LATE PENNSYLVANIAN AND EARLY PERMIAN STRATIGRAPHY OF THE NORTHERN SACRAMENTO MOUNTAINS, OTERO COUNTY, NEW MEXICO

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ABSTRACT

Late Pennsylvanian and early Permian strata in the northernmost Sacramento Mountains of New Mexico were studied in 1951-52 to aid in interpreting the complex depositional history of this time in south central New Mexico and to afford better understanding of the sedimentary and tectonic processes involved. For this investigation, which is largely a field study, five months were devoted to mapping a critical area of about 80 square miles, of which 30 square miles were covered in great detail, on a scale of four inches equal one mile.

The map area forms the northernmost extension of the Sacramento Mountain escarpment, which is formed by a block that has been uplifted along a fault on the west and tilted one or two degrees to the east. Prior to this late Cenozoic Basin Range faulting, the area was affected by early Tertiary gentle folding and intrusion of Tertiary (?) sills and dikes of acidic and intermediate composition that cover about five percent of the area. Minor high-angle faults that were largely associated with the boundary fault zone occur in the area and locally complicate the structure. Evidence of late Pennsylvanian and early Permian folding and high-angle faulting is present in the southeasternmost part of the area of investigation. Various Quaternary stream deposits cover about one-fifth of the area, which is otherwise unusually well exposed.

The evidence indicates that deposition was essentially continuous from late Pennsylvanian (Virgilian) into early Permian

(Wolfcampian) time within the area. This is significant in view of the relationships within four miles to the southeast, where a major angular unconformity separates Pennsylvanian and Permian strata. The sediments that are the time-equivalent of part of the hiatus represented by the unconformity have been designated by the author as the Laborcita formation. The lithologic and faunal character of the sedimentary deposits of the Laborcita formation indicate that abrupt lateral transition toward the east and southeast from open marine conditions to terrestrial flood plain environments must have occurred repeatedly within the distance of a few miles. The transition in environments was proved by lateral tracing of strata. One typical lateral succession of contemporaneous deposits was determined to be massive marine limestone; nodular argillaceous fusulinid-bearing limestone; silty limestones, bearing abundant shallow marine forms such as molluscs and brachiopods; dolomitic limestone; green shale; and marine to non-marine red shale and other terrigenous clastics. The lithology encountered in any one bed appears to be a function of the distance from shore line and depth of deposition, and the faunal content probably reflects the depth of deposition.

The cyclic repetition of certain sequences is locally conspicuous and appears to be related to the tectonic instability of this area and to the episodic nature of the deformation in the area 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 non-marine environments, although many fluctuations are recorded and periods of relative stability must have occurred.

Everywhere, the Laborcita formation overlies upper Pennsylvanian marine strata and underlies the red beds of the Abo formation. At the type locality, near the mouth of Laborcita Canyon about 2-1/4 miles northeast of the town of La Luz, the Laborcita formation is predominantly composed of marine beds and is 480 feet thick. About 3-1/2 miles to the southeast, a section of approximately the same thickness consists for about 80 percent of nonmarine red mudstones. Within two more miles to the southeast the Laborcita formation wedges out into the unconformity. About seven miles northwest of the type locality, in the vicinity of Tularosa, the Laborcita formation thickens to about 1,000 feet. This marked increase in thickness is partly caused by a gradual regression of the Laborcita sea toward the northwest and a successive transgression of time lines of the upper contact of the Laborcita formation.

On the basis of fusulinid occurrences throughout the Laborcita formation, the age has been determined as very late Virgilian and early Wolfcampian. In the lower part of the type section several zones yielded abundant fusulinids, which permitted an accurate location of the Pennsylvanian-Permian boundary about 90 feet above the base of the formation. Preliminary studies of the megafossils by various 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, that occur in a position about 150 feet stratigraphically above fusulinids of distinctly Wolfcampian age, are classified as early late Pennsylvanian. The gastropods also exhibit affinities with Pennsylvanian forms. On the basis of the field studies and detailed stratigraphic control, the author believes that the conflicting paleontologic age-assignments must be resolved by further study and collaboration among the specialists of the different faunal groups.

