BULLETIN 50

Late Pennsylvanian and Early Permian Stratigraphy of the Northern Sacramento Mountains, Otero County, New Mexico

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1959

STATE BUREAU OF MINES AND MINERAL RESOURCES
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY
CAMPUS STATION SOCORRO, NEW MEXICO

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Abstract

Late Pennsylvanian and early Permian strata in the northernmost Sacramento Mountains, New Mexico, were studied to interpret their complex deposition in the south-central New Mexico area, and to clarify the sedimentary and tectonic history. A critical area of about 80 square miles was mapped on a scale of 4 inches equals 1 mile, including 30 square miles covered in detail.

The map area covers the northern part of the Sacramento Mountains escarpment, which is a block that was uplifted in late Cenozoic time along a fault on the west and tilted to the east. Prior to this basin-and-range faulting, the rocks were gently folded in early Tertiary time and were intruded by Tertiary(?) sills and dikes of acid and intermediate composition. Minor high-angle faults, largely associated with the boundary fault zone, occur in the area and locally complicate the structure. Late Pennsylvanian and early Permian folding and high-angle faulting occurred in the southeasternmost part of the map area. Quaternary stream deposits cover about one-fifth of the area, which otherwise is unusually well exposed.

Deposition was essentially continuous from late Pennsylvanian (Virgilian) into early Permian (Wolfcampian) time within the area. This contrasts with the major angular unconformity that separates Pennsylvanian and Permian strata 4 miles to the southeast. The sediments that are the time-equivalent of part of the hiatus represented by the unconformity are named the Laborcita formation. The lithologic character and faunas of the Laborcita formation indicate that abrupt lateral transition toward the east and southeast from open marine to flood plain environments occurred repeatedly within a few miles. The transition in environments was deduced by lateral tracing of strata. A typical lateral succession of contemporaneous deposits is: massive marine limestone; nodular argillaceous fusulinid-bearing limestone; silty limestone, bearing abundant shallow marine forms such as molluscs and brachiopods; dolomitic limestone; green shale; and red shale and other terrigenous clastic rocks. The lithology and faunal content of any bed appear to be related to distance from the shore line and the depth of deposition.

Cyclic repetition is locally conspicuous and has been related to tectonic instability of this area and to episodic deformation to the southeast. From late Pennsylvanian to early Permian time, the deposits indicate a gradual emergence of the area and a transition from marine to nonmarine environments, although many fluctuations are recorded and periods of relative stability occurred.

The Laborcita formation overlies Upper Pennsylvanian marine strata and underlies the Abo red beds. At the type locality, near the mouth of Laborcita Canyon, about 21 miles northeast of the town of

La Luz, the Laborcita formation is composed predominantly of marine limestones and is 480 feet thick. About 31/2 miles to the southeast, a section of similar thickness is about 80 percent nonmarine red mudstones. Within 2 more miles to the southeast, the Laborcita formation wedges out into an unconformity. About 7 miles northwest of the type locality, near Tularosa, the Laborcita formation thickens to an estimated 1,000 feet. This marked increase in thickness was caused in part by a gradual regression of the Laborcita sea toward the northwest and by a successive transgression of time lines by the upper boundary of the Laborcita formation.

Fusulinids occurring throughout the Laborcita formation determine the age as very late Virgilian and early Wolfcampian. Fusulinid zones accurately located the Pennsylvanian-Permian boundary about 90 feet above the base of the formation. Preliminary studies of the megafossils by specialists indicate some disagreement with the Permian age of most of the Laborcita formation. The brachiopods indicate an early Permian age, but the ammonoids (from the clay pits east of Tularosa) occurring about 150 feet above fusulinids of distinctly Wolfcampian age, are classified as early late Pennsylvanian. The gastropods also exhibit affinities with Pennsylvanian forms.

The nonmarine strata overlying the Laborcita formation consist largely of red mudstone, fine-grained sandstone, coarse-grained arkose, and minor conglomerate of the Abo formation. In the Tularosa area, near the northern extremity of the Sacramento Mountains, the Abo formation intertongues at the base with the upper Lower Wolfcampian marine strata of the Laborcita formation and is about 1,400 feet thick. Twelve miles to the southeast, in the north-central part of the Sacramento Mountains, the Abo ranges from 250 to 500 feet in thickness and overlies with angular unconformity rocks ranging in age from early Mississippian to late Pennsylvanian. The source of the Abo clastic rocks is considered to be the Pedernal Landmass, a positive area of Precambrian rocks that existed during early Permian time (as well as parts of Pennsylvanian time) in northeastern Otero County, and which probably extended for at least 100 miles to the north.

Pray's work (1952, 1954) in the central and southern parts of the Sacramento Mountains indicates that the Abo formation is correlative with the bulk of the Hueco formation; therefore, he considers the top of the Abo formation to be either latest Wolfcampian or earliest Leonardian in age. As the Abo formation interfingers downward at the base with uppermost Lower Wolfcampian marine strata in the map area, it is considered to be largely of middle and late Wolfcampian age.

The Laborcita and Abo formations in the northern Sacramento Mountains indicate that deposition was essentially continuous from late Virgilian through Wolfcampian time, with a gradual emergence of the area and retreat of the marine waters to the west and northwest.

The Abo formation grades upward into the predominantly marine Yeso formation, which reaches a thickness of about 1,300 feet. The Yeso consists mostly of limestone, shale, gypsum, and sandstone and was not studied in detail. The overlying San Andres formation is the youngest Paleozoic formation of the Sacramento Mountains and forms the crest of the range.

A zone of lower Permian algal bioherms was discovered northeast of Tularosa in the uppermost Laborcita formation. Detailed studies indicated that algae probably formed the main sediment-binding organism in these moundlike features, which average about 35 feet high but locally stood about 60 feet above the level of contemporaneous sediments.

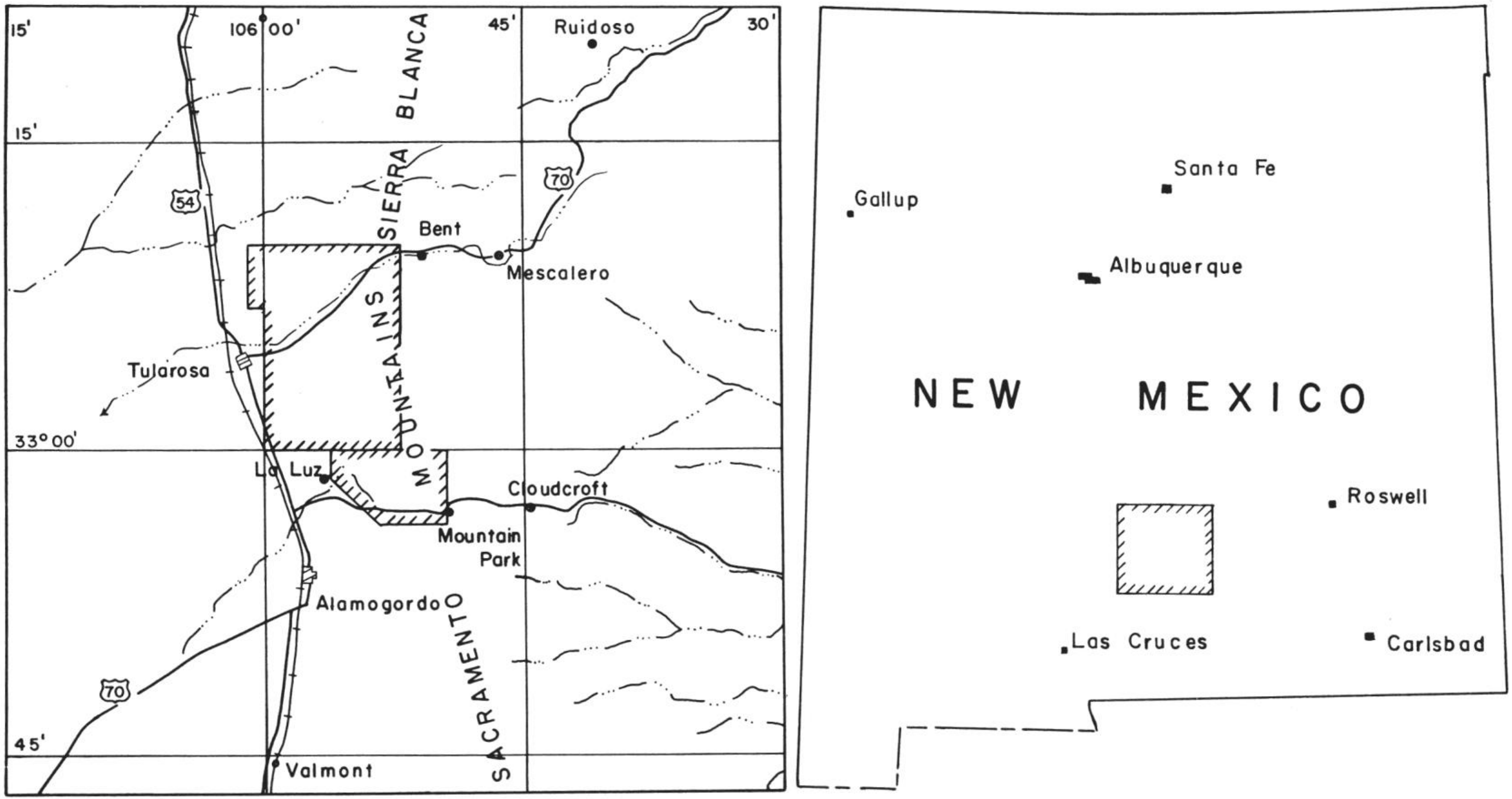


Figure 1
INDEX MAP OF A PART OF SOUTH-CENTRAL NEW MEXICO

Introduction

PURPOSE OF INVESTIGATION

In southern and central New Mexico, the Pennsylvanian system is composed largely of marine limestones usually called the Magdalena formation or group. The lower part of the Permian system consists either of nonmarine red mudstones and arkoses of the Abo formation or of marine limestones and interbedded red beds of the Bursum formation. Most early geologists placed the base of the Permian at the change from marine to nonmarine beds. Where the contact is an easily recognizable disconformity or an angular unconformity, as in most of the Sacramento Mountains and farther to the south, the Pennsylvanian-Permian boundary is not in doubt. Where deposition, however, was essentially continuous and the change from marine to nonmarine conditions was gradual, problems exist as to system and formation boundaries and nomenclature.

In the northern part of the Sacramento Mountains, east of Tularosa (fig. 1), dark-gray shale yielded an ammonoid fauna considered to be upper Pennsylvanian in age (Bose, 1920, and Miller, 1932). The shale is associated with a sequence of red beds, and Bose (1920) considered the entire sequence a part of the Abo formation. In La Luz Canyon about 8 miles southeast of Tularosa, the uppermost strata of a thick marine section at about the same stratigraphic position as the ammonoid-bearing beds, contain a Lower Permian (Wolfcampian) fusulinid fauna (Thompson, 1942, p. 82). On the basis of their lithologic characteristics, the fusulinid-bearing beds have been considered a part of the Magdalena formation by Darton (1928). These contradictory relationships have been interpreted in several ways:

1. The marine upper Pennsylvanian and lower Permian beds of the Magdalena formation in La Luz Canyon grade laterally toward the northwest (near Tularosa) into red beds, which mistakenly have been correlated with the Abo formation (fig. 2A).
2. The lower Permian beds near La Luz and the upper Pennsylvanian beds east of Tularosa are unconformably overlain by the Abo formation, an extension of the unconformity recognized in most of the Sacramento Mountains (fig. 2B).
3. Either the ammonoids or the fusulinids have been wrongly identified as late Pennsylvanian and early Permian forms respectively, or the paleontologic time scales of the ammonoids and fusulinids do not coincide.
4. Various combinations of any of these relationships.

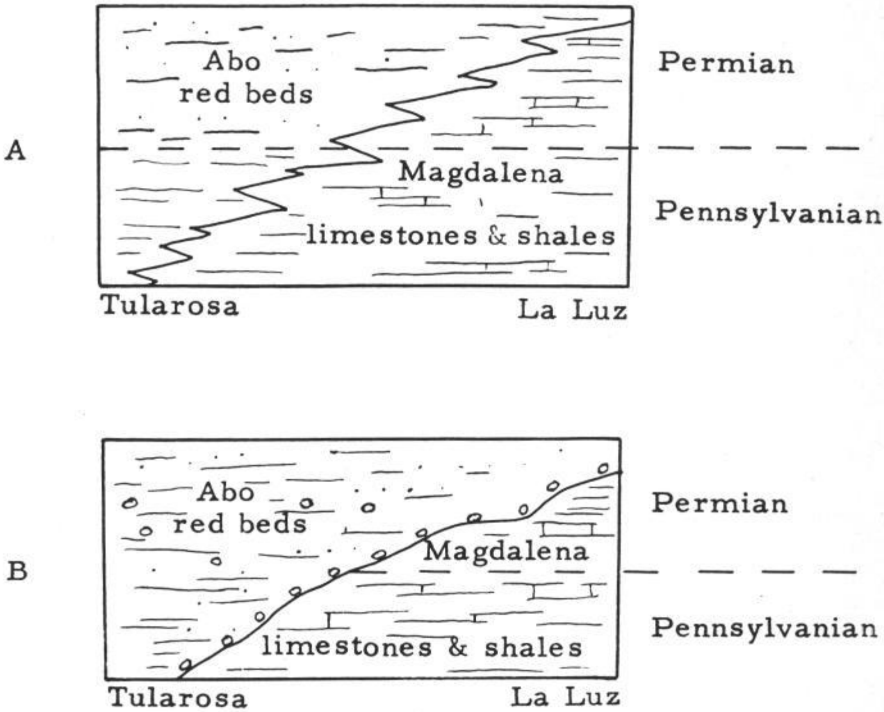


Figure 2

INTERPRETATION OF POSSIBLE STRATIGRAPHIC AND STRUCTURAL RELATIONSHIPS IN THE NORTHERN SACRAMENTO MOUNTAINS

Based on information published before 1952.

At the suggestion of Dr. Lloyd C. Pray, California Institute of Technology, the writer in 1951-52 undertook a detailed field study of the upper Pennsylvanian and lower Permian strata of the northern Sacramento Mountains. The objective was to determine the stratigraphic relationships between the La Luz Canyon and the Tularosa fossil horizons and to determine the position of the Pennsylvanian-Permian boundary. Moreover, Pray's work (1952) to the southeast indicated that detailed field study in this area of good exposures promised results of general stratigraphic significance, such as:

1. Description of one of the most complete sections of upper Pennsylvanian and lowermost Permian strata known in North America.

2. Abrupt lateral facies changes from rocks deposited in open marine environments to those of terrestrial flood-plain environments can be studied in a distance of a few miles.

3. Those sedimentary processes can be related to the structural development of adjacent areas.

4. The paleontologic significance of ammonoids, brachiopods, gastropods, and fusulinids can be compared to their biostratigraphic value, once the relative stratigraphic position of collecting localities is determined by field work.

The study of the fossils was turned over to specialists of each of the four major fossil groups. The results may have importance in solving similar stratigraphic problems in other areas, such as west Texas, where the lateral continuity of strata is more difficult to determine.

NATURE AND SCOPE OF INVESTIGATION

Parts of two 15-minute quadrangles, the southwestern part of Tularosa quadrangle and the north-central part of Alamogordo quadrangle (see fig. 1), were mapped by the writer in about 5 months during the summers of 1951 and 1952. The area includes about 80 square miles and was mapped on a scale of 4 inches equals 1 mile (1:15,625). Almost 30 square miles was mapped in detail during about 16 weeks, including all outcrops of the uppermost Pennsylvanian and lower Permian marine strata extending along the mountain front for about 12 miles. About half the area mapped in detail extends south of 33° N. lat. and was previously mapped at 1:31,250 scale by L. C. Pray in 1947; the geology of the formations underlying the uppermost Pennsylvanian strata on Plate 2 is largely from Pray's map.

The area of about 50 square miles north of 33° N. lat. (1 to 6 miles east of the mountain front) was mapped in lesser detail in about 4 weeks. Reconnaissance mapping of this area was justified in view of the main objective of the investigation. The lower Permian red beds in this area are uniform and are covered extensively by Quaternary stream deposits.

Aerial photographs of the area were taken in 1936 and 1941 for the Soil Conservation Service of the U. S. Department of Agriculture. These photographs were enlarged to a scale of 4 inches to 1 mile and served as base for the geologic mapping. The base for the geologic map of the area north of 33° N. lat. was the 1942 Soil Conservation Service planimetric map (scale 1:31,250). Vertical control was established by an inclinometer and handlevel, using as primary control points with known elevations south of 33° N. lat. The altitude of several control points in the northern part of the area was determined by aneroid. These controls were used to draw 100-foot contours. For the area south of 33° N. lat., the 1:31,250 Lincoln National Forest topographic sheet, with 100-foot contours, was enlarged to 4 inches to the mile. The narrow strip along the eastern edge of the southwest quarter of Tularosa quadrangle was also derived from the Lincoln National Forest map.

The abrupt lateral variations in facies and the cyclic sedimentation of certain sequences of beds made mapping difficult. Beds were mapped by lateral tracing. Where this was not possible, correlations were based on stratigraphic position. On the maps (pl. 1 and 2), the lower contacts of the most persistent or easily recognizable strata are indicated by green lines and numbered according to their relative stratigraphic position. Symbols show the lithology of the marker beds.

Ten days were devoted to a detailed planetable survey, on a scale of 50 feet to 1 inch, and field study of some algal bioherms that are exposed near the frontal escarpment northeast of Tularosa (Otte, 1954). These will be described in detail in a separate publication.

Laboratory investigations included petrographic and faunal studies of specimens from algal bioherms, petrographic studies of rock types, and preliminary studies of the thinsections from fusulinids. The original report was accepted as a Ph.D. thesis by the California Institute of Technology in 1954, and was revised for this publication.

LOCATION AND PHYSICAL FEATURES

The Sacramento Mountains are in south-central New Mexico. They trend slightly west of north for about 30 miles and rise abruptly 3,000 to 5,000 feet above, and to the east of, the Tularosa Basin. To the south, they decline into a low plateau, Otero Mesa, which extends to the Texas line. To the north, the range merges with Sierra Blanca (fig. 1), which is dominated by Sierra Blanca Peak at an altitude of 12,003 feet, the highest point in southern New Mexico. Tularosa Canyon forms the most natural geographic boundary between Sierra Blanca and the Sacramento Mountains. On the geologic map of New Mexico, the term "Sacramento Mountains" includes Sierra Blanca. The most recent maps, however, use the term in the more restricted sense, which is adopted in this report.

The Sacramento Mountains are an asymmetrical range with a bold west-facing escarpment and a gentle east slope extending 80 miles from the crest to the Pecos River. The crest of the Sacramento Mountains is about 9,700 feet above sea level in the center of the mountains, but declines toward the south and north and near Tularosa Canyon drops to an altitude of 8,200 feet. Because of the general northward plunge of the mountain mass, successively younger sedimentary formations form the low but abrupt frontal escarpment (pl. 3) toward the north.

The Tularosa Basin is bounded by the steep escarpments of the Sacramento Mountains and Sierra Blanca in the east and the San Andres Mountains in the west. This prominent valley is 30 to 40 miles wide and extends northward from the Texas line for more than 100 miles. The Tularosa Basin is an area of interior drainage, with its lowest point about 35 miles southwest of Tularosa, at an altitude of 3,900 feet above sea level. The surface of the basin adjacent to the mountain front ranges from 4,600 to 4,800 feet altitude in the map area.

The area investigated for this report lies in the northern part of the Sacramento Mountains (fig. 1).[1] New Mexico Highway 83, 4 miles north of Alamogordo, forms the approximate southern boundary. The area extends northward from this highway for 17 miles to 33° 10' N. lat., a line 5 miles north of Tularosa.

Alamogordo and Tularosa, located in the Tularosa Basin near the base of the Sacramento Mountains escarpment, are along U. S. Highways 54 and 70 and the main line of the Southern Pacific Railroad. U. S. Highway 70 crosses the northern part of the map area east of Tularosa. The part of the area within Alamogordo quadrangle is easily accessible by secondary roads in La Luz and Fresnal Canyons (pl. 3). Many dirt roads, particularly in Tularosa quadrangle, make the area north of 33° N. lat. fairly accessible during dry weather, so that a car can be driven to within 2 miles of any desired locality. The area is sparsely settled, except for the nearby towns of La Luz (population about 200) and Tularosa (population about 2,000).

The west side of the Sacramento Mountains is characterized in most areas by an upper and lower escarpment separated by a relatively flat bench. This two-step profile is particularly noticeable in the central and southern portions of the range (Pray, 1952, p. 9), and is less conspicuous but also recognizable in the northern part of the Sacramento Mountains. East of La Luz, the height of the lower escarpment ranges from 600 to 1,000 feet above the base of the range, as compared to 3,000 feet farther south. This bench is progressively lower to the north and 5 miles north of Tularosa reaches the level of the Tularosa Basin. Within the map area, this lower frontal scarp is dissected by many east-west canyons, of which the most prominent are from south to north: La Luz Canyon, Cottonwood Canyon, Laborcita Canyon, Domingo Canyon, and Tularosa Canyon (pl. 3).

From the frontal scarp, the surface of the bench rises gently to the east for a distance of 3 to 5 miles, beyond which it steepens sharply. The gently rising part of this ascending surface is underlain by the nonresistant mudstone and arkose of the Abo formation. The abrupt change in slope coincides approximately with the contact between the Abo and Yeso formations. Near the frontal escarpment, the rocks are well exposed, whereas the rocks underlying the gently rising surface are poorly exposed because of their nonresistant nature and the extensive cover of Quaternary deposits.

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

1. The area bounded by Tularosa Canyon and 33°10' N. lat. is **(pl.** 3) actually the southwesternmost part of Sierra Blanca, but for convenience is considered a part of the northernmost Sacramento Mountains.

climate, with summer precipitation and dry winters. The precipitation of about 10 inches is brought by thundershowers during the months of July and August. The vegetation is dominated by the common desert types of the Southwest, such as ocotillo, mescal, cholla, prickly pear, and mesquite. A few junipers and pifions grow in the slightly higher eastern part of the area. The area is used for grazing stock only in the colder winter months, as the extremely high temperatures in the summer offset the increase in moisture. The town of Tularosa is largely an agricultural community as a result of the extensive irrigation system set up at the mouth of Tularosa Canyon.

PREVIOUS WORK

No earlier systematic attempt was made to work out the upper Pennsylvanian-lower Permian relationships in the northern Sacramento Mountains. Previous work consisted mainly of paleontologic studies on faunas from isolated localities. The following chronologic review of the pertinent earlier works will show the status of geologic knowledge of the map area at the time this study was undertaken.

Bose (1920, p. 51-60) described several ammonoids collected by Baker and Drake 11/4 miles east of Tularosa from shales in the lower part of the Abo formation. According to Bose:

> There is not a single form related to Permian species, but everything indicates that the beds belong to the Pennsylvanian and especially to the upper part of this system.

Baker (1920, p. 109) noted that the ammonoid-bearing shales east of Tularosa occur 200 feet above the base of the Abo formation. In the same account, Baker (1920, p. 110) referred to the unusually thick Abo section north of Tularosa:

> The exposed Abo strata in the Coyote Basin, west flank of Sacramento Mountains at their north end five miles north of Tularosa, have a thickness of about 1400 feet, the base not being exposed there. This section is characterized by the presence of heavy arkose, interbedded with sandstones, clayey and shalt' sands and fossiliferous limestones.

Darton (1926, p. 834) was the first to question the stratigraphic position of the ammonoid-bearing strata near Tularosa. In a footnote he stated:

> The fossils reported by Bose east of Tularosa may have been obtained from this member [top member of the Magdalena group]. Although new species, they were thought to be Pennsylvanian, but G. H. Girty informs me that even if they were obtained from Abo beds they are not diagnostic as to present age.

Penn made a paleontologic study of faunas collected from several localities in the northern Sacramento Mountains. A few measured stratigraphic sections were included, but no detailed field investigations were made. In his unpublished report, Penn (1932, p. 33) concluded:

> that the contact between the Magdalena group and Abo formation was an erosional surface with as much as 50 feet of relief.

Penn (p. 1) also discussed a fauna collected by Beede and himself near Tularosa in a "red sandy series which is included in the Abo formation." The fauna, principally of molluscs and brachiopods, is supposed to be typically upper Pennsylvanian in age. However, Penn (p. 66) apparently included zones equivalent to the Wolfcampian in the Pennsylvanian system:

> The fauna . . . indicates that the fossiliferous part of the Abo correlates with the McKissick Grove shale of middle Wabaunsee formation of Kansas and Nebraska; with the middle part of the Wolfcamp formation of the Glass Mountains, Texas; with the Harpersville of middle Cisco group; and possibly with part of the underlying Thrifty formation of the same group of northcentral Texas; and with the lowermost Uralian of Ural Mountains, Russia.

The entire Wolfcamp formation and the top part of the Harpersville are now considered lower Permian (Cheney, 1940, p. 94).

Miller (1932, p. 59-93) restudied the fauna collected by Bose east of Tularosa and confirmed the upper Pennsylvanian aspect of the ammonoids. He regarded the sandstone and shale at Tularosa as the time equivalent of the upper part of the lower Cisco series. The Cisco series corresponds to the Virgilian of other areas (Moore et al., 1944, chart 6). Miller (p. 61) would place the beds near Tularosa in a different formation, or at least in a different zone of the Abo formation.

Moore (1940, p. 309) stated that P. B. King agreed with Miller's conclusion that the ammonoid-bearing beds near Tularosa do not belong to the Abo formation. King (1942, p. 676) wrote that the ammonoid collection from east of Tularosa probably came from the upper part of the Magdalena group, as Darton had suspected. The contact relationships between the Magdalena and Abo formations in the Sacramento Mountains were described by King and Read (King, 1942, p. 675) as follows:

> In the Sacramento, San Andres, and other mountains of southern New Mexico the usual limestones and other marine sediments of the Magdalena pass upward into several hundred feet of interbedded limestones, red and gray shales, sandstones, and arkosic conglomerates. The limestones contain fusulinids and other invertebrates, and the shales contain plants. Above these beds is the red, non-marine Abo sandstone.
>
> This unit forms the upper part of the Magdalena group as at present defined and mapped, and no doubt will be classed as a separate formation when further work is done. It appears to mark a transition from the marine conditions of Magdalena time to the non-marine conditions of Abo time. In most places, the sequence from Magdalena to Abo appears to be unbroken, although local unconformities may occur here and there. In a

> few places there is a pronounced unconformity, as at Caballero Canyon in the Sacramento Mountains [approximately 9 miles south of junction of La Luz and Fresnal Canyons], where the Abo lies on the upturned beds of the main part of the Magdalena, with the upper beds missing.

Contrary to the view held by King and Read, Thompson and Needham (1942, p. 907) stated that in many areas of New Mexico two unconformities of large magnitude are present between the Pennsylvanian Magdalena formation and Permian Abo formation. The lower unconformity marks the contact between fusulinid-bearing Pennsylvanian strata and fusulinid-bearing lower Permian strata. The other is higher and occurs above the fusulinid-bearing lower Permian strata and the base of the nonmarine Abo formation. This is the first statement that the basal Abo beds might be younger than the base of the Permian system.

Thompson (1942, p. 82) discussed the northern Sacramento Mountains, where he recognized lower Permian fusulinid-bearing strata:

> In Fiesnal Canyon in the north end of the Sacramento Mountains, upper Virgil strata of the Fresnal group are overlain unconformably by 250 feet of strata of undetermined age. These strata are composed largely of clastic red shale, grey shale, sandstones, and conglomerates. Although some of these rocks carry marine faunas, diagnostic fossils have not been determined. Permian fusulinids referable to the genera *Triticites* and *Schwagerina* are extremely abundant in immediately overlying strata that appear to be conformable. These fusulinids are closely similar to, and presumably are closely related in age to, fusulinids in the Foraker limestone of Kansas, the Saddle Creek limestone of Texas, and the unnamed limestone immediately over the Bruton formation of central New Mexico.

With respect to the fossil-bearing beds near Tularosa, Thompson (1942, p. 83) stated in the same account:

> The cephalopod-bearing shales in the clay pit east of Tularosa lithologically resemble more closely the strata above the Fresnal group in Fresnal Canyon than they resemble any part of the type section of the Fresnal group. However, the Pennsylvanian section is apparently changing rapidly northward toward Tularosa to non-marine and brackish-water types of rocks. It is possible that the shale of the Tularosa clay pit may be equivalent in age to a portion of the type section of the Fresnal group. The correlation between the shales in the Tularosa clay pit and the stratigraphic section exposed in Fresnal Canyon is at present a moot question.

Lower Permian fusulinids from limestones overlying strata of Pennsylvanian age, similar to the Permian fusulinids in Fresnal Canyon in the northern Sacramento Mountains, were also recognized at various other localities of central New Mexico. These strata were named the Bursum formation (Wilpolt et al., 1946). This name was adopted by E. R. Lloyd (1949) and L. C. Pray (1952) for the lower Permian marine beds and underlying 250 feet of strata of undetermined age in the northern part of the Sacramento Mountains.

In 1947, Pray started a detailed field and stratigraphic study of the Sacramento Mountains area, which included the lower Permian beds in Fresnal Canyon. In 1949, Pray was quoted by Lloyd (1949, p. 32-33) in describing the Bursum formation of the Sacramento Mountains:

> It is overlain with angular unconformity by a coarse quartzite conglomerate at the base of the Abo formation. The formation thickens to about 350 feet a mile north of Fresnal Canyon, but thins and disappears within a few miles to the south, and is not found farther south in the Sacramento Mountains where it is cut out by the unconformity at the base of the Abo.

Later Pray (1952, p. 228) stated:

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

Pray (1952, p. 357) noted the area extending from La Luz Canyon northward to Tularosa and stated:

> In most of this area, deposition appears to have been essentially continuous from late Pennsylvanian into early Permian time, and the formations deposited, the Holder, Bursum, and Abo, do not appear to be separated by unconformities.

Pray also discussed some of the structural features in the northern Sacramento Mountains and noted the pre-Abo and post-Abo deformation evidenced in the northern Sacramento Mountains. He concluded (p. 341):

> Although the major folding occurred during the pre-Abo deformation, later minor folding along the same lines occurred during and after the deposition of the Abo formation.

Pray (p. 344) treated more specifically the prominent Fresnal fault that occurs near Fresnal Canyon in the southeastern part of the area studied (pl. 3), and indicated both pre-Abo and post-Abo movements on this fault. He further suggested that the Fresnal fault continues as a buried feature northward for several miles.

ACKNOWLEDGMENTS

This investigation was directed by Dr. Lloyd C. Pray, then of the California Institute of Technology, now with The Ohio Oil Company, to whom the writer is indebted for suggesting the problem and for his advice and criticisms.

The New Mexico Bureau of Mines and Mineral Resources sponsored this project since the beginning of the second field season in 1952.

The author is grateful to Dr. Eugene Callaghan, then Director of the Bureau, for so generously making funds available for field and office expenses.

Messrs. A. L. Bowsher and W. T. Allen, at the time of the U. S. National Museum in Washington, D. C., made detailed faunal collections in the area during the summers of 1951 and 1952. The author sincerely appreciates identification of the fossils collected during the field work. Dr. M. L. Thompson, Illinois Geological Survey, identified the fusulinids; Dr. G. A. Cooper, U. S. National Museum, studied the brachiopods; Professor A. K. Miller, University of Iowa, examined the ammonoids; and Mr. A. L. Bowsher, then of the U. S. Geological Survey, now with the Sinclair Oil & Gas Co., identified the gastropods.

Many of the residents of the La Luz area, particularly Mr. and Mrs. H. L. Traylor, extended hospitality and courtesies to the author which aided considerably in the completion of this work.

The writer is indebted to Frank E. Kottlowski, Max E. Willard, and Edmund H. Kase, Jr. for the final technical editing of the manuscript.

Stratigraphy

NOMENCLATURE

The lithologic variation of the Pennsylvanian and lower Permian strata in large parts of New Mexico has resulted in the use of many names for rock units of approximately the same age. The boundaries of the units have not always been clearly defined, and indiscriminate use of time-rock and rock terms has added to the confused status of nomenclature. The history of some of these terms is reviewed briefly. Names used in this report are indicated in Figure 3.

TIME-ROCK UNITS

The Pennsylvanian was originally defined by H. S. Williams in 1891 as the term for the "Coal Measures" (Wilmarth, 1925, p. 72-73) and had series rank as the upper part of the Carboniferous system. Most North American geologists have used it with period or system rank, and in 1953 the U. S. Geological Survey officially adopted systemic or period rank for the Pennsylvanian. The Permian system was defined in 1841 by Murchison for the series of sediments overlying the Carboniferous limestones in Russia, and is used in this report.

The series names employed by the New Mexico Bureau of Mines and Mineral Resources (Lloyd, 1949, p. 16, 34) for subdivisions of the Pennsylvanian and Permian systems are used in this report, except that the "-an" or "-ian" suffixes are added. The terms Missourian, Virgilian, Wolfcampian, and Leonardian series then establish the framework for regional correlation. The use of modifying prefixes, lower and upper, followed by a series name, such as lower Wolfcampian, upper Virgilian, indicates a relative position for the strata and does not imply the presence of distinct faunal breaks nor a sharply defined formal subdivision of the series into stages.

Thompson (1942) classified the Pennsylvanian rocks in New Mexico into 8 groups and 15 formations mostly on the basis of fusulinids. These units are only recognizable as separate lithic entities near the type areas. The diagnostic fusulinid content has proved the usefulness of Thompson's divisions for long-distance correlation. The terms "Fresnal group" and "Keller group" will be used as stages of the Virgilian in a time-rock classification in this report.

The predominantly marine beds of early Wolfcampian age in Fresnal Canyon have been referred to as the "Bursum formation" (Lloyd, 1949, p. 32). The correlation of these beds with the type. Bursum formation in central New Mexico was based on the lower Wolfcampian fusulinids that occur in the upper part of this unit in the Fresnal Canyon area. As the two areas are about 90 miles apart and the lithologies are not very similar, it appears that Lloyd used "Bursum" in a time-rock sense as a stage.

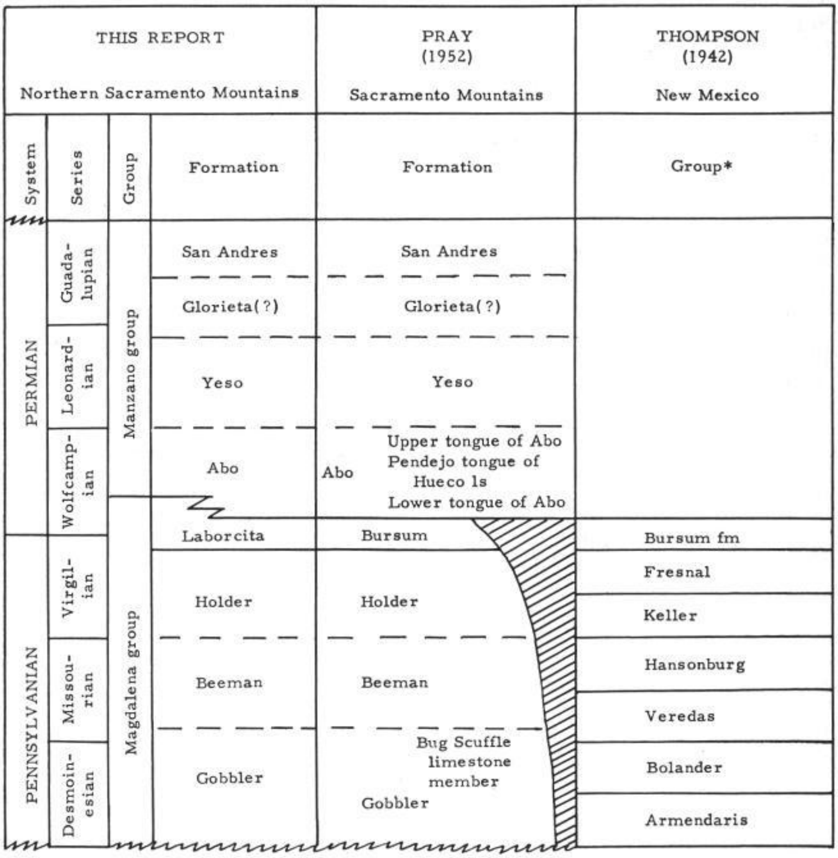


Figure 3

CLASSIFICATION OF ROCK UNITS OF PORTIONS OF THE PENNSYLVANIAN AND PERMIAN SYSTEMS

ROCK UNITS

Gordon (1907, p. 805) proposed the name Magdalena group for the rock unit, largely composed of marine limestone and sandstone, between the Mississippian Kelly limestone and the Manzano group in the Magdalena Mountains of central New Mexico. Herrick (1900, p. 4) had named as the Manzano series a section of red beds and associated strata in the Manzano Mountains of central New Mexico. The strata of the Magdalena and Manzano groups crop out over extensive areas in New Mexico and are regarded respectively to be largely Pennsylvanian and

* Thompson's lithologic subdivisions of the Pennsylvanian have only restricted application. Their diagnostic faunal content allows their usage as stages.

Permian in age. Many stratigraphers consider these two major units to be separated by an unconformity, which also formed the boundary between the Pennsylvanian and Permian systems in many places.

The term Magdalena has been frequently used in a time-rock sense, equivalent to the systemic term Pennsylvanian, because of the position of the Magdalena group between beds of Mississippian and Permian age. This has caused much confusion, as shown by Thompson's (1942, p. 21-24) careful review of the term. Thompson decided to abandon the term Magdalena. Most of the recent students of New Mexico geology have followed Thompson's suggestion.

Lee (1909, p. 12) subdivided the Manzano group into three formations, which are, in ascending order, the Abo sandstone, Yeso formation, and San Andres limestone. The Abo sandstone was later changed to Abo formation by Needham and Bates (1943, p. 1654). Under the new definition, the base of the Abo formation overlies the uppermost limestone layer of the lower Wolfcampian Bursum formation. The Bursum formation of central New Mexico forms the uppermost unit of the Magdalena group, as it was classified by King and Read (King, 1942, p. 675) and Stark and Dapples (1946, p. 1153).

