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# Outline of the stratigraphy and structure of the Sacramento Mountain escarpment

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This is one of many related papers that were included in the 1954 NMGS Fall Field Conference Guidebook.

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and green, the cleanliness of its vast expanse, and its appeal to the lover of the unexplored mark it as an area which attracts those discerning travelers who would see Nature's masterpieces."

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# OUTLINE OF THE STRATIGRAPHY AND STRUCTURE OF THE SACRAMENTO MOUNTAIN ESCARPMENT

Lloyd C. Pray\*

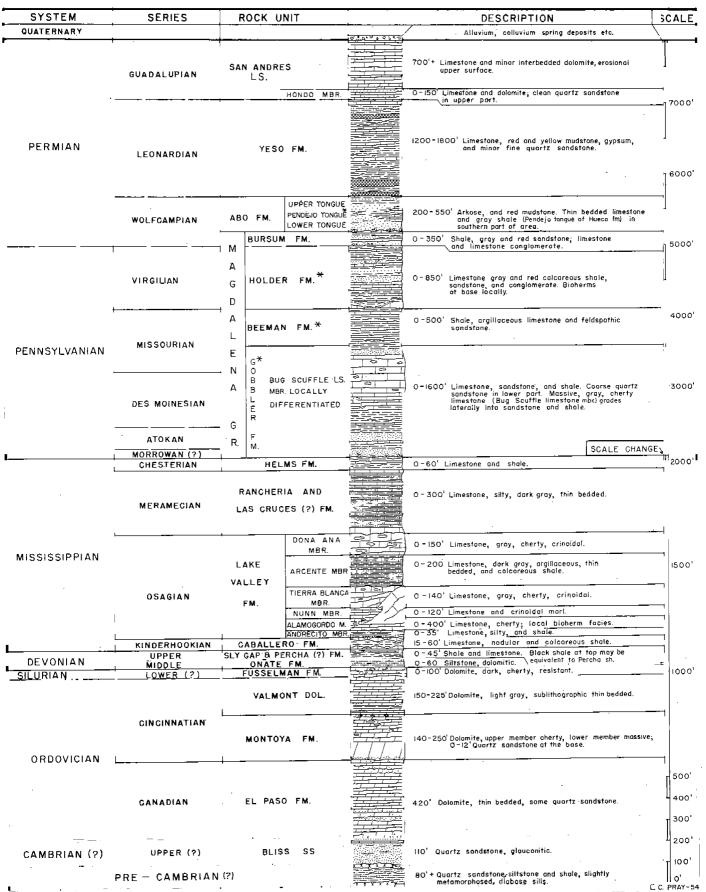
#### INTRODUCTION

The Sacramento Mountains form one of the major mountain masses in southern New Mexico. About mid-

 Division of Geological Science, California Institute of Technology. way between the east and west borders of the state, these mountains extend northward for 40 miles from a point about 40 miles north of the Texas border. The mountains are sharply asymmetrical and rise abruptly in two major steps to a mile above the Tularosa Basin on the west. From the crest, the range slopes almost imperceptibly eastward to the Pecos River, 80 miles away and about 6000 feet lower. Although the crest of the range lies about 9000 feet for more than 20 miles, no part is as high as 9700 feet. The Sacramento Mountains are a large east-dipping cuesta, uplifted on the west side along a normal or gravity fault zone. In this sense, they are structurally similar to, and en echelon with the Guadalupe Mountains to the southeast, and the Oscura Mountains to the northwest. The stratigraphic section is almost entirely composed of Paleozoic rocks, ranging in age from Cambrian (?) to middle Permian. Rock units of this area have many similarities with the Paleozoic sections of the Basin Ranges farther to the west, visited by the previous Field Conference, and with the down-dip subsurface sections of southeastern New Mexico. The outcrops along the Sacramento Mountain escarpment are the closest major surface exposures in the state to the subsurface pre-Permian stratigraphic section of southeastern New Mexico, a part of the section which has been of increasing significance in petroleum exploration in recent years.

This brief paper is designed to supplement the road log and the discussion at the stops in presenting the salient geological features of the western escarpment of the Sacramento Mountains, with particular reference to those features that will be seen during the Fifth Field Conference. An index map of the western part of the Sacramento Mountains is included. A generalized geologic map of the northwestern part of the escarpment area that will be viewed or visited during the Field Conference accompanies this paper. Essentially this same map was used during the 1949 G.S.A. field trip sponsored by the West Texas Geological Society (King, et al 1949). A composite stratigraphic section of the pre-Cambrian and Paleozoic rocks will be found in the guidebook and the structural features along two east-west cross sections from the base to the crest of the range are given elsewhere in this guidebook. Several aerial views of the western escarpment are shown.

The writer has worked intermittently in the escarpment area of the Sacramento Mountains since 1947, and has mapped most of the western escarpment and part of the crest of the range at a scale of two inches equals one mile. Geologic maps and a report will be published by the New Mexico Bureau of Mines and Mineral Re-



COMPOSITE COLUMNAR SECTION, SACRAMENTO MOUNTAINS, OTERO CO., NEW MEXICO

\* Manuscript name

sources as Bulletin 35. A 1952 report and a preliminary copy of the maps are on open file at the Bureau office in Socorro. Financial support, here gratefully acknowledged, has been furnished for the work by the New Mexico Bureau of Mines and Mineral Resources, and the California Institute of Technology. References to previously published data most pertinent to the area of the Sacramento Mountain escarpment is given in the bibliography.

#### STRATIGRAPHY

The stratigraphy of the Sacramento Mountain escarpment is almost entirely that of Paleozoic rocks. Although the composite thickness of the Paleozoic section is nearly 8000 feet, the actual thickness in most places is considerably less than this maximum amount. The Paleozoic stratigraphic sequence can be conveniently grouped into three parts, of a approximately equal composite thicknesses. The lowest of these includes rocks ranging in age from Cambrian (?) through Mississippian. These strata are mostly carbonate rocks of marine origin, deposited on relatively stable, shallow shelf areas. The older part of the sequence is mostly dolomite, with limestone occurring in the Upper Devonian and Mississippian strata. Terrigenous clastics are minor components in this lower part of the sequence, and most are at the base, or within the thin Devonian section. The middle third of the Paleozoic section consists of Pennsylvanian strata, largely but not exclusively of marine origin. These form a complex interbedded sequence of limestone, sandstone, and shale. Permian rocks form the upper third of the Paleozoic section, and include both marine and non-marine strata. Red beds are a conspicuous part of all but the top of the Permian sequence and evaporites are common in the middle part of this sequence.

The stratigraphic comments below are primarily concerned with the physical attributes of the section exposed in the escarpment area. Evidence concerning the age of many of the rock units in southern New Mexico, can be found in the excellent summary by Flower (1953 b) in the guidebook for the 1953 New Mexico Field Conference.