The non-marine strata overlying the Laborcita formation consist largely of red mudstone, fine sandstone, coarse arkose and minor conglomerate and comprise the Abo formation. In the Tularosa area near the northern boundary 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 1400 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 clastics is considered to be the Pedernal Landmass, a positive area of pre-Cambrian igneous and metamorphic rocks that existed during early Permian time in the northeasternmost part of the Sacramento Mountains, and which probably extended for 100 miles, or farther, to the north.

Pray's work in the central and southern parts of the Sacramento Mountains indicates that the Abo formation is correlative with the bulk of the Hueco formation. On this basis, Pray considers the age of the top of the Abo formation either latest Wolfcampian or earliest Leonardian. As the Abo formation interfingers at the base with upper lower Wolfcampian marine strata in the map area, it is largely considered to be of middle and late Wolfcampian age.

Thus, the Laborcita and Abo formations in the northernmost Sacramento Mountains indicate that deposition there was essentially continuous from late Virgilian through Wolfcampian time. The deposits indicate a gradual emergence of the area and retreat of the marine waters to the west and northwest, probably as a result of the late Virgilian-early Wolfcampian diastrophism of the Sacramento Mountains in the area to the east and southeast.

In the Sacramento Mountains the Abo formation grades upward into the predominantly marine Yeso formation, that reaches a thickness of about 1300 feet. It consists mostly of limestones, shales, gypsum and sandstones and was not studied in any further detail. The overlying San Andres formation is the youngest Paleozoic formation of the Sacramento Mountains and forms the crest of the range.

In the course of the field investigation a zone of lower Permian algal reefs was discovered northeast of Tularosa in the uppermost Laborcita formation. Detailed studies indicate that a filamentous alga is the main cement-binding and framework-building organism in these reefs, which average a height of about 35 feet, but which locally stood about 60 feet above the level of contemporaneous sedimentation.

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I. INTRODUCTION

PURPOSE OF INVESTIGATION

The position of the Pennsylvanian-Permian boundary has been a controversial subject for many years in various parts of the world. In southern and central New Mexico the Pennsylvanian System is largely composed of marine limestones and sandstones which comprise the Magdalena formation. The lower part of the Permian System consists mostly of non-marine red mudstones and arkoses which are included in the Abo formation. Therefore, in this area most early geologists placed the base of the Permian at the contact that marks the change from marine to non-marine deposition. Where the contact forms an easily recognizable disconformity or is an angular unconformity, as in most of the Sacramento Mountains and farther to the south and southeast, the position of the Pennsylvanian-Permian boundary is not in doubt. For the areas, however, where deposition was essentially continuous and the change from marine to non-marine conditions was gradual or where the relationships are less clearcut for other reasons, the position of the contact is more controversial.

In the northern part of the Sacramento Mountains east of Tularosa (Figure 1), dark gray shale yielded an ammonoid fauna that was considered to be upper Pennsylvanian in age (Böse, 1920, and Miller, 1932). The shale occurs within a series of red beds, and on this basis Böse (1920) considered the entire sequence of strata as belonging to the Abo formation. However, in La Luz Canyon about eight miles southeast of Tularosa, the uppermost strata

