills appear to be localized by the intersection of the feeder dikes with shaly sequences, or with parts of the section more easily separated along bedding planes than are the massive carbonate strata. Sills are most abundant in the lower part of the Gobbler formation, which is the lowest occurrence of a thick shaly sequence in the Paleozoic section. Lower strata that commonly are hosts to sills are present in the shaly units of the Devonian and the lower parts of the Mississippian section. Some relatively thick sills occur in the Bursum, Abo, and Yeso formations. Most of these are north of the mapped area (Otte, 1959b).

The largest single igneous body occurs in the area of Alamo and Ortega Peaks, in T. 16 S., R. 10 E. This mass (pl. 1; and pl. 3, cross-section B-B') is a composite body. It consists of a dike along a north-southtrending pre-Abo fault plane, and intersecting sills about 300 feet thick that are intrusive into the Gobbler formation on both sides of the fault. Other dikes, trending northeast-southwest, occur in the vicinity and may have served as feeders for the sills.

The age of the igneous bodies has not been established for the Sacramento Mountains area. They are younger than the Yeso formation and the small-scale thrust faults along the base of the escarpment, but are older than the major uplift of the range. The igneous activity of the Sacramento Mountains escarpment is probably related to similar but more extensive igneous activity in the Sierra Blanca and Capitan regions (Allen and Jones, 1952) directly to the northeast, where the igneous activity is dated as mid-Tertiary. Otte (1959b) considered the igneous intrusive rocks of the northwesternmost Sacramento Mountains as Tertiary(?) in age, a conclusion adopted here for the intrusive rocks of the remainder of the Sacramento Mountains escarpment, except for those within the Precambrian section.

# *Structure*

The overall structure of the Sacramento Mountains is that of a tilted fault block, with a regional dip to the east of about 1 degree. Along the crestal part of the block near the north and south ends, the strata dip several degrees to the north and south respectively, a reflection of the lesser amount of uplift in these directions than along the central zone. The Sacramento Mountains form the local eastern border of the Basin and Range Province and have many features typical of other mountains of this province.

The mappable structure of the area of the western escarpment is in few places as simple as the broad regional picture would suggest. Gentle folding and some faulting have affected the Permian strata in most of the escarpment area (so that the local details rarely reflect the regional structure), and the pre-Permian strata are more intensely deformed than the Permian, owing largely to folding and normal faulting during latest Pennsylvanian and early Permian time. In addition to this major diastrophism, tectonic events at other times since the Precambrian have modified the internal structure of the Sacramento Mountains block from that of a simple "layer cake." These include epeirogenic tilting and warping during pre-Pennsylvanian times, gentle folding and some faulting during deposition of the Abo (and possibly the later Permian strata), some folding and faulting during Mesozoic and early Cenozoic times, and additional folding and faulting within the mountain block during the uplift of the range.

The principal structural features of the Sacramento Mountains escarpment are delineated on the geologic maps (pls. 1, 2), and on the structure sections (pl. 3). As most of the structural features of the area trend north-south, the east-west orientation of the structure sections generally reflects true structural dips rather than apparent dips. The individual structural features of the escarpment area are not described in detail, but the structural details can be worked out from the strati-graphic and structural data given on the maps and in the structure sec tions (pls. I, 2, and 3).

Genetically, the structural features of the Sacramento Mountains escarpment can be divided into two major groups: (a) features related to the late Cenozoic deformation that resulted in the uplift of the range, and (b) structural features that predate the uplift of the range and which have either been unaffected or but slightly modified by basin-and-range deformation since its inception.

## FEATURES RELATED TO THE UPLIFT OF THE RANGE

The present mountains are believed by the writer to be largely the result of uplift with respect to the area of the Tularosa Basin along a normal or gravity fault zone that is at, or close to, the present base of the escarpment. The fault zone dips west at high angles. The uplift probably began in late Cenozoic time and appears to be still in progress. The faulting hypothesis accords with that of most geologists familiar with the area, but was not accepted by the writers of the two most extensive early published accounts of the structure of the Sacramento Mountains. Darton (1928) considered the mountains to be essentially anticlinal, somewhat modified by faulting. Baker (1928) appears to have been undecided as to a fault or fold origin for the uplift of the range. According to the hypothesis of origin by folding, the visible part of the range represents essentially the eastern gentle limb of a major north-trending anticline, and the much more steeply dipping western limb is interpreted to have been removed by erosion. Abundant surface evidence appears to favor the fault hypothesis, whereas evidence at the surface for the folding and removal by erosion of the western limb appears to be scanty at best.