The surface data of the escarpment area has recently been supplemented by record of a dry hole drilled to pre-Cambrian rocks by the Southern Production Co. (No. 1 Cloudcroft Unit) at a point just east of the crest in the middle of the range.

# Pre - Cambrian:

The oldest rocks exposed in the Sacramento Moun -

tain area are sediments, largely siltstones, shale, and fine-grained sandstone. These crop out only in the vicinity of Nigger Ed Canyon. Associated with the sediments are intrusive sills, mostly of diabase. Some are markedly porphyritic, and locally bear a superficial resemblance to plutonic intrusives. The sediments and the later intrusives are separated from the basal Paleozoic rocks by an unconformity with about 10 degrees of angular discordance. The stratigraphic position, the absence of fossils (except for obscure fucoidal markings), and the absence of deformation or regional metamorphism are suggestive of late pre-Cambrian age. The surface section is remarkably similar to that encountered in the Southern Production No. 1 Cloudcroft well, which drilled about 100 feet into a pre-Bliss section of quartz sandstone containing two bodies of diabase.

#### Bliss sandstone:

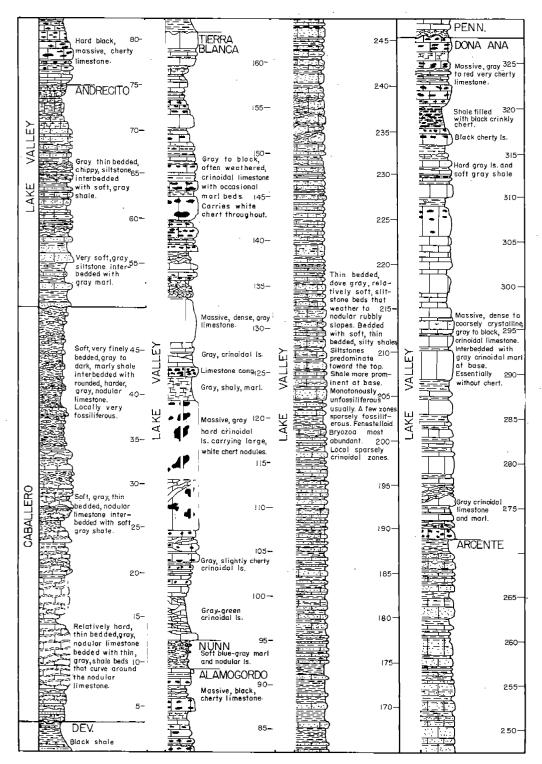
This basal unit of the Paleozoic sequence in southern New Mexico is exposed in the Nigger Ed Canyon area in the Sacramento Mountains. There it consists of 110 feet of quartz sandstone, with sandy, brownweathering dolomitic beds interbedded in the upper third of the section. Glauconite is abundant in some of the layers. Fossils consist of a few linguloid brachiopods, and numerous worm (?) borings, and add little to the controversey regarding the age of the Bliss sandstone. Flower (1953a) indicates that the unit is time transgressive, and that both Late Cambrian and Early Ordovician faunas are known in the state. The Residue Research Laboratory of Midland indicates the Bliss of this area to be Cambrian on the basis of their correlations (Roswell Geological Society 1953, p. 20). The base of the Bliss sandstone is an angular unconformity in this area.

# El Paso formation:

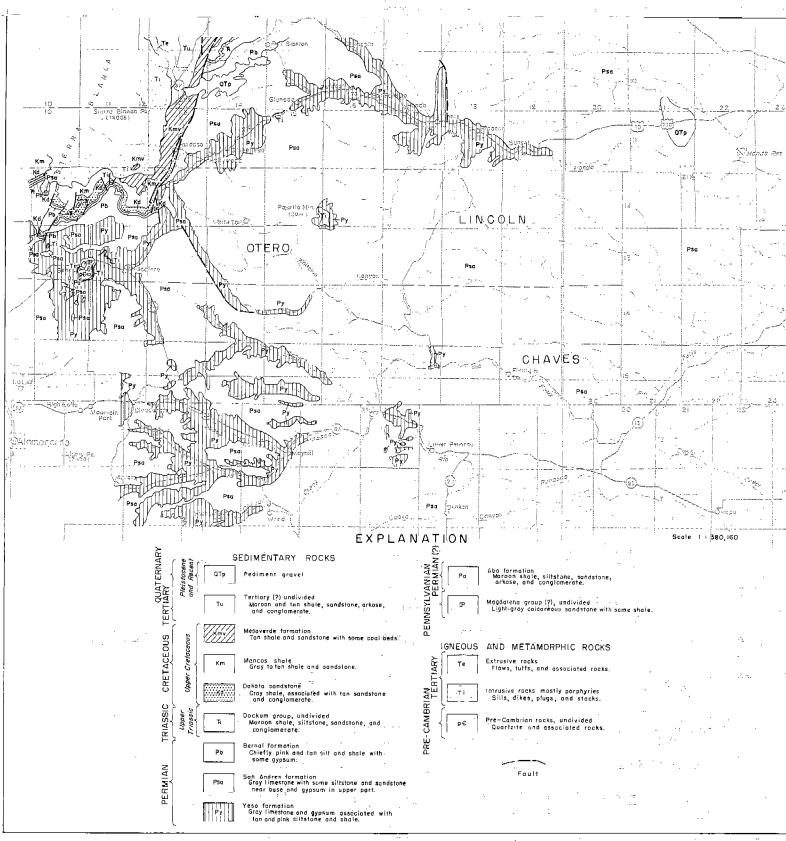
The only complete El Paso section exposed in the escarpment area is at the south near Nigger Ed Canyon, where the formation is about 420 feet thick. The surface section and that in the Southern Production No. 1 Cloudcroft test are closely similar in thickness and lithology. The El Paso consists largely of medium light gray to olive gray dolomite, that ranges in texture from very fine to medium grained. Much of it is light olive gray and fine-grained. Thin to medium beds predominate, and the formation weathers to a light brownish slope, commonly with only a few ledges more than 10-20 feet high. Chert occurs as sporadic nodules and forms but a minor part of the formation. Dolomitic quartz sandstone is common in the lower third of the formation. and quartz sand grains, rarely forming as much as half the rock, occur locally in the upper third of the El Pa-