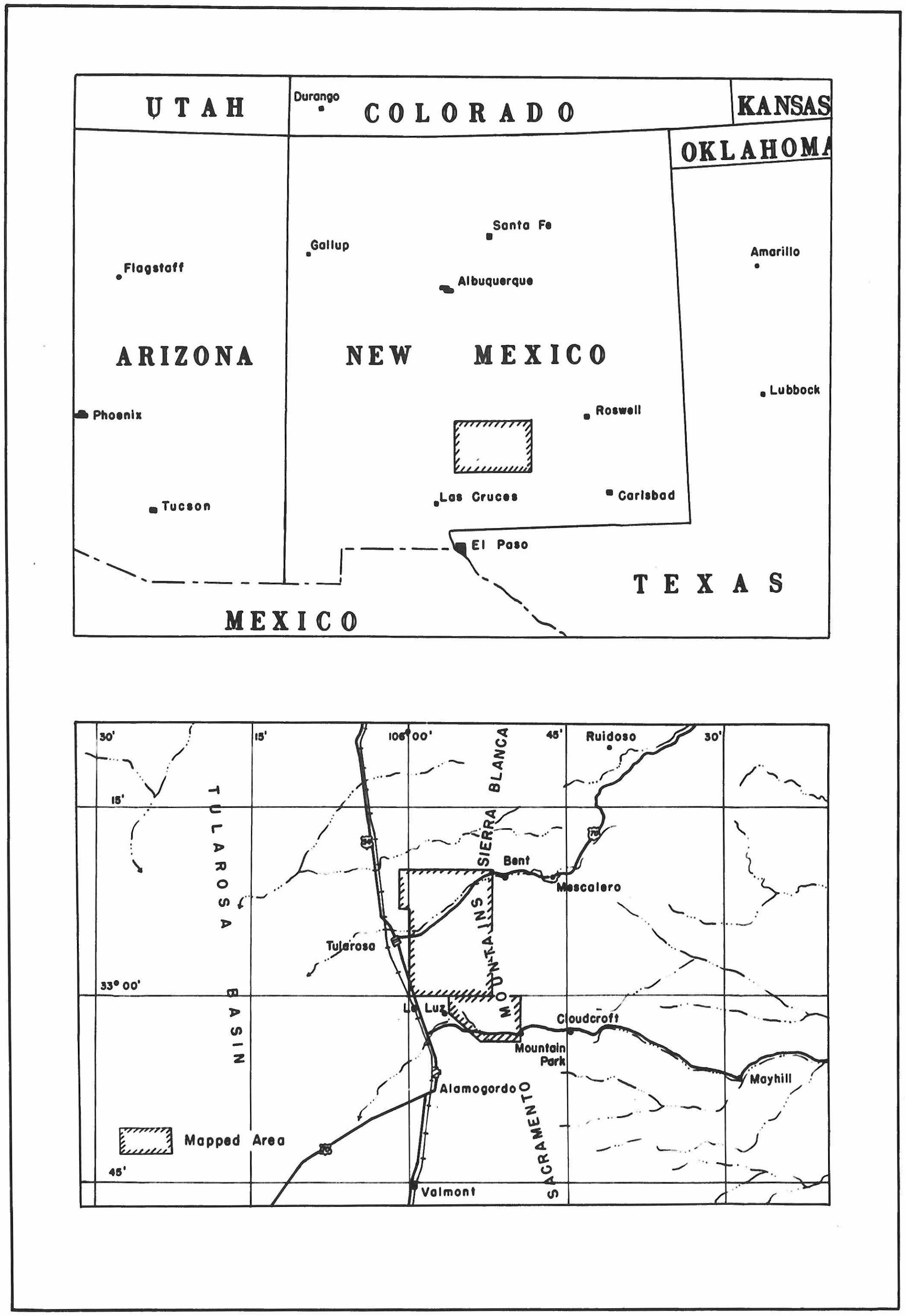

Figure 1. Index map of a part of south central New Mexico

of a thick marine section that occur approximately in 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 were considered a part of the Magdalena formation. 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 have been correlated with the Abo formation on the basis of lithologic similarity (Figure 2A).
2. The lower Permian beds near La Luz and the upper Pennsylvanian beds east of Tularosa are unconformably overlain by the Abo formation. This would simply involve extending the unconformity at the base of the Abo formation, recognized in most of the Sacramento Mountains and farther southeast, for 12 miles to the northwest (Figure 2B). The red strata underlying the ammonoid-bearing shale are explained by facies changes.
3. Either the ammonoids or the fusulinids have been wrongly identified as late Pennsylvanian and early Permian forms, or the paleontologic time-scales of the ammonoids and fusulinids do not coincide.
4. Various combinations of any of these relations.