Alluvial or piedmont scarplets occur along much of the length of the mountains at the base of the escarpment. These fault scarps are as much as 80 feet in height. All observed face the basin, and although largely in alluvial material, bedrock is commonly visible on the mountain side of the scarps where they have been dissected by recent drainage. These piedmont scarps are excellent evidence of major recent dislocation along the western edge of the escarpment and indicate the position of the major fault zone. As can be noted from Plates 1, 2, and 3, the alluvial scarps are generally within a few hundred feet of the bedrock outcrops of the mountain block. This, together with the general absence of upward convexities at local points along the longitudinal profiles of the alluvial fans farther toward the west, strongly suggests that the major fault zone occurs at and very near the line of present alluvial scarps.

A host of step faults near the edge of the mountain block furnish additional evidence for the presence of a major fault zone at the western edge of the block. These appear to be sympathetic structures along a major gravity fault zone. They increase in number and, to a lesser degree, in the magnitude of displacement toward the outermost portion of the mountain block. Most of these faults are west-dipping, high-angle, gravity faults with a predominant dip-slip movement. In many places, dips of strata steepen abruptly toward the west in the outermost 100 feet of exposures along the base of the escarpment. These effects are considered to be caused by drag along the frontal fault zone. The localized occurrence of these areas of western dips, as well as their close areal association with the irregular trace of the base of the range, is incompatible with the interpretation that they represent remnants of a steep western limb of the entire stratigraphic succession of the mountain block. The area along the west front of the Sacramento Mountains where west dips are most evident and laterally persistent is east of

Alamogordo, in a reentrant along the front of the range, suggestive of a lack of correlation with the boundary structure.

The base of the escarpment trends slightly west of north for much of its length but is irregular and somewhat angular in detail. There is a notable lack of correspondence between its trace and either the visible structure of the mountain block or the erosional resistance of the strata that locally form the edge of the mountains. These are typical features of basin-and-range mountains. It would appear that any major anticlinal structure in the area of the Sacramento Mountains escarpment is exceedingly gentle and broad. There is no more indication of western dips than would be expected near the faulted edge of a tilted block the size of the Sacramento Mountains. Beyond the area of the Sacramento Mountains, the regional evidence for faulting as the principal cause of uplift of similar mountain blocks is compelling.

The present need is for data on the missing part of the structure that underlies the alluvium of the Tularosa Basin to the west. Some geophysical work has been completed in recent years along the eastern edge of the basin, and it is to be hoped that at least the broad results of these seismic, gravity, and magnetometer surveys will be made generally available. Surface and well data, at present, are meager, being confined largely to scattered outcrops of Permian strata (Yeso and San Andres) 10 to 15 miles west of the base of the range, and to several water wells drilled at Alamogordo and Valmont to depths of about 1,200 and 1,800 feet, respectively. These wells are reported to have bottomed in alluvial material. It would seem likely that the alluvial fill is of maximum thickness near the base of the escarpment along the central part of the mountains, and that it decreases in thickness to the north, south, and west.

Total amounts of displacement on the hypothesized boundary fault are highly speculative on the basis of the present data. On the assumption of 2,000 feet of alluvium west of the boundary structure and of an alluvium-bedrock contact at the level of the Yeso-San Andres contact, the amount of displacement along the central 15 miles of the escarpment would be of the order of 7,000 feet. The estimates based on the same contact assumptions, but with diminished thicknesses of alluvial fill for the north and south ends of the mapped area, are of the order of 4,000 feet. These figures probably represent minimum rather than maximum displacements, as the thickness of the alluvium may be much greater than is assumed for these computations.

Several major lines of faulting occur within the mountain block that are similar in type and direction of movement to the frontal fault system. Combined with the geomorphic history of the surrounding region (Fiedler and Nye, 1933; Bretz and Horberg, 1949; and Motts, 1959), this faulting and locally associated folding afford a basis for estimating the time of the uplift of the Sacramento Mountains.