# DEADMAN CANYON

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

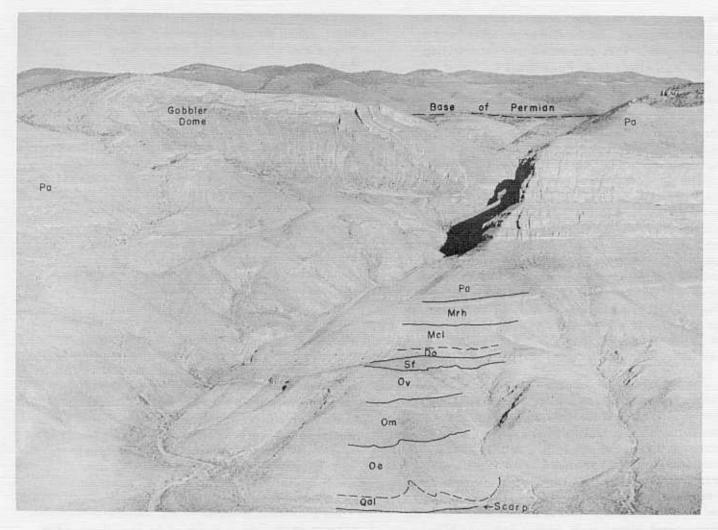


LAUDON & BOWSHER (1949)



RECONNAISSANCE MAP OF AN AREA SOUTHEAST OF SIERRA BLANCA IN LINCOLN, OTERO, AND CHAVES COUNTIES, NEW MEXICO

by George O. Bachman



View toward east in southern part of the Sacramento Mountains at Escondido Canyon from Sec. 25, R. 18 S., R. 10 E. Stratographic section exposed on the frontal escarpment on the right is about 3500' thick and includes the following: El Paso (Oe), Montoya (Om), Valmont or lower Fusselman (Ov), upper Fusselman (Sf), Onate (Do), Caballero and Lake Valley (Mcl), Rancheria and Helms (Mrh), and about 2200' of Pennsylvanian (Pa). The sharply folded structure is Gobbler Dome, formed and later eroded to Desmoinesian strata prior to Abo deposition. The distant slopes are Yeso, capped by several hundred feet of San Andres limestone. (Airphoto by David A. Dunn furnished through courtesy of the Roswell Geological Society).

so. Glauconite is generally absent. The El Paso appears to be transitional with the Bliss sandstone in this area although a disconformity could exist at the base of any of several sandstone beds in the transition zone. Fauna is sparse, and commonly poorly preserved, but that collected to date suggests a correlation with the lower part of the type El Paso section. Insoluble residue correlations (Roswell Geol. Soc. 1953, p. 21) suggest a Cambrian age for the El Paso of the Sacramento Mountains, but this conflicts with the faunal data in this area, and with the fauna at the type section, reported to be Lower Ordovician by Flower (1953b, p. 106).

Montoya formation:

The Montoya formation of the Sacramento Mountains correlates closely in thickness and lithology with the Montoya formation of the Franklin Mountains, the type area. Darton (1928) subdivided the Montoya into two members in the Sacramento Mountains and in much of southern New Mexico. These consist of a lower dark-colored cliff-forming dolomite with a thin quartz sand-stone at the base, and an upper cherty, slope-forming dolomitic member. Recently Kelley and Silver (1952) proposed to raise the Montoya to group status, and gave useful, formal names to the lithologic units recognised by earlier workers. These units are the Cable Canyon

sandstone at the base, the Upham dolomite (cliff-forming lower member), and the Aleman dolomite (cherty upper member). They also named the next overlying rock unit (Darton's lower Fusselman) the Cutter dolomite, and included it as the uppermost formation of the Montoya group. Detailed studies in the type area of the Montoya and Fusselman (Franklin Mountains) and elsewhere convince the writer of the correctness of Darton's pioneer work in considering the strata in New Mexico that occur above the upper Montoya member (or Aleman) to correlate directly with the lower part of the type Fusselman section. This evidence, and the fact that the Montoya is initially defined formed a readily recognizable rock unit as such, and one which since has been widely correlated as Montoya in both subsurface and surface areas suggests to the writer the advisability of not expanding the original limits of the Montoya to include a part of the Fusselman section. The fact that Upper Ordovician faunas occur above the top of the Montoya (Pray and Bowsher, 1952: Flower, 1953b) should not be a factor in the nomenclature of rock units.

The Montoya of the Sacramento Mountain escarpment ranges from about 140 to 250 feet thick. It is 200-225 feet thick in much of the area. Very coarse grained to granulitic quartz sandstone (Cable Canyon sandstone) occurs at the base at almost all localities and reaches a maximum thickness of about 12 feet. It generally grades upward into sandy dolomite and thence to sandfree dolomite that forms the bulk of the dark lower member (Upham dolomite). This is composed of fine to medium grained, olive gray to medium dark gray dolomite, thick bedded to massive, with little or no chert. It is generally 80 to 100 feet thick in the escarpment area. It appears to grade upward by an increase in the amount of chert, a decrease in grain size, and a change to thinner beds and to a lighter color into the slope formingconspicuously cherty, upper member (Aleman dolomite). This unit is generally 100 to 120 feet thick. The top contact is at the top of a very cherty zone, which locally consists of 1-3 feet of solid chert.

The basal contact of the Montoya is a remarkably smooth surface of disconformity. Fossils are locally abundant near the base, and top of the Montoya and are less common in the central portion. Corals and brachiopods predominate, and are considered to be Upper Ordovician in age.

#### Valmont dolomite:

This term was applied by the writer (Pray, 1953) to the distinctive rock unit of the Sacramento Mountain area termed the lower member of the Fusselman by Darton (1928). It appears to be the equivalent of the Cut-

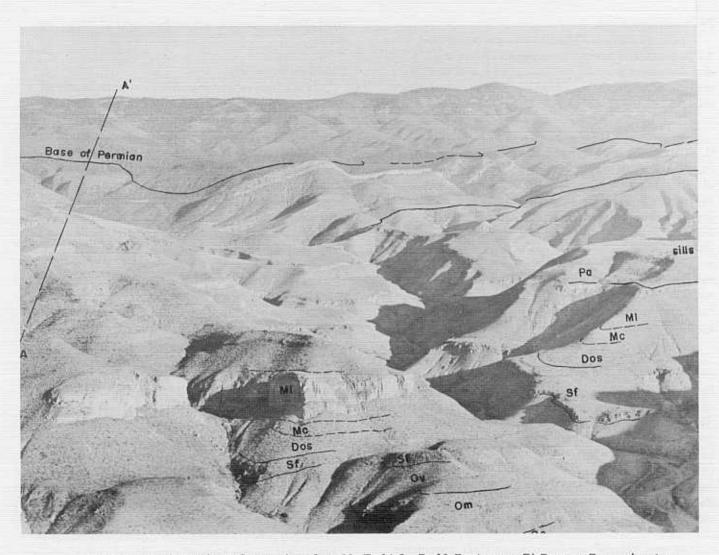
ter dolomite of southwestern New Mexico (Kelley and Silver, 1952), although of somewhat different facies. It correlates with strata that form the lower 160 feet of the Fuseslman section in the type area of the Franklin Mountains. The Valmont dolomite of the escarpment area ranges from 150 to 225 feet, commonly is about 180 feet thick, and is composed almost entirely of medium to very light gray, sublithographic to very fine grained dolomite. The fineness of grain results in a conchoidal fracture, a characteristic feature. Most bedding planes are sharply defined, laterally persistent and spaced a few inches to two feet apart. Chert is scarce, although brownish - weathering seams and large nodules of partially silicified dolomite are conspicuous in the upper part of the formation. A zone of argillaceous dolomite 40-70 feet above the base forms a persistent niche on the Valmont slope, and separates the formation into upper and lower members.