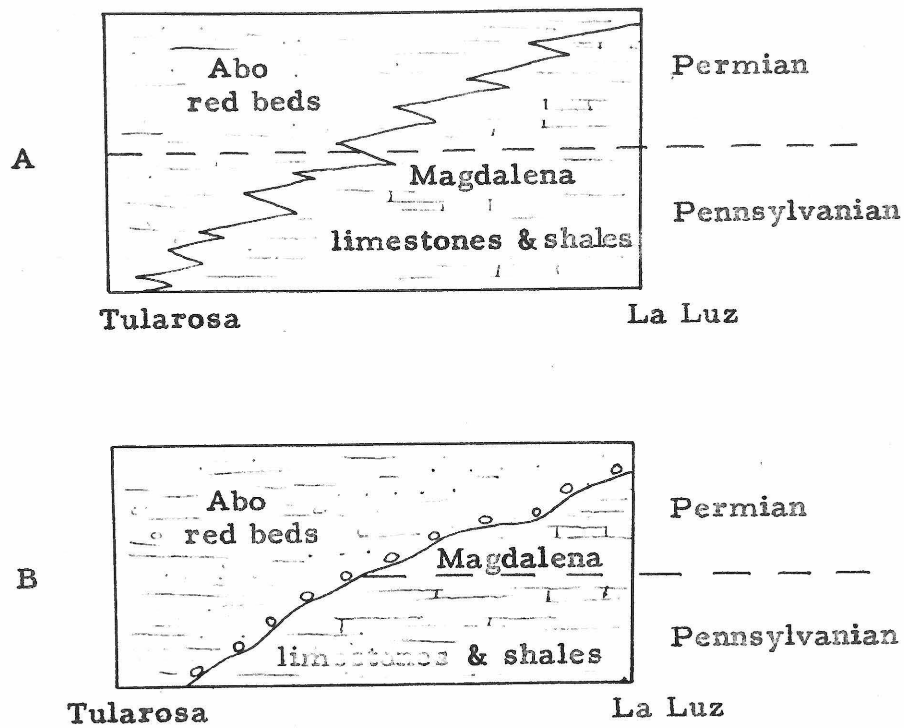

Figure 2. Interpretation of possible stratigraphic and structural relationships in the northern Sacramento Mountains based on information published before 1952.

At the suggestion of Dr. L. C. Pray, of the 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 immediate objective was to determine the exact stratigraphic relationships between the La Luz Canyon and the Tularosa fossil localities and to determine the position of the Pennsylvanian-Permian boundary. Furthermore, a comprehension of the nature and sequence of geologic events in this area in late Pennsylvanian and early Permian time is of more than local significance and can lead toward a better interpretation of the geologic record in other parts of New Mexico.

In addition, Pray's work in the area to the southeast had given indications that detailed field study in this area of such unusually good exposures afforded promise of results of general stratigraphic significance.

1. The area comprises one of the most complete sections of lowermost Permian strata known in North America.
2. The abrupt lateral facies changes from open marine conditions to terrestrial flood plain environments and related lateral and vertical rock sequences can be studied within a distance of a few miles.
3. Sedimentary processes can be investigated in relation to the structural development of adjacent areas.
4. The comparison of different groups of fossils, ammonoids, brachiopods, gastropods and fusulinids is of paleontologic significance, once the relative stratigraphic position of the various collecting localities is determined by field work.

The study of these groups has been turned over to specialists in each of the four major fossil groups, as the results could well be of importance in solving similar stratigraphic problems in other parts of the United States, such as West Texas, where the lateral continuity of strata is more difficult to determine.

NATURE AND SCOPE OF INVESTIGATION

The writer devoted about 20 weeks during the summers of 1951 and 1952 to field study of a critical area near Tularosa and La Luz in the northernmost Sacramento Mountains, Otero County, New Mexico. Mapping covered portions of two 15 minute quadrangles, namely the southwestern part of the Tularosa Quadrangle and the north central part of the Alamogordo Quadrangle (see Figure 1).

The area of study is about 80 square miles and was mapped at a scale of four inches equal one mile or 1:15,625. Of this area, about 30 square miles were mapped in detail during approximately 16 weeks. This detailed area includes all outcrops of the controversial uppermost Pennsylvanian and lower Permian marine strata that extend along the mountain front for about 12 miles. About half the area mapped in detail extends below 33° latitude and was previously mapped at 1:31,250 scale by L. C. Pray in 1947, and the geology of the formations underlying the uppermost Pennsylvanian strata on plate 2 is largely summarized from Pray's map.