Two of these features are the Mescalero fault (north of the mapped area, in T. 13 and 14 S.), discussed in the section on Mesozoic strata; and the folded and faulted belt along the Sacramento River in the southeastern part of the mapped area. Although the evidence is limited, these structures appear to have formed prior to the development of a widespread surface of erosion, the Sacramento plain of Fiedler and Nye (1933), in the crestal part of the range. This surface extends farther to the north and east. The time of this folding and faulting is post-middle Cretaceous (it involved the Dakota[?] sandstone along the Mescalero fault), and it may have occurred in early to mid-Tertiary time near or during the injection of igneous rocks into the region. As the Sacramento plain is not limited to the area of the Sacramento Mountains escarpment and the present fault block, uplift of a broader area is necessitated prior to the formation of the erosional surface. The age of this is not well established, although it is undoubtedly late Cenozoic. Pliocene was suggested by King (1948), Pliocene (Ogallala) by Pray and Allen (1956), and a pre-Ogallala, but presumably Pliocene, age by Motts (1959).

The major uplift of the Sacramento Mountains fault block was subsequent to the formation of the Sacramento plain, and has continued to the present time. The intermittent nature of the more recent uplifts is shown by the succession of erosional and constructional surfaces in the lower parts of the Sacramento Mountains.

## FEATURES THAT PREDATE THE LATE UPLIFT OF THE RANGE

Most of the structural features of the Sacramento Mountains block appear to have been formed prior to the late uplift of the block. These earlier structural features of the mountain block were formed largely during Paleozoic time, although some deformation occurred during the Mesozoic or early Cenozoic. The dating of the Paleozoic deformation is relatively precise, owing to the associated sedimentary record, but the virtual absence of Mesozoic and pre-Quaternary Cenozoic strata renders speculative the age of the post-Paleozoic events. In the following brief survey, the major structural events are discussed in chronological order.

### PRECAMBRIAN TO PENNSYLVANIAN FEATURES

The Precambrian structural history of the mountain block is almost entirely unknown. Clastic fragments in Paleozoic sediments indicate that areas of provenance for quartzite, granite, and some other intrusive and metamorphic rocks occur in the region, probably to the northeast. Direct observations indicate only that a slightly metamorphosed sedimentary terrane, injected with diabasic intrusive rocks, was slightly tilted prior to erosion and the subsequent deposition of the basal Paleozoic elastic rocks.

The area of the escarpment, in common with much of southern New Mexico, appears to have been tectonically stable, subject only to epeirogenic warping, intermittent marine inundations, and minor erosion, from early Ordovician into Devonian time. Known disconformities in this area occur at the base of the Montoya, the Fusselman, and the Onate formations, and may be present at the base of the El Paso and Sly Gap formations. During later Devonian and Mississippian times, somewhat increasing structural disturbance is recorded. Disconformities occur at the base of the Percha(?), the Caballero, and the Lake Valley formations, and possibly at the base of the Arcente member of the Lake Valley formation. A low angular discordance occurs at the base of the Las Cruces(?) and Rancheria formations throughout most of the escarpment. The unconformity at the base of the Pennsylvanian deposits, and the record of the ensuing Pennsylvanian strata, clearly indicate more tectonic instability in the local area than at any previous time during the Paleozoic era.

The transitional area between the Orogrande basin to the west and the Sacramento eastern shelf, as indicated by the outcrop and subsurface data of the southern Sacramento Mountains, is given in Figure 24. This transitional area is interpreted to trend north-south and to be only a few miles in width. This area may have shifted westward from Missourian into Wolfcampian time.

The increasing unrest culminated in the major deformation during latest Pennsylvanian and early Wolfcampian time, when many of the internal structural features of the Sacramento Mountains escarpment were formed.

## LATE PENNSYLVANIAN AND EARLY WOLFCAMPIAN FEATURES

The major period of deformation recorded in the internal structure of the Sacramento Mountains occurred during latest Pennsylvanian and early Wolfcampian times. Folds and faults were formed at this time throughout the area of pre-Abo exposures, and undoubtedly over a much broader area. The most distinct folds are anticlines, which can be traced along north-south axes for many miles. The faults are of high angle, and most are of gravity types with displacements of as much as one-third of a mile. The basal Abo unconformity truncates most of these features, locally with an angular discordance of 60 degrees or more. For simplicity, the features formed at this time are here referred to as pre-Abo, as is the period of deformation. The intensity of deformation appears to increase from west to east in the area of pre-Abo strata, and is at the observed maximum in the north-central part of the area. The area most affected by this deformation probably lies farther east and northeast of this area.