The basal contact is at the change from very cherty dolomite or solid chert upward into finer grained dolomite with little or no chert. Although this change appears to be at a persistent stratigraphic horizon in this area, and locally is sharply defined the contact does not appear to represent a disconformity. Upper Ordovician fossils occur in the lower member. The upper member contains a zone of favositid corals, but its age is not established. The entire Valmont is tentatively considered of Upper Ordovician age.

#### Fusselman formation:

The Fusselman formation of the Sacramento Mountain escarpment, the upper member of the Fusselman of Darton (1928), forms conspicuous cliffs in most of the area. It is composed of cherty dolomite, medium to finely crystalline, of color that ranges from light gray to olive and brown-gray, and which commonly weathers to a color darker than the fresh surface. Chert is abundant, but erratically distributed, and occurs as nodules and masses that are smaller and more irregular than in the Montoya or Valmont. Bedding is commonly obscure. The formation is generally about 70 feet thick. It does not exceed 100 feet in thickness within the area of the escarpment, and is absent, presumably by later Silurian or Devonian erosion, from the northernmost pre-Devonian outcrops.

Well preserved fossils are rare. A fauna of about 25 genera collected in this area has been studied by A.L. Bowsher, who considers that many forms are similar to those of the Lower Silurian Edgewood limestone of Missouri, and that diagnostic Niagaran or Middle Silurian forms are missing in the collections. The writer has not recognized in the thick Fusselman sequence in the



View to east along Alamo Canyon from Sec. 33, T. 16 S., R. 10 E. showing El Paso to Pennsylvanian strata in the foreground folded Pennsylvanian strata overlain unconformably by the Abo formation in the middle-ground, and the distant Yeso slope capped by several hundred feet of San Andres limestone. The line of the cross section from the Southern Production No. 1 Cloudcroft test to Alamogordo extends from A to A'. El Paso (Oe). Montoya (Om), Valmont or lower Fusselman (Ov), upper Fusselman '(Sf), Onate and Sly Gap (Dos), Caballero (Mc), Lake Valley (MI), Pennsylvanian (Pa). (Airphoto by David A. Dunn furnished through courtesy of the Roswell Geological Society).

Franklin or Hueco Mountains any stratigraphic break that he would interpret as a disconformity that could separate the zone of pentamerid brachiopods of presumed Middle Silurian age from the underlying strata that appear to correlate on the basis of lithology and stratigraphic position with the thin Fusselman section of the Sacramento Mountains. The present knowledge of the two faunas involved is probably inadequate to warrant further debate concerning whether or not a disconformity should be expected to separate the strata containing the two faunas. The zone containing the abundant pentamerid brachiopods in the Franklin and Hueco

Mountain area occurs at a somewhat higher stratigraphic horizon then the highest part of the Fusselman in the Sacramento Mountains.

The basal contact of the Fusselman with the Valmont in this area, and the equivalent contact in the Franklin Mountains is interpreted as a disconformity (Pray, 1953, pp. 1912-13), largely on the basis of the abrupt, persistent change in lithology, local basal zones of clastics (largely pebble conglomerates of dolomite and chert, quartz sandstone, and glauconite) and from widespread evidence of truncation of the underlying Valmont dolomite.

#### Devonian formations:

Three rock units of Devonian age are recognised along the Sacramento Mountain escarpment. These show a general though not precise, correspondence with rock units recognised by Stevenson (1945) in south-central New Mexico.

The Onate, the basal unit, occurs throughout the area. It consists nearly everywhere of medium dark gray or brown-gray rock that is composed of about equal amounts of very fine grained dolomite mixed granularly with coarse silt to very fine sand size quartz grains. Beds are somewhat massive and one to three feet thick. Shale is minor, but increases toward the south. The Onate is about 60 feet thick in the central part of the escarpment, and thins to both the north and south. It can be easily recognized in the Southern Production No. 1 Cloudcroft well, where it is about 25 feet thick. Fauna is considered upper Middle Devonian, and largely of bryozoans and brachiopods.

The Sly Gap consists of up to 50 feet of calcareous, yellow gray to dark gray shale, with irregular nodular limestone beds becoming predominant in the upper part of the section. Some layers of dark gray "black" nonfissile shale up to 6 feet thick occur in the upper portion. Fauna is abundant and considered to be lower Upper Devonian by Stevenson (1945) and Stainbrook (1935, 1948). It occurs in the Southern Production Co. No. 1 Cloudcroft well, but appears to be absent in the southern half of the escarpment. The lower contact may represent a disconformity in the escarpment area.

Dark gray "black" non-calcareous shale considered the equivalent of a part of the Percha shale (Stevenson's nomenclature) occurs in the southern part of the escarpment, thickens southward and is recognised farther southeast in the subsurface as part of the Woodford (Lloyd, 1949; Ellison, 1950). The only equivalent of this unit recognised in the northern part of the Mountains is in upper Marble Canyon, where 30-40 feet of similar shale occurs in a local channel filling cut into the Sly Gap formation.

#### Mississippian formations:

The rock units established for southern New Mexico by Laudon and Bowsher (1941, 1949) are very well exposed and developed in the Sacramento Mountain region. Mapping here has indicated the soundness of their detailed work, and has required only minor modification of their data regarding lithology. Thickness, and areal distribution of the units. Perhaps the major changes in the latter were the recognition of the Helms in the southern escarpment area, and of the persistence of the Ran-

cheris into the central and northern part of the escarp-

#### Caballero formation:

This distinctive lithologic unit consists largely of medium gray, markedly nodular limestone and interbedded calcareous shale. It occurs throughout the length of the escarpment. Thicknesses range from about 60 feet in the north to about 15 feet where exposed farthest to the south. The fauna is considered Kinderhookian in age and is abundant, though of rather small forms. The basal contact is a disconformity, marked by a zone about an inch thick with abundant small, irregularly shaped, black siliceous nodules, and occasional bone fragments or 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 with difficulty. The Caballero has been tentatively identified in the subsurface of eastern Lea County (Roswell Geol. Soc., 1953, p.