Approximately four weeks during the months of September and December of 1952 were devoted to mapping in lesser detail an area of about 50 square miles north of 33° latitude that lies 1 to 6 miles east of the mountain front. Reconnaissance treatment of this area seemed justified in view of the main purpose of the writer's investigation. Furthermore, the uniformity of the lower Permian strata in this area, all non-marine, and the extensive cover by Quaternary stream deposits of this part of the area, did not warrant a more detailed treatment.

Aerial photographs of the area were taken in 1936 and 1941 for the Soil Conservation Service of the United States Department of Agriculture. As almost no vertical topographic control was available of the southwest quarter of the Tularosa Quadrangle, aerial photographs were enlarged to a scale of about four inches equal one mile, which served as base for the geologic mapping. The base for the final geologic map of the area north of 33° latitude was compiled from a planimetric map issued in 1942 by the Regional Cartographic Division of the Soil Conservation Service, at a scale of 1:31,250. Apparently this planimetric map is prepared from the aerial photographs. Where vertical control was deemed most essential it was established by use of an Abney inclinometer and handlevel, using as primary control a number of points with known elevations south of 33° latitude. In addition, several points in the northern part of the area were determined by aneroid. These relatively crude controls were used to establish approximate 100 foot contours in the area near the frontal escarpment mapped in detail. For the area south of 33° latitude, the 1:31,250 topographic sheet with 100 foot contours of the Lincoln National Forest was enlarged to the scale four inches equal one mile. The narrow strip of topographic control along the eastern edge of the southwest quarter of the Tularosa Quadrangle was also derived from the Lincoln National Forest map.

The area is notable for the rapid lateral variation in facies. This feature, combined with cyclic phenomena of sedimentation resulting in many similar thin beds and sequences of beds at different horizons in the same formation, posed a difficult mapping problem.

Beds were largely mapped by lateral tracing. Where they could not be traced directly, correlations were based on lithologic characteristics, faunal content and/or known stratigraphic position with reference to other mappable horizons. On the maps (Plates 1 and 2) the lower contacts of the most persistent or easily recognizable marker beds are indicated by green lines and numbered according to their relative stratigraphic position. Symbols are added to indicate the lithology of the marker bed.

Ten days were devoted to a detailed plane-table survey, on a scale of 50 feet to one inch, and field study of algal reef masses that are exposed near the frontal escarpment northeast of Tularosa.

Approximately two months were spent on laboratory investigations. These included petrologic and faunal studies of specimens from the algal reefs, petrologic studies of rock types and preliminary studies of the thin sections from fusulinids.

LOCATION AND PHYSICAL FEATURES

The Sacramento Mountains are located in the south central part of New Mexico. In general, they trend slightly west of north for about 30 miles and rise abruptly 3,000 to 5,000 feet above the surface of the Tularosa Basin. To the south, they decline into a low plateau which extends to the Texas border. To the north, the range merges with the Sierra Blanca (Figure 1), which is dominated by Sierra Blanca Peak with an elevation of 12,003 feet, the highest point in southern New Mexico. Tularosa Canyon forms the most natural geographic boundary between the Sierra Blanca and the Sacramento Mountains*.

The Sacramento Mountains form an asymmetrical mountain range with a bold, west-facing escarpment and a gentle east slope that extends for a distance of 80 miles from the crest to the Pecos River. The crest of the Sacramento Mountains rises to about 9,700 feet above sea level in the center of the mountain mass, but no single peak dominates this crest. The crest declines toward the south and north, and near Tularosa Canyon, reaches a height of about 8,200 feet. Because of the general plunge of the mountain mass, successively younger sedimentary formations form the abrupt frontal escarpment (Figure 4) toward the north.

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

The area investigated for the purpose of this report lies in the northernmost part of the Sacramento Mountains (Figure 1)**.

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*On the geologic map of the State of New Mexico, the term "Sacramento Mountains" includes the Sierra Blanca. The most recent maps, however, use the term in the more restricted sense, which is adopted in this report. (See Pray, 1952, p. 1).