This pre-Abo deformation in the Sacramento Mountain area is considered to be a part of the deformation known in the area to the south and southeast that preceded the deposition of the Hueco formation above an angular unconformity cut onto strata from Precambrian to

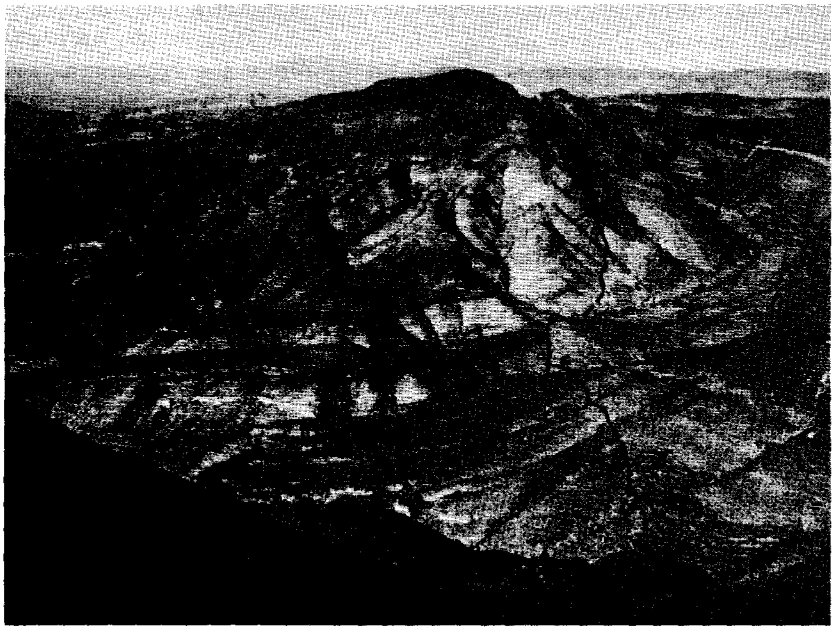


Figure 32

**VIEW FROM LONG RIDGE LOOKING NORTH ALONG TRACE OF ALAMO FAULT TOWARD ALAMO** PEAK

Hinge point of Alamo fault in foreground. Basal parts of units marked are: A, Abo formation; F, Fusselman formation; and P, Pennsylvanian strata. Sierra Blanca on distant skyline.

Pennsylvanian in age. Only in the northwesternmost part of the Sacramento Mountains was deposition essentially continuous from latest Pennsylvanian into middle Permian time. The stratigraphic and structural record of the area between La Luz Canyon and the Fresnal fault permits close dating of the deformation as extending from late Pennsylvanian to late Early Wolfcampian.

The principal structural features formed by the pre-Abo deformation are discussed briefly below. The major features are named on the geologic maps and on many of the structure sections (pls. 1, 2, 3). For many of the features, more details are provided in the road logs printed in the 1959 Field Conference Guidebook (Pray, 1959).

## Anticlines

Anticlines are the most prominent and persistent of the pre-Abo structural features. These anticlinal trends are characterized by the occurrence of distinct and locally sharply defined domes along the anticlinal crest. In the intervening low areas along the crest, the flank dips are locally so gentle that the continuity of the feature is in doubt except for the longitudinal persistence of the trend along which the anticlinal features and domes occur. The major anticlines of the area trend roughly north-south, and two of these trends, the Mule Peak and Gobbler anticlines, are truncated by the west front of the range. The most sharply defined of these is the Gobbler trend, shown in the frontispiece.

In the northern part of the area, the major trends are the La Luz and Caballero anticlines, the latter being the most tightly folded of the anticlines of the area. In the central and southern parts of the area, the Mule Peak, Gobbler (fig. 34), and Bug Scuffle anticlines are major features. The evidence of pre-Abo age for the major folding is established locally along these trends by Abo strata overlying the unconformity, or by the position of the exhumed pre-Abo unconformity. Most of these anticlinal features are associated with high-angle faults along the crest. In several areas along the Mule Peak and Gobbler anticlines, the upper Pennsylvanian strata are folded, and a fault either is exposed or can be postulated to occur in the lower Pennsylvanian strata and underlying section.

Faults

The major pre-Abo faults are generally localized along the anticlinal crests, especially along the domical features. The major faults of preAbo age are the complex Fresnal fault (or fault zone) in the northern part of the area; the Arcente fault; the Alamo fault (fig. 32); the faults along the Gobbler anticline near its southern limit; and the Bug Scuffle fault in the southern part of T. 19 S., R. 11 E., which probably extends southward beyond the map area. All these faults are high-angle or locally vertical features, and in most places dip toward the downthrown block.