In the Sacramento Mountains, Pray (1952), p. 174) proposed a threefold division of the Pennsylvanian strata. He distinguished, in ascending order, the Gobbler, Beeman, and Holder formations. In this report, the predominantly marine strata between the top of the Holder formation and the base of the Abo formation have been named the Laborcita formation. The lower part of this unit has formerly been called the Bursum formation. Although the Laborcita formation is a distinct mappable rock unit in the area where it was defined, a few miles away it becomes very similar to the underlying strata of the Holder formation. It appears desirable, therefore, to group the Holder and Laborcita formations together with the underlying Gobbler and Beeman formations as subdivisions of the Magdalena group. The largely marine character of the sediments of the Magdalena group is thus contrasted with that of the overlying nonmarine red beds of the Abo formation of the Manzano group.

PENNSYLVANIAN SYSTEM

In most areas in central and southern New Mexico, the Pennsylvanian system is several thousand feet thick and is composed largely of marine limestones and calcareous shales, with only small amounts of sandstones and red beds (Thompson, 1942, p. 17). The lack of persistent and clearly marked lithologic units or unconformities makes it difficult to distinguish rock divisions that can be mapped over a wide geographic area. Pray (1952) mapped the Pennsylvanian of the Sacramento Mountains as three formations, distinguishable throughout the range. The maximum thickness of the Pennsylvanian section in the Sacramento

Mountains is about 3,000 feet, but in most places the upper part has been eroded and the thickness is about 2,000 feet.

The lowermost unit of the Pennsylvanian system mapped by Pray is the Gobbler formation, composed largely of lower shale, argillaceous limestone, and very coarse-grained quartz sandstone, and upper massive gray cherty limestone or calcareous sandstone and shale. The Gobbler formation ranges in thickness from 1,200 to 1,600 feet. Where the gray cherty limestone is dominant, sheer cliffs, 500 to 700 feet high in some places, mark this part of the section. This conspicuous lithologic unit is termed the Bug Scuffle limestone member and forms much of the Gobbler formation in the High Rolls area near the southern edge of the area investigated. The Gobbler formation ranges from Atokan to lower Missourian in age.

The Beeman formation overlies the Gobbler, ranges from 350 to 450 feet in thickness, and is composed of shale, thin-bedded argillaceous limestone, and feldspathic sandstone in the western part of the Sacramento Mountains. The formation weathers to a gentle slope, in marked contrast to the cliffs of the underlying Bug Scuffle limestone member of the Gobbler formation. Toward the eastern part of the Sacramento Mountains escarpment, limestones are predominant in the Beeman formation. The age ranges from lower through upper Missourian. In many parts of the central and southern Sacramento Mountains, the Abo formation overlies the Beeman at a distinct angular unconformity.

The Holder formation is the uppermost of the Pennsylvanian formations named by Pray. In the northern part of the area, it is about 900 feet thick. Incomplete sections, generally less than 300 feet thick, form cliffs that cap the high ridges in the central and southern part of the escarpment. The formation is composed largely of white noncherty limestone interbedded with sandstone, conglomerate, and red and gray shale. The base is marked by the base of numerous discontinuous bioherms, 50 to 100 feet thick. In the northern part of the area, where the section is complete, the formation is overlain by the Laborcita formation. The Holder formation is entirely Virgilian in age. The upper two-thirds was termed the Fresnal group by Thompson (1942).

HOLDER FORMATION

The name Holder formation was proposed by Pray (1952, p. 208) for the strata that occur between the top of the Beeman formation and the base of the overlying Permian strata of the Bursum or Abo formation. Because of more recent evidence which indicates a very late Pennsylvanian age for the basal part of the overlying "Bursum formation" (Laborcita formation in this report), the writer suggests a slight revision of this definition, as follows: The Holder formation will include the strata that occur between the top of the Beeman formation and the base of the overlying Laborcita or Abo formation. The contacts remain unchanged and are as initially defined by Pray. The name is derived from Holder Ridge, which is capped by massive limestone of the basal Holder formation. The type section is located directly above that of the Beeman formation, in the NW $1/_4$ NW1/4 sec. 14, T. 17 S., R. 10 E., in the central part of the Sacramento Mountains. The Holder formation includes the. Fresnal and Keller groups in the classification of Thompson (1942). According to Pray (1952, p. 214):

> The Holder formation varies in both lithology and thickness along the Sacramento Mountain escarpment. The northernmost section [located near the south boundary of the map area of this report] is 900 feet thick, more than twice the thickness observed to the south. Part of this difference is caused by erosion of the upper part of the Holder formation at all localities except the northernmost. However, the differences in lithology of the strata remaining suggest that the Holder formation was probably initially thinner toward the south.

Thompson's detailed section of the Fresnal group forms the upper 530 feet of Pray's Holder formation and is overlain by the Laborcita formation. North of La Luz Canyon, along the frontal escarpment of the Sacramento Mountains, no post-Holder, pre-Laborcita erosion has been observed. The 900-foot-thick section of the Holder formation, therefore, appears representative for the northern part of the Sacramento Mountains and has been used in the structure sections (pl. 2).

In most of the map area (pl. 1, 2, and 3), only the upper part of the Holder formation is exposed, largely that part discussed by Thompson as the Fresnal group. The type section of the Fresnal group is exposed in La Luz Canyon along the old highway from Cloudcroft to La Luz. The base of the type section is about 20 feet above the roadbed in the fourth major arroyo, about 0.6 mile northwest of the junction of the roads in La Luz and Fresnal Canyons. The top of the section is in the roadcut in the second arroyo, 0.1 mile from the road junction. At the type locality, the Fresnal group is 530 feet thick (Thompson, 1942, p. 73).

Areal **Distribution**

The strata of the Holder formation are widespread along the fringe of the Tularosa Basin in the north and south ends of the Sacramento Mountains. In the central area, the formation occurs as isolated resistant caps on many of the high ridges at the west front of the mountains (Pray, 1952, p. 209); in the eastern part, the beds of the Holder are absent, cut out beneath the unconformity at the base of the Abo formation.

Within the area of investigation, the base of the Holder formation is exposed along the front of the range as far north as the mouth of Cottonwood Canyon, about **1** mile northeast of La Luz. From this canyon northwestward to the mouth of Domingo Canyon, a distance of about $41/_2$ miles, the Holder formation forms the lower part of the frontal escarpment (pl. 3) and extends about three-quarters of a mile upstream along Laborcita Canyon. The upper part of the Holder formation is exposed in a few erosional windows through the overlying Abo formation at the upper end of La Luz Canyon and along the west side of Fresnal Canyon, between La Luz Canyon and State Highway 83.

Lithology

According to Thompson (1942, p. 67), the lithology of the Virgilian series varies more markedly geographically than the lithology of any of the other Pennsylvanian series. The variations are especially marked in the Fresnal group part of the Holder formation, as shown by Pray's (1952, p. 187) graphic log of the 900-foot section of the Holder formation. The base of the formation in most of the Sacramento Mountains is formed by many biohermal masses, with a maximum thickness of about 100 feet (Pray, 1952; Plumley, 1953). The Virgilian bioherms have not been observed north of sec. 3, T. 16 S., R. 10 E., and were not found in the map area.

A nearly complete section of the Holder formation, shown by graphic log in Plate 14, is exposed in the La Luz anticline 1 1/2 miles northeast of the center of the town of La Luz. The base of the section is located 800 feet southeast of the center of sec. 24, T. 15 S., **R.** 10 E. The basal 100 feet is not exposed. The lower 300 feet of the exposed part of the section (approximately Thompson's Keller group) is marked by the large amount of coarse and fine terrigenous clastic rocks. Only about 8 percent of this part of the section consists of limestone. The sandstones are largely well-sorted calcareous sandstones and were probably laid down in normal marine or brackish waters. About 20 percent of the lower 300 feet consists of sandstones and pebble conglomerates, the remainder being poorly exposed greenish-gray to gray shales. This lithology contrasts markedly with Pray's section in Indian Wells Canyon (1952, p. 187), where almost half of the lower 300 to 400 feet consists of limestone.

The upper part of the section in the La Luz anticline does not differ much from Thompson's Fresnal group in La Luz Canyon, where thin medium-gray dense limestone beds are interbedded with gray and red shale, arkosic sandstones, and conglomerates. The average thickness of the limestones is about 4 feet, with only 3 limestone beds over 10 feet in thickness. The accumulative thickness of the limestones in the Fresnal group is about 160 feet (30 percent of the section), compared with about 90 feet (16 percent) in the corresponding part of the La Luz anticline section. Feldspathic sandstones and conglomerates occur in both sections in about equal amounts up to 14 percent. Limestone conglomerates, of limited areal extent, are generally closely associated with the massive limestone beds and are probably intraformational in origin, although they might indicate an erosional break of minor extent. Greenish-gray and purplish-red shales and siltstones form the remainder of both sections (56 percent in the Fresnal group, and 70 percent in La Luz anticline). The total amount of red shale decreases noticeably in the upper part of the section toward the northwest. Cyclically deposited beds have been observed, and Pray (1952, p. 213) described one common cycle as follows:

> ... limestone that grades upward into white, massive limestone, and thence gradationally or abruptly to pale reddish brown marl, and thence to nodular limestone.

Pray (p. 209) reported that the proportion of red beds, limestone conglomerates, and nodular limestones increases toward the top of the Holder formation throughout the Sacramento Mountains. The abundant coarse clastic rocks that occur in the section of the La Luz anticline above the level of the bioherms and below the red shales and nodular limestones are believed by Pray to thin out toward the south, where the Holder formation is about 400 feet thick.

An overturned anticline in upper Pennsylvanian rocks occurs at the north side of Salada Canyon, in SW1/4 sec. 34, T. 15 S., R. 10 E., in the southeastern part of the map area. From the core of this anticline, Missourian fusulinids have been collected, probably belonging to the Beeman formation. Fusulinids, identified by Thompson (personal communication) as of middle Fresnal age, occur stratigraphically 210 feet higher in the section in strata that are unconformably overlain by the Laborcita formation. These determinations indicate that the lower part of the Holder formation thins as much as 400 feet in a lateral distance of about 2$1/_2$ miles from west to east. The reduction in thickness of the Holder formation toward the east, shown in the structure sections (pl. 2), is caused partly by primary differences in stratigraphic thickness and partly by later removal of the upper part of the Holder formation.

Strata of Pennsylvanian age are exposed in a few erosional windows in the Abo formation in the upper part of La Luz Canyon, in secs. 22, 23, and 27, T. 15 S., R. 11 E. In a few places, fusulinid-bearing limestones occur interbedded with gray shales and pebble conglomerates. On the basis of a late Virgilian age of the fusulinids, the outcropping strata have been correlated with the Holder formation. Some massive limestone beds with abundant chert and large amounts of green sandstone may belong to the Beeman or Gobbler formations. The pre-Abo structural relationships are complex in that area and are difficult to interpret.

Conditions of Deposition

The various marine organisms in the strata of the Holder formation indicate a largely marine environment of deposition. The red mudstones in the upper part of the Holder formation indicate very shallow water or local terrestrial deposition. Fluctuations of sea level probably phere, preserving the original red color of the terrigenous clays. Under exposed the near-shore mud banks to oxidizing conditions of the atmos-reducing conditions, which might have prevailed on the ocean bottom, the original red shales probably became green in color.

Elsewhere, evidence of cyclic repetition of lithologic sequences indicates advance and retreat of the sea, each cycle representing a marine invasion. The intraformational limestone conglomerates may have been caused by local emergence of the depositional area or by erosion at the wave-base level. In both instances, diastems of very limited extent occur.

The crossbedding in the sandstones suggests shallow-water conditions. Locally, a brackish-water environment may have existed. Large chert and quartzite pebbles in some of the conglomerates are evidence of a nearby source for most of the clastic material of the Holder formation. Much of the material was probably derived from a landmass to the east that became an increasingly more positive area toward the end of Pennsylvanian and the beginning of Permian time. Thompson (1942, p. 12) introduced the name "Pedernal Landmass" for this positive area, after the Pedernal Hills 120 miles north of the map area in central New Mexico.

Contact Relationships

According to Pray (1952, p. 215), the Holder formation appears conformable with the underlying Beeman formation; evidence of a persistent erosional surface at the contact has not been observed. 'The upper contact of the Holder formation is mostly with the Laborcita formation in the map area. In the southeastern part, the Holder formation underlies the Abo formation unconformably. In the western part of the area, the Holder and Laborcita formations are essentially parallel. In Fresnal Canyon, south of the junction of Fresnal and La Luz Canyons, the upper contact is considered a disconformity, or slight angular unconformity, separating fusulinid-bearing marine strata from the unfossiliferous, possibly lagoonal or brackish-water, beds of the Laborcita formation.

In the exposures along State Highway 83, about three-quarters of a mile west of the tunnel and east of the synclinal axis (pl. 3), the conglomerates and red shales of the basal part of the Laborcita formation overlie the strata of the Holder formation with an angular unconformity of as much as 15 degrees. As is shown in the structure sections HH' through NN' (pl. 2), the contact between the Holder and Laborcita formations becomes a more markedly angular unconformity toward the east, cutting out the top part of the Holder formation. L. M. Cline, University of Wisconsin (oral communication from L. C. Pray), noticed a slight convergence between the Holder and Laborcita formations in Fresnal Canyon southward on the west flank of the syncline. In the 3 miles from Thompson's type section of the Fresnal group to State Highway 83, about 160 feet of the upper strata of the Holder formation appears to be cut out beneath the basal member of the Laborcita formation (Oppel, 1957). In the upper part of La Luz Canyon, in secs. 22 and 27, T. 15 S., R. 11 E., about 60 feet of conglomerate and shale, correlated with the Laborcita formation, overlie with distinct angular unconformity the eroded upper part of the Holder formation (pl. 2).

From the top of Thompson's type section of the Fresnal group southward in Fresnal Canyon, the upper contact of the Holder formation has been considered to coincide with the base of a pebbly conglomerate. The unit is discontinuous and as much as 6 feet thick. This bed has been mapped as marker bed 5 (pl. 2, 4) but only persists for 800 feet northwest along the strike. Farther north, the upper contact of the Holder formation was taken as a phantom horizon, mapped at a position 30 feet above marker bed 4. The contact between the Holder and Laborcita formations north of La Luz Canyon is essentially gradational, with no direct evidence of interruption in the sedimentation. The conglomerate noted by Thompson and said to mark "an obvious physical unconformity," must represent only a diastemic break of local extent. Significantly, in this area the lithology of the two formations near the contact is very similar. The upper contact of the Holder formation is discussed in more detail under the Laborcita formation.

Fauna and Age

According to Pray (1952, p. 216), "a wide assortment of brachiopods, corals, bryozoans, pelecypods and gastropods" are abundant near the top of the Holder formation in the area between Dry and Fresnal Canyons. Also in La Luz Canyon, in the excellent exposures of Thompson's type Fresnal group, the same fossil groups occur in large quantities. So far, no detailed studies of the megafossils have been published. A comparison of this fauna with the collections of the overlying Laborcita formation, which are discussed in the appendix, may yield important guides for investigations of the Pennsylvanian-Permian boundary in other areas.

Fusulinids are abundant, Thompson (1942, p. 74) having recognized at least 20 fusulinid-bearing strata in the fossiliferous type section of the Fresnal group, which is the upper part of the zone of *Triticites.* Fusulinids of the Fresnal group are highly developed forms of *Triticites.* Fifty feet below the top, the large obese species like *Triticites yentricosus* var. *sacramentoensis* Needham, *Triticites yentricosus* Meek & Hayden, and *Triticites consobrinus* Galloway and Ryniker have been identified (King et al., 1949, p. 62). Thompson (1942, p. 74) stated that the upper part of the Fresnal group represents a part of the Virgilian that is "amongst the youngest stratigraphic portions of the series known from North America." As will be shown later in this report, the lowermost 90 feet of the overlying Laborcita formation is also considered to be of Virgilian age. A very complete record of the upper Pennsylvanian appears to be present in the northernmost Sacramento Mountains.

Thompson places the boundary between the Missourian and Virgilian series at the base of the massive biohermal limestone (Lloyd, 1949, p1. 4), which is the horizon mapped as the base of the Holder formation by Pray (1952).

Correlation and Regional Relationships

Regional correlation is based on Thompson's recognition of the Keller and Fresnal groups in various areas of New Mexico. As the fusulinid content was the basis for correlation, his formation and group names are used as stages.

"The Virgilian is very widespread in New Mexico and has been recognized at the surface as far northeast as the Pecos River, as far northwest as the Nacimiento Mountains, as far southwest as Silver City, and near the south border of the state in the Hueco Mountains" (Thompson, 1942, p. 67). Subsurface studies show that east and southeast of the Pedernal Mountains the Virgilian is one of the most widespread divisions of the Pennsylvanian system (Lloyd, 1949, p. 37). In some areas, the late Virgilian sea persisted, as in the northern Sacramento Mountains, where the Virgilian is very thick. In other areas, the upper part of the Virgilian, corresponding to the upper part of the Fresnal group, appears never to have been deposited or was removed by later erosion.

At the outset of Virgilian time, the sea extended over wide areas of New Mexico. The lower Virgilian or Keller stage has been recognized in all areas where Virgilian rocks are known. Toward Fresnal time, a gradual shallowing of the ocean took place, leading toward the development of more or less separate, but not isolated, basins of deposition. The presence in some areas of the red bed fades of the Bruton formation (lower Fresnal stage), which reaches a thickness of 120 feet and is composed of red shales and arkoses, with interbedded fossiliferous nodular limestones, indicates this development. Despite the gradual restriction of the basins, the strata of the lower Fresnal stage are still relatively widespread and occur throughout the State except on Pennsylvanian land areas such as the Pedernal landmass. In the eastern part of the Oscura Mountains, the Bruton formation grades southward into the limestones, sandstones, and shales of the lower part of the "Fresnal group" (Thompson, 1942, p. 81).

The area of the northern Sacramento Mountains, the Tularosa Basin, the central and southern San Andres Mountains, northern Franklin Mountains, and northern Hueco Mountains appears to have been part of one large marine basin that received sediments throughout Virgilian and early Wolfcampian time (Thompson, 1942; Pray, 1952; Kottlowski et al., 1956). Read and Wood (1947, fig. 2) showed that in the northern half of New Mexico, deposition during the Pennsylvanian was controlled by the development of a number of generally north-south-trending positive areas and depositional basins which persisted through the Virgilian. The evidence suggests that this general structural trend was also dominant in the southern half of the State during the deposition of the Virgilian and lower Wolfcampian strata.

PERMIAN SYSTEM

The Sacramento Mountains are northwest of the Permian Basin, which, in southeastern New Mexico and west Texas, contains the thickest known succession of marine Permian strata in the world (Pray, 1952, p. 219). In 1939, Adams et al. proposed a standard Permian section and divided the Permian into four series based on type sections in the southeastern New Mexico-western Texas area. His classification, from oldest to youngest, of the Wolfcampian, Leonardian, Guadalupian, and Ochoan was adopted widely and is followed in this report.

The Permian strata of the Sacramento Mountains range in age from early Wolfcampian to Guadalupian. This study involves the strata of Wolfcampian age, which occur here in two distinctly different facies. The lower, dominantly marine facies is here named the Laborcita formation, and the upper, nonmarine facies comprises the Abo formation. The younger Permian strata, according to the classification used by Pray (1952, fig. 35a), are from oldest to youngest, the Yeso, Glorieta(?) and San Andres formations, as indicated in Figure 3.

LABORCITA FORMATION

In 1942, Thompson (p. 82) described the strata overlying the upper Virgilian beds in La Luz Canyon. These beds, composed of red and gray shale, sandstone, conglomerate, and a few limestones, contain fusulinids of early Wolfcampian age in the upper part. Beds of similar age occurring in central New Mexico directly below the nonmarine Abo formation received three different names in 1946. Kelley and Wood (1946) introduced the Red Tanks member of the Madera limestone in the Lucero uplift about 140 miles north-northwest of the northern Sacramento Mountains. Stark and Dapples (1946) assigned the name the Aqua Torres formation to a predominantly red bed sequence interbedded with marine limestones in the Los Pinos Mountains about 100 miles north-northwest of the map area. Wilpolt et al. (1946) designated the same sequence the Bursum formation, which term has been widely adopted. Lloyd (1949) and Pray (1952) applied the same name to Thompson's sequence of "transition beds" that overlie the strata of the Fresnal group in La Luz Canyon.

In the Sacramento Mountains, the "transition beds" consist largely of a marine sequence of fossiliferous gray shale, limestone, and sandstone, whereas in central New Mexico the Bursum formation is predominantly red beds that occur interbedded with a few thin fusulinid-bearing limestones. In addition, the upper part of the "transition beds" occurring north of Tularosa are younger than "Bursum" age. The term Laborcita formation is proposed, therefore, for the strata, consisting largely of gray and red mudstone, gray limestones, sandstones, and conglomerates, between the top of the Holder formation and the top of the highest marine limestone underlying the main mass of Abo red beds. The base of the type section is 700 feet southeast of the center of sec. 13, T. 15 S., R. 10 E., at the north side of Laborcita Canyon, from which the name of the formation is derived. The top of the type section is about 1 mile northeast of the base. The Laborcita formation is 480 feet thick at the type locality, which was measured along lines 18, 19, and 20 of Plate I.

Areal Distribution

The Laborcita formation crops out as a narrow 17-mile-long strip through the entire length of the map area (pl. 3). The beds form a narrow band of outcrops east of the Holder formation from a point one-quarter mile south of State Highway 83 to Cottonwood Canyon, a distance of about 5 miles. For 4 miles from Cottonwood Canyon northward to Domingo Canyon, the lower half of the Laborcita formation crops out on the crest of the frontal escarpment. North of Domingo Canyon, the upper part of the Laborcita formation forms the entire frontal escarpment for a distance of about 8 miles.

A few conglomerate beds of the Laborcita formation, exposed through windows in the overlying Abo formation, are 3 miles east of the junction of La Luz and Fresnal Canyons. Southeast of the map area, the Abo formation directly overlies the truncated beds of Pennsylvanian and Mississippian age, and the Laborcita formation has not been recognized in that area.

Lithology

General features. The Laborcita formation is composed of many different sedimentary rock types, reflecting the change from a dominantly marine to a dominantly terrestrial environment of deposition. Argillaceous massive or nodular limestones occur interbedded with gray, green, and red, commonly calcareous mudstones and shales. Quartz sandstones, feldspathic sandstones, arkoses, and subgraywackes are present; sandstones grade into conglomerates with clasts of different composition and size. Except for the shaly intervals, single lithologic units are rarely over 15 feet thick. Many of the beds occur in a cyclical repetition, but less distinctly than in the underlying Holder formation. Many of the strata extend laterally only a few hundred yards and lens out or grade laterally into a different rock type. The abruptly changing lithologies cause sections only a few hundred feet apart to differ considerably. It is nearly impossible, therefore, to subdivide the Laborcita formation into members that could be recognized over much of the map area. To work out the abrupt variations in rock types, a large number of stratigraphic sections were measured in detail. The laterally more persistent rock units were used to correlate the measured sections, and the relative stratigraphic position of previously known and of newly discovered fossil occurrences could be determined.

To portray the abrupt facies variations in the Laborcita formation, graphic logs of 34 of the correlated sections are plotted in Plate 4 on a scale of 50 feet to an inch. The mapped horizons are numbered consecutively upward in the section. Fossils collected along the line of a measured section have their collection number preceded by the number of the section. For instance, 18-F-3 indicates the third fusulinid collection along the line of measured section 18. The stratigraphic position of a fossil locality not along the line of a measured section is indicated with respect to the nearest measured section. The locations of the measured sections in Plate 4 are recorded on the geologic maps (pl. 1 and 2). Different base lines have been used for plotting the graphic logs in the correlation diagram. Marker horizons 42, 37, 53, and 55 were used from right to left respectively in the diagram.

The description of the type section would not present an adequate picture of the various facies in the Laborcita formation. For this reason, four measured sections that were considered representative of the lithologies of the Laborcita formation in different areas are described in detail and shown graphically. These are, from south to north respectively, Plates 5, 6, 7, and 8. The four sections, including the type section, are composites of several measured sections that are indicated separately in the correlation diagram of Plate 4.

Local features. From south to north, the deposits of the Laborcita formation exhibit a gradual transition from a nonmarine red bed facies to a largely marine facies of interbedded limestones and shales. The deposits also indicate a gradual emergence of the area and a transition from marine to nonmarine environments upward in the section. For the purpose of discussion, the long narrow strip of outcrops of the Laborcita formation can be subdivided broadly into three areas. The southern area, which extends for 3 miles from a point one-quarter mile south of State Highway 83 to La Luz Canyon, includes most of the red bed facies of the Laborcita formation (pl. 3). The central area extends from La Luz Canyon to Domingo Canyon, a distance of 6 miles, and comprises most of the near-shore and open-marine facies of the Laborcita formation. The remainder of the area, from Domingo Canyon northward, a distance of 8 miles, forms the northern area and involves here only the upper half of the largely marine Laborcita formation. The progressive northward decrease in displacement on the boundary fault system, as far north as Tularosa Canyon, causes successively younger strata to form the frontal escarpment. The basal part of the Laborcita formation is no longer exposed north of Domingo Canyon. For the area between Tularosa Canyon and a point 5 miles to the north, the displacement appears to be relatively uniform, and the same portion of the section is exposed continuously. The few isolated outcrops of the Laborcita formation about 3 miles east of the junction of La Luz and Fresnal Canyons are discussed under the Upper La Luz Canyon Area (p. 36-37).

Southern area. The southern area, extending from a point one-quarter of a mile south of State Highway 83 to La Luz Canyon, comprises most of the red bed facies of the Laborcita formation. These rock units are shown diagrammatically by the graphic logs of sections 1 to 10 in Plate 4. Sections 7 and 6, considered representative of the southern nonmarine facies of the Laborcita formation, have been combined and are shown graphically in Plate 5. The base of this composite section is in the creek bottom, 11/4 miles southeast of the junction of the roads from Fresnal and La Luz Canyons. Red mudstones constitute about three-quarters of this section, which is 560 feet thick. The remainder consists of about equal amounts of thin-bedded gray argillaceous limestones, which occur largely in the lower portion of the section, and sandstones and pebble and cobble conglomerates, which are restricted mainly to the upper portion. The sandstones are resistant, medium-grained well-sorted calcareous quartz sandstones. The conglomerate clasts consist of limestone, chert, and quartzite, the quartzite increasing in amount upward in the section.

The Laborcita formation extends southeastward of measured sections 7 and 6 for 2 miles and thins abruptly in that direction. As indicated in Plate 4, the lower 430 feet of the measured section below horizon 42 is equivalent to a 200-foot-thick red bed sequence 2 miles farther south. The limestones, which are very persistent in the lower part of the section, lens out. Limestone-pebble and cobble conglomerates constitute about 20 percent of section 1 in Plate 4, as compared to less than 10 percent of conglomerates and sandstones in the section 2 miles to the northwest. The abrupt lateral changes in the section are illustrated diagrammatically in Plate 9, where three sections, 1, 2, and 4 (see geologic map, pl. 2), are plotted in an isometric diagram. The increase in thickness between sections 1 and 2 takes place principally between horizons 5 and 16. Over a lateral distance of about 1,500 feet, a 70-foot interval nearly doubles in thickness to 135 feet. The onlap of the basal portion of the Laborcita formation on the strata of the Holder formation and abrupt wedging in the basal portion are shown in Figure 4.

The conglomerates of the Laborcita formation in this southernmost part of the area are interformational in origin as compared to some of the intraformational conglomerates near La Luz Canyon in the Laborcita and underlying Holder formations. Limestones, derived from Pennsylvanian rocks, predominate in the conglomerate clasts. Brachiopods, horn corals, and fusulinids are present in the pebbles and cobbles. On the basis of lithology and color, the rocks appear to have been derived from the upper part of the Holder formation. Chert and quartzite occur in minor amounts in the conglomerates. The increasing coarse-

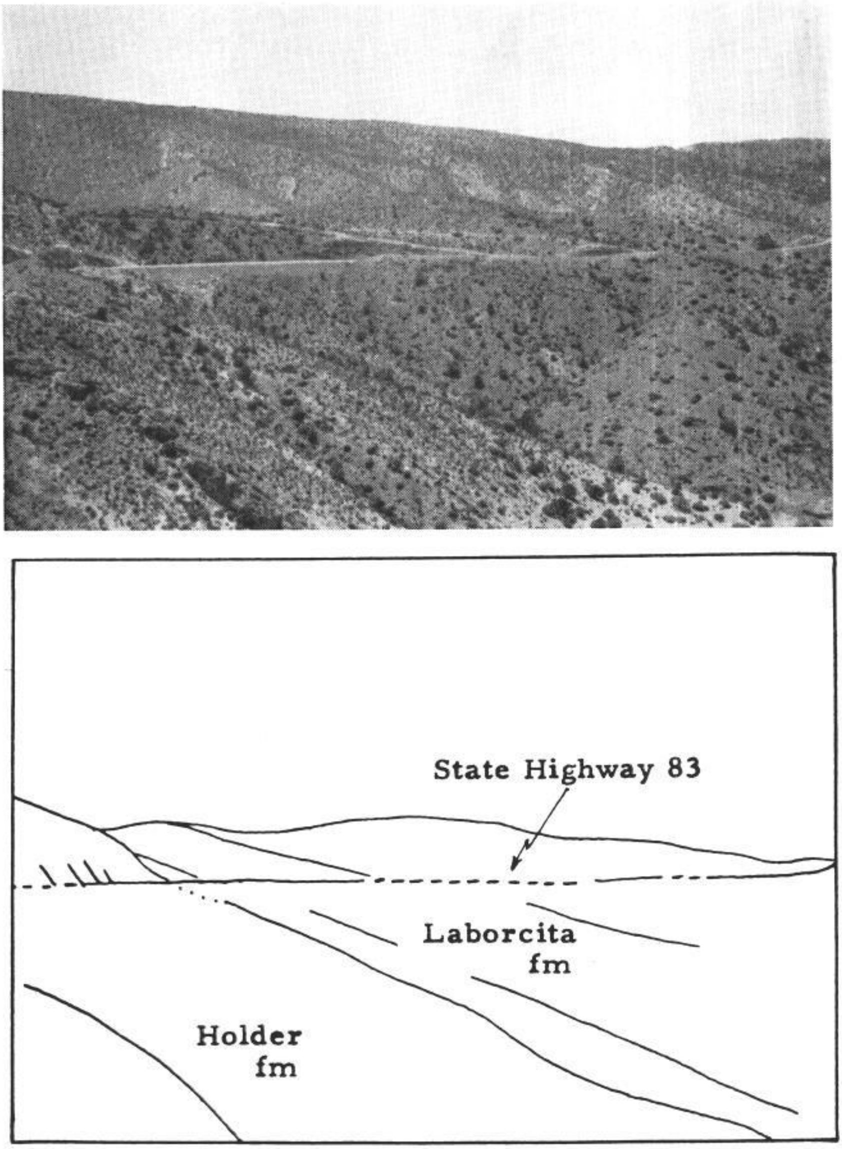


Figure 4

ANGULAR ONLAP OF THE BASAL PART OF THE LABORCITA FORMATION ON THE HOLDER FORMATION

Note wedging in the lower portion of the Laborcita formation. View southwest from a point north of State Highway 83, near center of SW¼NW¼ sec. 6, T. 16 S., R. 11 E.

ness and thickness of the conglomerate beds toward the southeast and east suggest that the source for the clastic sediments was in that direction.

The writer believes that the conglomerates and coarse sandstones, and their abrupt variations in thickness, are indicative of a piedmont environment. The red silty shales probably indicate deposition on broad flood plains.

Central area. The central area extends 6 miles from La Luz Canyon to Domingo Canyon. Here the Laborcita formation is predominantly a marine facies of red and gray mudstone interbedded with limestone and sandstone. The rock units of the central area are shown graphically in Plate 4, sections 11 to 24.

Details of the Laborcita formation overlying Thompson's type section of the Fresnal group (near the junction of La Luz and Fresnal Canyons) are given in Plate 6. This measured section appears as sections 11 and 12 of Plate 4. The lower section is summarized from Pray (1952, pl. 17). Because of the writer's revision of the base of the Abo formation, the 200 feet of red beds that overlies Pray's section of the Bursum formation is included in the Laborcita formation. The total thickness of the section at this point is 536 feet, essentially the same thickness as $1\frac{1}{2}$ miles to the southeast. In La Luz Canyon, only the top 160 feet consists of red beds, in contrast to the section three-fourths mile to the southeast along Fresnal Canyon (section 9, pl. 4), where red beds constitute three-fourths of the section. The red beds in La Luz Canyon are composed largely of red mudstones interbedded with calcareous quartz sandstones and quartzite-pebble conglomerates. About two-thirds of the underlying 370 feet, which corresponds to Pray's Bursum formation, consists of gray calcareous shale. Red mudstone and thin-bedded argillaceous or silty limestones each form about 10 percent of the section. Pebble conglomerates of limestone and chert, and relatively pure quartz sandstones, make up the remainder of the section. A comparison of sections 9 and 11 (pl. 4) illustrates the abrupt lithologic changes between the southern and central area. Within three-quarters of a mile, a probably nonmarine red bed sequence grades into a series of gray limestones, shales, and sandstones predominantly of marine or brackish-water origin.

The type section of the Laborcita formation is located near the mouth of Laborcita Canyon. A detailed description of this section is shown in Plate 7 (see also sections 18, 19, and 20, pl. 4). Although about 20 feet of the section is missing as result of an igneous intrusion, this was considered to be the most representative section of the marine Laborcita facies and is reasonably accessible. Furthermore, the upper and lower contacts are well exposed.

The Laborcita formation is about 480 feet thick at the type locality. One-third of this section is composed of red mudstones, which occur mainly in the top part. Limestones, ranging from thin, argillaceous, dark- and light-gray to nodular and massive types, form about 25 percent of the section as opposed to 10 percent limestone in the La Luz Canyon section. The percentage of coarse clastic rocks decreases from La Luz to Laborcita Canyon. Quartz sandstones and conglomerates form about 8 percent of the section in Laborcita Canyon, which is about half of the amount in La Luz Canyon. Many fusulinid zones occur in the lower part of the type section, permitting determination of the Pennsylvanian-Permian boundary within narrow limits, as well as indicating open marine conditions. The many limestones, mainly of coarse skeletal debris, also suggest deposition in a dominantly marine environment, with the possible exception of the top 110 feet of this section, which is mainly composed of red mudstones. The possibly brackish-water and/or near-shore conditions in La Luz Canyon show a transition into predominantly marine conditions near Laborcita Canyon, which lasted throughout the deposition of the lower two-thirds of the Laborcita formation.

A very abrupt lithologic change from west to east is observed in the vicinity of Laborcita Canyon and its tributaries. This change is partially illustrated on the correlation diagram by the logs of the Laborcita type section and section 17, which occurs half a mile farther southeast. Section 17 has more red shale beds than the type section, the limestone content is considerably less, and coarse clastic rocks predominate. The change from marine to nonmarine conditions appears to take place toward the east as well as southeast.

At the mouth of Laborcita Canyon, the upper part of the Holder formation and the lower part of the Laborcita formation cannot be separated on a lithologic basis, as is demonstrated by section 18 (pl. 4). No persistent erosional break was observed, and the contact between the Holder and Laborcita formations is probably gradational in this part of the map area. From a point half way between Cottonwood and Laborcita Canyons, where the basal conglomerate dies out, the contact was projected northward for 3$1/_2$ miles as a phantom horizon, 30 feet stratigraphically above a persistent limestone marker. From Laborcita Canyon to Domingo Canyon, this upper part of the Holder formation and the lower two-thirds of the Laborcita formation form the frontal escarpment. The measured sections 18, 22, 23, and 24 (pl. 4) illustrate the persistent limestone markers and the relative uniformity of the lithology. Certain lithologic sequences appear in cyclical repetition on both sides of the contact. Although laterally uniform, open-marine conditions prevailed in this area, many repeated fluctuations in sea level must have occurred. These conditions of deposition persisted throughout late Pennsylvanian and early Permian time, providing the writer's main reason for grouping the Holder and Laborcita formations together in the Magdalena group.

Northern area. The northern area extends 8 miles from Domingo Canyon to a point about 5 miles north of Tularosa. The slightly discordant sill near the mouth of Domingo Canyon forms a natural boundary between the central and northern areas. This fine-grained acidic intrusive, which occurs largely in the Laborcita formation and reaches locally a thickness of 200 feet, intruded successively younger strata toward the southeast and east, as shown in Plates 1 and 4, and prevented the lower portion of the Laborcita formation from being exposed directly north of Domingo Canyon. The uppermost part of the Laborcita formation, which overlies the intrusive sill in the central area, is continuous and permitted a direct correlation between the central and northern areas.

The various rock units in the Laborcita formation of the northern area are shown by the logs of sections 25 to 34 (pl. 4). In this area, the lithology is considerably more uniform than in the southern area, the structure is much less complex, and a few marker beds readily established correlation of the measured sections. The lowermost strata of the Abo formation in the area south of Domingo Canyon interfinger toward the north with marine beds. This partially marine section, between marker bed 49 and the top of marker bed 55, is included in the Laborcita formation. Thus, the upper contact of the Laborcita formation transgresses time lines and is younger toward the north than in the area south of Domingo Canyon, as shown in Plate 4. In the northern area, the Laborcita formation consists predominantly of coarse- and fine-grained terrigenous clastic rocks, but, in contrast to the section in the central and southern areas, these beds are more continuous and can be mapped over wider areas. The few limestone beds (which are about as abundant in this part of the Laborcita formation as farther south) are also persistent.

The total thickness of the Laborcita formation northeast of Tularosa is estimated to be about 1,000 feet by projecting the base of the formation northward into this area.

Details of the exposed upper part of Laborcita in the northern area are illustrated by the stratigraphic section in Plate 8 that was measured by L. C. Pray and the writer. The section is about 525 feet thick, of which almost 40 percent is composed of sandstones and conglomerates. About 35 percent consists of dark-red mudstones and gray and green shales. Limestones and dolomitic limestones constitute the remaining 25 percent of the section and occur mainly in the upper part, which is equivalent to Abo red beds to the south. A few gypsiferous siltstone beds, several inches thick, were noted in two places associated with greenish-gray siltstones, and occur in very porous aggregates.