#### Lake Valley formation:

This formation has a maximum thickness of about 400 feet in the northern and central parts of the Sacramento Mountains, and thins to the east and southward along the escarpment, probably both by non-deposition, and by tilting and subsequent erosion following its deposition. It is absent from the easternmost exposures in the escarpment area, and is not known to occur farther to the south. The Lake Valley formation has been subdivided into six members by Laudon and Bowsher (1949). All six are typically developed in the Deadman Canyon area of Alamo Canyon where Laudon and Bowsher (1949) measured the section reproduced in this guidebook. The range in thicknesses of the members of the Lake Valley formation in the area is given on the composite section. The basal member of the Lake Valley formation is the Andrecito. It is relatively uniform in lithology and depositional thickness in the escarpment area, and is composed largely of argillaceous to silty, thin to medium bedded, medium gray limestone and interbedded calcareous shale. The most characteristic features are the abundance of the swirl-like branching patterns of the fossil, Taonurus; the relatively even bedding; and the non-resistant nature of the unit, which forms slopes in marked contrast to the prevailing cliff or scarp of the overlying Alamogordo member. The basal contact is a disconformity, locally showing low angular discordance.

Spectacular bioherms profoundly affect the thickness, distribution, and to a lesser degree, the lithology of the

uppermost five members of the Lake Valley formation. The biohermal structures are most abundant in the northemmost part of the area, between Indian Wells and Alamo Canyons. In this area many of the structures are elongate along north - south trends. The largest of all the biohermal structures occur along the central part of the escarpment, in the vicinity of San Andreas Canyon, where several are nearly 400 feet in thickness. These appear to be circular in plan, rather than elongate. The photographs show the major features of one of these large biohermal structures. One shows a cross-sectional view of one of the elongate structures of the Alamo Canyon area. The bioherms appear to have formed during the deposition of the lower part of the Lake Valley formation. Many are largely restricted to the Alamogordo member. The larger ones commonly rise from within the Alamogordo member. The genesis of these structures is not well understood, but several independent investigations currently are in progress. The biohermal cores appear to represent areas of profuse crinoidal growth, at least some of which clearly stood higher than the level of adjacent contemporaneous deposition, though perhaps not above wave base. A puzzling aspect of some of the more abrupt structures is the apparent absence of a sediment binding organism, such as colonial algae, that could build and maintain the steeply-sloping structures. The biohermal cores consist largely of light gray, essentially massive, very fine grained limestone that contains abundant partially recrystallized, crinoidal debris; some of it concentrated in streaks or irregular layers, and some as isolated fragments in the dense matrix.

The Alamogordo member, where not directly affected by the biohermal structures, is a medium light gray, somewhat cherty, calcilutite; commonly about 35 feet thick where not affected by subsequent erosion. The Nunn member is a soft crinoidal marl, which ranges widely in thickness and is locally not developed. Most of the specimen crinoids are collected from this member. The Tierra Blanca is a coarse, well cemented, crinoidal limestone that forms conspicuous light colored cliffs, in many places showing very irregular beds. Chert is common. The Tierra Blanca thins gradually away from the major areas of bioherms.

The uppermost two members of the Lake Valley formation, the Arcente and the overlying Dona Ana, appear to have been deposited in much of the escarpment area after the major period of biohermal growth. The conditions that led to the deposition of the thin bedded, medium gray, argillaceous limestone and dark calcareous shale of the Arcente probably were distinctly unfavorable for crinoidal growth, if emergence of the area had

not already stopped it. The basal Arcente contact appears disconformable in the southern part of the escarpment, but perhaps is gradational with the Tierra Blanca to the north. The Dona Ana member is gradational with the Arcente, and marks a return to clear seas and profuse development of crinoids. The Dona Ana is a cherty, coarse light gray, irregularly bedded crinoidal limestone, very similar to the Tierra Blanca. 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 range, where they may have initially been but thinly developed, and from which they were stripped by erosion prior to the deposition of the Rancheria formation.

#### Rancheria formation:

This formation consists largely of medium to dark gray, argillaceous and silty, locally siliceous, thin bedded limestone, with minor calcareous shale and some massive strata of medium - gray crinoidal limestone. The Rancheria is about 300 feet thick in the southern end of the escarpment, and thins progressively northward to Mule Canyon. A thin shoreward remnant may occur locally in Alamo Canyon. The formation is similar to the section of the Franklin and Hueco Mountains. It is possible that the lithologically similar Las Cruces formation that underlies the Rancheria formation in the Franklin Mountain area may be included with the Rancheria in the southern part of the Sacramento Mountains. The northernmost, onlapping part of the Rancheria along the escarpment has characteristics of shallower water than most of the formation, which has a basinal aspect. The sparse fauna is considered to be Meremecian in age by Laudon and Bowsher, but Weller and others consider the same fauna as uppermost Osagian. (See discussion in Jones, 1953). The basal contact is a clearly marked unconformity that progressively cuts out the underlying Lake Valley and Caballero formation from north to south. Locally angular discordances of 5-10 degress have been noted.

#### Helms formation:

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

Pennsylvanian:

The Pennsylvanian section of the Sacramento Mountain area stands in sharp contrast to the older Paleozoic section. It is as thick or thicker than the entire underlying Paleozoic section, it contains large amounts of terrigenous clastics, and lithologic changes both laterally as well as vertically in the section occur with rapidity that leads to despair if one attempts to subdivide the Pennsylvanian section on the basis of mappable 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 more localized basins and source areas 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 deposits found in the escarpment area of the Sacramento Mountains.

In general, the Sacramento Mountain escarpment appears to lie to the southeast of a positive area that furnished terrigenous clastics intermittently during Pennsylvanian time. The positive area was termed the Pedernal Landmass by Thompson (1942). Though of major importance in early Permian and latest Pennsylvanian time, its role is less clear earlier in the Pennsylvanian period. It seems probable that the outlines of this positive area, and its degree of activity, varied widely during Pennsylvanian time. Unfortunately, the details may never be learned. Much of the pertinent record was obliterated by erosion that occurred during the major uplift of this area at the end of Pennsylvanian and in early Permian time. Moreover, Permian strata now blanket much of the area, and the likely prospect of encountering pre-Cambrian strata directly beneath the Permian undoubtedly will discourage much drilling of pertinent

The Pennsylvanian section of the Sacramento Mountains has a maximum thickness of about 3000 feet, and the deposits appear to span a time range from possible Morrowan at the base throughout the remainder of Pennsylvanian time (Thompson, 1942). Most strata are of marine origin. Field evidence suggests that deposition continued with no major interruptions throughout this time, at least, no persistent erosional surfaces have been recognised within the Pennsylvanian section in the mapping of the escarpment area. Three formations and one member have been used in mapping to subdivide the Pennsylvanian section in this area. Along most of the western edge of the mountains the Pennsylvanian section is nearly complete, ranges commonly from 2000

to 2500 feet, and includes 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, and locally has removed all of the Pennsylvanian section.

The basal Pennsylvanian strata of the area were deposited on a surface that had at least 100 feet of local relief. The low parts of this surface, some of them abrupt channels, are commonly filled with coarse quartz sandstone or with cobble conglomerates of Mississippian cherts. Shales and dark limestones are commonly interbedded with the lower 200 to 500 feet of the Pennsylvanian section, but rarely occur in the lowest parts of the basal Pennsylvanian surface. The coarseness and amount of the terrigenous clastics in the lowest part of the Pennsylvanian section diminishes toward the south.