The Fresnal fault in the north is complex (see Otte, 1959a; Pray, 1959). Major movement occurred along this fault at several times. Late Pennsylvanian and pre-Bursum, post-Bursum and pre-Abo, and post-Abo displacements involving several hundreds of feet can be proved. Overall stratigraphic displacement along this west-dipping normal fault is about 1,600 feet near the intersection with Fresnal Canyon.

The Alamo fault is superbly exposed (fig. 32), and details can be determined with some confidence. It is a high-angle scissors fault having a displacement of about 500 feet down on the west in its southern portion, and a reversed displacement with about 1,500 feet of strati-graphic separation occurring about 3 miles to the north. The age is clearly pre-Abo in the southern portion, and is presumed to be pre-Abo throughout its length.

The Bug Scuffle fault is a long, high-angle fault with the anomalous occurrence of "half domes" in the lower Paleozoic strata occurring on opposite sides of the fault and separated by a distance of about a mile. This aspect suggests strike-slip displacement subsequent to folding of a dome, but the available evidence of drag and a few slickensides indicate dip-slip displacement. The feature is interpreted as a scissors fault with a pivot point between the two "half domes." Perhaps these scissors faults in the escarpment area are localized by major lines of weakness in the underlying Precambrian block, and responded in different directions at somewhat different times during the pre-Abo period of deformation.

### Synclines

The most sharply defined and tightly folded syncline in the area is the Dry Canyon syncline in Tps. 16 and 17 S. Locally, this has dips of 60 degrees or more on the flanks, and the western limb in the Dry Canyon area has several conspicuous zones of drag folding. The feature is clearly of pre-Abo age. The other syncline of pre-Abo age is the Joplin syncline occurring between the Mule Peak and Gobbler anticlines in the central part of the area. This is an obscure feature except where the adjacent anticlines converge toward the north. The shallow synclines shown on the map along the western edge of the mountains probably are not pre-Abo in age, as the western limb appears to be related to gentle eastward tilting along the frontal fault system.

In summation, the pre-Abo structures have north-south trends throughout the area; the sharpest folds are the anticlines; anticlinal crests are characterized by local domes; synclines are obscure and broad; and the faults are of high-angle, gravity types, largely along anticlinal trends. These features are suggestive of a "Plains type" of deformation (Powers, 1925), with a predominance of vertical movements of the underlying rocks, rather than a predominance of lateral compression. The tight structures, however, in the north-central part of the area must have involved lateral compression.

## POST-EARLY WOLFCAMPIAN FEATURES

Evidence in the central Sacramento Mountains indicates that gentle folding along the lines of the earlier structures continued throughout the deposition of the Abo formation. As the Abo-Yeso contact is folded along the same structural axes, some deformation probably continued into late Permian time; with the virtual absence, however, of strata younger than middle Permian, it is not possible to distinguish between later Permian or more recent folding. The present upper limit of the San Andres limestone in most of the Sacramento Mountains and in the region to the west probably is near the level of a late Permian or early Mesozoic surface of unconformity.

Several anticlinal domes occur in the crestal part of the Sacramento Mountains. These have several hundred feet of closure, the Hondo member of the San Andres limestone providing the datum plane. The northernmost of these was drilled (dry hole) in 1952 by the Southern Production Co. Two other local domes occur along the Sacramento anticline farther south. The age of these structures is not closely determinable. They are older than the summit peneplain, which probably formed in late-Cenozoic time. The local faults in the crestal part of the range could be of equivalent age, but evidence for close dating is not available.

## Low-Angle Thrusts and Related Folding

Low-angle thrust faults and closely associated folds (which are interpreted as zones of incipient thrusts) are common small-scale features along the west front of the escarpment. These occur in the area from Alamo Canyon, on the north, southward to a mile beyond Negro Ed Canyon, near the southern limit of the mapped area. The features appear to be restricted to the westernmost part of the escarpment, and in few places occur more than one-half mile east of the base of the range. A thrust and related zone of flexure typical of these features along the front of the range are shown in Figure 33. Most of the thrusts occur in the pre-Devonian strata, but several have been observed to penetrate upward in the section to the Pennsylvanian rocks. Displacements are commonly less than 200 feet. The fault planes strike parallel to the mountain front and dip west from 15 to 30 degrees; most dips are about 20 degrees. Wherever observed, the hanging-wall block has moved eastward relative to the footwall block. The larger of these thrusts have been plotted on the geologic maps; many, too small for the map scale, have been indicated by the occurrence of an abnormally steep east dip of the strata. The associated folding is almost everywhere on the hanging-wall side of the fault break.