The increase of coarse clastic content is the most marked feature of this area as compared to the described sections to the south. Hardly any quartz sandstones occur; instead, coarse greenish-gray arkoses and feldspathic sandstones predominate. Some sandstones can be classified as subgraywackes (Pettijohn, 1949, fig. 66), owing to the presence of a "pastelike" matrix consisting largely of chlorite and possibly some calcite. For example, one typical sandstone from the lower part of unit 27 consists of 30 percent feldspar, 31 percent quartz, and 39 percent matrix material. Because of the absence of rock fragments, this rock is called a subgraywacke rather than a graywacke. A more typical subgraywacke, with a composition of 50 percent quartz, 13 percent feldspar, and 37 percent matrix of chlorite and other dark minerals, forms unit 37. The conglomerates of the northern area consist largely of quartzite and pink feldspar porphyry. The pebbles and cobbles of one typical conglomerate of section 29 are composed of two-thirds quartzite and one-third feldspar porphyry.

Plant remains and petrified wood in the sandstone units 2, 11, and 37 were noted. Some of the thicker sandstone members, such as unit 27, show marked crossbedding, with the crossbeds dipping west. On the basis of the lateral continuity of the thin sandstones and siltstones, high clay content, and the presence of plant remains, near-shore marine or lagoonal conditions of deposition are inferred.

The Laborcita formation in the northern area is marked by a sequence of red and green terrigenous clastic rocks of unusual lateral persistence. These beds occur about in the center of the measured section between horizons 39 and 51 (pl. 4) and are largely red and green arkose and red mudstone, about 150 feet thick. The corresponding interval in the central and southern areas consists entirely of red beds and is about 100 feet thick. The difference in thickness is caused by a 45-foot-thick coarse-grained greenish-gray calcareous sandstone bed, which is indicated in section 26 (pl. 4) as underlying horizon 48. The unit is very lenticular and markedly crossbedded, with the foreset beds dipping east (fig. 5). The laterally persistent red color of the sequence between horizons 39 and 51 probably indicates a widespread emergence of large parts of the map area, and deposition under alluvial-plain and possibly near-shore marine conditions. These beds are perhaps fluvial and deltaic in origin. The large amount of feldspar in the sandstones and of feldspar porphyry clasts in the conglomerates of the northern area, and their absence in the equivalent sediments to the south, suggest, at least in part, a different source area for this feldspathic material. This source area was probably more to the east and/or northeast.

The limestones of the northern area, particularly in the lower part of the section, are thin and commonly dark gray and argillaceous. Locally, they contain round laminated algal structures about 3 inches in diameter. Two limestone beds, units 28 and 33, are laterally persistent and have been mapped as marker beds 51 and 52 (fig. 6). They extend for 7 miles and 41/2 miles respectively and are locally dolomitized, as shown by a distinctive rusty-brown color.

A relatively persistent limestone unit is exposed conspicuously on the crest of the frontal escarpment from a point northeast of Tularosa for a distance of about 3 miles (fig. 6). The unit extends about one-third of a mile in east-west direction. In the main area of development, the

Figure 5

CROSSBEDDED SANDSTONE AND CONGLOMERATE OF THE LABORCITA FORMATION

Near mouth of Domingo Canyon, SE¼NE¼ sec. 34, T. 14 S., R. 10 E. View looking north.

unit is uniformly about 60 feet thick. Detailed field and petrologic studies revealed that, in the main, this limestone unit is composed of two members that appear to be genetically different. A number of moundlike bodies, consisting of massive, largely accretionary limestone, form the lower member. The upper member consists mainly of locally well-bedded fine- to coarse-grained detrital limestones. The lenticular mounds are interpreted as bioherms.

The lenticular structures in the lower member average about 40 feet in height, but in a few places are as much as 60 feet high. The dip of the flank of the structures is locally as much as 35 degrees. The bulk of the massive lenticular structures is silt and clay-size calcite. Thin laminae or bands are noticeable on the weathered surface, in polished sections, and in thinsections, caused by slight color and particle-size differences between the laminae. The laminae and bands are both concave and convex upward. Thickening of the bands in the parts that are convex upward suggests an organic form of accretion and is difficult to explain solely by physical agents. The writer believes that a filamentous type of algae formed the main binding agent for the fine-grained lime sediments in these mounds. Remains of small brachiopods, crinoids; fusulinids, and other organisms occur locally in small pockets. The clay content of the lenticular masses is low and ranges from 0.5 to 2.5 percent.

The distribution of the upper detrital limestone member is restricted to the area of biohermal development. Locally, the upper member caps the bioherms and ranges in thickness from a few inches to 60 feet, filling in the topographic depressions between the bioherms. The upper member is composed of fragments of loose platelike algae, crinoid columnals, brachiopods, fusulinids, and other organic remains.

The slightly dolomitized limestone unit 33 (pl. 8) forms the base on which the bioherms developed. Locally, a thin gray fusulinid-bearing shaly limestone marker overlaps the detrital limestone member to the east where the detrital member disappears. There, the fusulinid limestone is separated from unit 33 by about 10 feet of dark-gray calcareous shale. This evidence indicates that the bioherms, locally 60 feet thick, are equivalent to a few feet of calcareous shales in adjacent areas. The bioherms apparently grew above the level of contemporaneous sediments, taking postdepositional compaction of the shaly sediments into consideration. The low content of clay in the biohermal member as compared to the adjacent beds indicates development in a zone of water

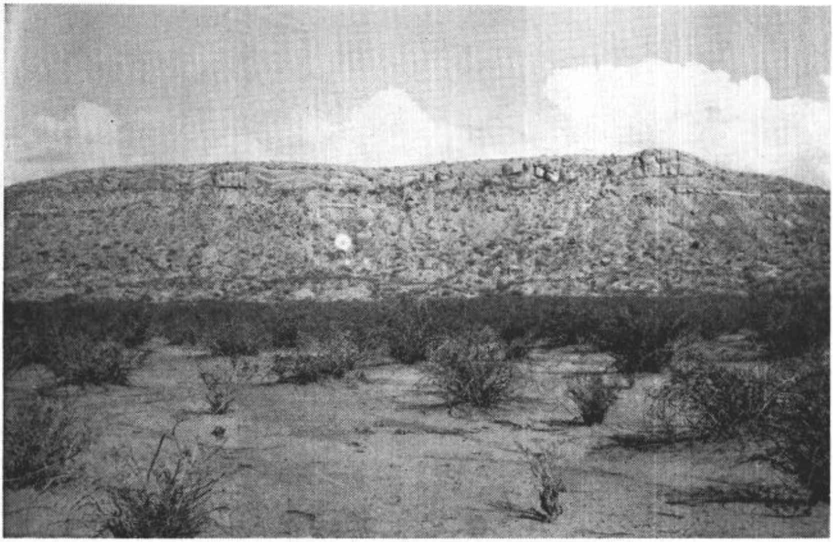


Figure 6

ALGAL BIOHERMS AND OVERLYING DETRITAL LIMESTONE BEDS FORMING RESISTANT LEDGE ON CREST OF FRONTAL ESCARPMENT

The thin continuous lower band is dolomitic limestone (bed 51, pl. 4). Northeast of Tularosa.

agitation. The apparent absence of brecciated material on the flanks of the bioherms that could be interpreted as rough-water deposits, suggests no growth into the zone of active wave action. A thin shale between the lower biohermal member and the detrital limestone suggests that biohermal growth was terminated by the influx of terrigenous clastic rocks. The bioherms probably continued to have a topographic expression on the sea floor, thereby restricting arealy deposition of the detrital limestone. These detrital deposits were also laid down in agitated water above wave base, as indicated by the low content of terrigenous clastic rocks and the bedded and sorted nature of the deposits.

The zone of biohermal development was probably one-quarter to three-quarters of a mile wide and perhaps did not extend much beyond the area of present exposure, which is about 3 miles long. The organic structures probably developed under optimum growth conditions on the gently sloping, relatively stable sea floor that bordered the lower Permian landmass which lay to the east and southeast. Water depth, temperature, and currents are inferred to have been favorable for algal growth in a zone which probably extended parallel to the ancient sea coast.

Upper La Luz Canyon area. Several isolated outcrops of Pennsylvanian and lower Permian strata, exposed through the windows in the Abo formation, are located about 3 miles east of the junction of La Luz and Fresnal Canyons. These outcrops cover parts of secs. 22, 23, and 27, T. 15 S., R. 11 E. (pl. 2 and 3). Here, a sequence of limestone and conglomerate beds is overlain with an angular discordance of about 15 degrees by a quartzite-cobble conglomerate at the base of the Abo formation. A few limestones, interbedded with several pebble-conglomerate layers of varying composition, contain locally abundant fusulinids. Identification of the fusulinids by M. L. Thompson showed an upper Fresnal age for these strata, which correlate, therefore, with the Holder formation. This correlation might be questioned for the Pennsylvanian strata exposed in sec. 23 and the northern part of sec. 22, T. 15 S., R. 11 E. (pl. 2), as these beds are probably part of the Beeman and Gobbler formations. In the southern part of sec. 22 and the northern part of sec. 27, T. 15 S., R. 11 E., where the age of the Holder formation beds is firmly established, a few pebble- and cobble-conglomerate beds and interbedded shale overlie in a few places the upper Fresnal-age strata with a marked angular discordance of as much as 40 degrees. The conglomerates consist mainly of limestone, chert, and quartzite and are distinctly different from the unconformably overlying quartzite-cobble conglomerate of the Abo formation. The conglomerates and the interbedded nonexposed intervals, which form a wedge-shaped unit about 60 feet thick, are bound on either side by angular unconformities. Because of the stratigraphic position and composition of the conglomerate, this 60-foot interval is correlated with the Laborcita formation to the west. Near the junction of Fresnal and La Luz

Canyons, deposition appears to have been essentially continuous, and the Laborcita formation is separated by minor disconformities from the underlying Holder formation and overlying Abo formation. Thus, a sequence of limestones, shales, and sandstones, 530 feet thick, grades eastward within a lateral distance of 3 miles into 60 feet of conglomerates and shales. Some of this extreme wedging was probably depositional, and some was caused by post-Laborcita, pre-Abo erosion.

Two miles due south of the Upper La Luz Canyon area, near Salada Canyon, the Laborcita formation lenses out into, and is truncated by, the unconformity at the base of the Abo formation; similar conditions are inferred for the area directly north of the Upper La Luz Canyon area, as is indicated in cross-section FF' of Plate 2. Deposition of the Laborcita formation occurred from east to west and possibly from southeast to northwest. The writer believes that the nearly north-northwest orientation of the correlation diagram in Plate 4 is in part along the strike of deposition of the Laborcita formation, which would explain the relatively uniform thickness of the Laborcita formation in the central area, and in the southern area northwest of measured sections 7 and 6 (pl. 4).

Marker beds. The more persistent marker beds are discussed in order to illustrate in detail some of the abrupt lithologic changes in the Laborcita formation. The same number has been applied for both a marker bed and the mapped horizon at its base. The usage of the term will readily indicate which meaning is implied. As the marker beds essentially represent time lines, they indicate the various depositional environments at any given time in different parts of the map area.

The marker beds can be divided into two broad groups on the basis of geographic location. The marker beds of the uppermost part of the Holder and the entire Laborcita formation crop out in the area south of Domingo Canyon (the southern and central areas of the previous sections). Only the marker beds of the upper portion of the Laborcita and the lowermost Abo formation (pl. 4) are exposed in the northern area. The individual marker beds are discussed in ascending order from the oldest to youngest. The lateral lithologic variation, continuity, and approximate geographic extent of the marker beds are illustrated by Plate 4, and shown diagrammatically in Figure 7.

Southern and central areas.

No. 4.—A medium-gray, resistant, fragmental limestone unit persists for about 33/4 miles, extending northward from a point one-half mile north of Cottonwood Canyon to Domingo Canyon, where it is last observable. This limestone is composed largely of coarse organic detritus, is locally as much as 25 feet thick but averages about 10 feet, and is in most places a massive cliff-former. Northward it grades into nodular limestone.

No. 5.—The base of the Laborcita formation in La Luz Canyon (section 11, pl. 4) is marked by a sandy conglomerate layer about 4 feet thick. Pebbles in this unit consist of limestone and chert. The limestone pebbles contain Pennsylvanian fossils. The conglomerate does not persist as a continuous layer toward the southeast but was recognized in many places at the same strati-graphic position, overlying fusulinid-bearing nodular limestones and shales of the Holder formation. The unit extends for a distance of about 3 miles in Fresnal Canyon, with perhaps a disconformity at its base. About 900 feet northwest of the base of section 11, the conglomerate lenses out and has not been observed farther toward the northwest, nor was any evidence of an erosional discontinuity observed beyond this point.

No. 8.—A thin-bedded medium dark-gray silty limestone about 20 feet thick, has been mapped as bed 8; it directly overlies a dark-gray to almost black carbonaceous shale about 38 feet thick. The shale and limestone beds are easily recognizable for about 2 miles between sections 5 and 11 south of La Luz Canyon. The limestone varies only slightly in thickness. In section 7, the shale contains plant fossils and a few coaly layers. Southeast of section 5, within one-third of a mile, the underlying dark-gray shales grade into red mudstones with abundant fusulinids which, according to Thompson (personal communication), are of late Virgilian age. The limestone shows undulatory bedding toward the southeast and gradually lenses out. Northwest of section II, within one-quarter of a mile, the limestone becomes more massive and is light medium gray, very similar to the limestones that occur in the underlying section of the Holder formation, such as bed 4. The thick-bedded limestone can be recognized for about one-quarter of a mile to the northwest. Beyond that point, it appears to grade into shale.

A medium-gray slightly nodular fusulinid-bearing limestone occurs in section 16, about half a mile south of Laborcita Canyon. This bed was recognized for about 31/2 miles and was traced from Cottonwood Canyon in the southeast toward Domingo Canyon in the northwest. The bed occupies the same stratigraphic position as the thin-bedded argillaceous limestone layer 8. Because of complex structural relationships in the vicinity of Cottonwood Canyon, the writer does not know whether these beds grade into each other.

No. 9.—Marker bed 9 has been traced for about 1 mile and has been observed in measured sections 16, 17, 18, and 20 near Laborcita Canyon. It is described in section 18 as unit 37 (pl. 7). This medium-gray resistant limestone unit consists mostly of skeletal debris and is about 12 feet thick. Fusulinids of early Wolfcampian age occur in a 3-foot-thick argillaceous nodular limestone sequence 6 feet above the base. This is the lowest limestone unit in the Laborcita formation with Permian fusulinids, and the Pennsylvanian-Permian boundary has been placed at the base of this bed, coinciding with horizon 9. Bed 9 grades laterally into dark-gray shale, and to the north the Pennsylvanian-Permian boundary has been taken as a phantom horizon about 15 feet above the base of bed 8. Southeast of La Luz Canyon, the boundary approximately corresponds to the top of the thin-bedded carbonaceous limestone of bed 8 (pl. 4).

No. 10.—An argillaceous very fine grained medium-gray unfossiliferous 5-footthick limestone bed has been mapped as bed 10 in the area of Fresnal Canyon. The bed extends for 13/4 miles between sections 4 and 9. Toward the southeast, the limestone becomes nodular and is interbedded with red shales, and gradually pinches out. In the direction of La Luz Canyon, this layer is more sandy and grades laterally into a gray shale.

A thick-bedded medium-gray fragmental limestone, about 20 ***feet*** thick, extends for about half a mile north of Cottonwood Canyon and has been correlated with the argillaceous limestone that was mapped to the southeast. In a few places, as in section 13, it grades into an intraformational limestone conglomerate.

No. 22.—Marker bed 22 can be traced from section 11 in La Luz Canyon southeast for more than 3 1/2 miles, where the Laborcita formation is no longer present. This crossbedded calcareous quartz sandstone with pebbles of limestone gradually grades toward the southwest into a 4-foot-thick fragmental limestone bed largely composed of bioclastic debris. Pebbles of chert and limestone are scattered throughout. Near section 1, the limestone is very argillaceous, fine grained, and grayish red.

No. 25.—Marker bed 25 is a thin-bedded medium-gray argillaceous limestone in section 22 about 1 mile north of Laborcita Canyon, and extends northward for 4 miles. This unit overlies directly the igneous intrusive in the area behind the frontal escarpment and is important in correlating sections 22 and 25. In this area, it is very silty. Between sections 25 and 26, toward the northwest, the limestone grades into a crossbedded sandstone containing pebbles of limestone and chert. The bed is no longer observable 1 1/4 miles north of Domingo Canyon.

No. 27.—A calcareous quartz sandstone about 10 feet thick occurs for about 6 miles, from a point about 3 miles southeast of La Luz Canyon to about three-quarters of a mile north of Laborcita Canyon. The thickness remains relatively uniform throughout. In the vicinity of Laborcita Canyon, where it is last observable, the sandstone grades into a very sandy limestone. Toward the southeast, about 1 mile south of La Luz Canyon, the sandstone grades into a medium-gray very sandy limestone. A thick pebble and cobble limestone-conglomerate occurs farther southeast at the same stratigraphic position.

No. 29.—The conglomerate bed that Pray (1952, p. 228) considered the base of the Abo formation has been mapped as marker bed 29. It consists of pebbles and cobbles of quartzite, limestone, and chert, and is continuously exposed for nearly 5 miles from the extreme southern part of the map area to a point half a mile north of Cottonwood Canyon. This conglomerate is in places about 30 feet thick. The lower contact is very irregular, as can be observed with respect to the underlying sandstone marker 27, and shows scour-andfill structures. Locally, bed 29 fills channels cut down below the level of bed 27 and contains reworked material of this layer. Toward the southeast, bed 29 grades 1 3/4 miles southeast of La Luz Canyon into a quartz sandstone and does not correspond to the basal Abo conglomerates of the High Rolls area, as considered by Pray (1952, p. 251). Toward the north, the conglomerate lenses out gradually at a point about half a mile north of Cottonwood Canyon.

No. 37.—A limestone bed, locally as much as 25 feet thick and containing abundant fusulinids, occurs 80 feet above the pebble- and cobble-conglomerate layer 29. This medium-gray argillaceous limestone has nodular to undulatory bedding, and extends from Cottonwood Canyon to a point slightly north of Laborcita Canyon for about 1 1/2 miles. About half a mile south of Laborcita Canyon, in section 15, the limestone is very thick bedded and contains abundant algae. The limestone grades southeastward, within half a mile of Cottonwood Canyon, into a fossiliferous black shale containing brachiopods and molluscs. South of Cottonwood Canyon, in section 11, an argillaceous dolomitic limestone occurs in the same stratigraphic position as bed 37 and is probably correlative. The dolomitic limestone grades southeastward into a red unfossiliferous mudstone. From Laborcita Canyon northward to section 19, a distance of one-quarter mile, the fusulinid limestone grades into a dark silty limestone containing brachiopods and pelecypods, and then into a silty shale containing small platelike algae. Beyond this point, the bed lenses out. •

No. 38.—Marker bed 38 is a dark 4-foot-thick bluish-gray fine-grained argillaceous limestone that forms an excellent marker bed in the vicinity of Domingo Canyon. The bed was traced for about 3 miles, with little change in lithology and thickness, from section 21 to a point north of section 25. Locally, the limestone contains dark-gray limestone inclusions about 1 inch in diameter that are probably algal in origin. 'Toward the northwest, the limestone grades into a dark-red calcareous siltstone. Toward the southeast, it was traced into a dark-gray, poorly exposed shale.

No. 42—A persistent conglomerate bed, about 9 feet thick, extends for 4 miles in the area between Cottonwood Canyon and State Highway 83. The conglomerate clasts consist of limestone, quartzite, and chert. Toward the northwest, the conglomerate grades into a calcareous quartz sandstone and then lenses out into red mudstones. Toward the southeast, the limestone and chert content increases markedly. The conglomerate wedges out into the unconformity at the base of the Abo formation in Salada Canyon (pl. 2). No large amount of channeling was observed at the base of this unit.

No. 49.—A quartzite-pebble and cobble conglomerate was mapped as marker bed 49 from the extreme southern end of the area to as far north as Domingo Canyon, a distance of about 81/2 miles. The conglomerate ranges in thickness from a few feet to 15 feet. North of Cottonwood Canyon, the amount of limestone and chert increases with respect to the quartzite clasts. Where the conglomerate is coarser, as in the southern part of the map area, the pebbles and cobbles consist almost entirely of quartzite. The compositional change may be due to sorting. The bed appears to have been deposited on a surface with moderate relief, as can be determined with respect to the underlying persistent marker beds 37 and 38 between Laborcita and Domingo Canyons (pl. 4). Locally, the bed shows evidence of scourand-fill structures. Clasts about 2 feet in size and derived from the underlying limestone, were incorporated in the conglomerate layer. These features, in addition to the lateral continuity of the bed, suggest a break of at least diastemic nature at the base of bed 49. Because of the close stratigraphic position of horizon 49, with the unconformity at the base of the Abo near High Rolls (bed 50), and its lateral persistence, bed 49 was mapped as the base of the Abo formation in the southern half of the map area.

No. 50.—In the southeastern part of the map area, between High Rolls and Salada Canyon, the Abo formation overlies strata of Pennsylvanian age with angular unconformity. The base of the Abo formation is formed by a quartzite-cobble conglomerate that was mapped as bed 50. Detailed tracing of this bed toward the west showed that the base of the Abo conglomerates, horizon 50, overlies horizon 49 by approximately 10 feet (pl. 2, sec. 34, T. 15 S., R. 11 E.). Slightly west of this point, bed 50 lenses out.

Northern area.

No. 32.—A greenish-gray, relatively pure quartz sandstone has been mapped as bed 32 from Domingo Canyon northward for about 41/2 miles. This resistant layer is about 4 feet thick and forms a narrow ledge above the alluvium of the Tularosa Basin at the base of the frontal escarpment. Farther north, it is no longer exposed at the surface. Toward the south, the sandstone dies out as a resistant ledge, and its position cannot be determined accurately. North of Tularosa Canyon, it is thinly bedded. Locally, the sandstone is calcareous and contains minor amounts of feldspar, up to about 10 percent. In the southeast, it is conglomeratic and crossbedded. In a few places, the sandstone contains plant fossils, but no marine fossils were noted.

No. 35.—A medium-gray argillaceous limestone extends northward from 1 mile northeast of Tularosa for 4 miles, where it is no longer exposed. The limestone is about 3 feet thick and contains dark-gray nodules probably algal in origin. Toward the south, it grades into a brown-weathering sandy argillaceous limestone and then into a greenish-gray mudstone.

No. 51.—Marker bed 51 is a laterally persistent medium-gray very thick bedded limestone, about 10 feet thick, extending from half a mile north of Domingo Canyon for 71/2 miles to the north, where it is no longer exposed. The limestone is largely of coarse skeletal remains and shows a characteristic rusty-brown color near Tularosa Canyon, between sections 28 and 29, for a distance of 2 miles. The color is associated with dolomite. Both toward the north and south, the limestone shows a transition into medium-gray argillaceous limestone and occurs interbedded with gray shale. Toward the southeast, it grades laterally into a red mudstone interval, which is indicated in section 25.

No. 52.—A dolomitic limestone, similar to parts of bed 51, was mapped as bed 52. This persistent layer, which has a thickness of about 3 feet, extends for 41/2 miles in the vicinity of Tularosa Canyon. Toward the south, the limestone extends for 2 more miles, where it grades into gray shale and then red mud-stone, as is indicated in sections 27 and 25. Toward the north, it grades into a 6-foot-thick medium-gray skeletal limestone which consists mainly of unidentified algal fragments.

No. 53.—Marker bed 53, a conglomerate, has been recognized from Domingo Canyon northward for a distance of 71/2 miles. Between Domingo and Tularosa Canyons, it consists mainly of cobbles of quartzite. Feldspar porphyry constitutes about 5 percent of the clasts. North of Tularosa Canyon, the conglomerate grades into a greenish-gray feldspathic obscurely cross-bedded sandstone, which is 15 feet thick in places. Farther north, it appears to grade into a sequence of gray shale. The base of this conglomerate layer is considered to form the base of the Abo formation between Domingo and Tularosa Canyon.

No. 54.—Marker bed 54 is a resistant medium-gray very fine grained brown-weathering limestone in the northernmost 2 miles of the map area. In section 33, it is about 8 feet thick, very sandy at the base, and grades near section 34 into a 15-foot limestone unit that is very thick bedded at the top and consists of coarse bioclastic debris. Between sections 33 and 30, a distance of 21/4 miles, it grades southward into a very nodular sandy and argillaceous limestone interbedded with red shale. Farther south, it grades into red calcareous shale.

No. 55.—A thick-bedded medium light-gray limestone, about 12 feet thick, forms marker bed 55. It has been traced from Tularosa Canyon northward for 5 miles. In the northern part of the area, the bed contains locally abundant fusulinids and grades laterally into a limestone marked by medium dark-gray algal nodules about 1 inch in diameter. Within half a mile south of Tularosa Canyon, the thick-bedded limestone grades into a very silty limestone and then into a medium dark-gray calcareous siltstone. This siltstone contains abundant irregular platelike algae and some fusulinids. Farther south, the *bed* grades into red mudstones overlying marker bed 53 and is no longer recognized. In the area north of Tularosa, bed 55 is overlain by the main mass of the Abo red beds, and the top of this unit marks the top of the Laborcita formation.

Conditions of Deposition

Sedimentary facies.

Conglomerates. Most conglomerates in the map area are poorly sorted, wedge-shaped deposits that evidence scour-and-fill at their base.

The composition of clasts and matrix varies widely. In general, three different types can be distinguished in the map area:

1. Pebble and cobble conglomerates, largely composed of various types of limestone, some with diagnostic Pennsylvanian fossils and minor amounts of chert, occur mainly near State Highway 83 in the southernmost part of the area (pl. 4, 9). These deposits locally reach a thickness of 20 feet and commonly grade into red mudstones within a mile. Their development suggests conditions in the source areas which permitted the erosion of limestone clasts, rather than removal by solution with resultant accumulation of only the insoluble parts, such as chert. The association with red beds is indicative of a warm, relatively humid climate (Van Houten, 1948, p. 2116). The writer believes that the limestone conglomerates are the products of rapid erosion of a limestone terrain and rapid burial after relatively short transport. Their short lateral extent, absence of marine fossils in the matrix, and poor sorting are indicative of deposition on a subaerial surface of appreciable gradient, adjacent to an area actively undergoing erosion. Away from the area of erosion, the slope is interpreted as more gentle, allowing finer materials to be deposited. The steeper parts of the area of aggradation probably represent a piedmont environment. The term alluvial-plain environment is applied to the more gentle portions and was probably a surface of low relief. Rapid erosion of the limestone terrain and rapid burial after relatively short transport is compatible with the proposed piedmont environment of the limestone conglomerates.
2. Conglomerates that are more continuous than the limestone conglomerates and that extend laterally from 4 to 8 miles, are mostly confined to the upper part of the Laborcita and basal part of the Abo formation. The thickness ranges from a few feet to 20 feet. These conglomerates, such as beds 29, 42, and 53 (pl. 4), are predominantly composed of cobbles of quartzite; limestone and chert are generally present in only minor quantities, but locally they form as much as 50 percent of the clasts. In most places these conglomerates grade laterally into quartz-rich sandstones. They are interpreted as piedmont deposits because of the lack of marine fossils in the matrix, dominance of cobble-sized clasts, irregular thickness, and basal channel features. The lateral persistence of these conglomerates is possibly caused by deposition near the base of one or several coalescing alluvial fans that formed a continuous apron of waste at the base of an area undergoing erosion.

Locally, these conglomerates consist entirely of quartzite cobbles. This phenomenon is attributed to selective sorting according to size. The smaller size particles, composed mainly of limestone and chert, were removed, leaving the conglomerate richer in quartzite. Observed lateral transitions, such as beds 29 and 49, from quartzite-cobble conglomerate into pebble conglomerate of quartzite and limestone, and to granule conglomerate of chert and limestone, support this suggestion. The laterally more extensive conglomerates possibly were deposited less rapidly than the interformational limestone conglomerates, as suggested by the better and more complete sorting and the smaller size of the limestone clasts.

3. A few limestone conglomerates in the area occur in close association with massive marine limestones, such as bed 10, and have been tentatively interpreted as intraformational conglomerates. The clasts of these conglomerates are of pebble size and appear to, be composed of one rock type. Temporary withdrawal of the marine waters, mud cracking, and subsequent flooding of the mud-cracked limy layers may explain their formation. A fluvial origin, however, cannot be ruled out.

Coarse-grained sandstone. The sandstones of the Laborcita formation fall into two broad groups on the basis of grain size: coarse-grained and fine- to medium-grained sandstones. Very coarse grained arkose and feldspathic sandstone are most abundant and constitute about 40 percent of the Laborcita formation in the area north of Domingo Canyon (pl. 4). These sandstones contain a few scattered pebbles of chert and limestone (fig. 5) and occur interbedded with thin layers of red or green mudstone. Most of these coarse-grained deposits are red or greenish gray, and show marked cross-stratification and an absence of marine fossils. The dip of the crossbedding, which averages about 15 degrees, is predominantly toward the west, although local variations occur. These thick sequences are evidence of fluvial deposition and possibly represent river-channel and/or deltaic deposits. The relatively unweathered feldspar suggests rapid erosion in the source areas.

Fine- and medium-grained sandstone. Most sandstones of the Laborcita formation are of local extent, but a few sandstone beds are relatively uniform in thickness and laterally persistent, extending for as much as 6 miles. In general, these are well sorted, fine to medium grained and do not show marked crossbedding. Most of these sandstones are quartzose, commonly with calcareous cement. Marker bed 27, in the southern part of the map area, is of this type. This bed grades laterally into a very sandy thin-bedded limestone (fig. 7). Others, such as bed 53, grade laterally into conglomerates. A few sandstones, such as bed 32, which are confined largely to the area north of Domingo Canyon, are classified as subgraywackes because of the large amount of interstitial clay material. Marine fossils were not found.

The relatively "clean" quartz sandstones of the southern part of the map area were formed possibly in a near-shore marine environment, where the more turbulent waters winnowed otit the fine-grained terrigenous elastic rocks. The relatively extensive stibgraywackes of the area north of Domingo Canyon have a "pastelite" matrix and feldspar content of about 15 percent, and locally contain carbonized plant remains. The features are suggestive of deposition under laterally uniform, quiet water conditions, such as possibly prevailed in a lagoonal environment.

Nodular limestone. This facies includes several varieties of limestone with nodular characteristics. The most common are the argillaceous medium-gray limestones with typical undulatory bedding as much as 4 inches thick, and layers that are mainly composed of separate limestone nodules bedded in a red or green mudstone matrix. In many places, the obscurely bedded massive limestones show a transition at their upper and lower contacts into the undulatory limestones. These limestones are fine grained and are composed of skeletal limestone particles of about 0.2 to 0.5 mm packed in a very fine-grained matrix. Fusulinids are found most commonly in limestones of this type and locally form about half the rock. These deposits occur most abundantly in the central area between La Luz and Domingo Canyons.

An area of active erosion is postulated east, southeast, and possibly northeast of the map area, based on various lines of evidence. Many of the nodular-bedded limestones grade laterally toward this land area into gray, green, or red mudstone (shown diagrammatically by beds 8, 9, 10, 37, and 54; fig. 7). These limestones were deposited in an area directly seaward from the zone of maximum deposition of terrigenous elastic rocks, probably in shallow water.

The limestone nodules occurring in zones in red or green shales are, at the most, 3 inches in diameter, and are sublithographic in texture. The lack of organic structures in the limestone nodules is striking, and locally they are dolomitic. Their accumulation may be chemical or biochemical in origin in either shallow-marine or fresh waters.

Massive limestone. Many of the laterally persistent limestone strata extend as much as 7 miles in the Holder and Laborcita formations, and either are obscurely bedded or occur in beds over 1 foot in thickness. The limestones consist mainly of skeletal debris in a very fine grained matrix. The coarser particles range from 0.1 to 0.4 mm. Fragments of algae dominate, although fragments of other, largely benthonic, marine invertebrates are present. The average clay content of the fragmental limestones is about 4 percent, based on insoluble-residue determinations of 6 typical samples. The massive obscurely bedded limestones probably represent a seaward extension of the nodular limestones, as is suggested by the lateral transition of the nodultar limestones (fig. 7) into massive limestones in a direction away from the inferred shoreline. The slightly smaller particle size of the massive limestones as compared to the nodular limestones might indicate that the source of at least some of the detrital fragments was from areas nearer the shore. The low clay content indicates a reduced influx of fine-grained terrigenous clastic rocks during deposition of the massive limestones.

The massive biohermal limestone lenses that are 40 to 50 feet thick in the area northeast of Tularosa were formed apparently by sediment-binding algae. They can be considered accretionary marine limestones as opposed to the massive obscurely bedded detrital skeletal limestones. These bioherms developed in agitated waters, as is suggested by their low clay content.

Dolomitic limestone. In a few places, massive or nodular limestones grade toward the south and southeast into light-brown or tan dolomitic limestones (beds 37, 51, and 52; fig. 7), which are shoreward extensions of the massive limestones. McKee's explanation (1945, p. 62) of the formation of the "rusty brown dolomites" in the Cambrian of the Grand Canyon region is believed applicable to these dolomitic limestones of the Sacramento Mountains. McKee stated that as a result of a marine transgression, the zone of clastic deposition shifts toward the source area. Conditions favorable to calcium carbonate accumulation do not move shoreward in a corresponding amount; so a specialized facies develops, intermediate in position between areas of elastic and of pure-lime deposition. The near-shore position suggests shallow-water conditions, resulting in relatively high water temperatures, increased evaporation and salinity, and carbonate precipitation, which is probably what McKee meant in stating "that this facies is controlled by waters of fairly high concentration."

Gray and green mudstone. Gray and green mudstone are the dominant rock type in the Laborcita formation north of La Luz Canyon (pl. 4). In most places, these mudstones are distinctly calcareous and occur commonly on the shoreward side, but interbedded with marine limestones (fig. 7). They locally contain abundant fossils, such as brachiopods, molluscs, and calcareous algae, types usually found in shallow marine water. During periods of relative tectonic stability permitting deep weathering in the source areas, the stream detritus consisted largely of fine-grained terrigenous clastic rocks. Much of this probably was deposited in a zone bordering the land areas, and general reducing conditions of the marine environment removed any red color of the source-area detritus.

In a few places, such as the shale zone below marker bed 8 in the southeastern part of the map area, the gray shales grade laterally into very dark gray, almost black, carbonaceous shales containing some coaly layers that locally yield abundant plant fossils. These beds may represent brackish-water deposits, possibly in a lagoonal environment.

Red beds. Red mudstones, sandstones, and conglomerates occur throughout the entire Laborcita formation and are particularly abundant in the southern part of the map area (pl. 4). The red coloring in the sandstone and conglomerate is largely due to the red clays, as shown by thinsection study. This contrasts with some of the arkoses in the overlying Abo formation, which locally are colored red by pink orthoclase. In the red mudstones, the quartz fragments, although present in substantial amounts, do not affect the coloring of the rock, and no pink feldspar is present.

Various lines of evidence suggest that the red beds were deposited terrestrially:

1. To the east, southeast, and probably to the northeast of the map area, there was an area of active erosion during much of Laborcita time. Considering the Laborcita formation as a whole, the red-bed facies occurs between an area actively undergoing erosion and one of marine deposition.
2. Individual marker beds grade from marine limestones and green or gray shales toward the east and southeast into red mudstones (fig. 7). In these lateral sequences, the limestones and gray or green shales contain in many places marine invertebrates, but the contemporaneously deposited red shales are generally barren of marine fossils.
3. Sedimentary features such as channeling, irregular crossbedding, and lateral discontinuity of the beds are suggestive of fluvial deposition; the coarse-grained deposits in stream channels, and the fine-grained clays and silts on broad flood plains.
4. The red beds, particularly those of the overlying Abo formation, contain locally abundant petrified wood.
5. Reducing conditions generally prevail in normal marine environ- ments, whereas oxidizing conditions required for preservation of the red color are prevalent in a subaerial environment.

Although these criteria suggest a nonmarine environment of deposition of the red shales in the map area, they fail to explain the origin of the red coloring. The writer has made no detailed study of the nature and origin of the red color. Some of the published opinions on red coloration are briefly summarized below:

Van Houten (1948, p. 2116) pointed out that a sufficiently warm and humid climate in a source area will produce a red soil which could be the source of the coloring matter and of much of the fine-grained clastic material in red beds. Ferric oxide and ferric hydroxide, derived from iron-bearing minerals in the source area, ,will be transported with the clay minerals and become a part of the shales; dehydration turns brown and yellow colors to red (Pettijohn, 1949, p. 173). An oxidizing environment in the site of deposition will preserve the red color and remove carbonaceous or other reducing components that might otherwise reduce the iron compounds during diagenesis. Such an oxidizing environment prevails during subaerial deposition in piedmont and alluvial-plain environments. The deposits formed in this manner are classed by Krynine (1949, p. 60) as primary red beds. In addition, the oxidizing environment at the site of deposition may change the color of blue and green sediments to red.