Overlying the lower 200-500 feet of the Pennsylvanian section are two contrasting contemporaneous facies. One of these, a shelf limestone facies, and regionally the more extensive, consists almost entirely of somewhat cherty calcilutites, up to about 1000 feet in thickness. These are conspicuous along the western escarpment south to Alamo Canyon, and also to the northeast in upper Fresnal Canyon. Separating these shelf limestones and grading into them with extreme abruptness, is a comparable thickness of quartz sandstones, subgraywackes, shales, and minor limestones. This sequence is considered a deltaic facies. The shelf limestone facies and the deltaic facies are both largely of Desmoinesian age, but extend into the Missourian.

As much as 500 feet of thin bedded, argillaceous limestone and shale of Missourian age overlies the shelf limestone and deltaic facies. In most of the area these are of somewhat basinal aspect, but locally sequence changes laterally into massive limestones, with interbedded limestone conglomerates, and other suggestions of cyclical deposition in a turbulent, shallow water environment. The uppermost Pennsylvanian deposits are those of Virgilian age. The base of these reflects another change in type of deposition as algal reefs, and reef-like masses up to 100 feet in thickness were formed throughout most of the area. The Virgilian strata grade upward into more uniformly bedded, light colored limestone, interbedded with shale and minor sandstone. Red shales, and limestone conglomerates are repeated somewhat cyclically with non-red shales, and massive to nodular limestones in the uppermost Pennsylvanian strata in the area. The deposits appear to indicate, in addition to repeated fluctuations of the

depth of deposition, a gradual transition toward emergence of the area. The final emergence was followed by erosion of previous deposits at the end of the period in most of the area.

#### Bursum and Abo formations:

In the escarpment area, the strata of Wolfcampian age are assigned to the Bursum and Abo formations. Rapid changes in facies and thickness occur in strata of this age, in response to the deformation that occurred in late Pennsylvanian and early Wolfcampian time, and some continued structural disturbances that lingered into later Permian time. For the purposes of this brief outline, the area of the escarpment can be divided into two unequal parts, a sector that extends to the north and west from a point along the Fresnal fault west of High Rolls (see geologic map), and a much larger area that lies east and south of this point.

in the northwestern sector, detailed investigations have recently been completed by C. Otte (Otte, 1954). These indicate that deposition in a basin that occurred in this sector north of the vicinity of La Luz Canyon was essentially continuous from Pennsylvanian through Wolfcampian time, and probably on into middle Permian time. In this basin, a gradual transition from marine to non-marine conditions occurred, accompanied by repeated fluctuations of the strand line in the area of present exposures. Lower Wolfcampian strata, correlated with the Bursum formation and dated on the basis of contained fusulinids, are about 400 feet thick a mile north of La Luz Canyon. These strata thin to the southeast toward the Fresnal fault, change into a non-marine section of red beds and limestone conglomerates in a few miles. Traced further, they appear to pinch out in the unconformity that represents much of lower Wolfcampian time on the deformed and positive area east and south of the Fresnal fault.

The Abo formation was deposited over the entire escarpment area, but varies considerably in the two areas mentioned above. In the basinal area east of Tularosa it is about 1,100 feet thick and composed principally of dark reddish brown mudstone and arkose. Here it grades into underlying latest early Wolfcampian marine strata (Otte, 1954). The Abo thins rapidly toward the positive block to the southeast, and is about 400 feet thick in the High Rolls area. It here is composed of basal quartzite cobble conglomerates, and an overlying much thicker sequence of dark reddish brown mudstones and arkose. Farther to the south along the escarpment, it is 200 to 550 feet thick, and splits into an uppermost and a basal series of red beds, and a middle sequence composed principally of thin bedded limestone, dolo-

mitic limestone, and non-red shales. This middle sequence thickens southward all the way to the Hueco Mountains, changes from brackish to marine facies, and forms most of the Wolfcampian portion of the Hueco limestone in the Hueco Mountains. The upper tongue of Abored beds (the entire Abo of Darton) can be traced nearly to the Texas border, and forms the Deer Mountains red shale of the Hueco limestone. The lower tongue of Abored beds probably correlates with the Pow-wow conglomerate of the Hueco limestone.

Throughout the area of the Sacramento Mountain escarpment, exclusive of the small northwestern sector, the Abo lies above an angular unconformity cut on folded and faulted pre-Permian strata. This angular unconformity is believed to be coextensive and contemporaneous in development with the angular unconformity at the base of the Hueco limestone over wide areas of the Diablo Platform to the south.

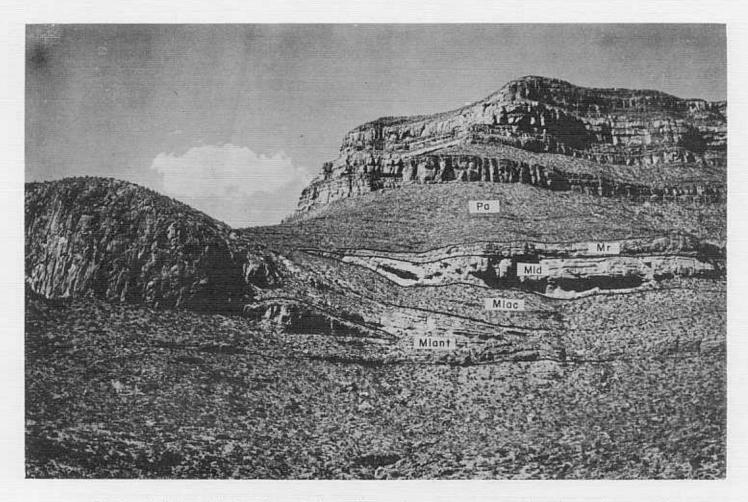
### Yeso formation:

This unit, considered Leonardian in age, but not dated in the escarpment area, is 1200 to 1800 feet thick. It consists of the usual widely varying lithologies so characteristic of the Yeso. These include carbonates, mostly limestone; red, yellow, and gray siltstones and shales; evaporites, largely anhydrite (gypsum at surface exposures) with some halite; and yellowish, silty, fine grained sandstones. Rapid lateral and vertical variation in lithology is normal to the Yeso. Carbonates become increasingly prevalent in the upper part of the section, and red beds and evaporites are most abundant in the lower part. Exposures of the Yeso are too poor in most of the escarpment area to make it feasible to subdivide the Yeso. The basal contact appears conformable with the Abo.