These thrusts are older than the intrusive dikes and sills of Ter-tiary(?) age, as can be demonstrated in the Alamo Canyon area (pl. 1). The reason for their constant association with the present western fault zone is not understood. Perhaps it is coincidental. On the other hand, it may indicate that the position of the frontal fault zone (along which the recent uplift has occurred) was established by earlier move -ments prior to the injection of the Tertiary(?) intrusive rocks.

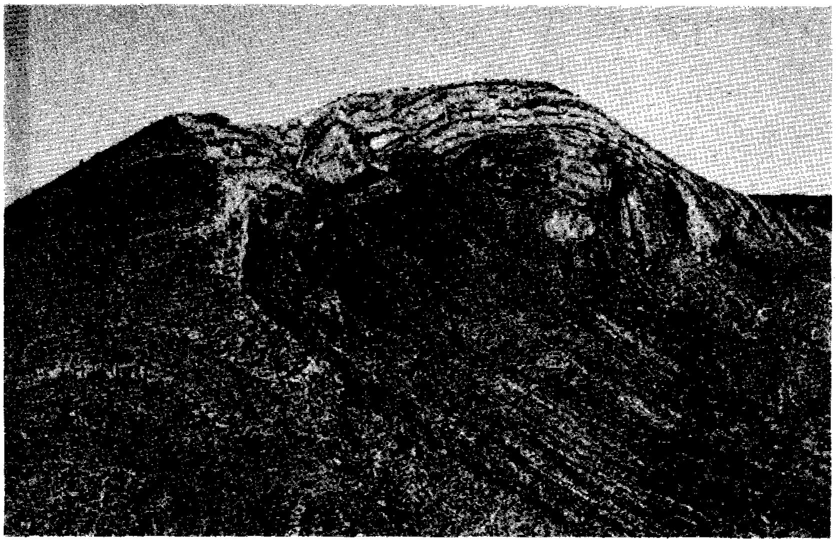


Figure 34

GOBBLER DOME, ALONG CREST OF GOBBLER ANTICLINE, SEC. 19, T. 18 S. R. 11 E.

This sharp domical fold, interpreted to *be* faulted at depth, is developed in Bug Scuffle limestone member of Gobbler formation. Even truncation of limestone beds on crest of dome is interpreted as exhumed pre-Abo angular unconformity.

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# *Addenda*

*Sacramento River* (p. 15). Stream capture of the upper part of the Sacramento River by the headwaters of Grapevine Canyon in T. 19 S., R. 12 E., is imminent.

*Bliss sandstone* (p. 27). The Bliss sandstone is interpreted to represent deposition in shallow, agitated, marine water.

*Montoya formation* (p. 43). Howe, H. J. (1959) reported on the Montoya group of the Franklin Mountains, and included a measured section from the Sacramento Mountains.

*Valmont dolomite* (p. 43) The Valmont dolomite is about 180 feet thick in much of the outcrop area.

*Biohermal strata* (p. 63). The term "interreef" does not imply that the bioherms were reefs in the sense of Lowenstam (1950), as noted previously (Pray, 1958a).

*Mississippian biohermal strata* (p. 64). Part of the core facies of some larger bioherms consists almost exclusively of a fenestrate bryozoan meshwork, interpreted as growth framework, and of sparry calcite cement.

Crinoids were largely flank-dwelling organisms and were not required for growth of the bioherm core.

*Bursum formation* (p. 90). The outcrop and subsurface data of the Bursum formation indicate an emergent source area near the present crest of the range, flanked by a narrow shelf sloping westward into the Orogrande basin. Across this north-south-trending marginal area, the Bursum formation thickens and becomes marine to the west. The relationships shown in Figure 24 may be applicable from the northern Sacramento Mountains southward into Texas.

*Cenozoic rocks* (p. 118). Hood, J. W. (1959) discussed in detail the valley fill and ground water in the Tularosa Basin. He inferred that 90 percent of the fill is of Tertiary age and the remainder is Quaternary in age.

*Step faults near the west edge of the Sacramento Mountains* (p. 124). Most of these faults dip west 55 to 75 degrees; displacements of 200 to to 300 feet are common.

*Faults within the Sacramento Mountains that are similar to the frontal fault system* (p. 125). Some of these faults appear to be older than the uplift of the present Sacramento Mountains fault block, but may be related to earlier regional uplift.

# *Index*

**Boldface** indicates main references; numbers in *italics* indicate figures and plates.