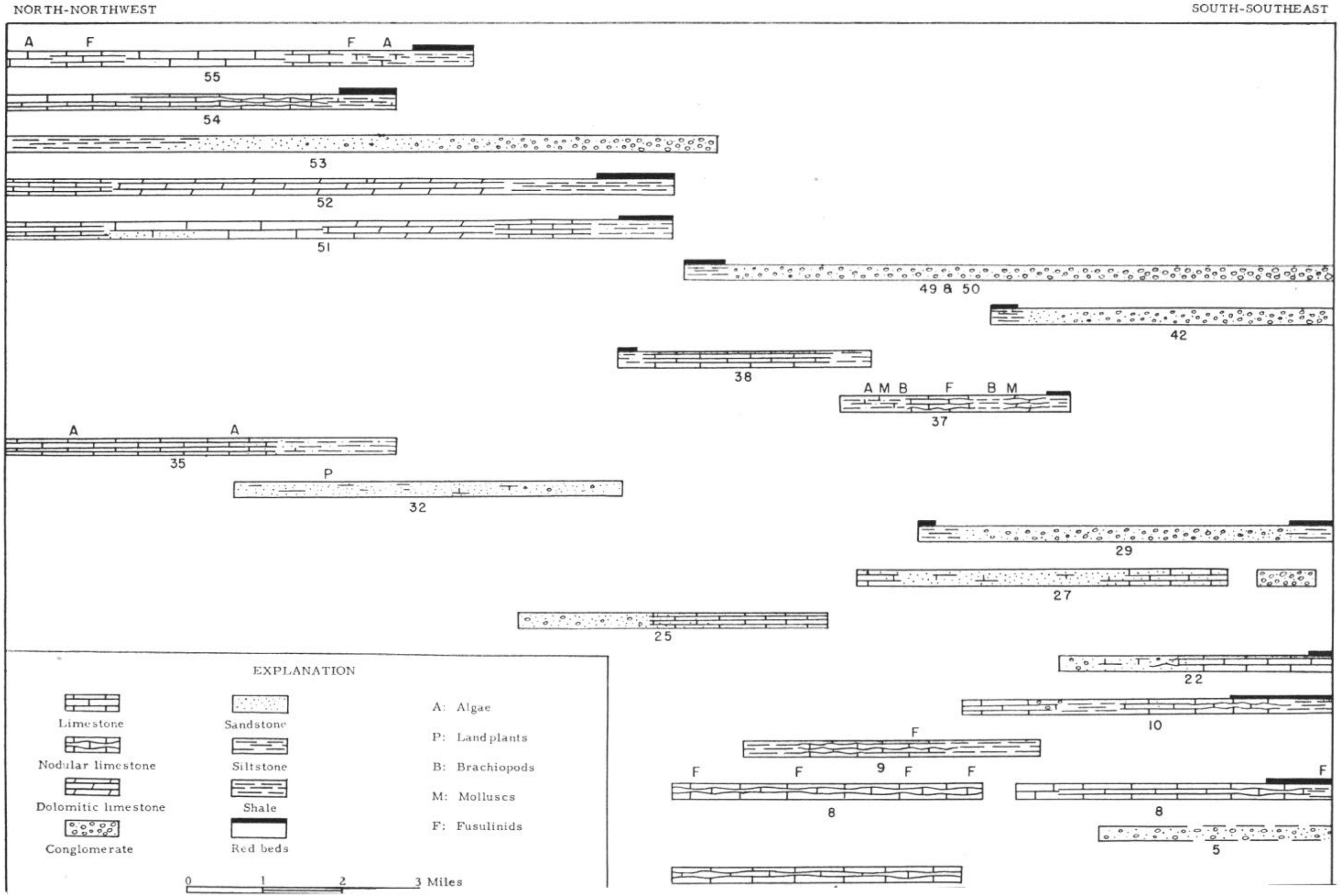
The local occurrence of nodular limestones interbedded in red shales, and of red shales containing locally abundant fusulinids, may be explained by deposition in the marine littoral zone with repeated emergence and flooding of the area, possibly associated with conditions of rapid burial. These occurrences support the primary nature of the red color. The loss of the red color in marine sediments is probably a diagenetic process that takes place after burial, when the organic content of the marine sediments will tend to reduce the ferric oxide, resulting in greenish or gray colors.

Lateral and vertical rock sequences.

Lateral sequences. In the Laborcita formation, marker bed 37 (fig. 7) laterally shows a complete gradation from massive obscurely bedded limestone through nodular limestone, silty limestone, and black or green calcareous shale into red shale. Similar transitions, possibly not as complete, have been observed in other strata, such as marker beds 9, 10, 51, 54, and 55 (see fig. 7). These gradual changes in lithology represent a gradual transition from open marine environments to littoral and terrestrial environments.

Gradual changes in faunal content correspond to the lateral litho-logic changes. This is demonstrated clearly by beds 37 and 55, where the nodular limestones contain abundant fusulinids, the silty limestones contain brachiopods and pelecypods of shallow-water types, and the gray calcareous siltstones are rich in small, but distinct, platelike algae. This gradual faunal change is interpreted as being controlled largely by the depth of the marine waters, although many other factors, such as temperature, water turbulence, salinity, and turbidity, are active. Similar faunal changes were observed by Elias (1937) in the Big Blue sediments of Permian age in Kansas. Elias inferred a depth of 160 to 180 feet for the fusulinids, 90 to 160 feet for the brachiopods, and 75 to 110 feet for the calcareous algae. These depths are probably not applicable in absolute terms to the various fossil groups of the Laborcita formation, but the writer believes that the faunal content is a key in establishing the relative depths of the various rocks. The gradual transition in any marker bed from obscurely bedded marine limestones at one end, into red shales at the other, is probably indicative of a gradual shallowing of the Laborcita sea in the direction of the shoreline.

The depth of the Laborcita sea within the map area probably did not exceed the depth of the euphotic zone at any given time, as the probably benthonic calcareous algae, which appear to be such large contributors to the obscurely bedded massive limestone, require sunlight for their photosynthesis. Kuenen (1950, p. 8) stated that the depth of penetration of sunlight is a "few dozen meters," and Sverdrup (1942, p. 774) gave a figure of 80 meters or more, which is generally considered a maximum. Extrapolation of Elias' maximum depth figures for the various faunal zones, with postulation of gradual increase in depth in


NORTH-NORTHWEST
SOUTH-SOUTHEAST
55
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49 & 50
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38
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35
32
29
27
25
22
10
9
8
8
5
EXPLANATION
Limestone
Nodular limestone
Dolomitic limestone
Conglomerate
Sandstone
Siltstone
Shale
Red beds
A: Algae
P: Land plants
B: Brachiopods
M: Molluscs
F: Fusulinids
0 1 2 3 Miles

a dircction away from the shoreline, indicates an approximate depth of 200 feet for the zone of deposition of the massive limestones. Although the author believes that this figure is a high estimate of the depth of deposition of the massive limestones, it is still within the euphotic zone.

Marker bed 37 exhibits the complete transition from massive limestone into red shale within a lateral distance of about 9,000 feet in a southeast direction (fig. 7). If the maximum water depth represented by this limestone is 200 feet, an average slope of about 120 feet per mile (slightly more than a 2-percent slope) is indicated for the submarine surface during deposition. This is a maximum slope, as the example involves one of the most abrupt of the facies changes in the area, as well as the maximum depth estimate for the massive limestone.

Vertical rock sequences; cyclothems. The limestones and shales in the upper part of the Holder and lower part of the Laborcita formations in Laborcita Canyon occur in cyclic repetition, as can be noted from sections 17, 18, and 19 (pl. 4). Pray (1952, p. 213) previously noted these cyclic sequences in the Holder formation of the Sacramento Mountains. Following the usage of Wanless and Weller (1932, p. 1003), the cyclic sequence is referred to as a cyclothem. The cyclothems of the Laborcita formation appear to be developed less perfectly than those of the underlying Holder formation; most sequences are probably incomplete, but several complete or ideal cyclothems that are typical of the cyclic deposition of the Laborcita formation can be inferred. Two types are most common (fig. 8).

The neritic cyclothem (fig. 8A) consists of a thin conglomerate or sandstone that is overlain by a red calcareous mudstone or shale. This grades upward into a nodular limestone that contains locally abundant fusulinids. The nodular limestone is overlain gradationally by obscurely bedded, fragmental limestone. A red or green shale directly overlies this limestone and completes the cycle. The total thickness of this sequence is approximately 50 feet. This ideal cyclothem is generally not fully developed, but numerous partial cycles are present. The thin sandstone or conglomerate is commonly absent. In a few places, intraformational limestone conglomerates occur at the top of the obscurely bedded or thick-bedded limestones. In other places, the entire massive limestone unit is missing, and the nodular limestones grade upward directly into red or gray shales.

Significantly the vertical succession from sandstone to obscurely bedded limestone is essentially the same as the transition in the lateral rock sequences. In a few places, such as marker bed 37 (fig. 7), a nodular limestone clearly grades both laterally and upward into a massive limestone, which (on the basis of the previous discussion) suggests increasing depth of the marine waters during the deposition. Each cycle appears to represent one complete marine transgression and regression. As the depth of deposition of the massive limestone is inferred

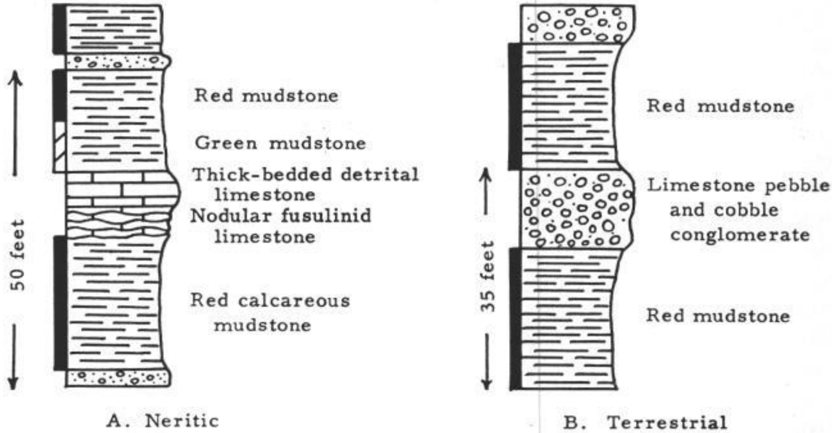

Figure 8
CYCLOTHEMS OF THE LABORCITA FORMATION

to be 200 feet, and as the basal thin sandstone and the red mudstone are terrestrial in origin, the sea level must have fluctuated about 200 feet during one complete cycle. This is a max mum figure and may be several times higher than the actual amount. A cyclothem of this type, with a dominance of marine deposits, is classed as deltaic or neritic (Wanless and Shepard, 1936). A similar sequence was reported by Wan-less (1947, fig. 4, col. 10) in the Molas formation in the San Juan Mountains, in southwestern Colorado. Wanless and Shepard (1936) suggested that each cycle might start with a basal conglomerate overlying a disconformity at the base. The thin sandstone or conglomerate in the cyclothems of the Laborcita formation may represent only slight diastemic breaks.

The interbedded limestone conglomerates] and red shales (fig. 8B) that occur in the southeasternmost part of the map area are interpreted as terrestrial cyclothems (Wanless and Shepard, 1936). Each sequence averages about 35 feet thick. The conglomerates probably overlie a disconformity at the base.The neritic cyclothems indicate repeated fluctuations of sea level and alternating periods of transgression and regression. During periods of widespread transgression and of maximum limestone deposition, the zone of clastic deposition shifted toward the source area; as a result, deposition of fine-grained terrigenous clastic rocks was at a minimum. The repeated fluctuations in sea level may be related to the general instability of the area, and may indicate episodic deformation occurring contemporaneously with the deposition of the Laborcita formation in the areas to the east and southeast. Thus, the terrestrial cyclothems would be explained by recurrent uplifts of the source area. An initial period of rapid erosion in the source area and rapid burial of the limestone conglomerates in the piedmont areas was followed by a period of relative stability and deep weathering in the source area. During these relatively stable periods, the thick red shale sequences were deposited on a broad surface of low relief and low gradient, such as an alluvial plain, and maximum deposition of fine-grained terrigenous elastic rocks occurred in the adjacent marine basins. The cycle ended with reduced influx of fine-grained elastic rocks from a worn-down source area, less turbid waters, and widespread carbonate rock deposition.

The concept that different types of erosion occur in sequence is an oversimplification, as the different processes of weathering and erosion, and formation of coarse-grained and fine-grained elastic rocks, are generally active simultaneously. The occurrence of the interbedded conglomerates and shales does not necessitate recurrent uplifts in the source area, and the presence of discontinuous conglomerates in a dominant shale section may be explained by relatively short periods of great carrying capacity of the streams (i.e., floods).

Depositional history. In the Sacramento Mountains, the Laborcita formation forms the transition zone between the marine Holder formation and the nonmarine Abo formation. The unit appears to have been deposited contemporaneously with late Pennsylvanian-early Permian diastrophism that occurred east and southeast of the map area. The deposits indicate the gradual emergence of the area, and transition from marine to nonmarine environments, with many fluctuations. Roughly, three phases can be recognized in the depositional history of the Laborcita formation:

1. The *first phase* was deposition of the lower two-thirds of the Laborcita formation, the portion between the basal contact and horizon 39 (pl. 4). A gradation from nonmarine conditions in the southeast and east to marine conditions toward the northwest and west is indicated by the red beds in the area south of La Luz Canyon, which grade into marine limestones and shales in the area between La Luz and Domingo Canyons. Locally, lagoonal or fresh-water conditions may have existed, as is suggested by the abundant plant fossils and coaly layers in certain shale beds. The section near La Luz Canyon is relatively rich in nonred sandstones and conglomerates, which may indicate local deltaic conditions. North of Domingo Canyon, only the upper part of the lower two-thirds of the Laborcita formation is exposed, and here this portion is marked by the lack of distinct limestone beds, as well as by a significant increase in the amount of nonred sandstones. These changes suggest a transition from Domingo Canyon northward into near-shore marine or lagoonal environments with a different source of supply of coarse-grained elastic rocks. Possible evaporative conditions are indicated by minor amounts of gypsum.

During the first phase, the main basin of marine deposition prob.

ably extended west of the presently exposed part of the Laborcita formation. Terrestrial deposition is inferred for the area north of Domingo Canyon within a few miles to the east or northeast of the present frontal escarpment of the Sacramento Mountains. Most of the fluctuations of sea level recorded by the Laborcita formation occurred during this phase.

2. The *second phase* includes roughly the strata between horizons 39 and 49 (pl. 4). This interval consists of 106 to 150 feet of red beds throughout the entire exposed part of the Laborcita formation, and is interpreted as due to a prolonged period of low emergence. Deposition probably occurred on a broad alluvial plain, With possibly deltaic conditions for the area north of Domingo Canyon, where red and green coarse-grained crossbedded arkoses are present in the section.

3. The *third phase* is characterized by the interbedded marine limestones and nonmarine red beds that occur between horizons 49 and 55 in the area north of Domingo Canyon. This sequence, about 250 feet thick, corresponds to the lowermost part of the Abo formation in the southeastern part of the map area. Apparently, the northern area subsided with respect to the central and southern areas and was flooded repeatedly by marine waters from the west.

Source areas. The source of most of the clastic sediments was to the southeast, east, and northeast, a land area considered to be a part of the Pedernal Landmass. The increase in the amount and size of the coarse clastics toward the southeast and east indicates the source in that direction. The conglomerates in the Upper La Luz Canyon area grade westward into the sandstones, shales, and limestones near the junction of La Luz and Fresnal Canyons. Within a distance of about 3 miles, the formation increases in thickness from about 60 feet to about 550 feet (HH', pl. 2). This marked wedging is partly caused by post-Laborcita and pre-Abo erosion, but does reflect the presence of a positive area to the east with deposition toward the west. During the early stages of the uplift (early Laborcita time), the Pennsylvanian and older sediments were probably sources for much of the material. Continued erosion in late Laborcita time must have exposed large areas of Precambrian quartzite in the source area, as abundant quartzite cobbles and pebbles occur in the upper part of the Laborcita formation.

The high feldspar content of the subgraywackes, arkoses, and feldspathic sandstones north of Domingo Canyon is in marked contrast with the relatively pure quartz sandstones in the area to the south. The conglomerates in the Laborcita formation north of Domingo Canyon are characterized by about 30 percent pink feldspar porphyry clasts, which do not occur in the conglomerates farther south. The difference in feldspar content of the coarse clastic rocks of these two areas is attributed to differences in composition of the source-area rocks; the area north of Domingo Canyon probably received its detritus from feldspar-bearing rocks to the east or northeast.

Contact Relationships

Within the area of investigation, the Laborcita formation underlies the Holder formation. Near the junction of La Luz and Fresnal Canyons, the contact was selected at the base of a 4-foot-thick conglomerate layer, marker bed 5, which directly overlies Thompson's (1942) type Fresnal group. Toward the southeast, in Fresnal Canyon, this bed does not persist as a continuous layer, but reappears in many places at the same stratigraphic position and is the best mappable contact. The contact occurs above interbedded nodular fusulinid-bearing limestones and red shales, and below plant-bearing dark carbonaceous shales and limestone. The conglomerate marks a change from marine to brackish-water conditions. More recent work by T. W. Oppel (1957) seems to indicate that the contact should perhaps be placed above the black carbonaceous shales.

About 900 feet northwest of the top of Thompson's type section, the conglomerate lenses out and has not been observed farther toward the northwest. No evidence of an erosional discontinuity was observed beyond this point, and the base of the Laborcita formation was traced as a phantom horizon, about 30 feet above the persistent limestone bed 4. The strata on either side of horizon 5 are very similar in this area, and no recognizable break exists. The contact is considered gradational, and deposition appears to have been essentially continuous in the area north of La Luz Canyon.

Limestones of the Holder formation are overlain with an angular discordance of about 10 to 15 degrees by red Laborcita conglomerates and shales in the southeasternmost part of the map area, in the exposures near and along State Highway 83, about three-fourths of a mile west of the tunnel. The beds directly overlying the unconformity occur in about the same stratigraphic position as the conglomerate bed 5 in Fresnal Canyon. The abrupt wedging of several beds in the lower part of the Laborcita formation (pl. 9, sections 1 and 2) was partly caused by an onlap of these strata on a preexisting anticlinal structure in the Holder formation (pl. 2, MM' and NN').

Further evidence of post-Holder and pre-Laborcita folding and faulting exists in Salada Canyon, about 1 mile north of State Highway 83. These faults are a northward extension of the Fresnal Canyon fault zone in the southeasternmost part of the map area (pl. 2). Directly west of this major fault zone, near Salada Canyon, red conglomerates and shales of the Laborcita formation are conformable with limestones of the Holder formation (pl. 2, LL'). Ventricose *Triticites* in the limestones indicate a late Fresnal age. About 1,000 feet northeast of these outcrops, in the Fresnal Canyon fault zone, similar red conglomerates and shales of the Laborcita formation overlie with an angular discordance of about 15 degrees the overturned beds of the Holder formation, which are dated by Thompson (personal communication) as middle

Fresnal on the basis of fusulinids. In the fault zone, the Laborcita strata overlie the eroded top part of the folded Holder formation, and perhaps as much as 200 feet of Holder strata is missing.

In the Upper La Luz Canyon area, 3 miles east of the junction of La Luz and Fresnal Canyons, conglomerates of the Laborcita formation overlie upper Virgilian strata of the Holder formation with a distinct angular unconformity of as much as 40 degrees.

Known angular discordance between the Holder and Laborcita formations occurs east of a line that trends northward from State Highway 83, where it coincides with the Fresnal Canyon fault zone (pl. 2). Similar structural discordances are inferred in the subsurface north of the Upper La Luz Canyon area (pl. 2).

The lower contact of the Laborcita formation is an example of an abrupt disappearance of an angular unconformity. This lower contact appears to be gradational in the area northwest of La Luz Canyon, gradually becomes a disconformity, and then comes a marked angular unconformity toward the southeast and east, within a lateral distance of 3 miles. In that direction, uplift and folding must have been initiated prior to and during the deposition of the Laborcita formation.

The upper contact of Pray's (1952) Bursu formation was selected at the base of marker bed 29, a relatively persistent conglomerate. The base of this bed was considered by Pray (19 2, p. 251) to be a slight angular unconformity. Tracing of bed 29 toward the southeast revealed that it grades into a quartz sandstone 13/4 miles southeast of La Luz Canyon. Conglomerate bed 29 lenses out about half a mile north of Cottonwood Canyon, where fusulinid-bearing shales and limestones overlie the conglomerate. The quartzite-cobble conglomerate of the basal Abo in the High Rolls area was traced into marker bed 50 (pl. 2; sec. 34, T. 15 S., R. 11 E.). This bed lenses out in a very short distance, but overlies a similar conglomerate, bed 49, by about 10 feet. Bed 49 is very extensively exposed and is easily mappable. The upper contact of the Laborcita formation was selected at the base of bed 49 south of Domingo Canyon, where it is considered a disconformity, and the 200 feet of strata that occurs between the top of Pray's Bursum formation and the base of bed 49 is included in the Laborcita formation.North of Domingo Canyon, where marine and nonmarine beds interfinger, the contact is gradational and was selected successively at the base of bed 53 and the top of bed 55, marking the top of dominantly marine strata (pl. 4). This contact is also an excellent example of a major unconformity that dies out within *al* relatively short lateral distance.

Fauna, Flora, and Age

In the course of field tracing of individual beds, the stratigraphic position of some known fossil localities was determined, and other localities were discovered and the fossils collected. The collections contain a wide variety of marine fossils, such as fusulinids, brachiopods, cephalopods, gastropods, and pelecypods. Rocks in one locality yielded abundant plant fossils. The fossils were studied by specialists in each of the four major fossil groups: fusulinids, brachiopods, cephalopods, and gastropods. These studies indicated a definite conflict in age assignments for correlative parts of the Laborcita formation. This is significant in view of similar conflicts in other parts of the United States, especially west Texas, where lateral continuity of strata is difficult to determine. The detailed results and conclusions of the various specialists are given in the appendix of this report.

The fusulinids, commonly used for regional correlation of Pennsylvanian and Permian rocks, occur more abundantly through the Holder and Laborcita formations than any other fossil group. For this reason, the writer used fusulinid zoning as a basis for regional correlation and for determination of the Pennsylvanian-Permian boundary in the map area. Dr. M. L. Thompson identified the fusulinids.

In the mouth of Laborcita Canyon, the upper part of the Holder formation and the lower part of the Laborcita formation contain many fusulinid-bearing limestones (pl. 7, section 18). M. L. Thompson (personal communication) considers the fusulinids of sample 18-F-4 to be Virgilian in age. *Schwagerina* sp. of "Bursum" age occurs in 18-F-5, about 29 feet higher in the section, and sample 18-F-6, another 34 feet higher, contains a *Dunbarinella* sp. which is found in the Texas Wolfcampian and is definitely Permian in age. Therefore, the base of the Permian was selected at the base of the limestone bed that contains the *Schwagerina* sp. of sample 18-F-5, which corresponds to horizon 9. The lowermost 90 feet of the Laborcita formation at the type locality is considered late Virgilian in age, and corresponds to about 60 feet of strata in the section that overlies Thompson's type section of the Fresnal group.

This position of the base of the Permian agrees with other microfossil data. Pray and Covington (Pray, 1952, p. 227) collected fusulinids from a zone 20 feet above the top of the Holder formation, about 300 feet northwest of the type section of the Fresnal group. R. C. Spivey, Shell Oil Co., identified these as Virgilian forms. The fusulinids that occur in the southern part of the area, a quarter of a mile north of Highway 83, in the red shales (4-F-1 and 4-F-2) of the basal part of the Laborcita formation, are also considered to be Pennsylvanian forms by Thompson (personal communication). Near Fresnal Canyon, horizon 9, the base of the Permian, coincides approximately with the top of the carbonaceous limestone that was mapped as bed 8.

The middle part of the Laborcita formation is lower Wolfcampian in age. In section 11, sample 11-F-2 is from the zone of Wolfcampian fusulinids reported by Thompson (1942, p. 82) and Bowsher (King et al., 1949, p. 61).

Fusulinids collected north of Tularosa aided in determining an upper age limit for the beds of the Laborcita formation. Collection 30-F-1 (section 30), found on the flank of the algal bioherms, occurs about 800 feet above the base of the Laborcita formation and contains Wolfcampian *Schwagerina* and *Dunbarinella* species. According to Thompson (personal communication), these forms should be correlated above the top of the type Bursum formation, but they appear to be older than the fusulinids in the Powwow conglomerate in the southern part of the State. The *Schwagerina* sp. in sample 28-F-1 of bed 55, which is the uppermost member of the Laborcita formation and occurs about 1,000 feet above the base, is, according to Thompson (personal communication), younger than any of the forms known from the Bursum formation. In the same bed 55, farther to the north, the writer identified some fusulinids from sample F-9 as *Schwagerina cf. hueco-ensis,* a form that also occurs in the lower division of the Hueco limestone overlying the Powwow conglomerate. According to Lloyd (1949, p. 31), the Hueco limestone is of middle and upper Wolfcampian age, suggesting that the uppermost part of the Laborcita formation in the northern part of the map area is perhaps as young as middle Wolfcampian.

On the basis of the fusulinid identifications, the basal portion of the Laborcita formation, perhaps as much as 90 feet, is late Virgilian in age. The overlying part, which has a total thickness of about 900 feet, is considered by the writer to form the lower Wolfcampian, and the overlying Abo formation represents the middle and upper Wolfcampian, as will be discussed later.

Dr. G. A. Cooper studied the brachiopods and considers them Permian rather than Pennsylvanian in age (personal communication). His conclusions are based largely on a group study of the brachiopods collected from several localities in the Laborcita formation. According to Cooper, the occurrence of *Dictyoclostus welleri*, *Derbyia* sp., and *Wellerella* sp. is indicative of a Permian age. They were found in localities M-3, 11-M-1, 13-M-1, and 30-M-3, which are in a position at least 250 feet above the base of the Laborcita formation, or about 160 feet above the base of the Permian as determined on the basis of fusulinids.

Dr. A. K. Miller examined the cephalopods from the clay pit east of Tularosa and concluded, as in his previous study in 1932, that the beds are upper Pennsylvanian (personal communication). This locality (M-1) occurs about 450 feet above the base of the Laborcita formation and occurs, therefore, stratigraphically above both diagnostic Wolfcampian fusulinids and brachiopods. According to Bowsher (personal communication), the gastropods of the Tularosa clay pits also resemble Pennsylvanian forms more closely than Permian ones.

Fossil plants collected by C. B. Read east of Alamogordo in the upper unit of the Magdalena group (Read in King, 1942, p. 676) probably were derived from the dark shales that overlie the base of the Laborcita formation in Fresnal Canyon at the locality of section 7.

These plants belong to the *Callipteris* floral assemblage, which is considered basal Permian. This is not in accord with this report, as the base of the Permian selected on the basis of fusulinids is at the top of the overlying carbonaceous limestone, about 40 feet higher in the section. However, the detailed correlation of faunal and floral assemblages is still poorly established, and this conflict in age may not be of much significance.

Correlation and Regional Relationships

Rock units of early Wolfcampian age have been recognized in surface outcrops and in the subsurface in many parts of New Mexico. In central New Mexico, thin marine limestones interbedded with coarse conglomerates and red sandstones have been named the Bursum formation (Wilpolt et al., 1946). The limestones contain several types of fusulinids, such as *Schwagerina emaciata* var. *jarillensis, Schwagerina emaciata,* and *Triticites* sp. (Stark and Dapples, 1946). According to Thompson (1942), this fauna is slightly younger than the basal Permian Wolfcampian faunas of Kansas and northern Texas. An almost identical fauna was collected from a locality near the La Luz pottery plant (11-F-2) in the map area, 280 feet above the base of the Laborcita formation. Thompson (1954) later showed that the basal type Bursum is late Virgilian in age. The upper part of the Laborcita formation is younger than any Bursum beds in the State, as was shown above. The Bursum formation, therefore, corresponds to the lower and middle portion of the Laborcita formation.

In the Oscura Mountains, basal Permian fusulinid-bearing limestones and interbedded red beds overlie red beds of Fresnal age (Thompson, 1942, p. 82). The limestones are disconformably overlain by red beds of the Abo formation, and are probably, at least in part, equivalent to the Laborcita formation of the northern Sacramento Mountains. Thompson (1942, pl. 2; 1954) recognized lower Permian marine limestones in Rhodes Canyon in the San Andres Mountains, and in southern New Mexico in the Robledo Mountains. The lower Permian marine strata in southern New Mexico, which Thompson (1942, 1954) considered younger than earliest Wolfcampian, are probably correlative to the limestones indicated in Plate II of Thompson's paper. They correspond in age to the middle portion of the Laborcita formation.

Pray (1952, p. 254) has given convincing evidence that the Hueco limestone of southern New Mexico and northwest Texas correlates with the Abo formation of the Sacramento Mountains. The Hueco limestone is of middle and late Wolfcampian age (Lloyd, 1949, p. 33). In Plate 13, the relative stratigraphic position of the Laborcita formation and Hueco limestone is indicated. Contrary to King and Read (King, 1942, p. 677), the Laborcita formation is older than the Hueco limestone, and the bulk of the Laborcita formation is probably older than the Powwow conglomerate, as was determined by Thompson on the basis of fusulinids. Only the uppermost 200 feet of the Laborcita formation in the area north of Tularosa may be the time equivalent of the Powwow conglomerate. In this report, the Laborcita formation is considered to be latest Virgilian and early Wolfcampian in age.

In many places in central and southern New Mexico, the Pennsylvanian-Permian boundary is marked by either a regional disconformity or an angular discordance, as in the central arid southern Sacramento Mountains and areas to the southeast. The absence of uppermost Virgilian and lowermost Wolfcampian strata indicates a period of nondeposition or erosion, and widespread retreat of the ocean. In a few places, such as north and west of the Sacramento Mountains in south-central New Mexico, more or less isolated marine basins of deposition must have existed that received detritus without interruption. During middle Laborcita time, transgressions of the sea at times covered many parts of central and southern New Mexico, and were followed by a period of nondeposition or by deposition of Abo red beds. The early Wolfcampian sea persisted in the area of the northern Sacramento Mountains and apparently retreated toward the northwest and west (pl. 2 and 13) at the end of Laborcita time. The section of the Laborcita formation in the Sacramento Mountains is thicker and contains fewer red beds than the Bursum formation of central New Mexico.

Deposition of the Hueco limestone marked a new invasion of the Wolfcampian sea, which extended as far north as the northern San Andres Mountains (Kottlowski et al., 1956), but in the northern Sacramento Mountains, Abo-type deposition continued. A tongue of the Hueco limestone in the southern Sacramento Mountains is discussed under the Abo formation.

In the southeastern part of the State, beds of Laborcita and Hueco age have been recognized in the subsurface on the basis of fusulinids (Lloyd, 1949, p. 33):

> Over most of the area the rocks are limestone and dolomite with interbedded gray, black and red shale. There is a gradual increase in the amount of clastic material to the north and west and near the old Pedernal Mountains red shale and sandstone are the predominant constituents.

The Pedernal Landmass and ancestral Sacramento Mountains appear to have formed a land barrier between the early Wolfcampian sea in the southeastern part, and the south-central and central parts of the State of New Mexico.

ABO FORMATION

The Abo sandstone was originally defined by Lee (1909, p. 12) as a distinctive lithologic unit of coarse-grained sandstone, dark red to purple, commonly conglomeratic at the base, and with a subordinate amount of shale. According to Lee, the Abo sandstone forms the lowermost unit of the Manzano group and rests unconformably on the Magdalena limestone in central New Mexico. The name was derived from Abo Canyon at the south end of the Manzano range. Lee did not designate a precise type locality, nor did he describe a type section for the Abo sandstone. This deficiency was corrected by Needham and Bates (1943, p. 1654). The type section of the Abo formation is near the village of Scholle, in Abo Canyon. As mudstones and shales constitute about two-thirds of the type section, the name Abo sandstone was changed to Abo formation.

At the type locality, the Abo formation is 914 feet thick and overlies a thin lower Permian limestone, now mapped as the Bursum formation. According to Needham and Bates (1943), the lower contact of the Abo formation is an unconformity. The formation rests on beds ranging in age from early Wolfcampian, in the area of the type locality, to Precambrian, in the Zuni Mountains. In the description by Needham and Bates (1943, p. 1655), the Abo section included 104 feet of pinkish sandstone at the top, but upon the recommendation of C. B. Read (Bates et al., 1947, p. 26-27), this uppermost unit has been assigned to the overlying Yeso formation. The contact with the Yeso formation appears to be gradational in many places.

A thick succession of dark-red mudstones, arkoses, and subordinate amounts of limestone is exposed in the central and northern parts of the Sacramento Mountains. No identifiable marine fossils have been collected from these strata. Petrified wood is locally abundant, and the beds are considered to be terrestrial in origin. The beds have been correlated with the Abo formation of central New Mexico because of the distinctive coloring and similar stratigraphic position.

The Abo formation in the Sacramento Mountains varies markedly in thickness. Near High Rolls, in the southern part of the map area, the formation is about 400 feet thick (Pray, 1952, pl. 18). North of Tularosa, the Abo formation has a thickness of 1,400 feet. The Abo formation overlies beds of Pennsylvanian age with a sharp angular discordance in many parts of the central and southern Sacramento Mountains. Where the Abo formation is in gradational contact with the underlying Laborcita formation, as in most of the northern Sacramento Mountains, it is thicker. The Abo and overlying Yeso formations appear to be essentially parallel in the Sacramento Mountains. According to Pray (1952, pl. 18), in the central and southern part of the Sacramento Mountains, thin beds of limestones and shale form a wedge that thickens markedly toward the south. The wedge separates thinning tongues of the Abo red beds, as has been indicated in Plate 13 of this report.

Areal Distribution

The Abo formation is exposed throughout the entire length of the Sacramento Mountains escarpment. The western profile of the Sacramento Mountains is characterized in most areas by an upper and lower escarpment separated by a relatively flat bench. The relatively non-resistant Abo strata underlie most of this gently rising surface or bench.

Southward from High Rolls, the outcrops of the Abo formation form a narrow band a quarter of a mile wide, according to Pray (1952, p. 235). Between High Rolls and Laborcita Canyon, the Abo formation underlies the eastern edge of the southern part of the map area (pl. 3). Near Laborcita Canyon, the Abo bench is about 3 miles wide and gradually widens to about 6 miles near Tularosa, which is in part caused by the northward increase in thickness of the Abo formation. About 5 miles north of Tularosa, the Abo formation is covered by overlapping Quaternary gravel deposits.

Lithology

In the northern part of the Sacramento Mountains, the Abo formation consists of a thick monotonous sequence of red beds. Dark-red mudstones occur interbedded with arkoses, conglomerates, and minor amounts of limestones. In the southern part of the escarpment, the section is composed dominantly of brackish to marine deposits of limestone and shale (Pray, 1952, p. 235). The thickness of the Abo formation varies considerably throughout the length of the escarpment. In the central part of the Sacramento Mountains, the Abo formation is 250 to 500 feet thick (Pray, 1952, pl. 18) and thickens progressively toward both the south and the north. Generalized stratigraphic sections of the Abo formation along the length of the Sacramento escarpment are indicated in Plate 13. Measured sections 5, 6, 7, and 8 in this diagram illustrate the changes that take place in the Abo formation in the northern part of the escarpment. On the basis of the location of these sections, the discussion of the Abo formation in the map area is subdivided as follows: the High Rolls area, the Upper La Luz Canyon area, the Cottonwood Canyon area, and the Tularosa area. The stratigraphic sections of the last three areas have been shown in detail in Plates 10, 11, and 12.

High Rolls Area. Section 5 (pl. 13), which is described in detail by Pray (1952, pl. 19), is representative of the Abo formation in the southernmost part of the map area, near High Rolls, where the formation is 420 feet thick. Dark-red mudstones constitute about three-fourths of the section; nearly 10 percent is coarse-grained arkose, and the remainder consists of a quartzite-cobble conglomerate that forms most of the lower 60 feet of the Abo. This conglomerate overlies the truncated edges of the Pennsylvanian rocks in the southeastern part of the map area. Toward the west, it overlies beds of the Laborcita formation and has been mapped as bed 50 (pl. 2). Horizon 50 occurs about 10 feet higher than the base of bed 49, which is also a quartzite-cobble conglomerate that has been defined as the base of the Abo formation toward the northwest.

Upper La Luz Canyon area. The stratigraphic section of the Abo formation measured in the upper part of La Luz Canyon is about 21/2 miles north of the High Rolls section. The base of the La Luz Canyon section, shown in detail in Plate 10, is near the center of NE1/NE1/4 sec. 27, T. 15 S., R. 11 E.

Three-fourths of the section, which is 727 feet thick, is composed of dark-red mudstones. Conglomerates, arkoses, and sandstones constitute the remainder of the section. They are laterally discontinuous, in many places lens out abruptly, and show marked crossbedding and scour-and-fill structures at the base. The part of the Abo formation shown in Figure 9, which corresponds to unit 11 (pl. 10), is typical for much of the Abo section.

The lower 74 feet of the Abo formation in this measured section is correlative with 267 feet of the Abo west of the area of Pennsylvanian outcrops in the upper part of La Luz Canyon. This correlation was determined by detailed tracing of units 1 and 4 (pl. 10) from east to west in La Luz Canyon. The thicker western section contains red mudstones and thin argillaceous limestone layers, and zones with limestone nodules. The limestones are absent in the thinner eastern section.

Cottonwood Canyon area. The Cottonwood Canyon section northeast of La Luz is almost 1,000 feet thick (pl. 11). Two-thirds of the section is red mudstone, and nearly 30 percent consists of coarse sandstones, arkoses, and conglomerates. The remainder is formed by a few thin, very argillaceous limestone layers and zones of limestone nodules, interbedded with dark-red mudstones.

Near the middle of the section, a 66-foot-thick zone of quartzite-cobble conglomerate, which contains about 10 percent of feldspar porphyry in an arkosic matrix, forms a distinctive and resistant ledge. This is unit 29 in Plate 11 and is correlated with unit 10 in Plate 10. The base of this bed could not be mapped much north of Cottonwood Canyon but marks a distinctive break in the Abo formation in the southern part of the map area. The section below this unit is characterized by a complete lack of arkose and a scarcity of feldspathic sandstone and clasts of feldspar-bearing igneous rocks, such as granite and feldspar porphyry, in the conglomerates (pl. 10 and 11). The sandstones in this part of the section are commonly very calcareous quartz sandstones. In the Cottonwood Canyon section, the minor amounts of unfossiliferous grayish-red very argillaceous limestone are restricted to the lower part of the Abo formation below the quartzite-cobble conglomerate, as in the section in La Luz Canyon, west of the area of Pennsylvanian outcrops.