## San Andres limestone:

The San Andres limestone forms the resistant uppermost strata of the crest and of much of the eastern slope of the Sacramento Mountains. Although over 1000 feet thick to the east, less than half this thickness is preserved along most of the crestal portion of the mountains. Progressively thinner sections occur to the south. The San Andres is composed largely of thin to medium bedded limestone, of various shades of gray. Some strata are dolomitic. Fusulinids are not known in the San Andres limestone in the escarpment area, and the known fauna adds little to the problem of the age of the San Andres with respect to the type Permian sections.

In most of the crestal part of the range, quartz sandstones of the "Glorieta" type (clean, rounded, frosted,



South side of the Muleshoe Canyon bioherm showing the abrupt transition from the core facies to the much thinner, contemporaneous deposits of detrital limestone and marl of the Alamogordo, Nunn, and Tierra Blanca members (Mlant) of the Lake Valley formation. The Arcente (Mlac) and Dona Ana (Mld) members of the Lake Valley formation, the Rancheria formation (Mr), and the lowest of the Pennsylvanion (Pa) strata pinch out near the top of the core facies. (Photo by L. Pray).

fine-medium grained orthoguartzites) do not separate typical Yeso and San Andres lithologies, but instead occur within limestones of the San Andres type, commonly as much as 100 to 150 feet above the highest lithology characteristic of the Yeso formation. More than two layers of quartz sandstone are rarely found in any one 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 or 3 feet is more common. Despite the fact that exposures of these thin sandy zones are widely scattered, and that if exposures were better, it could probably be demonstrated that the highest quartz sandstone at different localities along the crest are not all at the same stratigraphic horizon, the top of these sandstones forms the best marker for structural mapping above the Abo-Yeso contact.

These thin quartz sandstones probably correlate with the Hondo sandstone named by Lang (1937) near Hondo, New Mexico, northeast of the escarpment area. It is possible that they 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.

# Mesozoic and Cenozoic strata:

Strata of Mesozoic age are known in the region on all sides of the uplifted Sacramento Mountain block, and once probably were continuous over the entire region. However, they have been eroded completely from almost all of the uplifted block. The only outcrops known to the writer occur along the Cloudcroft-Mescalero highway (N. Mex. 24), at a point where it crosses the local Sacramento Mountain divide, nine miles by road

north of Cloudcroft. The rocks here consist largely of olive, gray, and purplish shales, variegated quartz silt-stones, and some quartz sandstones, locally conglomeratic. They probably are correlative with a part of the Mesozoic section reported in the Sierra Blanca and Capitan region to the north (Allen and Jones, 1952).

Tertiary strata may well be present below the present surface of the Tularosa Basin, but in the absence of the Basin deposits, this will be difficult to determine.

#### **STRUCTURE**

The overall structure of the Sacramento Mountains is that of a large cuesta, with a regional dip to the east of about one 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 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 has affected the Permian strata in most of the escarpment area so that the local picture rarely reflects the regional gentle cuesta structure. The pre-Permian strata are more intensely deformed than the Permian, as a result of deformation by both folding and faulting during late Pennsylvanian and early Wolfcampian time. Additional complications of the broad sturctural picture occur along the margin of the escarpment, and presumably are related to the uplift of the mountain block.

Most of the structural features of the escarpment area have a northerly trend. An indication of the types of structural features and their magnitudes can be noted on the drawing, which shows two cross-sections from the Tularosa Basin to the crest of the range in the northern part of the escarpment area. These two sections are typical of the features found throughout the length of the escarpment.

Genetically, the structural features of the Sacramento Mountain escarpment can be divided into to major groups, those which are related to the late Cenozoic deformation that resulted in the uplift of the range, and those structural inheritances that pre-date the uplift of the range, and which have either been unaffected or but slightly modified since the inception of Basin Range deformation.

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 Tularosa Basin along a normal or gravity fault zone that is at or close to the present base of the escarpment. The uplift probably began in late Cenozoic time, and appears to still be in progress. The faulting hypothesis accords with that of most geologists familiar with the area, but is not shared by the writers of the two most extensive published accounts of the structure of the Sacramento Mountain, Darton (1928) considered the mountains are 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 for the origin of the range 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 range at the base of the escarpment. These scarps are up to 80 feet in height, all observed face the basin, and although largely in alluvial material, bed-rock 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 dislocation in recent time along the western edge of the escarpment.

A host of minor faults near the edge of the mountain block, that appear to be sympathetic structures along a major gravity fault zone, furnishes additional evidence for the presence of a major fault zone at the western edge of the block. It is striking to note the increase in number, and to a lesser degree, in the magnitude of displacement of faults, as one approaches the outermost portion of the mountain block. Most faults are west-dipping, gravity faults with a predominant dip-slip movement. In many places dips 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 base of the escarpment trends generally slightly west of north for much of its length, but is irregular and somewhat angular in detail. There is a notable lack of 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. It would appear that any detectable anticlinal structure in the area of the Sacramento Moun-

tain escarpment is exceedingly gentle, and shows no more indication of western dips than would be expected near the faulted edge of a tilted block the size of the Sacramento Mountains.

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 is meagre. It consists largely of scattered outcrops of Permian strata (Yeso-San Andres) 10 to 15 miles west of the base of the range, and several water wells drilled at Alamogordo and Valmont to depths of about 1200 and 1800 feet, respectively. These are reported to have bottomed in alluvial material. It would seem likely that the alluvial fill is a 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 hypothetical boundary fault are highly speculative on the basis of the present data. On the assumption of 2000 feet of alluvium west of the boundary structure, and on 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 7000 feet. This figure is probably a minimum, rather than a maximum.

In the southeastern part of the escarpment area, a major northwest trending fault, and associated sharp flexure in the Permian strata, as well as several small faults of similar trend, may have been formed contemporaneously with the major uplift of the range.

Features that pre-date the late uplift of the range

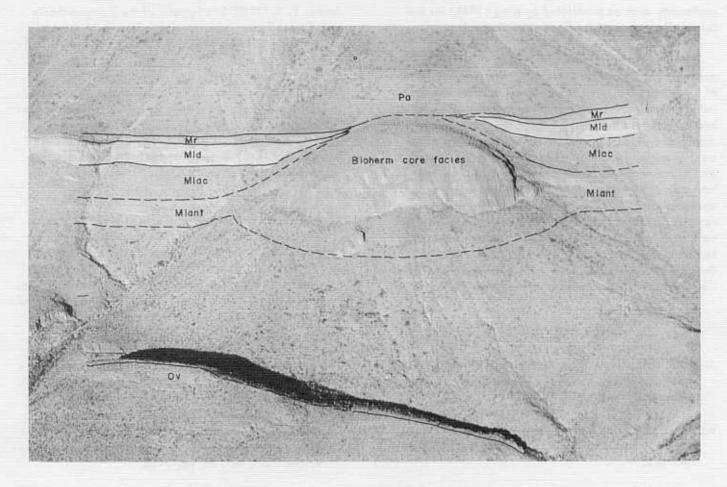
Most of the structural features of the Sacramento Mountain block appear to have been formed prior to the late uplift of the block. These earlier structural features of the mountain block were largely formed during Paleozoic time, although some deformation occurred during the mesozoic or early Cenozoic.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

The pre-Cambrian 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 only indicate that a slightly metamorphosed sedimentary terrane, injected with diabasic intrusives, was slightly tilted prior to erosion and the subsequent deposition of the basal Paleozoic clastics.