Tularosa area. North of Tularosa, the Abo formation has a measured thickness of almost 1,400 feet. Details of the Abo section measured here by L. C. Pray and the writer are shown in Plate 12. The uppermost 250 feet of the underlying Laborcita formation, above horizon 49, corresponds to Abo beds in the southern part of the area (pl. 13). Between Cottonwood and Tularosa Canyons, a distance of about 10 miles, the increase in thickness of the strata overlying bed 49 amounts to approximately 650 feet. About half of the Abo section north of Tularosa is composed of dark-red mudstones. Coarse arkoses and conglomerates make up about 40 percent of the section. Argillaceous limestones and nodular limestones, which are largely restricted to the lower 500 feet of the section, constitute the remaining 10 percent.

Rock types.

Conglomerates. Conglomerates of the Abo formation are marked by the abundance of quartzite clasts. In many places, almost pure quartzite-cobble conglomerates occur in the lower part of the Abo formation. Although quartzite pebbles and cobbles also have been observed in the upper part of the Laborcita formation in the southern part of the map area, they generally occur mixed with substantial amounts of limestone and chert. Several of the monolithic quartzite conglomerates, such as beds 49, 50, and 53, were mapped for several miles and have been used to define the basal contact of the Abo formation. The size of the quartzite fragments and sorting of the conglomerate are shown in Figure 10.

Figure 9

INTERBEDDED DARK-RED MUDSTONES AND ARKOSES OF THE ABO FORMATION
Note lenticularity of the units. Roadcut on south side of La Luz Canyon, SE1/4NW1/4 sec. 25, T. 15 S., R. 11 E.

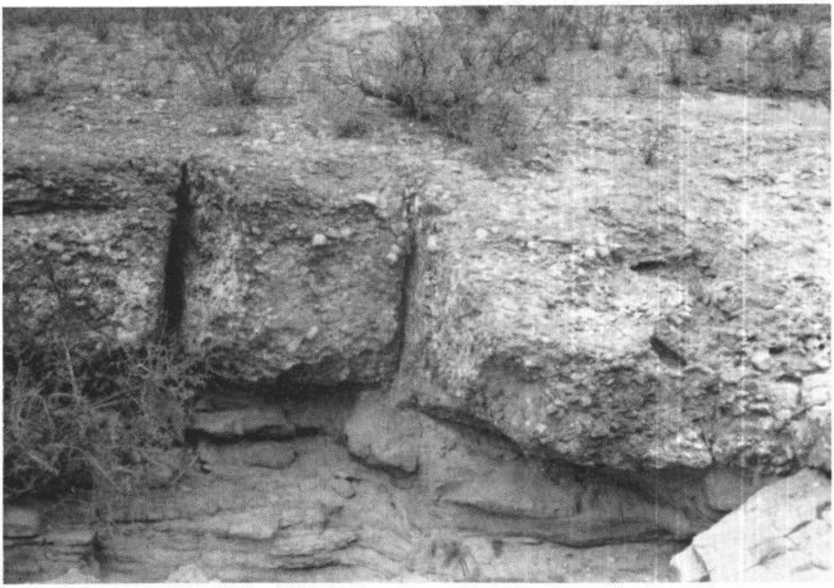

Figure 10

BASAL ABO QUARTZITE-PEBBLE AND COBBLE CONGLOMERATE *(BED 53)* OVERLYING GREENISH SILTSTONES OF THE LABORCITA FORMATION

One-quarter mile north of Domingo Canyon.

Both fresh and weathered feldspars were observed. The feldspar content of the arkoses appears to decrease with the grain size, and the finer grained rocks are generally composed of feldspathic or quartz sandstones. Thinsection study of a few Abo siltstones and arkoses indicated that the rock color is caused by the dark-red clays of the matrix.

Mudstones. Dark-red to dusky-red mudstones form about two-thirds of the entire formation. The total amounts decrease toward the north. Mudstone is the dominant rock type but less conspicuous than any of the other rocks because of its nonresistant nature. In many places, the mudstone is calcareous and very silty.

Limestones. Limestone beds or zones of limestone nodules are in most places restricted to the lower part of the Abo formation. More massive limestone ledges occur in the Abo section exposed near Tularosa. The limestones are characterized by a high clay content. The insoluble clay residue of one limestone formed 26 percent of the original sample. However, the average clay content of the Abo limestones is about 13 percent, as opposed to a clay content of 4 percent for the Laborcita limestones. The reddish color of many of the limestones and limestone nodules probably is caused by the interstitial red clay.

A few of the argillaceous limestones in the lower part of the Abo section near Tularosa are relatively more continuous, and unit 16 of Plate 12 could be traced for nearly 4 miles. In thinsection, these limestones show remains of invertebrate shells; therefore, they probably were deposited in a shallow-water marine environment, although a fresh-water origin cannot be ruled out. The grayish-red very fine grained argillaceous limestones with undulatory bedding and the nodular limestones are shoreward, apparently shallow-water extensions of the thin-bedded argillaceous limestones.

Local correlation. The increase in thickness between the sections of the Abo formation in the central and northern parts of the Sacramento Mountains is striking and is caused mainly by the addition of strata in the basal portion of the Abo formation toward the west and northwest, as is shown in Plate 13. The Abo formation south of High Rolls overlies with angular unconformity rocks of Pennsylvanian or older age and is approximately 400 feet thick. Because of the presence of arkoses, the 300-foot section overlying the basal quartzite-cobble conglomerate has been correlated with the top 400 feet of section 35 (pl. 10), in La Luz Canyon, and the uppermost 500 feet in section 36 (pl. 11), in Cottonwood Canyon. The twofold division of the Abo formation in this southern area is not as distinct in the Tularosa area. The massive conglomerate that marks the base of the upper member can be traced only for about a mile north of Cottonwood Canyon, and arkoses occur through the Laborcita and entire Abo sections near Tularosa, not being restricted to the upper portion of the Abo formation as in the area to the south. However, the lower part of the section in Cottonwood Canyon, as well as in Tularosa Canyon, is characterized by the occurrence of limestones, which are almost completely lacking in the upper portions. On this basis, the writer believes that the lower 500 feet of the Cottonwood section is approximately the time equivalent of the uppermost 250 feet of the Laborcita formation above horizon 49 and the lower 500 feet of the Abo section in the Tularosa area (pl. 13).

The lower part of the Abo formation in the northern Sacramento Mountains, the part that thickens so markedly toward the northwest, corresponds approximately to the quartzite-cobble conglomerate of the High Rolls area, and possibly to the zone of limestone conglomerates in the area 5 miles to the south (Pray, 1952, pl. 18). The unconformity at the base of this conglomerate dies out to the northwest and corresponds in the main to the entire Laborcita formation, as shown in Plate 13. A great many diastemic breaks at the base or within the coarse clastic units of the Abo formation undoubtedly occur in the southern part of the map area. These local breaks are probably the equivalent of strata in the lower part of the Abo formation farther to the northwest; for example, of conglomerate bed 53, which does not appear south of Domingo Canyon.

The upper part of the Abo in the northern Sacramento Mountains has been correlated southward with the bulk of the Abo formation overlying the quartzite conglomerates near High Rolls and the limestone conglomerates in the central part of the Sacramento Mountains. If this correlation is correct, the "upper" Abo has a relatively uniform thickness throughout the area.

Conditions of Deposition

Environment. The Abo formation of the northern Sacramento Mountains was deposited largely under continental conditions. Abundant petrified wood, lack of marine fossils, discontinuous nature of the beds, channel fillings, crossbedding, and the dark-red color are factors suggesting the terrestrial origin of most of the Abo beds.

Laterally extensive quartzite-pebble and cobble conglomerates are largely restricted to the Abo formation in the area south of Tularosa Canyon. Particularly noteworthy are the beds at the base of the Abo formation, such as beds 49 and 53, and the conglomerate that forms the base of the upper arkosic part of the Abo formation in the area south of Domingo Canyon. The large clasts of the conglomerates indicate deposition on a surface of appreciable gradient, not far from an area undergoing active erosion. The relatively great lateral extent (as much as 8 miles) of some of these beds suggests deposition near the broad base of one or several coalescing fans, forming a continuous apron of waste in a piedmont area.

The crossbedded, discontinuous, coarse-grained sandstones and arkoses characterized an alluvial-plain environment and were probably the channel deposits of continuously shifting streams. Thin, very lenticular conglomerate beds are in most places associated with these deposits. The dark-red mudstones and siltstones probably indicate fluvial deposition on broad flood plains. The prevailing oxidizing conditions in the piedmont and alluvial-plain environments tended to preserve the red color of the source-area detritus. Conditions of deposition of red beds were discussed in more detail for the Laborcita formation.

Depositional history. The lower part of the Abo formation in the map area was deposited largely northwest and west of an area of minor Abo sedimentation in the present central part of the Sacramento Mountains. The lower part of the Abo thickens markedly, grades into finer grained sediments, and contains more limestones in those directions. The limestone beds and zones of limestone nodules in the lower Abo in the western and northern part of the map area probably suggest an environment of broad alluvial plains containing shallow fresh- or brackish-water bodies marginal to the sea. Brief marine incursions, probably from the northwest and west, alternated with prolonged periods of emergence. The quartzite-cobble conglomerates of the lower Abo in the northern Sacramento Mountains do not extend much south of the High Rolls area, and a Precambrian quartzite source mostly to the east, as near Bent, is proposed for the Abo formation in the southern part of the map area. The Abo formation north of Tularosa probably received much of its detritus from a separate source to the northeast or east, as indicated by the abundance of feldspars in that section. Both areas of provenance are inferred parts of the Pedernal Landmass, which locally must have been formed by mountains of considerable height.

The upper part of the Abo formation in the northern Sacramento Mountains is relatively uniform in thickness and composition, and is characterized by a considerable increase in the amount of arkose and absence of limestone as compared to the lower part of the Abo formation. Coarse-grained, poorly sorted arkoses, in association with conglomerate lenses containing much granitic or feldspar porphyry debris, are considered the products of rapid erosion of the Precambrian-rock source areas. The detritus accumulated as stream-channel deposits in piedmont and alluvial-plain environments.

The thick sequences of red mudstones interbedded with irregular bodies of coarse-grained arkose probably indicate periods of deep weathering and soil formation alternating with periods of rapid erosion. This suggests recurrent uplift of the source areas. Pray (1952) showed that the deposition of the Abo formation in the central part of the Sacramento Mountains was in part contemporaneous with folding, which is supporting evidence for continued unrest in south-central New Mexico during deposition of much of the Abo formation.

Contact Relationships

The basal contact of the Abo formation changes toward the west and northwest from a major angular unconformity to a disconformity to a gradational contact in a distance of 10 miles.

In most of the Sacramento Mountains escarpment, the Abo formation overlies rocks of Pennsylvanian age with distinct angular unconformity. According to Pray (1952, p. 250), the angular discordance is locally as high as 60 degrees in the central and southern parts of the mountains. In the southeastern part of the map area, the Abo formation occurs in angular discordance of about 20 degrees with the strata of the underlying Holder and Laborcita formations. In the upper part of La Luz Canyon and near Salada Canyon (sec. 34, T. 15 S., R. 11 E.), folding and faulting preceded deposition of the Abo beds (pl. 2). Field evidence indicates that the pre-Abo erosion surface was one of low relief in the Sacramento Mountains, as is supported by Pray's findings (1952, p. 251).

West and northwest of the Fresnal Canyon fault zone, between Fresnal Canyon and Domingo Canyon, the lower contact of the Abo formation is defined respectively by the base of the coarse quartzite-cobble conglomerate beds 50 and 49. Where these beds form the contact, it is considered a disconformity. The nonmarine red beds of the Laborcita formation directly west of the Fresnal Canyon fault zone, although in part lithologically very similar to the strata of the overlying Abo formation, can be separated from the Abo beds on the basis of these conglomerates and the marked increase of quartzite clasts.

North of Domingo Canyon, the Abo beds intertongue with the uppermost beds of the Laborcita formation, and the contact is gradational. The contact was selected successively at the base of bed 53 and the top of bed 55 (pl. 13).

The Abo formation above the unconformity is younger than bed 49 (pl. 13) and is of late early Wolfcampian age, on the basis of fusulinids in this zone north of Tularosa. Inasmuch as upper Virgilian strata are locally present below the unconformity (e.g., just north of Salada Canyon, in NE1A sec. 34, T. 15 S., R. 11 E.), the major period of deformation in the Sacramento Mountains area must have taken place between late Virgilian and late early Wolfcampian time. That interval coincided with the deposition of the Laborcita formation in the northern Sacramento Mountains, where the Abo formation is essentially parallel to the underlying beds.

The upper contact of the Abo formation with the Yeso formation is thought to be gradational. The lowermost Yeso beds are greenish shale or siltstone, thin limestone, or orange mudstone containing abundant gypsum. Within the map area, the contact is in most places not very well exposed. Where the exposures permitted, the contact was selected at the base of the first light-colored gypsum-bearing beds overlying the dark-red mudstones of the Abo formation. The lithologic change is transitional in many places.

Fauna

According to Pray (1952, p. 252), gastropods occur in the Pendejo tongue of the Hueco limestone in the Sacramento Mountains (pl. 13) but have not been studied in detail. The more continuous and massive limestone ledges in the Abo section near Tularosa contain unidentified fragments of invertebrate fossils. These appear to be remains of pelecypods and gastropods but are not diagnostic for either marine or fresh-water origin. The invertebrate fossils from previously known fossil localities in "questionable" Abo strata in the Sacramento Mountains are in beds now included in the Laborcita formation.

No vertebrate remains were collected from the Abo formation in the Sacramento Mountains. In the map area, the Abo formation contains abundant quantities of petrified wood.

Age and Correlation

Pray (1952, pl. 18) demonstrated that the Abo formation of the central Sacramento Mountains is equivalent to much of the Hueco limestone of western Texas. The threefold division of the Abo formation in the central and southern parts of the escarpment is correlated with the Hueco limestone as defined by King and Knight (1945). The lower tongue of the Abo formation grades into the Powwow conglomerate; the Pendejo tongue is correlative with the lower and middle divisions of the Hueco limestone; and the upper tongue of the Abo formation is considered to grade into the Deer Mountain red shale, which forms the basal part of the upper division of the Hueco limestone. The age of the Abo formation in most of the Sacramento Mountains is largely dependent upon the age of the Hueco limestone.

King and Knight (1945) assigned a Wolfcampian age to most of the Hueco limestone, with a possibly Leonardian age for the upper part. According to Lloyd (1949, p. 31), the Hueco limestones above the Powwow conglomerate (i.e., the limestones of the lower division) do not contain the lowermost Wolfcampian fusulinids. He considered the Hueco limestone to be late Wolfcampian, or possibly middle and late Wolfcampian. On the basis of the stratigraphic information from the Sacramento Mountains and the fusulinid identifications by M. L. Thompson, the Laborcita formation is considered to be of early Wolfcampian age. Fusulinids in the Tularosa area, 200 feet below the top of the Laborcita formation (30-F-1), and about 700 feet above the Pennsylvanian-Permian boundary, are older than those of the Powwow conglomerate (M. L. Thompson, personal communication). *Schwagerina* cf. *huecoensis*, collected in the limestone that forms the top of the Laborcita formation (bed 55), occurs in the lower division of the Hueco limestone directly overlying the Powwow conglomerate. The Powwow conglomerate corresponds then to the uppermost 200 feet of the Laborcita formation of the Tularosa area and is considered late early Wolfcampian. In this report, the lower division of the Hueco limestone is considered middle Wolfcampian, and the middle division, together with the Deer Mountain red shale, comprises the upper Wolfcampian. The remainder of the upper division of the Hueco limestone is possibly Leonardian in age. The suggested regional correlation of the Abo formation and Hueco limestone is indicated in Figure 11.

The lower, nonarkosic member of the Abo formation of the northern Sacramento Mountains, which includes the intertonguing portion of the Abo and Laborcita formations, thins abruptly toward the south and correlates with the lower 100 feet of the High Rolls Abo section (pl. 13), which contains the quartzite-cobble conglomerates, and with the Abo of the central Sacramento Mountains containing limestone conglomerates. This entire lower part of the Abo formation is considered to represent the late early and middle Wolfcampian, cor-

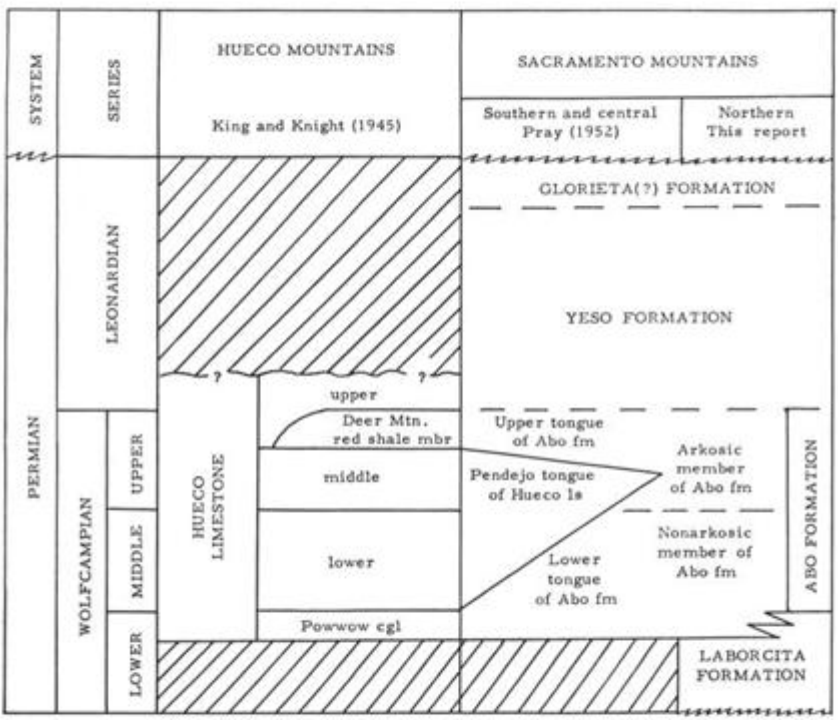

Figure 11

Age and regional correlation of Abo formation in the Sacramento Mountains responding to the Powwow conglomerate and lower division of the Hueco limestone. The upper part of the Abo formation, the arkosic member of the southern part of the map area, is of relatively uniform thickness and is considered of upper Wolfcampian age, the time equivalent of the middle limestone member of the Hueco limestone and the Deer Mountain red shale member of the upper division of the Hueco limestone.

Pray (1952, p. 255) indicated that the evidence from the flora conflicts with the Wolfcampian age of the Abo formation. C. B. Read identified plants of the *Supaia* floral assemblage from the Abo of Otero Mesa, between the Sacramento Mountains and the Hueco Mountains (King, 1942, p. 690). These plants probably came from the upper tongue of the Abo formation. The *Supaia* assemblage is indicated by King (1942, pl. 2) as Leonardian in age. The *W alchia* flora that came from the Abo formation in the Sacramento Mountains probably indicates an early Permian age (King, 1934, p. 747).

Vertebrate fossils from the Abo formation, collected largely in central and northern New Mexico, have been reviewed by Romer and Price (1940, p. 29), who concluded that the fossils are of the same age as the vertebrates in the upper part of the Wichita group of central Texas, which is Leonardian in age (King, 1942, pl. 2). More recently, Langston (1949, p. 1903) concluded that the amphibian fauna from northern New Mexico is slightly more primitive than that found in the Clear Fork or Wichita groups of central Texas. This may indicate Wolfcampian age.

Regional Relationships

Beds of the Abo-type lithology occur mostly north of the south-central part of New Mexico. Toward the south, they grade into the Hueco limestone or equivalent marine deposits in west Texas. Limestones similar to the Hueco strata extend westward into southern New Mexico and Arizona. In the southeastern part of New Mexico, in Chaves County, a Wolfcampian section 2,100 feet thick was encountered in the subsurface (Lloyd, 1949). Hueco fusulinids have been found in the upper part of the section, and early Wolfcampian, pre-Hueco types in the lower part.

The pre-Abo unconformity, although not present everywhere, is nonetheless very widespread in New Mexico and west Texas (Pray, 1949). Beds of the Abo formation and Hueco limestone overlie rock units ranging in age from Precambrian to early Permian. In the subsurface, east of the crest of the Sacramento Mountains, the Abo formation is interpreted to rest on the Precambrian rocks of the Pedernal Landmass.

The Abo-Yeso contact cannot be determined satisfactorily southeastward from the Sacramento Mountains, inasmuch as both formations grade into carbonate rocks in that direction (R. E. King, 1945). In the southeasternmost part of the State, Lloyd (1949, p. 28) considered a sequence of limestone and dolomite interbedded with red and green shale to be correlative with the Abo formation on the basis of lithologic similarity. However, these strata contain fusulinids of Leonardian age and are not the time equivalent of the Abo formation west of the Pedernal Landmass.

YESO FORMATION AND YOUNGER PERMIAN STRATA

The Yeso formation was originally defined by Lee (1909, p. 12) and applied to a 100- to 2,000-foot-thick section of sandstone, shale, limestone, and gypsum overlying the Abo formation of the Manzano group in central New Mexico. Needham and Bates (1943, p. 1657-1661) redescribed the Yeso formation in the type area, where it is 593 feet thick. According to Pray (1952, p. 259), the four members that have been distinguished in other parts of New Mexico are difficult to recognize in the Sacramento Mountains and do not form practical subdivisions.

The Yeso formation has been recognized from north of Tularosa to beyond the southern extension of the Sacramento Mountains. In the area of study, the formation extends from northeast of Tularosa southward to Laborcita Canyon along the eastern boundary (pl. 3). R. C. Northup and L. C. Pray (Pray, 1952, pl. 20) measured a section near Tularosa Canyon, just east of the map area, which is representative for much of the Yeso formation in the northern Sacramento Mountains. They described 1,200 feet of the Yeso, which probably represents 90 percent of the total section. The section consists of silty shales, gypsum and gray limestones, and minor amounts of sandstone. The color varies and is pale red, pink, yellowish, or gray, but in general contrasts sharply with the dusky red of the underlying Abo beds. According to Pray (1952), the amount of red beds and evaporites that occur throughout this section decreases toward the south in the Sacramento Mountains, and the amount of limestone and dolomitic limestone increases in that direction. The limestones and interbedded shales contain invertebrate fossils, largely brachiopods and molluscs. However, the age of the Yeso formation is established in general on the basis of regional correlation and is considered Leonardian. The uniformity in thickness of the Yeso formation and general similarity of lithology over broad areas indicate that deposition in most of the area of the Yeso formation took place on a stable shelf.

In the Sacramento Mountains, the Yeso formation overlies the Abo red beds. In the map area, the lower contact was mapped for about 12 miles from Laborcita Canyon to a point about 2 miles north of Tularosa Canyon. The contact is locally poorly exposed as a result of slump features in the basal part of the Yeso. For a total distance of about 6 miles, the contact is hidden under Quaternary deposits. Where the contact was studied, it appears to be gradational, and no single laterally persistent bed in either the uppermost Abo or lowermost Yeso formation marked a break in the succession of strata. In general, the contact was placed at the major lithologic change from strata typical of the Abo formation to strata more characteristic of the Yeso formation. The upper part of the Abo formation consists largely of dark-red mudstone interbedded with coarse-grained arkose, which locally grades upward into a zone of interbedded red and green mudstone layers 1 or 2 feet thick. In other places, the dark-red mudstone occurs interbedded with yellow or green sandy siltstone and thin layers of dolomitic limestone or silty limestone. In this zone, which commonly is not over 15 feet thick, gypsum is generally present in large amounts. The contact was placed at the base of this transition zone, which probably marks a gradual change of nonmarine to marine environments. According to Pray (1952, p. 274), the transition zone between the Abo and Yeso formations probably records fluctuations of a major northward advance of the seas at this time.

East of the map area, the Yeso formation is overlain by the Glorieta(?) and San Andres formations, which are the youngest Paleozoic strata in the Sacramento Mountains. The Glorieta(?) formation is dominantly gray and olive-gray limestone and dolomite, with a few beds of white to yellow-gray calcareous fine- to medium-grained well-sorted quartz sandstone. The formation is about 60 feet thick in the northern Sacramento Mountains. Gray limestones of the San Andres formation crop out on the crest of the Sacramento Mountains. To the east, in the subsurface, the formation has been reported to be as much as 1,400 feet thick, but at most places on the crest of the range only the basal few hundred feet remain.

MESOZOIC STRATA

Sedimentary strata of Mesozoic age have been observed in the Sacramento Mountains only in a small outlier 20 miles east of Tularosa (Pray and Allen, 1956). Development of the present erosion surface in late Cretaceous or early Tertiary time in the western Sacramento Mountains caused the removal of most of the Mesozoic strata and the upper part of the San Andres formation.

Rocks of Triassic(?) and late Cretaceous age are known from the Capitan region (Wegemann, 1912), about 40 miles northeast of the map area, and were discussed more recently by Allen and Jones (1952, p. 1320). R. F. Schmalz (personal communication) observed the same strata in the Phillips Hills, about 25 miles north-northwest of Tularosa. He reported that limestones of the San Andres formation underlie 159 feet of Permian(?) Bernal orange-red mudstone and 185 feet of maroon and green mudstones assigned to the Chinle formation. The Santa Rosa quartz sandstone that occurs between the Bernal and Chinle formations in the Capitan region is not present in the Phillips Hills section. Rocks of Jurassic or early Cretaceous age are not known from these two areas. Upper Cretaceous Dakota sandstone, Mancos shale, and Mesaverde sandstone, shale, and coal have been observed in the Phillips Hills section, but individual thicknesses were not definitely determined. This Upper Cretaceous section reaches a thickness of about 1,500 feet, as compared to about 1,000 feet in the Capitan region (Allen and Jones, 1952). In the Phillips Hills area, the Cretaceous strata are unconformably overlain by Tertiary andesite flows and pyroclastic rocks.

Igneous Rocks

Sills and dikes of igneous rocks occur in many parts of the northern Sacramento Mountains and comprise about 5 percent of the map area. They offer greater resistance to erosion than the surrounding sediments and commonly are conspicuously exposed. Based on mineralogical composition, three rock types are recognized, which are listed in Table 1.

TABLE 1. COMPOSITION, DIMENSIONS, AND STRUCTURAL CONFIGURATION OF IGNEOUS ROCKS IN THE NORTHERN SACRAMENTO MOUNTAINS

ROCK NAME	TRINCIPAL FELDSPAR		DIMENSIONS		FORM AND STRUCTURAL CONFIGURATION
	TYPE	AMOUNT	AVERAGE THICKNESS (feet)	MAXIMUM LENGTH (miles)	
Quartz albitite	Albite	80%	50-100	4	Sills; laccoliths; locally discordant
Andesite porphyry	Andesine	70%	5-20	2	Sills; concordant
Felsite	Albite	60%	1-15	3½	Dikes

The structural configuration of the igneous rocks locally affected the nature of the exposures of the Laborcita formation and is used as a basis of discussion in this report.

SILLS

The sills in the area are composed of two types of rock, an andesite porphyry and a quartz albitite. The magma from which these rocks crystallized penetrated mostly the shale or mudstone portions of the Laborcita and Abo formations. The intrusive masses of andesite porphyry in most places are thin, very tabular sheets. The fine-grained intrusives of more acidic composition in a few places cut across the sedimentary strata to form discordant bodies.

QUARTZ ALBITITE

Fine-grained intrusive quartz albitite forms about three-fourths of the igneous rocks in the map area. These intrusives reach a thickness of 200 feet in many places and largely occur in the Laborcita formation, but in the La Luz Canyon area some intruded into the lowermost units of the Abo formation. Locally, the uppermost resistant ledge of the frontal escarpment is of tabular albitite masses that are nearly parallel to the underlying and overlying strata (fig. 12). Toward the east and southeast, the quartz albitite cuts slightly across bedding planes and intruded successively younger beds (pl. 4), but is tabular in shape and can be considered a sill.

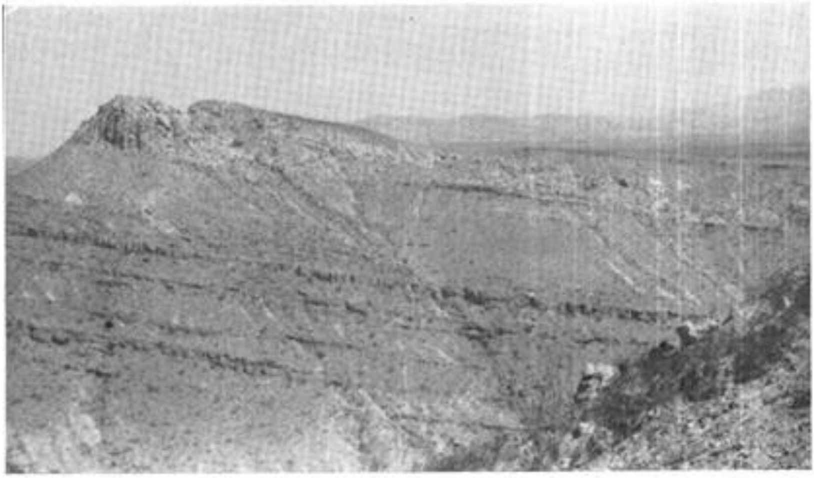

Figure 12

QUARTZ ALBITITE SILL FORMING RESISTANT LEDGE ON FRONTAL ESCARPMENT
View north, 1 mile south of Domingo Canyon.

Lath-shaped albite (An 5-10) crystals, 1 /6 to 1/4 mm long, form 80 percent of the rock. Quartz occurs in amounts up to 15 percent. Locally, biotite is relatively abundant (up to 20 percent) but generally is present only in small quantities and is commonly chloritized. Orthoclase was not found. A similar rock type was named a quartz albitite by Johannsen (1932, v. 2, p. 375). Drag features occur locally in the sedimentary beds near the intrusive contact, suggesting that the magma was relatively viscous during the intrusion, which might be attributed to its acidic composition. In NW1/4 sec. 19, T. 15 S., R. 11 E., tight folds in the fusulinid-bearing limestone bed 37 were caused by the quartz albitite intrusive, which is in this locality distinctly laccolithic in shape. The shales and thin sandstone beds underlying this intrusive are undisturbed (GG', pl. 2).

ANDESITE PORPHYRY

Although variations in composition exist, the dark-colored, thin, very tabular sills are generally an andesite porphyry. Examination in thinsection indicates that a microcrystalline groundmass, which probably consists mostly of feldspar and small quantities of quartz, constitutes about 50 percent of the rock. Plagioclase phenocrysts, 2 to 10 mm in size, form about 35 percent of the rock. The plagioclase feldspar appears to be andesine, although extensive alteration, largely to calcite, sericite, and kaolinite, prevented accurate determination. Hornblende is the major mafic mineral and commonly forms 15 percent of the rock.

The hornblende phenocrysts are 1 to 2 mm in size and are altered to epidote and chlorite. Magnetite is the most abundant accessory mineral.

The andesite porphyry sills range from a few to several tens of feet in thickness. Very thin sills were not mapped, so that the andesite porphyry is actually more abundant than appears on the map. The two largest sills occur in the north end of the map area, north of Tularosa Canyon. One forms the uppermost resistant ledge of the frontal escarpment, about 4 miles north of Tularosa; the other crops out continuously for a distance of about 4 miles near the Abo-Yeso contact.

DIKES

Intrusive dikes form distinctive, narrow linear features in the map area, and some extend for at least 31/2 miles. They are commonly 1 to 15 feet wide and are vertical or dip steeply. Because of their greater resistance to erosion, they form conspicuous topographic features, as shown in Figure 13. Most observed dikes occur in the mudstones and arkoses of the Laborcita and Abo formations and appear to be less abundant in the limestone-bearing portion of the lower Permian strata. The dikes generally trend between 20 and 30 degrees east of north, similar to the trend of the dikes in the Capitan region (Allen and Jones, 1952).

Megascopically, the dike rocks are fine grained and dark, and all appear to be of acidic to intermediate composition. Thinsections from the two parallel dikes that cross La Luz Canyon in sec. 26, T. 15 S., R. 11 E., show that small laths of albite, i/Ei to 1/4 mm in size, form about 60 percent of the rock. Magnetite is finely disseminated and constitutes about 12 percent of the rock. Biotite and chlorite, up to about 10 percent, form the rest of the dark mineral content. Calcite is locally abundant and forms the remainder of the rock. Quartz and potash feldspar were not recognized. On the basis of color, the dike rocks and the andesite porphyry appear to be similar, but mineralogically the quartz albitite sills and the dark felsite dikes are more closely related.

The relative age of the acidic intrusives and the dikes was determinable at one place in the area, near the boundary of secs. 19 and 20, T. 15 S., R. 11 E., where a sill of quartz albitite cuts across a dike of more intermediate composition and is clearly the younger.

AGE

The igneous rocks are presumed to be related to a major period of igneous activity recognized in many parts of New Mexico during Tertiary time. Their age cannot be closely determined in this area. These rocks intrude beds as young as the Permian Yeso formation and are truncated by the late Cenozoic faults of the frontal escarpment.

Figure 13
INTRUSIVE DIKE
South side of La Luz Canyon, NE1/4 sec. 26, T. 15 S., R. 11 E.

A basic dike swarm and larger siliceous bodies in Capitan quadrangle (Allen and Jones, 1952), about 40 miles northeast of the map area, were dated as middle Tertiary. The intrusives of the northern Sacramento Mountains appear to be similar in composition to these intrusives of the Capitan region. In view of the uncertainties, the igneous rocks of the northern Sacramento Mountains are considered in this report Tertiary(?) in age.

Geologic Structure

GENERAL DISCUSSION

The Sacramento Mountains form a part of the boundary between the Basin and Range province to the west and the Great Plains province to the east. The range is essentially a block that has been uplifted, with respect to the Tularosa Basin, along a fault zone on the west and tilted eastward. The western part of the range is structurally similar to the scarps of the Basin and Range province. The eastern portion possesses many structural features characteristic of the Great Plains region. From the crest of the mountains, the strata dip 1 to 2 degrees eastward and can be traced in that direction with only a few structural deviations for more than 50 miles.

The displacement on the frontal fault system of the Sacramento Mountains is known to be a minimum of 6,500 feet in the central part of the escarpment (Pray, 1952, p. 321) and decreases both toward the south and north. The fault, which defines the frontal escarpment of the northern Sacramento Mountains, is abruptly terminated by eastward trending structural features at a point about 5 miles north of Tularosa. Sierra Blanca, although topographically a northward extension of the Sacramento Mountains, appears to be developed along a different fault system, northeast of the fault zone at the base of the Sacramento Mountains. King (1942) interpreted the western escarpments of the Sacramento Mountains and Sierra Blanca to be the product of en echelon faulting. Structurally, Sierra Blanca is different from the Sacramento Mountains and represents a volcanic mass in a structural basin rather than a high tilted block.

The uplift of the Sacramento Mountains was during the latest period of tectonic activity in this area and apparently occurred in late Cenozoic time. Earlier periods of crustal deformation are recorded in the rock units of the northern Sacramento Mountains. In the southeastern part of the map area, there is evidence of a late Pennsylvanian and early Permian period of deformation, here referred to as the preAbo deformation. Evidence of post-Abo gentle folding was observed in the area south of Laborcita Canyon. Owing to the absence of sedimentary strata in the map area younger than the Yeso formation, and older than the Quaternary surficial deposits, this period of deformation could not be dated more closely. However, one of these later folds is cut by the boundary fault zone, indicating a period of deformation prior to late Cenozoic time. The numerous high-angle normal faults in the map area near the boundary fault zone probably are related to the late Cenozoic basin-and-range faulting. Thus, at least three periods of tectonic activity can be distinguished in the northern part of the Sacramento Mountains.

PRE-ABO DEFORMATION

One of the major angular unconformities within the Paleozoic sequence of the Sacramento Mountains occurs at the base of the Abo formation. The pre-Abo deformation caused major folding and faulting. According to Pray (1952, p. 332),

> The intensity of the deformation appears to increase toward the east across the narrow belt of pre-Permian outcrops and the area most influenced by this deformation probably lies farther to the east where it is concealed by the younger Permian deposits.

Pre-Abo high-angle faulting and folding were recognized in the south-eastern part of the map area east of a line that extends northward from a point 1 1/2 miles west of High Rolls to La Luz Canyon (pl. 2).

FAULTS

Resistant strata of the Bug Scuffle limestone member of the Gobbler formation rise abruptly above the less resistant strata of the Holder and Laborcita formations in the southeastern part of the map area. This is mainly a result of pre-Abo high-angle normal faulting (pl. 2). Between Fresnal Canyon and Salada Canyon, displacement occurred on a system of two essentially parallel faults, with the western sides downthrown. The western fault, called the Salada Canyon fault, was mapped for about 1 1/2 miles from Salada Canyon to Fresnal Box Canyon but may extend farther south. The Fresnal Canyon fault is the eastern fault and is exposed continuously for about 5 miles between Salada Canyon and Arcente Canyon to the south, as mapped by Pray (1952). There is evidence that the faults occur as buried structural features at least as far north as La Luz Canyon (pl. 2). The writer believes that these faults are parts of one major fault zone at depth and that movement took place along these various branches at different times during late Pennsylvanian and early Permian time. Parts of this fault system were re-activated in post-Abo time.

Salada Canyon Fault

Several periods of movement occurred along the Salada Canyon fault in late Pennsylvanian and early Permian time. Post-Holder, preLaborcita displacements took place at the north end, in the canyon one-third of a mile north of Salada Canyon (pl. 2). Here, the Salada Canyon fault offsets strata of the Holder formation about 200 feet, whereas these strata are overlain by undisturbed beds of the Laborcita formation. The pre-Laborcita displacement probably increases southward, where the Beeman formation is exposed in the fault zone. Between Salada and Fresnal Box Canyons, the lower part of the Laborcita formation is truncated by the Salada Canyon fault, necessitating movement on this fault in post-Laborcita and possibly post-Abo time.

The present elevation of the Abo formation east of the Salada Canyon and Fresnal Canyon faults, in the area adjacent to Fresnal Box Canyon, is about 800 feet above its restored position to the west (MM', pl. 2). This indicates post-Abo movement on this system of parallel faults, although as much as half the difference in elevation may be the result of folding. If a 350-foot-thick section of Holder and/or Laborcita strata were restored on top of the Beeman formation in the fault zone between the Salada Canyon and Fresnal Canyon faults, the base of the Abo formation in the fault zone would occur at the same elevation as the base of the Abo on the High Rolls block (MM', p1. 2). An estimate of 350 feet of post-Beeman and pre-Abo strata in the fault zone is not excessive, considering the thickness of about 850 feet for the corresponding section directly west of the Salada Canyon fault. Therefore, most of the post-Abo movement along this fault zone occurred on the Salada Canyon fault. Truncation of the lower part of the Laborcita formation by the Salada Canyon fault is probably the result of this post-Abo movement. According to Pray (1952, p. 334), post-Abo uplift also occurred in the area south of Fresnal Box Canyon but appears to have died out toward the north in the vicinity of Salada Canyon.

Fresnal Canyon Fault

The Fresnal Canyon fault was mapped by Pray (1952) for about 5 miles from Arcente Canyon, in the south, to Salada Canyon. In the canyon one-third of a mile north of Salada Canyon, the Fresnal Canyon fault offsets strata of the Laborcita formation that occur on the down-thrown side of the fault (pl. 2). These beds are overlain by undisturbed strata of the Abo formation. On the upthrown (eastern) side of the fault, the Abo formation is in depositional contact on beds of the upper Holder formation, which indicates at least a 400-foot movement on this fault during Laborcita and post-Laborcita, pre-Abo time. The displacement increases toward the south. Near Fresnal Box Canyon, the Abo formation overlies the Beeman and Gobbler formations, and the preAbo displacement is about 1,000 feet (MM', pl. 2), indicating that the major amount of displacement on the system of parallel faults occurred on the Fresnal Canyon fault, where the total stratigraphic separation on both the Salada Canyon and Fresnal Canyon faults is about 1,600 feet. According to Pray (1952, p. 334), this displacement decreases again southward, and the fault dies out in the vicinity of Arcente Canyon.

A north-trending high-angle fault in La Luz Canyon in a few isolated exposures of deformed Pennsylvanian strata about 2 miles north of Salada Canyon may be a northward extension of the Fresnal Canyon fault. Although this is a structurally complex area, the strata east of this fault appear to be stratigraphically older than the strata on the west, indicating an upthrown eastern block. Locally, the strata on the eastern block resemble the Beeman formation, and west of the fault they belong to the upper part of the Holder formation. More recent displacement, however, offsets the basal strata of the Abo formation and indicates a downward component for the eastern block (pl. 2).

FOLDS

The folds resulting from pre-Abo deformation appear restricted to the southeastern part of the map area, in a zone that extends for about 3 miles northward from Salada Canyon to about 1 mile north of La Luz Canyon (pl. 2).

A number of small, asymmetric, plunging folds occur in the fault zone between the Salada Canyon and Fresnal Canyon faults near Salada Canyon. The folds are en echelon, the average spacing of the northwest-trending axial planes being about 1,000 feet. An overturned anticline occurs at the north side of Salada Canyon (fig. 14). The axial plane dips about 45 degrees toward the east, and the fold plunges steeply toward the northwest. Toward the northeast, en echelon with this anticline, red beds of the Laborcita formation are folded in a plunging syncline and overlie with angular unconformity beds of the Holder formation of middle Fresnal age [2] (LL', pl. 2). The strata of the Abo formation appear to be unaffected by the folding, indicating that some deformation occurred in post-Holder and pre-Laborcita time, but the sharply folded structures formed largely in post-Laborcita, pre-Abo time. This folding is, therefore, contemporaneous with the movements on the Salada Canyon and Fresnal Canyon faults, and the plunging folds are interpreted as the result of a shearing stress that was produced in the fault zone by oblique displacements along the system of nearly parallel faults.

Near La Luz Canyon, in a few isolated exposures through the overlying Abo formation, the Pennsylvanian formations occur in a number of northwest-trending asymmetric plunging folds. Within an area of about 11/2 square miles, eight separate en echelon folds were observed. The western limb of most of the anticlines dips 30 to 50 degrees toward the southwest. The dip of the eastern flank is commonly less than 10 degrees. The average plunge on the fold axis is about 5 degrees. A few of the folds are doubly plunging structures. Strata that have been correlated with the Laborcita formation overlie with angular unconformity the upper Holder formation. The beds of the Laborcita formation are folded along the same structural axes but are overlain by the relatively undisturbed Abo red beds. This indicates several periods of folding during late Virgilian and early Wolfcampian time. The folds in the La Luz Canyon area may have been formed in the same manner as the folds in the Salada Canyon area to the south, although in La Luz Canyon a system of parallel faults cannot be demonstrated. Significantly, all these folds occur en echelon and are restricted to this north-south belt of late Pennsylvanian-early Permian deformation.

2. Fusulinid identification by M. L. Thompson.

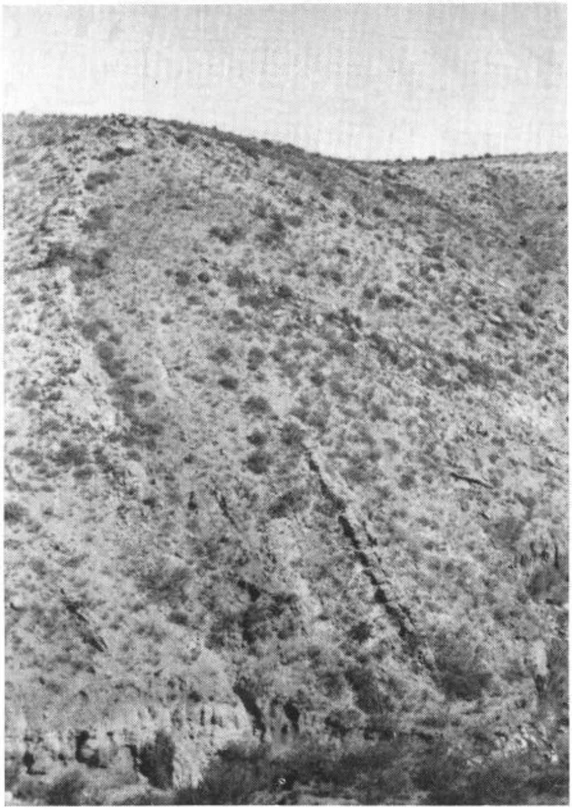

Figure 14

OVERTURNED ANTICLINE IN UPPER PENNSYLVANIAN STRATA

Uppermost gray limestone bed contains fusulinids of middle Fresnal age. The beds in the core are Missourian in age. Salada Canyon, looking north.

POST-ABO DEFORMATION

Evidence of post-Abo deformation occurs in the map area south of Laborcita Canyon, where three gentle folds, the La Luz anticline, the Dry Canyon syncline, and the Maruchi Canyon arch, are believed to be results of post-Abo deformation. Both the Dry Canyon syncline and the Maruchi Canyon arch occur in strata of the Abo formation, but in the map area, the age of this deformation is poorly defined, as the folding is younger than the Abo formation and older than the Quaternary surficial deposits. According to Pray (1952, p. 346), strata as young as the San Andres formation are gently folded in other parts of the

Sacramento Mountains escarpment, which suggests a post-San Andres age for this deformation. Truncation of the La Luz anticline by the boundary fault zone, and the occurrence of numerous small, high-angle faults of probable late Cenozoic age that offset the strata of the La Luz anticline, indicate development prior to late Cenozoic time. In the Phillips Hills area, about 25 miles north of Tularosa, R. F. Schmalz (personal communication) discovered evidence of early Tertiary folding, and the post-Abo folding in the northern Sacramento Mountains may be of the same age. Some of the displacement on the Fresnal Canyon-Salada Canyon fault system occurred in post-Abo time. The movement on these faults is related to this post-Abo gentle folding.

LA Luz ANTICLINE

In the map area, the La Luz anticline is near the front of the escarpment and extends for about 2 miles from La Luz Canyon to Laborcita Canyon (pl. 1, 2). This symmetrical fold trends approximately north-northwest and plunges northward about 10 degrees in the vicinity of Laborcita Canyon, where it is truncated by the boundary fault. The limbs of this anticline show dips of about 30 degrees. At the present depth of erosion, beds at least as young as the Laborcita formation are affected by the folding. As the beds of the Laborcita and Abo formations on the east flank of the La Luz anticline are parallel, and rocks of older formations are absent in the basal conglomerates of the Abo formation near the fold, the anticline was formed after the deposition of the Abo formation. This structural feature may be a northward continuation of the anticline mapped by Pray (1952, p. 340) for about 6 miles north-northwestward from Alamo Peak to Dry Canyon.

DRY CANYON SYNCLINE

In the map area, the Dry Canyon syncline is a broad open fold that extends for about 4 miles from State Highway 83 to a point about a mile north of La Luz Canyon, where it gradually widens and dies out. This asymmetric fold trends, with minor variations, east of north. The locally steep eastern limb attains dips of about 30 degrees (pl. 2) near the Fresnal Canyon fault, indicating the same age for the folding and the post-Abo displacement. The average dip of the western limb is about 4 degrees. Because of reversal of plunge of the axis in the map area, several structural basins occur along the length of the syncline. The plunge is generally about 2 or 3 degrees.

South of State Highway 83, the Dry Canyon syncline was mapped by Pray (1952) for a distance of 8 miles as a tight asymmetric syncline in Pennsylvanian and earlier strata, generally trending north-northwest. According to Pray (1952, p. 341), the major deformation occurred in this area prior to the deposition of the Abo formation, although later minor folding along the same line occurred during and after the deposition of the Abo formation. The Dry Canyon syncline formed during the pre-Abo deformation could not have extended much north of State Highway 83, as in the map area the strata of the Holder, Laborcita, and Abo formations are essentially parallel on the west limb of this fold (pl. 2). The angular discordance at the base of the Laborcita formation on the east limb of this syncline probably was caused by general uplift or drag of the strata along the Fresnal Canyon fault zone in post-Holder, pre-Laborcita time. In the map area, the Dry Canyon syncline was formed after deposition of the Abo formation.

MARUCHI CANYON ARCH

About 3 miles east of the junction of La Luz and Fresnal Canyons, the basal strata of the Abo formation are folded in a gentle arch (HH', p1. 2), named the Maruchi Canyon arch after a tributary of La Luz Canyon. This structure is about half a mile wide and is a part of the narrow deformed belt that extends northward for about 4 miles from Fresnal Box Canyon to La Luz Canyon and includes the Fresnal Canyon fault zone. Apparently, portions of this belt were folded in post-Abo time (pl. 2). Erosion of the basal Abo beds from the higher portions of the structure locally exposed the Pennsylvanian formations that were folded prior to the deposition of the Abo formation. The arch plunges northward and is apparently no longer present north of Cottonwood Canyon, where the regional dip of the Abo and Yeso strata is 1 or 2 degrees to the east and the beds are seemingly unaffected by the post-Abo deformation.

CENOZOIC DEFORMATION

Pray (1952, p. 306) stated that the Sacramento Mountains formed during late Cenozoic time, and discussed the fault versus the fold origin of the Sacramento Mountains escarpment. Most of the features presented by Pray as evidence in support of the fault hypothesis were observed also in the northern part of the Sacramento Mountains. These features, such as piedmont scarps, step faults, small high-angle normal faults, isolated gravel cappings adjacent to the mountain front, truncation of internal structure, and fault drag, are briefly described in the following section. The phenomenon of "reverse drag" near the frontal escarpment, and the abrupt termination of the boundary fault north of Tularosa by structural features related to Sierra Blanca, are discussed separately.

BOUNDARY STRUCTURAL FEATURES

Piedmont Scarps

The margin between the mountains and the Tularosa Basin is locally marked by scarps up to 20 feet high and about 2 miles long. These piedmont scarps are considered to mark the surface trace of the major boundary fault. Most occur within a few hundred feet of the ase of the escarpment and separate alluvium on the west from bed cock on the east. In the area between Laborcita and Domingo Canyons, here the scarps occur 1,500 feet west of the base of the mountain -scarpment (pl. 1), the area east of the piedmont scarp is essentially a is ediment with a thin alluvial cover.

tep Faults

Between Cottonwood and Tularosa Canyons, two normal faults near the frontal escarpment are interpreted as step faults (p1. 1 and 2). The faults dip westward at an angle of about 70 degrees, and the west side is downthrown, with a dominant dip-slip movement. The western fault has an approximate displacement of 700 feet; the eastern one has a maximum displacement of about 300 feet and is characterized along its entire length of about 7 miles by a narrow zone of fault drag about 100 feet wide (fig. 15). These two step faults merge with the frontal fault near Tularosa Canyon, and farther to the north the escarpment appears caused by displacement on a single boundary fault.

High-Angle Normal Faults

In the area between Laborcita and La Luz Canyons, the step faults are not as well defined as separate faults, but there are numerous high-angle normal faults. These faults are in general nearly vertical, and the displacements appear to be largely dip-slip, averaging about 100 feet. Locally, displacements up to 400 feet have been measured. As these faults offset the folded strata of the La Luz anticline, they are younger than the post-Abo deformation (FF' and GG', pl. 2). A few affect the Tertiary(?) intrusive rocks and associated features. The author considers most of the small-scale faulting in the area near the frontal escarpment to be contemporaneous and related to the formation of the boundary fault zone in late Cenozoic time. The presence of the La Luz anticline near the front of the range, between La Luz and Laborcita Canyons, may have caused the relatively large number of minor faults in that area.

Gravel Cappings

A few isolated ridges near the frontal escarpment (pl. 2) near Tularosa are capped by gravel deposits that occur 100 to 200 feet above the present drainage. They are considered to be remnants of gravels deposited on a once continuous older erosion surface that extended between the Yeso slope and the Tularosa Basin. The Tularosa Basin was probably a basin of internal drainage during the relatively recent time when the older gravels were deposited (Pray, 1952, p. 314); there probably was no lowering of the base level of erosion to account for the dissection of the older erosion surfaces. The raised position of the older gravels above the present level of erosion is evidence of the relative uplift of the mountain block with respect to the valley block. As these

Figure 15
FAULT DRAG ON STEP FAULT NEAR FRONTAL ESCARPMENT
About 2 miles south of Domingo Canyon.

gravel cappings occur on a flat unwarped surface near the frontal escarpment, the uplift probably was caused by faulting rather than folding.

Truncation of Internal Structure

In the map area, the frontal escarpment intersects the La Luz anticline near the mouth of Laborcita Canyon. This truncation by the present mountain front of the internal structure of the range is a feature characteristic of many faulted basin ranges and, according to Pray (1952, p. 314), is common along most of the Sacramento Mountains escarpment.

Fault Drag

Between Laborcita and Tularosa Canyons, the strata in the zone bounded by the piedmont scarps on the west and the step faults on the east dip dominantly toward the west (CC' and DD', p1. 2). This zone, locally as much as 1,500 feet wide, is interpreted as one of large-scale fault drag along the major boundary fault.

These various structural features led the writer to agree with Pray's interpretation (1952) that the overall uplift of the mountain block has taken place along normal faults very close to the present base of the escarpment. The total stratigraphic displacement appears to diminish toward the north. Near Laborcita Canyon, the minimum displacement is estimated at 4,300 feet, and north of Tularosa, at 3,800 feet. These displacements are based on the following assumptions: 1. The thickness of the alluvium of the Tularosa Basin is 1,000 feet near La Luz and diminishes toward the north to about 500 feet at Tularosa. 2. The base of the alluvium is at the base of the San Andres limestone, which probably gives a low estimate of the displacement.

REVERSE DRAG

The regional dip of the beds in the Sacramento Mountains is 1 to 2 degrees to the east. In the relatively undeformed parts of the northern Sacramento Mountains, such as in the area north of Laborcita Canyon, the amount of east dip increases toward the front of the escarpment, and in the area north of Tularosa Canyon, dips as steep as 25 to 30 degrees were recorded. This gradual steepening of the strata generally occurs within a zone about half a mile wide (pl. 1 and 2). The feature is common along the Sacramento Mountains escarpment, as noted by Pray (1952). So far, no satisfactory explanation has been advanced to explain this feature. The writer favors the interpretation of fault drag on the major boundary fault as a result of relatively recent subsidence of the main mountain block with respect to the Tularosa Basin. As the net displacement on the boundary fault is downward on the west side, this feature may be called reverse drag.

TRUNCATION OF THE BOUNDARY FAULT

Along the northernmost edge of the map area (pl. 1), the strike of the Abo beds turns sharply from the north toward the northwest, and the dip increases toward the northeast. This change may be due to a major east- or northeast-trending fault that is buried under the recent gravel deposits farther to the north. About 5 miles north of Tularosa, the boundary fault is truncated by a north-northeast-trending fault. These features are probably related to structures prevailing in the Sierra Blanca region that are younger in age, and different in trend and type from those prevailing along the Sacramento Mountains escarpment.

Quaternary Deposits

Sediments of Quaternary age form surface deposits in a large part of the northern Sacramento Mountains, where they obscure the bedrock geology. Relatively little time was devoted to the differentiation of the various Quaternary sediments. The few reconnaissance observations helped to interpret the more recent geologic and topographic development of the escarpment, but many problems remain untouched and require more detailed investigation.

Four groups of Quaternary deposits are distinguished on the geologic maps. They are, in order of decreasing age: the older gravel deposits; the younger gravel deposits; undifferentiated and reworked gravels; and older valley fill, pediment gravels, and recent alluvium. As the composition of most of these deposits is similar, their differentiation is based primarily on the relative position of the erosion surfaces on which the deposits occur.

OLDER GRAVEL DEPOSITS

Throughout the entire length of the map area from High Rolls to north of Tularosa, gravel deposits occur on the broad area of low relief that rises gently from the low frontal escarpment in the west to the steep slope of the Yeso formation in the east. The high interstream ridges are capped by conspicuous light-colored limestone gravels. Not all the gravel cappings occur on the same level, but roughly two surfaces of deposition were distinguished.

The highest of the gravel deposits is very widespread, was recognized throughout the map area, and is referred to as the older gravel deposits. The base of these older gravels in the southern part of the area is generally 200 to 300 feet above the present level of the stream. This elevation decreases northward to 50 to 150 feet near Tularosa Canyon. The surface on which these gravels are deposited was recognized by Pray (1952, p. 294) and was called the Ranchario pediment. The older gravels are composed almost entirely of cobbles and boulders of light-gray fossiliferous limestones from the San Andres formation. The maximum observed thickness of the gravel deposit is 56 feet, but in most places does not exceed 20 feet.

These high, isolated gravels are remnants of a thin continuous sheet of gravel that extended with a westerly dip of about 3 to 4 degrees from the steep mountain front in the east, to the Tularosa Basin in the west. The slope tilts slightly northward toward Tularosa. The surface on which these gravels rest as a thin veneer is interpreted as a pediment, truncating the underlying Abo beds, and probably formed during the retreat of the old mountain front toward its present position. Early stages of uplift along the present boundary fault zone were probably responsible for the formation of this old escarpment.

YOUNGER GRAVEL DEPOSITS

The younger gravel deposits are much less sharply defined than the older gravels. Like the older deposits, they are composed of pebbles and cobbles of San Andres limestone. The younger gravels form cappings on isolated interstream areas and stream terraces, and occur about 50 to 100 feet below the older gravel deposits. The younger gravels were recognized mainly in the southern part of the map area. Near La Luz Canyon, the Burro Flats surface (Pray, 1952, p. 299) has been correlated with this younger level of erosion and gravel deposition. The older and younger erosion surfaces converge both toward the west and north. North of Tularosa Canyon, the younger surface is no longer recognizable.

The younger gravels are probably fluviatile, laid down on a surface that was eroded after a period of uplift, during which the crest of the range to the east and south of the map area was uplifted to a greater extent than the front and northern part of the range. This renewed period of erosion did not last long enough to obliterate the earlier pediment surface covered by the older gravels. It was succeeded by the third and last period of uplift, which caused the present development of the low frontal escarpment in the northern part of the Sacramento Mountains adjacent to the boundary fault zone.

UNDIFFERENTIATED AND REWORKED GRAVELS

Gravels classed under this heading are composed mainly of limestone clasts of the San Andres formation. North of Domingo Canyon, a few gravel deposits appear to occur at levels intermediate between the older and younger surfaces. The convergence of the older and younger erosion surfaces in this area eliminates the distinguishing feature of these various gravel deposits. In addition, many gravel deposits, primarily the younger gravels, have been regraded to a level of broad valley alluviation. The undifferentiated and regraded gravels are all grouped as one unit for mapping convenience. Future study, with the aid of detailed topographic maps, will permit differentiation between these surface deposits.

The younger gravel deposits grade imperceptibly into reworked gravels toward the west, and on the geologic map (pl. 1) the contact between these two units was chosen arbitrarily. The contact of the reworked gravels and the extensive alluvial deposits of flat-lying silts is more sharply defined, and is based on a distinct break in slope and the difference in composition and grain size.

RECENT ALLUVIUM, PEDIMENT GRAVELS, AND OLDER VALLEY FILL

Different types of relatively recent surface deposits are widely distributed throughout the map area. They were not differentiated and were classed as Quaternary alluvium for mapping convenience.

Between Laborcita and Tularosa Canyons, surficial deposits, forming broad flats as much as three-fourths of a mile wide, occur in all the larger valleys and extend up the smaller ones as narrow tongues. These deposits are generally less than 15 feet thick and cover a total area of about 8 square miles (pl. 1). The alluvium is generally composed of flat-lying silts, sands, and thin light-gray or pink gravels. The flat surface, on which the thin alluvial veneer occurs, is slightly higher than the surface of the Tularosa Basin bordering the frontal fault scarp. Both surfaces are recent in age. The position of the higher surface, east of the frontal escarpment, is controlled by the uppermost resistant ledges of the Laborcita formation, which act as local base levels of erosion for the individual drainage courses (pl. 1).

Recent gravel deposits rest as a thin layer on the truncated Abo and Yeso beds along the northern edge of the map area (pl. 1). The erosion surface, on which these gravels rest, rises gently toward the steep east-trending mountain front and is interpreted as a pediment. A surface with similar thin gravel cover extends as a narrow strip, with a maximum width of 1,500 feet, east of the major boundary fault at the base of the low frontal escarpment between Laborcita and Domingo Canyons; this too is considered a pediment (pl. 1). The valley alluvium and the pediment gravels and erosion surfaces are being dissected, so that bed rock is exposed along and in the bottom of many of the drainage courses. This dissection and some of the piedmont scarps that are about 20 feet high are probably the result of a minor uplift in very recent time.

The Tularosa Basin was probably a basin of internal drainage throughout the time that the various erosion surfaces were developed. This suggests a tectonic origin rather than change in base level for the formation of the surfaces. Climatic changes may also have been of significance.

The alluvium of the Tularosa Basin was discussed by Pray (1952, p. 295). The clays, silts, sands, and gravels, of red color, that are reported in the well records were probably deposited on alluvial fans by intermittent floods from the mountains. In the map area, the thickness of the alluvium is unknown. According to Pray (1952, p. 297), a well near Alamogordo was carried to a depth of a little over 1,000 feet without reaching the bottom of the unconsolidated fill. About 12 miles northwest of Tularosa, the depth of the valley fill is about 370 feet (Darton, 1928, p. 218). The San Andres formation appears in the surface outcrops about 25 miles north of the map area. The depth of the alluvium near La Luz is estimated at about 1,000 feet, and is inferred to decrease gradually in thickness northward to about 500 feet at the northern end of the map area (pl. 2). Probably Tertiary, as well as Quaternary, alluvium is present in the Tularosa Basin (Pray, 1952, p. 298).

Stream terraces occur along Tularosa Canyon at different levels, with the highest one about 50 feet above the present stream bottom. I'hey mark distinctive episodes in the development of this major drainage course and probably correlate with uplifts of the mountain mass in more recent time. These various terraces have been mapped as a part of the Quaternary alluvium.

Geologic History

This section presents a chronologic summary of the major geologi events that occurred in the northern Sacramento Mountains since the start of Virgilian time.

1. About 900 feet of marine interbedded limestone, sandstones, an shales was deposited during most of Virgilian time. These beds contai a rich invertebrate fauna and are designated as the Holder formation. The thickness decreases toward the east and south. Much of the clasti material was derived from a positive area to the northeast, the Pedernal Landmass. Biohermal masses, about 100 feet thick, locally form the base of the Holder formation and probably were formed under stable shelf conditions. The proportion of red beds, limestone conglomerates, and nodular limestones increases toward the top of the Holder formation as a result of more shallow or near-shore conditions. Cyclical repetition of beds and associated occurrence of diastemic breaks in the upper part of the Holder formation may be an indication of increasing tectonic instability in this area during late Virgilian time:

2. In late Virgilian time, the first deformation occurred in the Sacramento Mountains. In the northern Sacramento Mountains, faulting and related subsidiary folding took place in a zone extending northward from State Highway 83 to La Luz Canyon, and general minor uplift of the southeastern part of the map area resulted in nondeposition or slight erosion. The intensity of the deformation appears to have diminished toward the west and north, where marine deposition was essentially continuous through Virgilian and early Wolfcampian time.

3. During late Virgilian and early Wolfcampian time, deposition of the lower two-thirds of the Laborcita formation took place under laterally abruptly changing conditions northwest and west of the rising central and eastern part of the ancestral Sacramento Mountains. The fault zone in the southeastern part of the map area approximately separates the areas of denudation and deposition. Conglomerates and red mudstones were deposited in alluvial fans and broad flood plains adjacent to, and on the flanks of, the rising landmass. The lower two-thirds of the Laborcita thickens considerably toward the northwest and west, where the terrestrial environment graded into a dominantly marine environment within 3 miles. Fusulinid-bearing limestones of late Virgilian and early Wolfcampian age were deposited interbedded with gray and green shales and sandstones. Imperfectly developed cyclothems occur in the continental and marine facies of the Laborcita formation, reflecting the episodic nature of the diastrophic forces that continued to affect the source and adjacent shelf areas throughout late Virgilian and early Wolfcampian time.

4. Widespread retreat of marine waters resulted in deposition of ed mudstones and sandstones of the upper one-third of the Laborcita ormation over the entire area of the northern Sacramento Mountains.

5. Recurrent faulting and subsidiary folding in the zone between I a Luz Canyon and State Highway 83 was accompanied perhaps by a !eneral downward tilt of the area northwest of Domingo Canyon. trata of the Laborcita formation were removed from the eastern, or upthrown, block of the Fresnal Canyon fault zone in the southeastern 'art of the map area.

6. During late early Wolfcampian time, deposition of the lowermost Abo beds took place in piedmont and alluvial-plain environments. Within and east of the Fresnal Canyon fault zone, the Abo deposits were laid down on the folded and faulted Pennsylvanian and lower Permian strata of the Holder and Laborcita formations. For 10 miles toward the northwest, the Abo formation disconformably overlies the Laborcita formation. North of Domingo Canyon, marine waters alternately flooded and retreated from the adjacent flat coastal-plain area. In this area, deposition was essentially continuous from Laborcita into Abo time but shifted from predominantly marine to terrestrial conditions.

7. Final retreat of marine waters from the Tularosa area occurred at the end of early Wolfcampian time toward the west and northwest.

8. Middle Wolfcampian time marks the deposition of red mudstones, conglomerates, and nonfeldspar-bearing sandstones of the Abo formation on piedmonts and alluvial plains in the area between High Rolls and Cottonwood Canyon. Contemporaneous deposition of a thicker, more feldspathic section with a few limestone in terbeds occurred toward the northwest, north of Cottonwood Canyon and east of Tularosa.

9. During late Wolfcampian time, coarse-grained arkoses, conglomerates, and red mudstones of the Abo formation were deposited in alluvial fans and on broad alluvial plains throughout the Sacramento Mountains. The Pedernal Landmass continued to be a positive area throughout middle and late Wolfcampian time and locally must have formed mountains of considerable magnitude.

10. The beginning of the Leonardian epoch registered a gradual major northward advance of the sea and general marine deposition of 1,300 feet of limestones, shales, gypsum, and sandstones of the Yeso formation.

11. At the end of Leonardian time, shallowing of marine waters and the deposition of pure quartz sandstones of the Glorieta(?) formation probably took place.

12. Early Guadalupian deposition consisted of a 1,400-foot-thick marine-limestone section of the San Andres formation.

13. No record of the time interval between the early Guadalupian and the Tertiary was preserved in the northern Sacramento Mountains. In adjacent areas, about 350 feet of red beds was deposited during Triassic(?) time. The Jurassic and early Cretaceous was a period of nondeposition or eros:on. Late Cretaceous time is represented by deposition of about 1,000 feet of Dakota sandstone, Mancos shale, and Mesaverde sandstone, followed in either late Cretaceous or early Tertiary by development of an erosion surface that caused removal of all Mesozoic formations and the upper part of the San Andres formation in the Sacramento Mountains.

14. During the early Tertiary, gentle folding and recurrent faulting took place on the preexisting Fresnal Canyon fault system.

15. Intrusion of sills and dikes of acidic and intermediate composition occurred probably in early or middle Tertiary time.

16. Since late Tertiary time, basin-and-range faulting has occurred along or close to the base of the present escarpment. Periods of prolonged erosion with development of extensive pediment surfaces alternated with intermittent periods of differential uplift and warping. Earlier erosion surfaces were dissected and newer ones developed. These events have persisted into relatively recent time.

Conclusions

LABORCITA FORMATION

1. The Laborcita formation is named in this report for the strata hat occur between the Holder formation and the Abo formation in the northern Sacramento Mountains. The lower portion of this section was previously known as the "transition beds" or the Bursum formation. The Laborcita formation is about 500 feet thick in the southeastern part of the area, where both top and bottom are exposed. The thickness increases to about 1,000 feet (estimated by projecting the subsurface base northward) toward the northwest. The lithologic and faunal characteristics of the sediments show that abrupt lateral transitions from open-marine conditions, in the northwest and west, to terrestrial flood-plain environments, in the southeast and east, occurred repeatedly within a distance of a few miles.

2. The abrupt lateral transition from open-marine to terrestrial flood-plain environments was shown by tracing of individual beds. One complete lateral succession of contemporaneous deposits occurring within 11/2 miles is: massive marine limestone; nodular argillaceous fusulinid-bearing limestone; silty limestone containing many shallow-marine invertebrates, such as molluscs and brachiopods; dolomitic limestone; green shale; and red shale and other terrigenous clastic rocks. This gradual change in lithology shows a gradual transition from deeper marine waters toward littoral and terrestrial conditions of deposition.

3. The transition from open-marine sediments to terrestrial flood-plain deposits is expressed also in vertical cyclic sequences of strata, called cyclothems. The vertical succession in an ideal neritic cyclothem is similar to the above-listed lateral succession. Terrestrial cyclothems of interbedded red mudstone and limestone conglomerate occur in the nonmarine facies of the Laborcita formation.

4. The lower contact of the Laborcita formation with the Holder formation is a disconformity or slight angular unconformity to the south and east of the junction of Fresnal and La Luz Canyons. Toward the northwest and west, the disconformity dies out, and the formations are gradational and represent essentially continuous deposition.

5. On the basis of fusulinid identifications, the Laborcita formation is very late Virgilian and early Wolfcampian in age. The uppermost 250 feet of the Laborcita formation near Tularosa is in part the time equivalent of the lowermost Abo beds toward the south and east. The Pennsylvanian-Permian boundary, which by earlier stratigraphers was taken at the base of the Abo formation, occurs 90 feet above the base of the Laborcita formation, as determined on the basis of fusulinids.

6. The Laborcita formation was deposited contemporaneously with, and as a result of, the deformation that affected the central part of the Sacramento Mountains area during late Virgilian and early Wolfcampian time. The clastic sediments of the formation probably were derived from a source area to the east or southeast.

7. The zone of algal bioherms in the upper part of the Laborcita formation north of Tularosa is of economic significance. These limestone masses locally show recrystallization porosity and could form reservoirs for the accumulation of oil and gas.

8. The upper part of the Holder formation and the marine facies of the Laborcita formation appear to form one of the most complete upper Virgilian and lower Wolfcampian marine sections known in North America. The beds of both formations locally yield many marine invertebrates whose relative stratigraphic position has been determined. This area, therefore, offers excellent opportunities for specialists to make biostratigraphic comparisons of the various fossil groups and to study the interdependence of environment, lithofacies, and faunas.

ABO FORMATION

1. The Abo formation was recognized by previous students of the area and consists of red mudstone, arkose, and conglomerate. The thickness of this wedge-shaped unit increases from about 500 feet, near High Rolls, to about 1,400 feet, north of Tularosa, excluding 250 feet here included in the Laborcita formation.

2. In the central part of the Sacramento Mountains and the southeastern part of the map area, the Abo formation overlies with sharp angular unconformity strata of Pennsylvanian and Mississippian age. The area to the west and northwest was one of essentially continuous deposition from late Pennsylvanian through early Permian time, with no major unconformity separating the deposits. Gradual emergence of the area and retreat of the marine waters toward the west and northwest caused interfingering of the uppermost Laborcita and lowermost Abo strata in the area north of Domingo Canyon. The lower contact of the Abo formation is at the base of a quartzite-cobble conglomerate between Fresnal Canyon and Domingo Canyon, where it is considered a disconformity. The base of the Abo formation occurs 200 feet stratigraphically above the upper contact of the Bursum formation as mapped by Pray (1952). The upper contact with the Yeso formation is gradational.

3. The conglomerates, coarse-grained arkoses, and mudstones of the Abo formation were derived from a Precambrian source area, the Pedernal Landmass. This mass appears to be composed chiefly of igneous and metamorphic rocks, in which feldspar porphyry, pink granite, and quartzite are the major rock types. This source area was mainly east and northeast, and possibly southeast, of the map area.

4. The Abo formation is a terrestrial facies and was deposited largely in a piedmont and alluvial-plain environment. In general, two members can be distinguished in the northern Sacramento Mountains: a lower member which is, in the main, nonfeldspar-bearing, containing a few limestone layers, and an upper member characterized by the lack of limestone and the presence of coarse-grained arkoses.

5. In the map area, the lowermost Abo strata correspond to the uppermost lower Wolfcampian. Pray (1952) indicated correlation of the Abo formation with the main part of the Hueco limestone of trans-Pecos Texas. On this basis, Pray considered the age of the top of the Abo formation either latest Wolfcampian or earliest Leonardian, and designated a middle and late Wolfcampian age for the bulk of the Abo red beds in the Sacramento Mountains. The lower ("nonarkosic") member of the Abo in the northern Sacramento Mountains is wedge shaped and is considered middle Wolfcampian and perhaps corresponds to the thin sequence of quartzite and limestone conglomerates in the central part of the range. The upper ("arkosic") member is considered upper Wolfcampian in age and is relatively uniform in thickness in the northern and central Sacramento Mountains.

Appendix

FAUNA AND AGE OF THE LABORCITA FORMATION

The upper Pennsylvanian and lower Permian marine beds of th - northern Sacramento Mountains are rich in fossil remains of man types. Fusulinids are the most abundant and occur predominantly i the light-gray nodular argillaceous limestones. A wide assortment o brachiopods, pelecypods, gastropods, cephalopods, bryozoa, corals, and algae occur in the silty limestone and calcareous siltstone facies. Faunas from a few isolated localities were described by different workers (Bose, 1920; Penn, 1932; Miller, 1932; and Girty, 1939). Up to 1951, when this study was started, no systematic faunal studies of the uppermost Pennsylvanian and lower Permian beds had been undertaken, and much of the knowledge was fragmentary and appeared contradictory.

To obtain a better understanding of some of the problems involved, A. L. Bowsher and W. T. Allen, then of the U. S. National Museum, made extensive fossil collections in the northern Sacramento Mountains during the summers of 1948 and 1951. Additional fossil occurrences discovered by the author during field studies were also collected by Bowsher and Allen. During the summer of 1952, Dr. G. A. Cooper, U. S. National Museum, joined Bowsher and Allen and revisited many localities in the area. The reports on the brachiopods, gastropods, and cephalopods are based on the National Museum collections.

Fusulinids occur extensively in the Pennsylvanian and lower Permian marine strata of the Sacramento Mountains. For this investigation, the beds of the Laborcita formation were collected systematically only in the measured sections. Fusulinids from a few isolated localities were sampled to establish local stratigraphic control for field mapping. Dr. M. L. Thompson, Illinois Geological Survey, determined the age of most of the critical fusulinid occurrences. As yet, no systematic study of the entire collection of fusulinids has been undertaken.

The brachiopods and gastropods of the Laborcita formation were examined successively by Cooper and Bowsher and are listed in Tables 2 and 3. Most localities (indicated by one locality number in this report) were collected at different times, resulting in several accession numbers for the U. S. National Museum collections.

BRACHIOPODS

The following summary is quoted directly from Cooper's report (dated June 2, 1953) to the author. In this quotation, "Bursum" is equivalent to "Laborcita." The table was made by the author from Cooper's information.

TABLE 2. BRACHIOPODS OF THE LABORCITA FORMATION

	U. S. NATIONAL MUSEUM LOCALITY NUMBERS													
	3378	3370	3022	3022a	3366	3379	3324	3371	3372	3374	3362	3361	3363	3294
Chonetes granulifer meekianus Girty												×		
Composita sp.													×	×
Crurithyris sp.												×		
Derbyia n. sp.												×		
Dictyoclostus americanus Dunbar				×	×	×			×	×		×		
Dictyoclostus welleri R. H. King					×		×					×		
Enteletes n. sp.												×		
Juresania nebrascensis (Owen)												×	×	
Linoproductus sp.	×	×	×	×	×						×	×	×	×
Meekella striatocostata (Cox)		×						×	×			×		
Neospirifer sp.	×						×			×	×	×		
Wellerella sp.												×	×	
LOCALITY NUMBERS OF THIS REPORT	11-M-1						13-M-1				13-M-3	M-3	30-M-3	30-M-2

Chonetes granulifer meekianus Girty.—This is a large chonetid that is abundant in the Brownville and higher beds. In this we have nothing definitive as to Permian identity.

Composita sp.—This is a large form like those in the high Pennsylvanian and low Permian.

Crurithyris sp.—Nothing definitive.

Derbyia n. sp.—This species is characterized by its alternating ornamentation, 1 strong rib alternating with 2 to 4 smaller ones. The species is a compressed form with a hinge narrower than the midwidth and a short interarea. A *Derbyia* very similar to this one occurs in the lower Hueco of the Franklin Mountains.