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 late Cambrian 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 time somewhat increasing structural disturbances is recorded. Disconformities occur at the base of the Percha (?), the Caballero, and the Lake Valley formations; possibly at the base of the Arcente member of the Lake Valley formation, and a low angular discordance at the base of the Las Cruces (?) and Rancheria formations can be detected 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 increasing unrest culminated in the major deformation during latest Pennsylvanian and early Wolfcampian time when many of the internal structural features of the Sacramento Mountain escarpment were formed.

Structural features such as the Caballero anticline, the Dry Canyon syncline, the Alamo Peak, Fresnal, and Arcente Canyon faults (see geologic map) were largely formed during the late Pennsylvanian - early Permian deformation. Most of these and other contemporaneous structure trend roughly north - south. The folds are open to moderately tight, with undulatory axial arests and troughs. Domes are conspicuous features stong some of the anticlinal crests. Faults are high angle and dip slip displacements range up to a third of a mile. The basal Abo unconformity truncates parts of all of these structures, with local angular discordance as high as 60°. As Virgilian strata occur below the basal Abo unconformity in parts of the area, the age of the deformation and subsequent erosion is largely late Pennsylvanian and early Wolfcampian. This deformation in the Sacramento Mountain area is considered to be a part of that long known in the area to the south and southeast that preceded the deposition of the Hueco formation



The Muleshoe Canyon bioherm (Sec. 28, T. 17 S., R. 10 E.), the largest single Mississippian bioherm exposed in the Sacramento Mountains, as viewed from the southewst. The resistant core facies is about 1000' in diameter and over 300' thick. Crinoid columnals are the most abundant fossils preserved in the core facies. Strata designated are the Valmont or lower Fusselman (Ov), upper Fusselman (Sf), the Alamogordo, Nunn, and Tierra Blanca members of the Lake Valley (Mlant), Arcente (Mla)e and Dona Ana (Mld) members of the Lake Valley, Rancheria (Mr), and Pennsylvanian (Pa). (Airphoto by David A. Dunn furnished through courtesy of the Roswell Geological Society.

above an angular unconformity cut onto strata from pre-Cambrian to 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 intervening between La Luz Canyon and the Fresnal fault permits closely dating the deformation as extending from late Pennsylvanian to late early Wolfcampian.

Evidence in the central Sacramento Mountains indicates that gentle folding along the lines of the earlier structures, continued throughout the time of deposition of the Abo. As the Abo-Yeso contact is folded along the same structural axes, some deformation probably continued into late Permian, although in the absence of strata younger than middle Permian, it is not possible to distinguish between later Permian or more recent folding.

Two large domes with several hundred feet of closure at the top of the Hondo sandstone occur along the crest of the range. One of these, the Penasco dome, was unitized and drilled by the Southern Production Co. in 1952-53. The time of formation of these structures is not known. They are post-middle Permian, and some evidence suggests they formed prior to the formation of a widespread surface of erosion that now forms much of the crest of the range. The age of this surface is uncertain. It seems probable that it formed in Cenozoic time prior to the late uplift of the mountain block, but the surface might represent an exhumed pre-Cenozoic un-

conformity such as postulated by King (1948) for the Summit Peneplain of the Guadalupe Mountains.

That some activity occurred prior to mid-Tertiary is suggested by the relationship of the igneous intrusives of the area to the small thrust faults that are a minor, but conspicuous feature along the central part of the escarpment near the front of the range. Many faults with displacements of a few hundred feet, which dip to the west at angles of 15-30°, have been noted in the older part of the section. These appear to be earlier than the intrusion of dikes and sills, commonly of hornblende andesite porphyry, into the sedimentary section. The igneous activity would appear to be related to that better known in the Sierra Blanca and Capitan regions (Allen and Jones, 1952) directly to the northeast of the Sacramento Mountains. They date igneous activity similar to that in the Sacramento area as mid-Tertiary.

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# THE OCCURRENCE AND DISTRIBUTION OF POTASSIUM MINERALS IN SOUTHEASTERN NEW MEXICO

by C. L. Jones <sup>2</sup>

The closing epoch in Permian time is especially known for the extensive evaporite deposits that fill the Delaware Basin and extend across the Capitan reef zone for considerable distances over the shelf area. This epoch is represented by the strata of the Ochoa series, which includes the following formations:

Dewey Lake redbeds Rustler formation Salado formation Castile formation

Extensive deposits of halite and anhydrite occur in each of the formations except the Dewey Lake, which does not contain evaporite deposits and which is composed entirely of red sandstone, siltstone, and minor amounts of shale. The Dewey Lake red beds form the protective cover that serves to retard the dissolution and removal of the soluble salts comprising the evaporite deposits

- 1 Publication authorized by the Director, U.S. Geological Survey.
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Note: Three abstracts containing material pertinent to the escarpment of the Sacramento Mountains have been accepted by the Geol. Soc. America in connection with the 1954 annual meetings in November. These will be printed in the December issue of the Bull. Geol. Soc. America, and are as follows: Otte, Carel Jr., Lower Wolfcampian deposition in the northermost Sacramento Mountains; Pray, L. C. & Graves, R. M. Jr., Desmoinesian facies of the Sacramento Mountains; and Pray, L.C. & Otte, Carel, Jr., Age and Correlation of the Abo formation in south-central New Mexico.

of earlier formations of the Ochoa series.

Extensive evaporite deposits are found in older Permian formations; but unlike the evaporite deposits of the Ochoa series, the older deposits are restricted entirely to the back-reef or shelf area. The evaporite deposits of the Ochoa series are more extensive and are better known because of their economically important deposits of potassium minerals. As the potash deposits represent a special phase of the evaporite deposits, a brief description of the saline rocks should be presented before discussing the occurrence and distribution of the potassium minerals.

The Ochoa series is conformably underlain by strata belonging to the Guadalupe series and unconformably overlain by strata belonging to the Upper Triassic Dockum group. Outcrops of the Ochoa series are not representative of the thick sequence found in the subsurface. The Dewey Lake red beds appear to be entirely confined to the subsurface; and the outcrops of the Rustler, Salado, and Castile formations contain only the insoluble or more slowly soluble constituents. Wherever these formations have been exposed to weathering conditions during either pre-Dockum time or post-Triassic time, all the halite and a part of the anhydrite have been dissolved and removed by ground water and surface streams; the anhydrite remnants have been completely altered to gypsum. Thus the outcrops contain only the more in-