Dictyoclostus americanus Dunbar—? = *D. huecoensis* R. E. King.—The upper Pennsylvanian and lower Permian are characterized by a large dictyoclostid (possibly a new genus) characterized by a strong and regularly reticulate visceral area, and a long quite evenly costellate trail. The Pennsylvanian and Permian representatives are very close and may be specifically the same; I cannot yet be sure. Specimens from the Brownville of Oklahoma and Permian of the Red Eagle of Oklahoma, as well as the Camp Creek of Texas, all seem identical.

Dictyoclostus welleri R. H. King—? = *D. wolf campensis* R. E. King.—The same situation exists with these two species as with the ones above. I think the two are the same, but both of these are Permian species. They are characterized by much finer ornamentation than the preceding and irregular reticulation.

Enteletes n. sp.—This species is characterized by its very large size, its short and low fold, the subdued and short lateral costae. Nothing like this is present in our collections from low in the Pennsylvanian, and the Wolfcamp species are not like this one. There is, however, a species in the Brownville formation of Oklahoma that appears to be identical. The Brownville is topmost Pennsylvanian in that State.

Juresania nebrascensis (Owen).—These are large specimens suggestive of those occurring in the lower Permian of Kansas.

Linoproductus sp.—This genus does not give much help because specimens have the characteristics of *L. prattenianus* and *L. magnispinus,* the latter a Permian species.

Meekella striatocostata (Cox).—All poorly preserved and nothing definitive in the species.

Neospirifer sp.—I am unable to place this species, which is actually more like specimens in the middle of the Pennsylvanian than any Permian species in the collection.

Wellerella sp.—This is like large specimens of W. *osagensis* (Swallow) and is like abundant Permian forms from the Hueco and elsewhere called W. *Texan* (Shumard). There are nomenclatural reasons for not using the latter name, but the general run of *W. osagensis* do not seem typical either. This is again a type that is abundant on both sides of the line. The Bursum [Laborcita] ones seem to have the greater angularity, which is common to the Permian specimens.

In the same report, Dr. Cooper stated:

They are a frustrating lot and as near as **I** can make out fall almost exactly on the Permian-Pennsylvanian line, just as others have said. In my opinion, however, they are rather Permian than Pennsylvanian, the Permian similarities resting on general appearance of the shells, the presence of a type

TABLE 3. GASTROPODS OF THE LABORCITA FORMATION

	U. S. NATIONAL MUSEUM LOCALITY NUMBERS																
	3017	3017a	3017b	3017d	3017f	3281	3283	3284	3285	3295	3297	3022	3022a	3282	3286	3293	3294
× *Ananias* cf. *A. marconianus* (Geinitz)		a	a	r	a	c	a	a	c	c	a				r	r	a
× *Baylea* n. sp.								r					r		r		
Bellerophon n. sp. cf. *B. graphicus* Moore					r			r						r	c	c	
Colpites n. sp.								r				c			r		
× *Euphemites* aff. *E. graffhami* Moore	c				a	c	c	r	r		r	c	c				
Girtyspira cf. *G. minuta* (Stevens)													a			a	
× *Glabrocingulum* n. sp. A	c	a	c					r	a	c					r	?	
Glabrocingulum n. sp. B																	r
Glabrocingulum n. sp. C					c	c		c			r						
Glabrocingulum n. sp. C ?																	
Goniasma lasallensis (Worthen)					r								a	c	a		
Hemizyga n. sp.												r			r		
× *Ianthanopsis paludinaeformis* (Hall)	r				r	c		a		c	r	c	c	r	c	r	
Meekospira cf. *M. peracuta* (Meek & Worthen)	c					r	r	c			r					r	
Naticopsis sp. A													r				
Ploeczyga sp. A												r					
× *Pharkidonotus* cf. *P. percarinatus*					c			r					r		r	c	c
Phymatopleura brazoensis (Shumard)		r															
Phymatopleura n. sp.					r												r
Pseudozygopleura n. sp.					r			r				a		r	a		r
× *Retispira* cf. *R. tenuilineatus* (Gurley)					r			r		r		a		c	c	a	
Retispira cf. *R. textiliformis* (Gurley)													r				
× *Retispira* n. sp.					c			r				a	a	a	a	c	c
Soleniscus ? n. sp.															r		
Stegocoelia n. sp.								r			r						
× *Straparolus (Amphiscapha) muricatus* (Knight)		r	c	r	a	r		a	r	r					r		
× *Taosia crenulata* Girty												a	a	c	c		
× *Taosia percostata* Girty					r			r				a	a		r		
Trachydomia n. sp.												r					
Trepospira aff. *T. illinoisensis* (Worthen)					c	r			r	r							
Worthenia cf. *W. tabulata* (Conrad)				r				r									
LOCALITY NUMBERS OF THIS REPORT								M-1					11-M-1		13-M-2	30-M-2	

× = important gastropods
a = abundant
c = common
r = rare

of Productid like *Dictyoclostus wolfcampensis (D. welleri), Derbyia* like one occurring in the Hueco, and large *Wellerella* like those of the Hueco. This statement of age is not a very definitive one and could well be debated. The only brachiopod type in the collection not occurring in the Upper Pennsylvanian is the *D. wolfcampensis (D. welleri),* which seems to be a definite Lower Permian brachiopod.

GASTROPODS

This section is summarized from a preliminary statement by Bowsher (dated July 8, 1953). Table 3 was composed by Bowsher and has been slightly modified by the author.

Gastropods that occur abundantly at various stratigraphic positions in the Laborcita formation have been listed in Table 3. The most important ones are marked. Calcareous shales and dark argillaceous limestones yielded many gastropods, and this suggests that the occur rence is strongly dominated by the facies. Despite the very extensive local collections, the overall sampling does not warrant a detailed dis cussion on relative abundance and distribution of the different species Bowsher stated:

> The study of these gastropods revealed several interesting facts. The gastropods found through the "Bursum" [Laborcita] represent a single faunule assemblage. Except for a few species, *Straparolus (Amphiscapha) muricatus, Glabrocingulum* n. sp. A, *Baylea* n. sp., these gastropods most resemble Pennsylvanian species. Most are new species, but close to described Pennsylvanian forms. Although very few gastropods were collected from the underlying Fresnal group (Pennsylvanian), those found seem to be the same or close to those in the "Bursum" [Laborcita]. Thus it appears that these gastropods are Pennsylvanian in age or at least have marked Pennsylvanian affinities.

CEPHALOPODS

Miller published (1932) a detailed account of collections made by Bose from beds of the Laborcita formation east of Tularosa, showing, that the fossils were late Pennsylvanian in age. The localities were re-collected in 1951 and 1952 by Bowsher and Allen to find more diagnostic forms. After examining these newly collected ammonoids (locality number M-1 in this report), Miller stated in a letter (dated April 23, 1953) to Dr. Cooper:

> Their preservation is quite good, and the variety is considerable. Nevertheless, diagnostic forms are, for the most part, conspicuous by their absence. My conclusion is that this fauna still seems to me to be Upper Pennsylvanian and not Lower Permian. . . . The great bulk of the collection is not diagnostic. Perhaps the best "proof" of Upper Pennsylvanian (rather than Permian) is the presence of *Gonioloboceras* in your collection, as well as in the one I studied years ago. If this fauna is Permian, it is the only fauna known to me in which *Gonioloboceras* ranges that high. Also, the John Britts Owen collection here contains a representative of *Shumardites* from the Tularosa clay pits, and that genus also is characteristic of the Upper Pennsylvania and not the Lower Permian. Meanwhile, I am convinced that from a study of the cephalopod fauna alone, one can conclude only that the age of the containing beds is Upper Pennsylvanian.

FUSULINIDS

Most of the fusulinid localities important for age determination of the Laborcita formation and the interpretation of the geologic history of the area are listed in Table 4. The most critical fusulinids have been identified by Dr. M. L. Thompson in reports to the author (March 18, 1952 and May 7, 1953). The remaining samples were examined by the writer, but the lack of reference collections did not permit an accurate determination on most of these. Wherever possible, quotations from Thompson's reports are given directly. In these quotations, "Fresnal" is used as a stage and is late Virgilian, corresponding

TABLE 4. FUSULINID LOCALITIES AND CORRESPONDING INVERTEBRATE PALEONTOLOGY COLLECTION NUMBERS OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY

MEASURED SECTIONS		ISOLATED LOCALITIES
4-F-1 = CIT 2010a	18-F-3 = CIT 2016c	F- 1 = CIT 2000a, b
4-F-2 = CIT 2010b	18-F-4 = CIT 2016d	F- 2 = CIT 2001
11-F-2 = CIT 2011	18-F-5 = CIT 2016e	F- 3 = CIT 2002a, b
13-F-1 = CIT 2012	18-F-6 = CIT 2016f	F- 4 = CIT 2003a, b, c
15-F-1 = CIT 2013	20-F-1 = CIT 2017	F- 5 = CIT 2004
16-F-1 = CIT 2014a	22-F-1 = CIT 2018a	F- 6 = CIT 2005
16-F-2 = CIT 2014b	22-F-2 = CIT 2018b	F- 7 = CIT 2006
17-F-1 = CIT 2015a	22-F-3 = CIT 2018c	F- 8 = CIT 2007
17-F-2 = CIT 2015b	22-F-4 = CIT 2018d	F- 9 = CIT 2008
17-F-3 = CIT 2015c	24-F-1 = CIT 2019	F-10 = CIT 2009
17-F-4 = CIT 2015d	28-F-1 = CIT 2020	
18-F-1 = CIT 2016a	29-F-1 = CIT 2021	
18-F-2 = CIT 2016b	30-F-1 = CIT 2022	

to the strata of the Fresnal group, which form the uppermost 530 feet of the Holder formation. Bursum age refers to the early Wolfcampian and corresponds largely to the lower two-thirds of the Laborcita formation, but exclusive of the lowermost 60 to 90 feet, which is very late Virgilian in age.

Identifications by Thompson:

F-2 = CIT 2001	*Triticites* sp. If this is Fresnal, it should be high in the group, but not uppermost.
F-3 = CIT 2002a	*Triticites* sp. Missourian in age.
2002b	*Triticites* sp. Middle Fresnal; not very diagnostic; CIT 2002b occurs about 210 feet stratigraphically above 2002a.
F-6 = CIT 2005	*Triticites* sp. Late Fresnal.
F-7 = CIT 2006	*Triticites* sp. Fresnal, probably, below F-6, but closely similar in age to it.
4-F-1 = CIT 2010a 4-F-2 = CIT 2010b	*Triticites* sp. Pennsylvanian, but above F-7. However, lowermost post-Fresnal fusulinids are not very well understood in the Fresnal Canyon area.
15-F-1 = CIT 2013	*Schwagerina pinosensis* Thompson Bursum in age. New species.
16-F-1 = CIT 2014a	*Triticites* sp. High Virgilian; probably upper Fresnal.
16-F-2 CIT 2014b	*Triticites cellamagnus* Thompson New species.
18-F-4 = CIT' 2016d	*Triticites* sp. Virgilian age; Fresnal group.
18-F-5= CIT 2016e	*Schwagerina* sp. Bursum age.

18-F-6 = CIT 2016f	*Dunbarinella* sp.
	Not much younger than 18-F-5; definitely Permian. Thi form found in Texas Wolfcampian.
28-F-1 = CIT 2020	*Schwagerina* sp.
	Possibly younger than any of type sections of Bursum. No sure of this.
29-F-1 = CIT 2021	*Schwagerina* sp.
30-F-1 = CIT 2022	*Dunbarinella* sp.
	These seem to be about Bursum in age, but if equivalent tı the Bursum, are high Bursum. They should be correlate. above the top of the type section of the Bursum. Rocks tha seem to be of this age are rare in New Mexico. They shoull fit within the Powwow conglomerate-Bursum formation ero sional interval.

Identified by Bowsher (King et al., 1949):

11-F-2 = CIT 2011	*Schwagerina emaciata* (Beede)
	Schwagerina emaciata var. *jarillaensis* Needham
	Schwagerina longissimoidea (Beede)
	Triticites ventricosus Meek and Hayden
	Triticites cf. *T. beedei* Dunbar and Condra
	Triticites sp.

Identified by the author:

F-9 = CIT 2008	*Schwagerina* cf. *S. huecoensis*
	Wolfcampian from Hueco Mountains and west Texas. Same horizon as 2020.
13-F-1 = CIT 2012	*Triticites* sp.
	Virgilian.

MISCELLANEOUS

According to Bowsher (personal communication, July 8, 1953), a *Myalina* sp. from the base of the Laborcita formation is a Wolfcampian species. Also, fish scales collected from the middle part of the Laborcita formation by Bowsher are from a fish known only in "Upper Pennsylvanian" strata, according to D. Dunkle, U. S. National Museum.

Algae, which are abundant in the area, have not been studied.

SUM MARY

On the basis of the fusulinids, which are abundantly and widely distributed through the unit, the Laborcita formation is very late Virgilian and early Wolfcampian in age. The brachiopods show, in general, greater affinities to Permian than to Pennsylvanian forms. However, both the gastropods and cephalopods indicate greater resemblance to Pennsylvanian forms. This conflict in age is especially surprising, because the gastropod and cephalopod collections came from the middle of the Laborcita formation, about 350 feet above the Pennsylvanian-Permian boundary based on the fusulinids.

A few cephalopod and gastropod species of the Laborcita occur in rocks of definite Permian age in other places of North America. *Gastri-*

oceras drakei Miller (personal communication from Bowsher, July 8, 1953), which is common in the collection of the Tularosa clay pits (M-1), was also found by W. T. Allen, A. L. Bowsher, and G. A. Cooper in the Red Eagle limestone in a quarry along the highway 1 mile east of Burbank, Oklahoma. The Red Eagle limestone is definitely Wolfcampian (O'Connor and Jewett, 1952), which indicates that at least some of the ammonoids from the Tularosa clay pits range stratigraphically higher than previously thought. *Glabrocingulum* n. sp. A occurs in the Wolfcampian of the Colorado River valley, Texas.

The views on the ages of various faunas from the Laborcita formation not only conflict with each other but do not agree with the field data. Much the same problem exists in the Glass Mountains area of west Texas, where Dr. Cooper is studying the upper Pennsylvanian and lower Permian strata and faunas. According to Cooper (oral communication), the limestones appear to contain mostly a Permian brachiopod fauna, and the interbedded shales a Pennsylvanian fauna, indicating a marked ecologic control for most of the forms. A similar facies control appears to be present in the Sacramento Mountains. Further systematic studies of the late Pennsylvanian and early Permian faunas in the Sacramento Mountains are needed, coupled with detailed comparisons of the faunas of other areas.

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Carel Otte, Jr.
The Pure Oil Co., Crystal Lake, Illinois.

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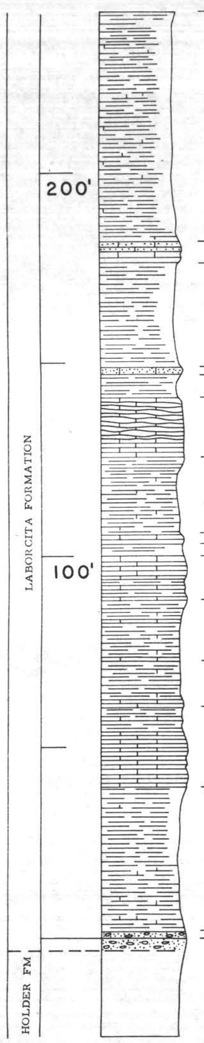
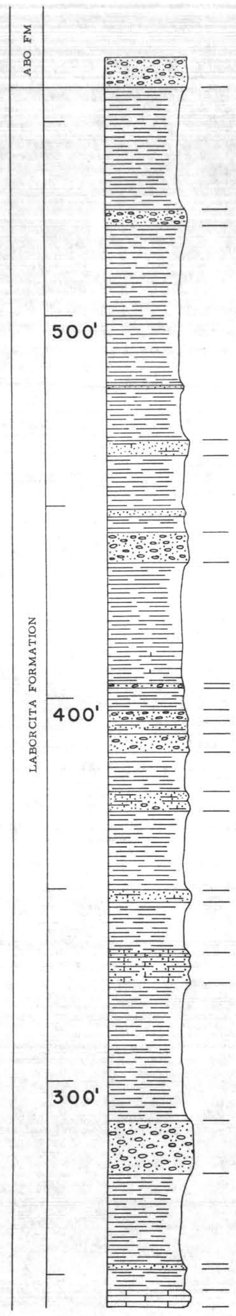


15	62'	Poorly exposed; largely calcareous red shale.
14	5'	Limestone, medium light-gray and fine-grained calcareous sandstone; oolitic, with gastropods.
13	28'	Poorly exposed; largely red mudstone.
12	1'	Limestone, medium dark-gray, sandy, massive.
11	7'	Covered; probably shale.
10	15'	Limestone, medium-gray to medium light green-gray, argillaceous, nodular; bottom 3' dense, algal.
9	20'	Mudstone, dark-red, calcareous.
8	2'	Limestone, medium dark-gray, argillaceous, dense.
7	3'	Covered; probably red mudstone.
6	12'	Limestone, light-gray, argillaceous, dense; interbedded with red mudstone.
5	22'	Shale, greenish-gray, calcareous, with limestone stringers.
4	12'	Mudstone, dark-red, calcareous, and argillaceous algal limestone.
3	14'	Limestone, dark-gray to black, argillaceous, sublithographic; carbonaceous and fossil plant remains.
2	38'	Poorly exposed; lower 20' dark-gray calcareous shale.
1	2'	Conglomerate; pebbles of limestone and quartzite in quartz sandstone matrix.

Contact: Bottom contact of the conglomerate is locally not exposed. The conglomerate can be traced to NW. for 1½ miles and toward SE. for 1 mile. No angular discordance noticeable with underlying strata. Contact is considered a disconformity.

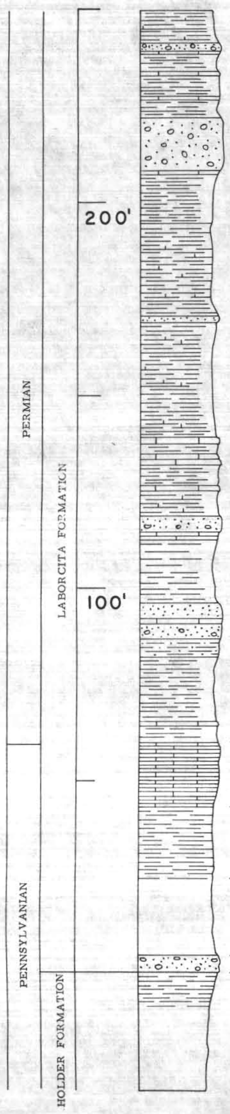
Base of measured section 7 in bottom of Fresnal Canyon 600' SW. of center sec. 32, T. 15 S., R. 11 E., NE. of road. Section measured toward ENE., in and S. of arroyo.



40	7'	Conglomerate; pebbles, cobbles, and boulders of quartzite (50%), limestone, and chert.
39	32'	Poorly exposed; largely red mudstone.
38	4'	Conglomerate; pebbles of limestone (50%), chert, and quartzite.
37	56'	Poorly exposed; largely red mudstone.
36	4'	Sandstone, quartz, light brownish-gray, medium-grained, calcareous, crossbedded.
35	19'	Poorly exposed; largely red mudstone; medium-grained sandstone stringer in lower portion.
34	9'	Conglomerate; pebbles of chert, cobbles of limestone and quartzite.
33	32'	Poorly exposed; largely red mudstone, with reddish-gray limestone nodules in lower portion.
32	1'	Conglomerate; limestone and chert pebbles.
31	6'	Covered; probably red mudstone.
30	3'	Conglomerate, fine-pebbly; predominantly limestone; some chert and quartzite.
29	3'	Mudstone, red, sandy.
28	5'	Conglomerate and sandstone, medium-gray; chert and some quartzite pebbles.
27	10'	Poorly exposed; largely red mudstone.
26	5'	Sandstone, quartz, light brownish-gray, coarse-grained, calcareous; chert pebbles in bottom 2'.
25	21'	Poorly exposed; largely red mudstone.
24	3'	Sandstone, quartz, medium light-gray, coarse-grained, calcareous.
23	13'	Poorly exposed; largely dark-gray shale.
22	8'	Limestone, medium-gray, very sandy.
		Overlying section measured along strike about 2,000' toward SE. (section 6).
21	37'	Poorly exposed; largely red shale.
20	11'	Conglomerate; limestone pebbles.
19	24'	Poorly exposed; largely red shale.
18	1'	Sandstone, quartz, yellowish-gray, medium-grained, calcareous.
17	5'	Mudstone, dark-red, calcareous.
16	3'	Limestone, medium dark-gray, argillaceous, sublithographic; algal structures present.

Section continued from top of column on left.

STRATIGRAPHIC SECTION OF THE LABORCITA FORMATION IN FRESNAL CANYON (SECTIONS 6,7)

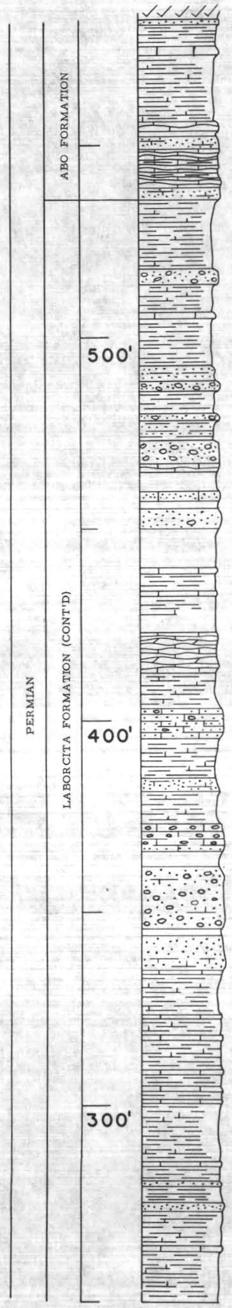


21	3'	Limestone, medium-gray; grades upward into sandy limestone conglomerate.
20	16'	Poorly exposed; largely greenish-yellow claystone, with minor interbedded dark silty limestone, fossiliferous.
19	14'	Conglomerate, sandy; pebbles and cobbles of limestone and chert.
		Overlying section measured N. 20° E. of base of Laborcita section.
18	1'	Limestone, medium-gray, argillaceous.
17	11'	Covered; probably gray shale.
16	25'	Claystone, red, very calcareous.
15	2'	Quartz sandstone, calcareous, brown-weathering; few chert pebbles.
14	30'	Largely covered; probably gray calcareous claystone.
13	12'	Limestone, olive-gray, argillaceous, thin-bedded; probably interbedded shale.
12	8'	Covered; nonred.
11	4'	Conglomerate; granules and pebbles of limestone; grades upward into calcareous medium-grained quartz sandstone.
10	18'	Largely covered; probably yellowish claystone.
9	6'	Quartz sandstone, medium-grained, calcareous; argillaceous limestone at base.
8	3'	Conglomerate, sandy, calcareous; pebbles of limestone and chert.
		Overlying section measured along strike about 500' to the north.
7	5'	Claystone and siltstone, dusky-yellow, calcareous; few 1" to 2" layers of argillaceous limestone.
6	18'	Covered; probably similar to underlying unit.
5	6'	Poorly exposed; light yellowish-gray calcareous claystone, minor argillaceous limestone.
4	15'	Limestone, medium dark-gray, silty, thin-bedded; upper 5' weathers yellowish gray; carbonaceous; streaks of chert, pebbles, and quartz sand in middle part.
3	19'	Shale and siltstone, dark-gray, calcareous, carbonaceous; grades into overlying limestone.
2	20'	Covered; probably dark shale.
1	4'	Quartz sandstone and pebble conglomerate; pebbles largely limestone and chert.

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

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

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

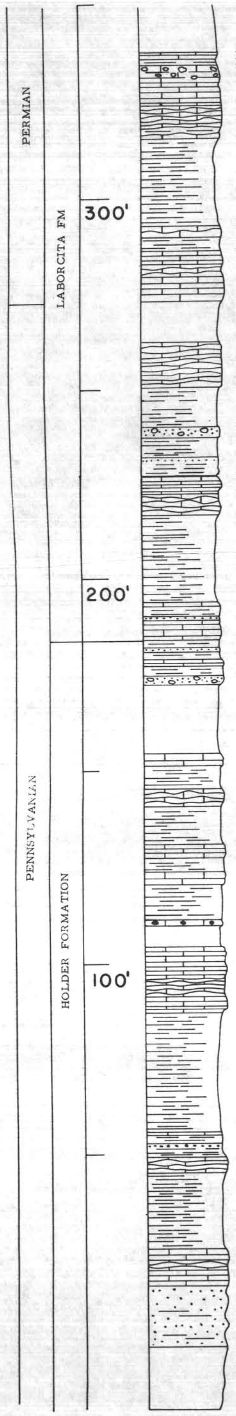


Section continued from top of column on left.

		Intrusive rocks.
66	1'	Sandstone, very resistant.
65	6'	Mudstone, dark greenish-gray.
64	2'	Limestone, grayish-red.
63	18'	Poorly exposed; largely red mudstone; limestone nodules.
62	2'	Limestone, light brownish-gray, argillaceous; undulatory bedding.
61	2'	Covered.
60	3'	Sandstone, dark-red, medium-grained.
59	10'	Limestone, light brownish-gray, argillaceous; undulatory bedding; interbedded with red mudstone.
58	3'	Sandstone, quartz, grayish-red, medium-grained, calcareous; grades along strike into cobbly quartzite conglomerate.
57	19'	Poorly exposed; largely red mudstone and limestone nodules.
56	3'	Conglomerate, pebbly, chert; top grades into calcareous sandstone.
55	8'	Poorly exposed; largely red mudstone and limestone nodules.
54	1'	Limestone, grayish-red, argillaceous, nodular.
53	13'	Poorly exposed; largely red mudstone.
52	4'	Sandstone, dark-red, medium-grained, interbedded with red mudstone.
51	2'	Conglomerate; cobbles of quartzite.
50	6'	Poorly exposed; largely red mudstone.
49	2'	Sandstone, quartz, very coarse-grained; chert pebbles.
48	5'	Mudstone and sandstone, dark-red.
47	6'	Conglomerate; pebbles and coarse quartz sandstone (60% chert, some limestone and quartzite).
		Overlying section 12 measured from a point 600' SE. of center of SE$\frac{1}{4}$ sec. 19, T. 15 S., R. 11 E., toward NE. along line of measured section 12. Base of section in bottom of gully.
46	2'	(46) Limestone, medium-gray, argillaceous, slightly nodular.
45	5'	(45) Covered.
44	2'	Limestone, dark yellow-brown, sandy, fragmental, dense.
43	2'	Covered.
42	5'	Sandstone, calcareous, thin-bedded; minor pebbles; forms resistant ledge.
41	26'	Poorly exposed; probably largely red-brown mudstone; minor exposed beds of gray and red-brown mudstone, calcareous sandstone, and argillaceous limestone nodules.
40	10'	Limestone, dolomitic, silty, argillaceous; bedding nodular to obscure; weathers mottled yellow brown and reddish.
39	7'	Mudstone, red, calcareous; minor sandstone and limestone.
38	7'	Limestone, sandy, and pebble and cobble conglomerate, about 40% quartzite fragments.
37	12'	Mudstone, very calcareous, moderate red-brown.
36	3'	Sandstone, fine- to medium-grained, calcareous, thin-bedded; minor limy streaks and soft shale.
35	8'	Poorly exposed; probably largely red-brown calcareous mudstone.
34	7'	Limestone and limestone conglomerate; medium-gray sandy limestone at base grades up into limestone pebble and cobble conglomerate.
33	4'	Covered.
32	15'	Conglomerate; cobbles of quartzite (40%), limestone, and chert; matrix sandy, calcareous. Channel at base.
		Overlying section measured along strike about 400' to the SE. in shallow draw.
31	2'	Covered.
30	10'	Quartz sandstone, fine-grained, calcareous; light-gray silty limestone at base grades upward into sandstone; unit forms resistant rim of hill, thickens to the NW.
29	17'	Shale, olive-gray, calcareous; 6' above base, 6" layer of gray argillaceous limestone, fossiliferous.
28	7'	Shale, medium-gray, calcareous, fossiliferous (brachiopods).
27	9'	Limestone, medium dark-gray, silty; interbedded with medium-gray calcareous silty shale; abundant fusulinids (Schwagerina). Fossil locality 11-F-2.
26	15'	Poorly exposed; largely nonresistant olive-gray calcareous shale.
25	5'	Shale, olive-gray, calcareous; capped by 6" argillaceous limestone; abundant brachiopods, gastropods, pelecypods. Fossil locality 11-M-1.
24	17'	Shale, olive-gray, calcareous, with interbedded feldspathic quartz sandstone and siltstone; carbonaceous.
23	1'	Limestone, pale red-brown, very argillaceous, massive.
22	21'	Poorly exposed; largely nonresistant olive-gray very calcareous shale.

STRATIGRAPHIC SECTION OF THE LABORCITA FORMATION IN LA LUZ CANYON (SECTIONS 11,12)

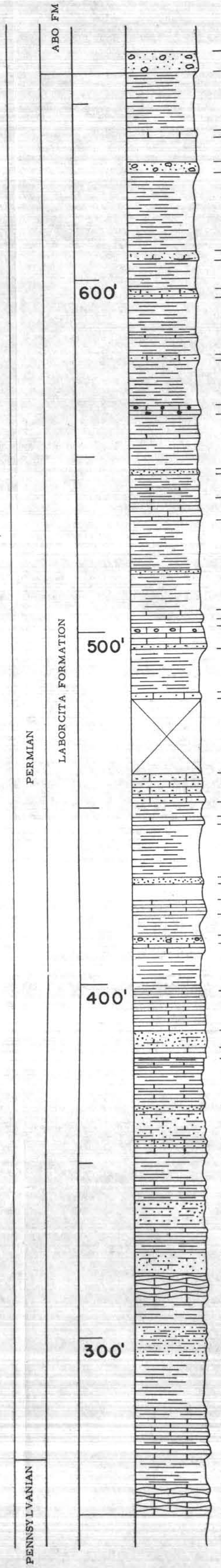
(Largely summarized from a section measured by L.C. Pray)



Remainder of section poorly exposed.

44	2'	Limestone, medium dark-gray, algal; weathers brownish gray.
43	2'	Covered.
42	9'	Limestone, medium dark-gray; algae; conglomeratic near top.
41	9'	Limestone, medium-gray; undulatory bedding; algae; basal 3' with nodular fusulinid limestone (Dunbarinella sp.). Fossil locality 18-F-6.
40	22'	Poorly exposed; largely red mudstone.
39	3'	Limestone, medium-gray, argillaceous, nodular; algae.
38	4'	Shale; poorly exposed.
37	12'	Limestone, medium-gray, massive; algal debris; 6' from bottom a 3' argillaceous zone with undulatory bedding; abundant fusulinids (Schwagerina sp.). Fossil locality 18-F-5.
36	11'	Covered; probably shale.
35	12'	Limestone, medium light-gray, very argillaceous; undulatory bedding; abundant fusulinids (Triticites sp.) near base; grades upward into algal limestone. Fossil locality 18-F-4.
34	11'	Covered; probably red shale.
33	3'	Conglomerate; limestone and chert pebbles in sandstone matrix.
32	5'	Covered; probably shale.
31	4'	Shale, dusky yellow-green; grades into calcareous siltstone.
30	4'	Limestone, grayish-red; algae; massive.
29	6'	Limestone, grayish-red, argillaceous; nodular to undulatory bedding; abundant fusulinids. Fossil locality 18-F-3.
28	23'	Poorly exposed; largely red mudstone.
27	4'	Shale and argillaceous limestone interbedded; abundant fusulinids in top layer. Fossil locality 18-F-2.
26	6'	Limestone, greenish-gray, sandy, well-bedded; grades upward into medium-grained olive-gray quartz sandstone.
25	5'	Contact of Laborcita formation projected to base of unit 26 (see correlation chart, pl. 4). Contact appears to be gradational. No significant difference in lithology on either side of contact.
24	2'	(25) Mudstone, dusky-red, with sandstone layer.
23	2'	(24) Limestone, medium light-gray, silty; algae in top part.
22	2'	(23) Covered.
		(22) Conglomerate; pebbles of limestone and chert in siltstone matrix.
21	18'	Covered.
20	3'	Limestone, medium-gray, massive; fossil debris; very lenticular.
19	6'	Poorly exposed; probably shale.
18	4'	Limestone, medium light-gray; nodular bedding, with shale intervals; brachiopods and fusulinids.
17	11'	Covered; probably shale.
16	3'	Limestone, medium-gray, argillaceous; 1' shale layer; fossiliferous (fusulinids, corals, brachiopods). Fossil locality 18-F-1.
15	4'	Covered, largely shale.
14	3'	Limestone, medium-gray, coarsely fragmental, massive.
13	9'	Covered; probably shale.
12	1'	Limestone; scattered pebbles of limestone and chert.
11	6'	Covered.
10	8'	Limestone, medium-gray, well-bedded, fossiliferous.
9	5'	Limestone, medium light-gray, argillaceous, nodular, interbedded with shale.
8	4'	Limestone, medium-gray; algal debris.
7	30'	Covered; probably shale.
6	1'	Limestone, medium-gray, nodular, algal.
5	6'	Shale, dusky yellow-green, with thin sandstone bed.
4	4'	Limestone, medium-gray, well-bedded; nodular limestone with fusulinids.
3	19'	Poorly exposed; probably red mudstone.
2	10'	Limestone, medium dark-gray, algal; center interbedded with shale.
1	16'	Sandstone, light brownish-gray, medium- to coarse-grained, strongly crossbedded.

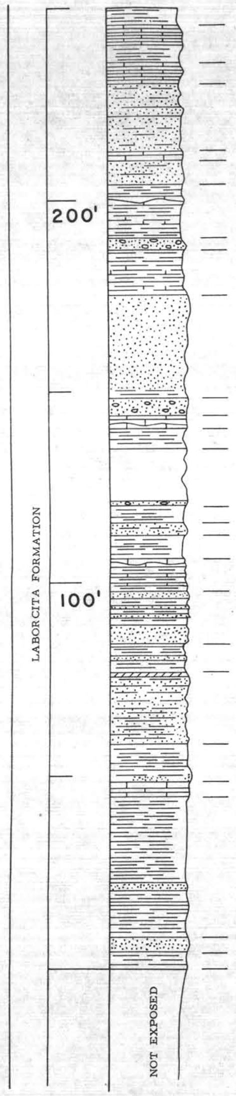
Base of measured section in bottom of Laborcita Canyon, 700' SE. of center of sec. 13, T. 15 S., R. 10 E., at N. side of canyon (section 18).



83	5'	Conglomerate, dark yellowish-brown; pebbles of quartzite, chert, and some limestone in sandstone matrix.
82	18'	Poorly exposed; red mudstone.
81	1'	Limestone, pale yellowish-brown, argillaceous.
80	7'	Covered.
79	3'	Conglomerate; pebbles of limestone and chert.
78	22'	Covered; red mudstone.
77	3'	Sandstone, quartz, dark yellowish-gray, medium-grained, calcareous.
76	9'	Poorly exposed; largely gray shale.
75	2'	Limestone, light brownish-gray, very coarse sandy.
74	17'	Poorly exposed; largely shale; thin silty limestone layers.
73	1'	Limestone, medium dark-gray, silty, algal; grades into fusulinid-bearing limestone toward the S. (horizon 37).
72	13'	Poorly exposed; largely shale.
71	2'	Limestone, medium light-gray, silty, detrital, locally conglomeratic.
70	16'	Mudstone, dusky-red; abundant limestone nodules; 2' argillaceous limestone bed.
69	1'	Sandstone, brownish-gray, medium coarse-grained.
68	7'	Poorly exposed; shale, with dark bluish-gray limestone layer.
67	6'	Limestone, medium-gray, silty, well-bedded; upper 1' very detrital, with crinoidal fragments.
66	26'	Poorly exposed; largely shale, with locally quartz sandstone layers.
65	2'	Limestone, medium bluish-gray; weathers olive brown.
64	2'	Covered; probably shale.
63	7'	Limestone, brownish-gray, sandy, conglomeratic at top.
62	12'	Shale, dusky-yellow (see unit 56).
61	1'	Limestone, dark bluish-gray, fossiliferous (crinoid stems, brachiopods, algal fragments).
60		Approximately 20' of stratigraphic section appears to be obliterated by a fine-grained acidic intrusive (correlation chart pl. 4, sections 19 and 20). Base of overlying section 19 near center of SE¼SE¼ sec. 7, T. 15 S., R. 11 E., at contact of intrusive with sediments. Section measured toward NE.
59	8'	Limestone, medium dark-gray, very silty, well-bedded; brownish-weathering crust.
58	4'	Poorly exposed; like unit 56.
57	2'	Limestone, medium dark-gray, very silty.
56	15'	Poorly exposed; largely dusky yellow-green shale; indurated, probably by overlying intrusive.
55	2'	Sandstone, quartz, olive-gray, fine medium-grained.
54	4'	Covered; probably shale.
53	4'	Limestone, medium dark-gray, silty, oolitic.
52	6'	Covered; probably shale.
51	2'	Sandstone, quartz, light brownish-gray, very coarse-grained; conglomeratic at top, with chert grains.
50	10'	Shale, medium bluish-gray, silty, calcareous, very fossiliferous; grades upward into medium dark-gray silty limestone.
49	11'	Limestone, dark bluish-gray to medium-gray, silty; algal detritus; interbedded with shale.
48	5'	Sandstone, light olive-gray, medium-grained; granules of limestone, quartzite, and glauconite.
47	16'	Limestone, dark bluish-gray, argillaceous, sublithographic, interbedded with shale.
46	10'	Sandstone, yellowish-gray, very fine-grained, calcareous, interbedded with thin limestone layers.
45	5'	Limestone, medium-gray, very sandy; granules of chert.
44	12'	Poorly exposed; shale and greenish-gray limestone at bottom.
43	8'	Sandstone, quartz, yellowish-gray, very fine-grained, calcareous, interbedded with siltstone.
42	7'	Limestone, grayish red-purple, finely granular, well-bedded, with silty partings.
41	6'	Siltstone, medium-grained, calcareous, interbedded with shale.
40	8'	Limestone, medium light-gray, argillaceous, with undulatory bedding.
39	6'	Siltstone, medium-grained, calcareous, interbedded with shale.
38	10'	Siltstone, grayish-red, calcareous, interbedded with shale.
37	17'	Poorly exposed; largely shale; nodular argillaceous limestone at bottom.
36	11'	Limestone, medium-gray, massive, with shaly parting; basal 1' of upper ledge contains abundant fusulinids. Fossil locality 20-F-1.
35	7'	Poorly exposed; largely red shale and nodular argillaceous limestone.
34	7'	Limestone, medium light-gray, very argillaceous; undulatory bedding; abundant fusulinids.

Base of overlying measured section 350' N. of center of NE¼ sec. 13, T. 15 S., R. 10 E., 1700' along strike of unit 35 of previous section toward NNE. (horizon 8 of correlation chart pl. 4, section 20).

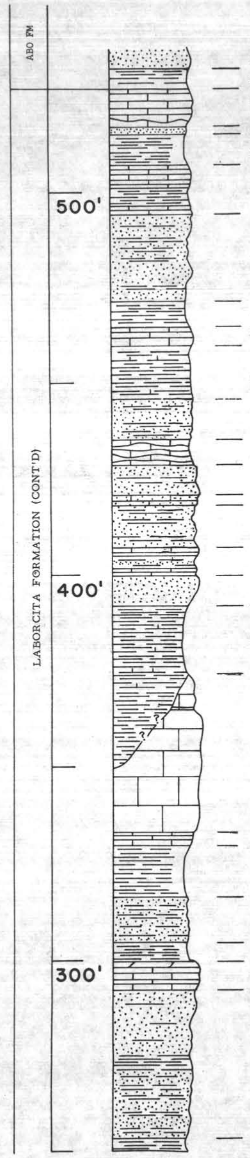
STRATIGRAPHIC SECTION OF THE LABORCITA FORMATION IN LABORCITA CANYON (SECTIONS 18, 19, 20)



25	10'	Limestone, light-gray; in part limestone conglomerate; top 3' dark gray and fossiliferous (brachiopods, pelecypods).
24	5'	Limestone, medium dark-gray, argillaceous, thinly bedded.
23	18'	Arkose; weathers red brown; medium- to very coarse-grained; interbedded with dark red-brown and gray shale.
22	3'	Shale, dark-gray, calcareous, thinly bedded; medium dark-gray argillaceous limestone.
21	6'	Arkose, brown-weathering, medium- to very coarse-grained.
20	19'	Mudstone, dark red-brown to dusky-red, slightly calcareous; nodular argillaceous limestone bed.
19	3'	Conglomerate, well-rounded cobbles of quartzite (2/3) and red rhyolite porphyry (1/3) in arkose matrix.
18	12'	Mudstone, dark red-brown to very dusky-red; nodular limestone and gray-green arkose in upper part.
17	27'	Sandstone, gray-green to pale-brown, coarse-grained to granules, feldspathic to arkosic, cross-bedded.
16	5'	Conglomerate; pebbles and cobbles of quartzite (2/3), rhyolite porphyry (1/3), chert, and limestone in coarse-grained arkose matrix.
15	3'	Limestone, medium dark-gray, argillaceous, sublithographic, nodular at base.
14	5'	Covered; shale, nonred.
13	15'	Arkose, gray olive-green, very coarse-grained, well-sorted, conglomeratic (quartzite, chert, limestone) at base; petrified wood.
12	4'	Covered; nonred shale and sandstone.
11	4'	Sandstone, pale-brown, very coarse-grained, feldspathic; plant remains.
10	6'	Covered; nonred shale.
9	9'	Limestone, medium-gray, argillaceous; slightly nodular bedding (algae in top 3'); interbedded with nonexposed shale (1 to 1 ratio).
8	14'	Sandstone, feldspathic, dark green-gray and pink arkose, medium- to very coarse-grained.
7	8'	Shale, dark red-brown, with layer of red-green feldspathic sandstone.
6	18'	Shale, olive-gray, interbedded with medium- to coarse-grained feldspathic sandstone (1 to 1 ratio).
5	10'	Poorly exposed; shale, dark olive-gray, with very coarse quartz sandstone at base.
4	4'	Limestone, dark-gray, argillaceous, brown-weathering; fossil fragments.
3	36'	Shale, olive-gray; poorly exposed.
2	4'	Sandstone, quartz, olive-gray, medium- to coarse-grained, platy; locally plant fossils.
1	4'	Shale, dark olive-gray.

Base of measured section 29 near center of SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 17, T. 14 S., R. 10 E., at the base of 10'-high scarplet.

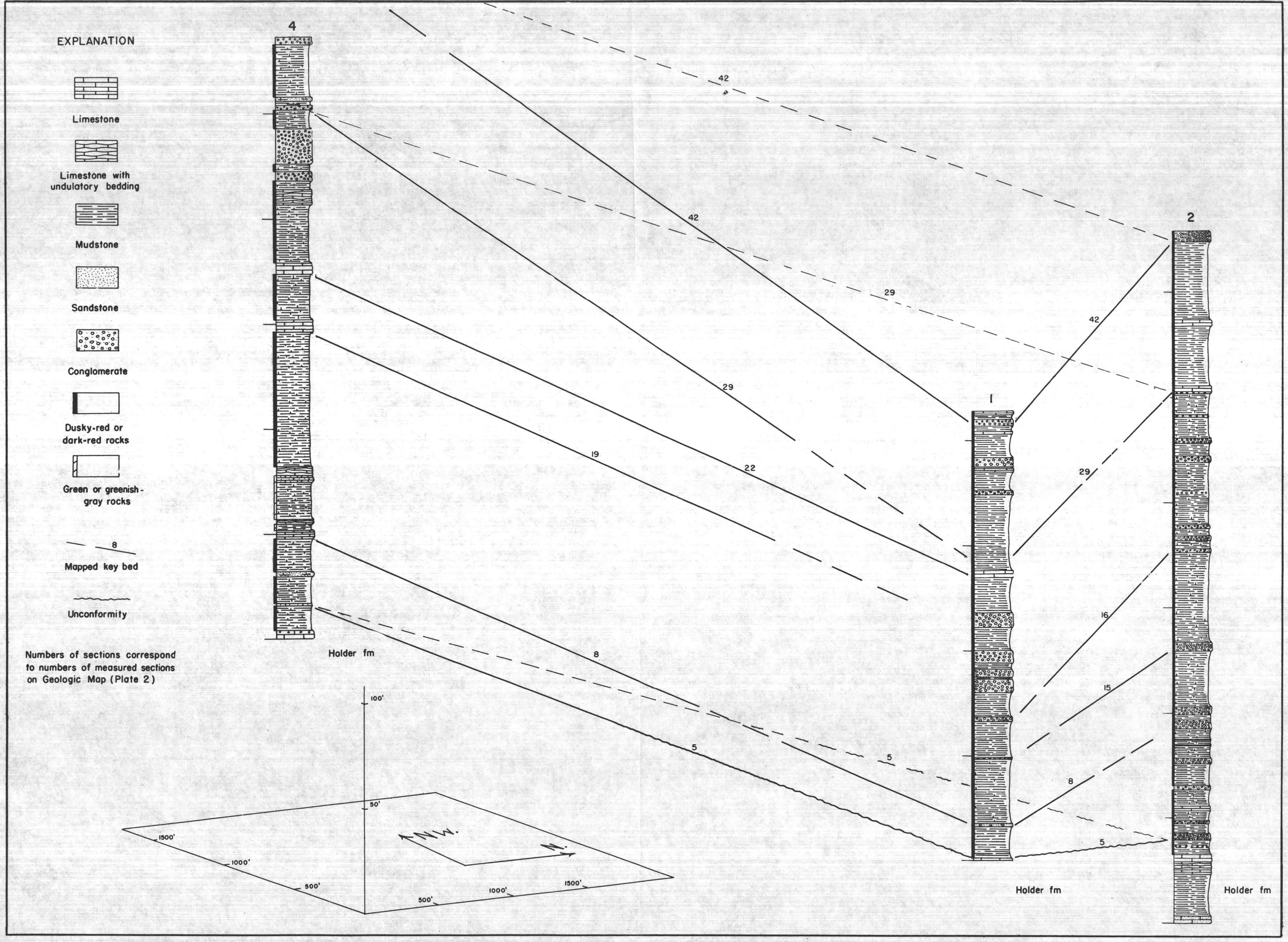
The base of the Laborcita formation, when projected to the N. on the stratigraphic correlation chart (pl. 4), occurs approximately 450' below horizon 32 (unit 2).



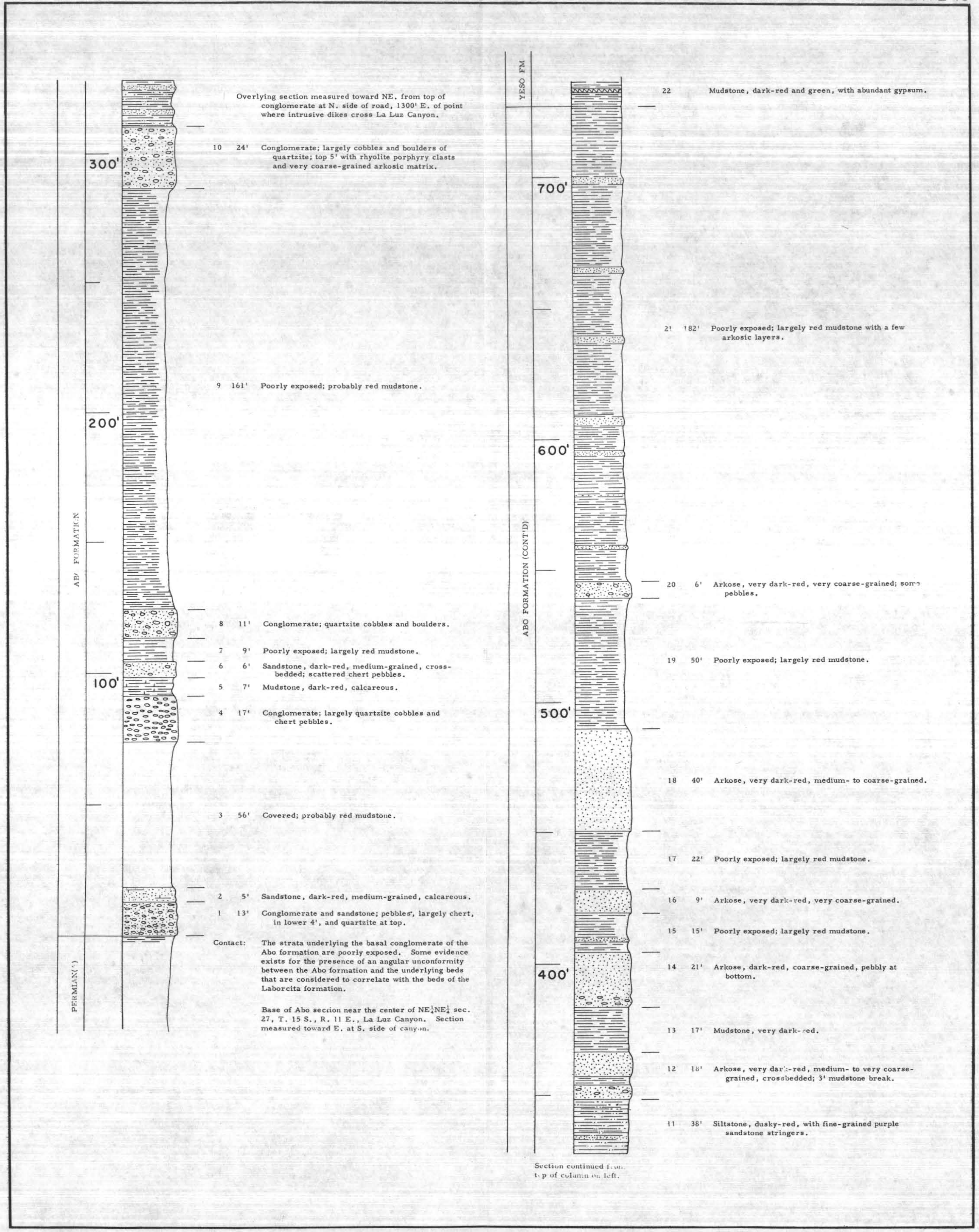
Section continued from top of column on left.

51		Arkose, dusky-red, coarse-grained; minor crossbedding.
50	5'	Shale, light olive-gray, noncalcareous; plant leaf impressions.
49	14'	Limestone, light-gray, very fine crystalline, massive; basal 2' nodular argillaceous; fossiliferous (brachiopods, fusulinids, algae).
48	2'	Arkose, greenish-gray, very fine to very coarse-grained.
47	10'	Covered.
46	18'	Limestone, light-brownish-gray, argillaceous, irregularly bedded; dark red-brown calcareous shale.
45	30'	Arkose, very dusky-red, coarse- to very coarse-grained; interbedded dark red-brown shale.
44	7'	Shale, dark red-brown, calcareous; top 1' sandy limestone.
43	5'	Limestone, medium light-gray, argillaceous, very fine-crystalline to sublithographic, massive; top 1' very fossiliferous (algae).
42	14'	Shale, dark red-brown; minor sandstone at base and limestone nodules near top.
41	11'	Sandstone, light brownish-gray to dark red-brown, very coarse-grained to conglomeratic, feldspathic; locally coquina; minor beds of dark-red shale.
40	7'	Limestone, white-weathering, argillaceous, very nodular and irregular.
39	8'	Sandstone, very coarse-grained, feldspathic, massive; interbedded dark red-brown shale.
38	2'	Limestone, light brown- to gray-weathering, sandy; top 1' coquina of small (brachiopod) shells.
37	11'	Subgraywacke, dark greenish-gray, medium coarse-grained, feldspathic; interbedded with poorly exposed dark red-brown shale with plant fossils.
36	7'	Limestone, medium-gray, argillaceous: algae; top brown-weathering; interbedded greenish sandstone and calcareous shale.
35	8'	Sandstone, greenish-gray, very coarse-grained, feldspathic, slightly crossbedded.
34	18'	Shale, medium dark-gray, calcareous, fissile; top 1' interbedded with argillaceous limestone; fossiliferous (pelecypods, brachiopods, gastropods). Fossil locality 30-M-3.
		Overlying section measured along strike 600' to NE. (section 30).
33	41'	Limestone, medium-gray, very fine-crystalline to sublithographic; irregular algal masses partly recrystallized; fusulinids on flank and top. Fossil localities 29-F-1 and 30-F-1.
32	3'	Limestone, medium-gray, very fine-crystalline, irregularly bedded; lower 1' brown-weathering dolomitic limestone.
31	14'	Covered; probably shale, nonred.
30	12'	Arkose, greenish-gray, silty to very coarse-grained; interbedded gray shale.
29	5'	Covered.
28	7'	Limestone, medium light-gray, very fine-crystalline; brown-weathering dolomite nodules near top.
27	39'	Graywacke, greenish-gray, fine- to medium-grained, thinly bedded, massive near top; 4' interval of medium dark-gray shale with plant fossils; top part arkosic in composition.
26	8'	Covered; probably silty shale.

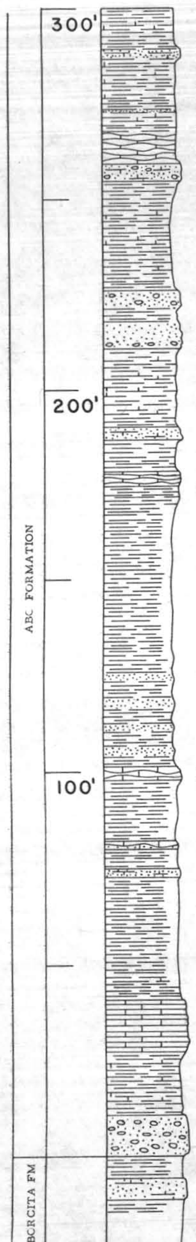
STRATIGRAPHIC SECTION OF THE LABORCITA FORMATION NORTH OF TULAROSA CANYON (SECTIONS 29, 30)



ISOMETRIC DIAGRAM OF THE SOUTHERNMOST PART OF THE LABORCITA FORMATION



STRATIGRAPHIC SECTION OF THE ABO FORMATION IN UPPER LA LUZ CANYON (SECTION 35)



14 40' Mudstone, dusky-red, very calcareous; locally thin dark-red medium-grained sandstone layers.

13 10' Limestone, brownish-gray, nodular.

12 4' Sandstone, quartz, dark-red, coarse-grained, calcareous; conglomeratic in places.

11 29' Mudstone, dusky-red, calcareous, with nodular limestone.

10 15' Conglomerate; pebbles to cobbles of predominantly quartzite in sandstone matrix. Partially covered; probably red mudstone.

9 32' Mudstone, dusky-red, calcareous, with fine-grained dark-red sandstone layer; nodular limestone in center of unit.

8 3' Limestone, brownish-gray, nodular.

7 48' Poorly exposed; probably like top 5', which consists of dusky-red calcareous mudstone.

6 25' Poorly exposed; probably red sandstone interbedded with red mudstone.

5 3' Limestone, brownish-gray, argillaceous, nodular.

4 57' Poorly exposed; probably red mudstone; locally outcrops of gray calcareous sandstone and reddish sandy limestone.

3 13' Limestone, light brownish-gray, argillaceous, thin-bedded.

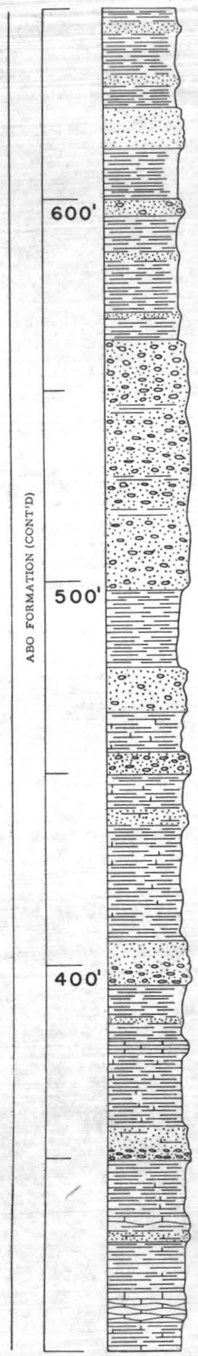
2 18' Mudstone, dusky-red, calcareous.

1 10' Conglomerate; pebbles and cobbles of quartzite (70%) and some chert.

Sandstone, medium-gray, calcareous, and dusky-red mudstone underlie the conglomerate bed that is considered the base of the Abo formation.

Contact: The base of a distinctive conglomerate bed is considered the base of the Abo formation. This predominantly quartzite-pebble and cobble conglomerate layer has been recognized over a 7-mile distance as key bed 49. No other lithologic distinctions exist between the underlying and overlying strata. In this part of the area, the contact does not represent a major interruption or change in type of deposition.

Base of section is located near the center of SW$\frac{1}{4}$SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 19, T. 15 S., R. 11 E., in canyon bottom just below horizon 49.



Section continued from top of column on left.

34 37' Poorly exposed; largely red mudstone; interbedded with two medium- to coarse-grained pale-red crossbedded arkosic layers.

33 11' Arkose, dark-red, very coarse-grained.

32 13' Poorly exposed; probably red mudstone.

31 5' Arkose, dusky-red, very coarse-grained, with quartzite pebbles scattered throughout.

30 32' Mudstone, dusky-red, interbedded with a few arkosic sandstone layers.

29 66' Conglomerate, dark-red; pebbles and cobbles of quartzite and about 10% rhyolite porphyry in arkose matrix; interbedded with dusky-red mudstone and siltstone.

28 21' Mudstone, dusky-red.

27 11' Sandstone, quartz, dark-red, medium-grained, with scattered quartzite pebbles.

26 11' Mudstone, dusky-red, silty, with limestone nodules.

25 5' Conglomerate, dark-red; pebbles and cobbles of quartzite in calcareous sandstone matrix.

24 43' Mudstone, dusky-red, silty, calcareous, with locally limestone nodules; medium-grained dark-red sandstone 10' from top.

23 12' Conglomerate, dark-red; pebbles and cobbles of quartzite in sandstone matrix; grades upward into medium-grained sandstone.

22 15' Poorly exposed; largely dusky-red mudstone, like bottom 4 feet.

21 3' Limestone, grayish-red, argillaceous.

20 19' Mudstone, dusky-red, calcareous, with gray limestone nodules.

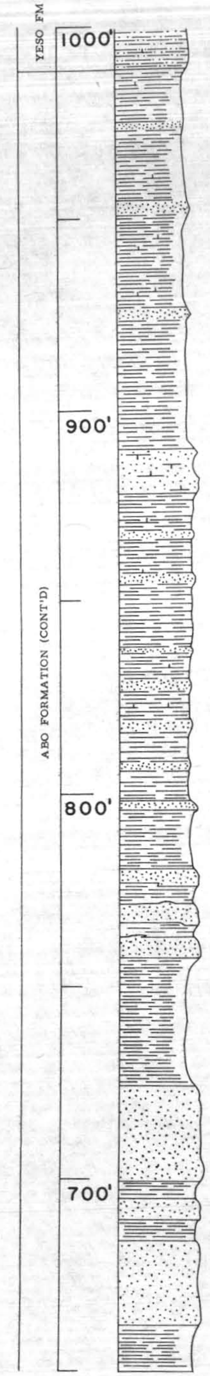
19 9' Sandstone, quartz, very dark-red, medium-grained, thin-bedded, calcareous; 3' quartzite-cobble conglomerate at base.

18 15' Mudstone, dusky-red, calcareous, sandy.

17 6' Limestone, brownish-gray, argillaceous, nodular, with calcareous sandstone at bottom.

16 14' Mudstone, dusky-red, calcareous.

15 7' Limestone, pale reddish-brown, argillaceous, nodular.



Section continued from top of column on left.

41 Siltstone, greenish-gray; consists largely of quartz. Contact appears to be gradational. A sill-like igneous body occurs directly above the contact.

40 100' Poorly exposed; locally dusky-red calcareous mudstone and coarse-grained dark-red arkose.

39 12' Arkose, dusky-red, very coarse-grained.

Overlying section measured northeast of Henry's ranch in stream bed. Horizon was projected from gravel-capped hill, assuming a 1° dip.

38 98' Mudstone, dusky-red, locally calcareous, interbedded with thin arkose layers.

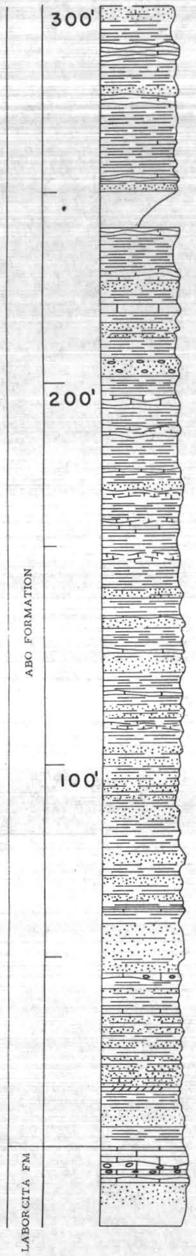
37 23' Arkose, pale-red to dusky-red, very coarse-grained, interbedded with red mudstone.

36 34' Poorly exposed; probably red mudstone.

Overlying section measured 2,000' N. on E. end of ridge, starting with equivalent horizon.

35 62' Arkose, dusky-red and pale-red, medium- to coarse-grained, strongly crossbedded, interbedded with poorly exposed red mudstone.

STRATIGRAPHIC SECTION OF THE ABO FORMATION NORTHEAST OF LA LUZ (SECTION 36)



10 69' Mudstone, very dark-red, and red arkose; locally calcareous mudstone, argillaceous limestone, and nodular limestone.

Fault; possibly 10' of section obscured.

9 3' Limestone, grayish-red, argillaceous, mottled.

8 12' Mudstone, very dark-red, and some red arkose.

7 5' Arkose, very dark-red, and pebble-cobble conglomerate (predominantly rhyolite porphyry and some quartzite).

6 94' Mudstone, very dark-red, and interbedded dark-red arkose; minor argillaceous nodular limestone layers.

5 46' Arkose, very dark-red, coarse-grained, interbedded (up to 40%) with dark-red mudstone.

4 17' Arkose, very dark-red, very coarse-grained, locally conglomeratic, interbedded with dark-red mudstone; top 2' gray-red limestone.

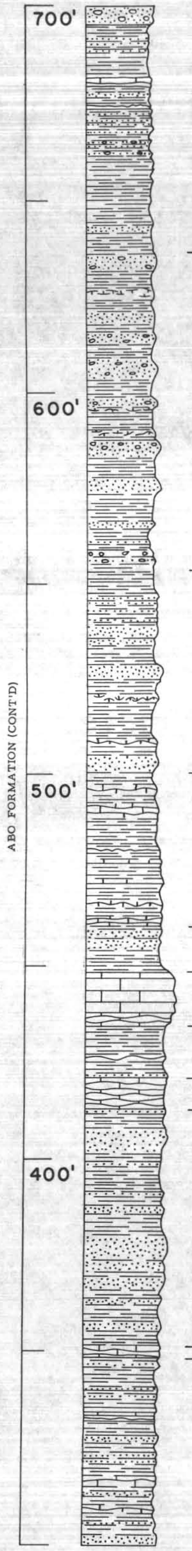
3 10' Mudstone, very dusky-red and nodularly bedded argillaceous unfossiliferous limestone.

2 30' Arkose, dusky-red, coarse-grained; minor cross-bedding; interbedded with dusky-red mudstone (20%).

1 6' Shale, light olive-gray, noncalcareous; plant-leaf impressions.

Contact: Gradational. The underlying limestone ledge contains fusulinids (Schwagerina and Dunbarinella) when traced to N. and S. and is considered to be the top of the Laborcita formation in the Sacramento Mountains.

Base of section is located in SW$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 9, T. 14 S., R. 10 E., at top of horizon 55, approximately 2$\frac{1}{2}$ miles N. of the Tularosa reservoir.



Section continued from top of column on left.

21 86' Mudstone, dark reddish-brown, and very coarse dusky-red arkose; locally conglomerate; minor amounts of gray argillaceous nodular limestone.

20 83' Conglomerate and very coarse arkose; pebbles and cobbles; 65% rhyolite porphyry, remainder quartzite; interbedded with dusky-red mudstone.

19 56' Arkose, very dusky-red, very coarse-grained, interbedded with dusky-red mudstone and minor amounts of nodular limestone.

18 40' Mudstone, very dusky-red, and grayish-red mottled argillaceous nodular limestone.

17 11' Arkose, very dusky-red, very coarse-grained to granular, and dusky-red mudstone.

16 14' Limestone, medium light-gray, fine-crystalline, very argillaceous; this massive ledge appears to be unfossiliferous; bottom 3' nodularly bedded.

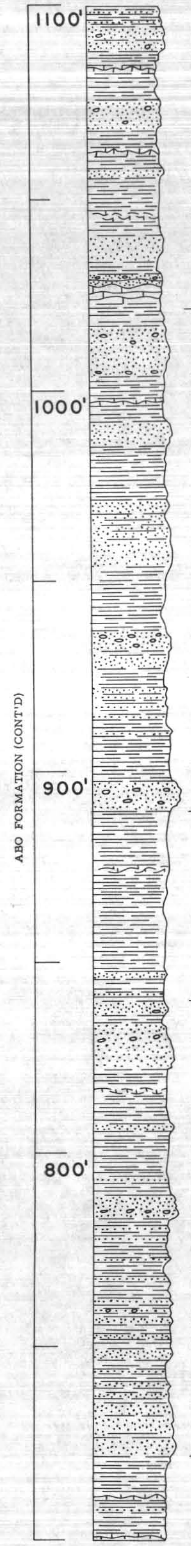
15 14' Mudstone, poorly exposed.

14 8' Limestone, grayish-red, argillaceous; nodular to undulatory bedding.

13 63' Arkose, dusky-red, coarse-grained, locally crossbedded; dusky-red mudstone interbedded.

12 3' Limestone, grayish-red, argillaceous and sandy, slightly nodular.

11 55' Arkose, dusky-red, crossbedded, interbedded with dark-red mudstone and medium-gray argillaceous limestone beds.

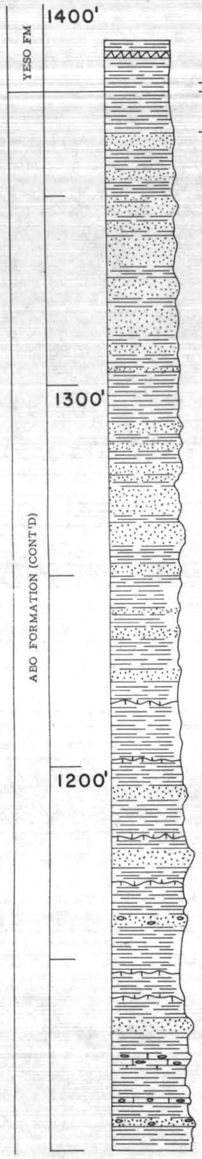


Section continued from top of column on left.

24 129' Arkose and conglomerate, very dusky-red, very coarse-grained to pebbly; mainly rhyolite porphyry; interbedded sandy, very dark-red mudstone.

23 51' Poorly exposed; largely dark-red mudstone; some gray nodular limestone.

22 119' Arkose, dark reddish-brown; granules to pebbles and cobbles of rhyolite porphyry and quartzite; minor amounts of dusky-red mudstone.



Section continued from top of column on left.

29 10' Shale and siltstone, dusky-red and green; considerable amount of gypsum.

28 3' Shale, dusky-red and green.

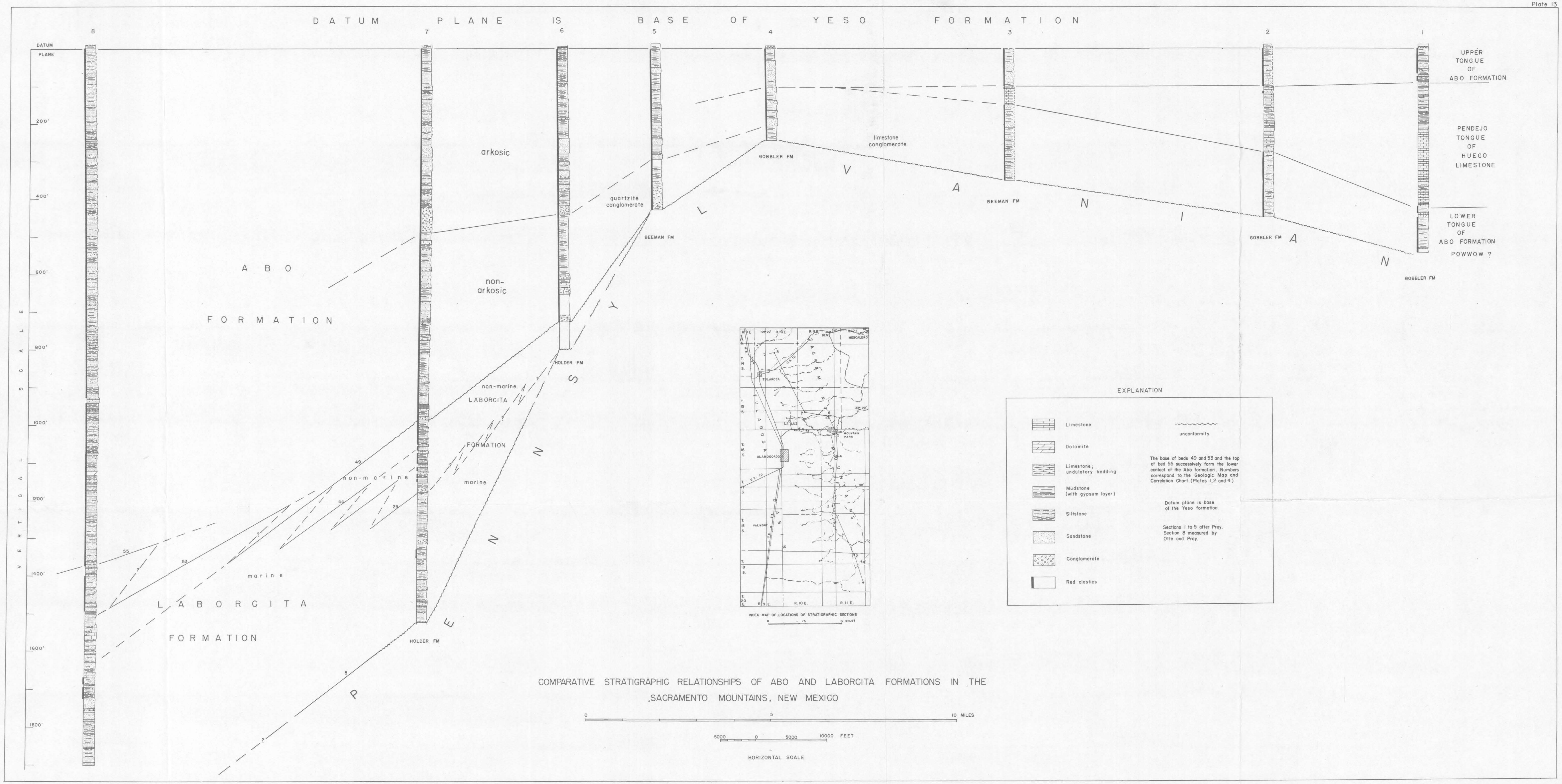
27 13' Mudstone, very dark-red, calcareous.

26 147' Arkose, very dusky-red, very coarse-grained to granular, calcareous; locally conglomeratic, with rhyolite porphyry pebbles; interbedded with dusky-red calcareous mudstone.

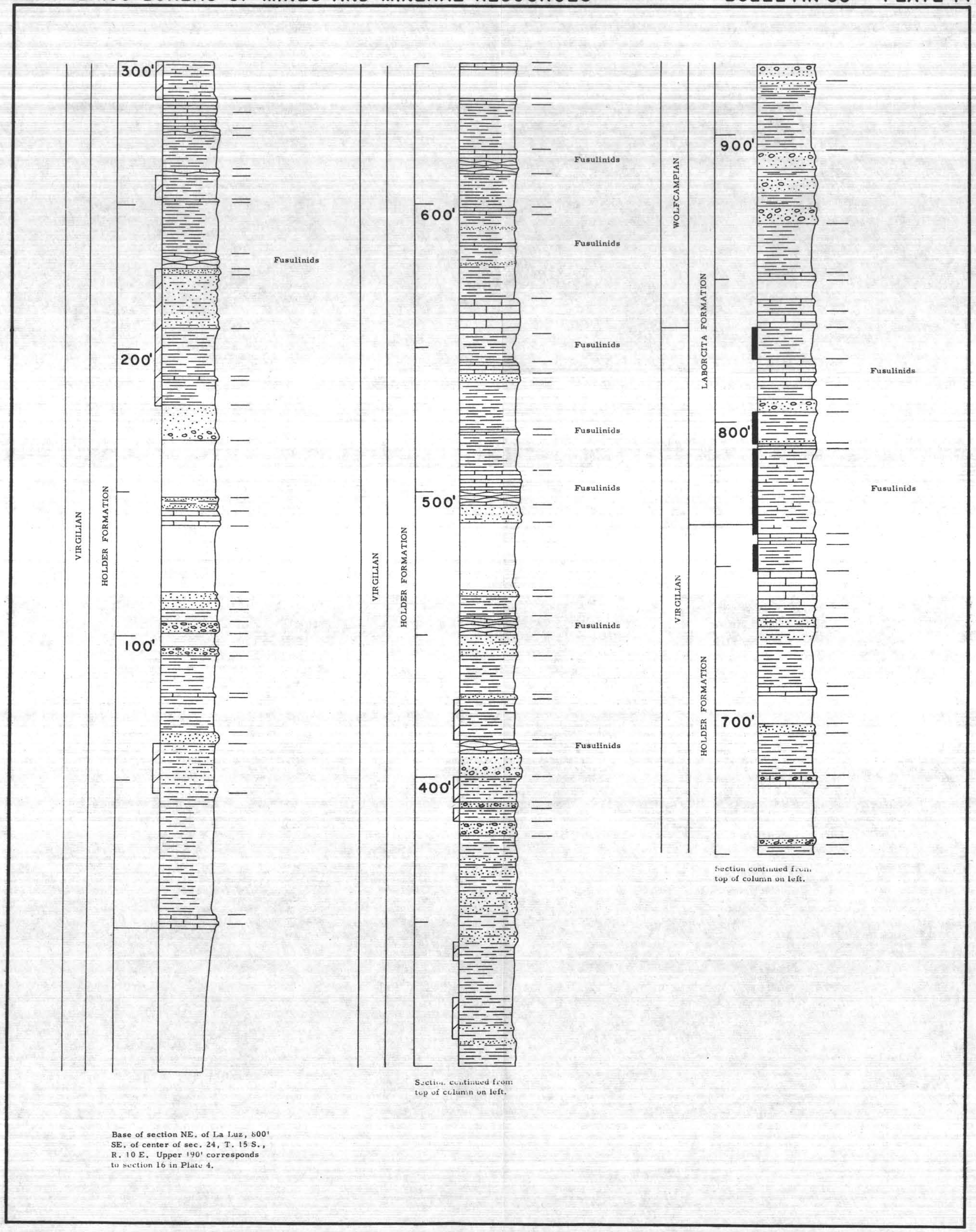
25 197' Mudstone, very dark-red, and limestone, very argillaceous, nodular; locally very coarse arkose and pebble conglomerate.

STRATIGRAPHIC SECTION OF THE ABO FORMATION NORTH OF TULAROSA (SECTION 37)

(Measured by C. Otte and L.C. Pray)



COMPARATIVE STRATIGRAPHIC RELATIONSHIPS OF ABO AND LABORCITA FORMATIONS IN THE SACRAMENTO MOUNTAINS, NEW MEXICO



STRATIGRAPHIC SECTION OF THE HOLDER FORMATION (SECTION 38)