**The area bounded by Tularosa Canyon and 33° 10' N. latitude (Figure 4), actually forms the southwesternmost part of the Sierra Blanca, but for convenience of reference it is considered a part of the northernmost Sacramento Mountains.

New Mexico Highway 83, four miles north of Alamogordo, forms approximately the southern boundary. The area extends northward from this highway for 17 miles to 33° 10' N. latitude, a point five miles north of the town of Tularosa.

Alamogordo and Tularosa, which are located in the Tularosa Basin near the base of the Sacramento Mountain escarpment, can be reached by U. S. Highways 54 and 70 and by the main line of the Southern Pacific Railroad from El Paso. U. S. Highway 70 crosses the northern part of the mapped area east of Tularosa. The part of the area that falls within the Alamogordo Quadrangle is easily accessible by the secondary roads in La Luz and Fresnal Canyons (Figure 4). Many unsurfaced roads, particularly in the Tularosa Quadrangle, make the area north of 33° fairly accessible during dry weather. A car can be driven to within two miles of any desired locality. The area is very sparsely settled, except for the nearby towns of La Luz (population about 200) and Tularosa (population about 2,000), which are located in the Tularosa Basin.

The profile of the Sacramento Mountains on its west side is characterized in most areas by an upper and lower escarpment separated by a relatively flat area or bench. This two-step profile is particularly noticeable in the central and southern portions of the range (Pray, 1952, p. 9). It is less conspicuous but also recognizable in the northern part of the Sacramento Mountains. East of La Luz, the height of the lower escarpment or elevation of the bench ranges from 600 to 1,000 feet above the base of the range, as compared to 3,000 feet farther to the south. It becomes progressively lower to the north and at a point five miles north of Tularosa, this bench reaches the level of the Tularosa Basin. The slope from the basin to the level of the bench is steep near the south and more gradual farther north. This frontal scarp within the map area is dissected by many east-west canyons, of which the most prominent, from south to north, are: La Luz Canyon, Cottonwood Canyon, Laborcita Canyon, Domingo Canyon and Tularosa Canyon (Figure 4). These canyons and their tributaries increase considerably the area of exposure of the Pennsylvanian and Permian strata in this critical area.

Above the level of the bench, the surface rises gently to the east for a distance of 3 to 5 miles, beyond which it steepens sharply. The gentle portion of this rising surface is largely underlain by the non-resistant mudstones and arkoses of the Abo formation. The abrupt change in slope approximately coincides with the contact between the Âbo and Yeso formations.

The field investigation covered mostly the area of the steep frontal escarpment and the gently rising surface of the bench. Near the frontal escarpment the rocks are very well exposed. The rocks underlying the gently rising surface are locally poorly exposed, because of their non-resistant 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 climate with summer precipitation and dry winters.

Most of the map area falls within the classification of a hot desert climate. 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 pinon pines grow in the slightly higher eastern part of the area. The area is only used for grazing stock in the colder winter months, as the extremely high temperatures in the summertime offset the effect of the increase in moisture. The town of Tularosa is largely an agricultural community as a result of extensive irrigation in the directly surrounding parts of the Tularosa Basin.

PREVIOUS WORK

In this section the literature dealing specifically with the upper Pennsylvanian and lower Permian stratigraphy of the northern part of the Sacramento Mountains is reviewed in chronologic order. References to previous work of a more regional or general nature will be made in other sections of this report.

In 1920, Emil Böse (1920, pp. 51-60) gave a detailed account of several ammonoids that were collected by Baker and Drake from shales in the lower part of the Abo formation 1-1/4 miles east of Tularosa. Böse stated:

> "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."

In the same year, Baker (1920, p. 109) briefly referred to the ammonoid locality east of Tularosa and indicated that the fossil-bearing shales occur 200 feet above the base of the Abo formation. About other parts of the northern Sacramento Mountains he states:

> "In the lower end of La Luz Canyon, east of Alamogordo, the lower massive cliff-forming limestone of the Magdalena is unconformably overlain by Abo conglomerates, shales, limestones and sandstones. The conglomerates contain bowlders of Magdalena limestone in sizes up to two feet. The basal Abo bed here contains more Fusulina than any other stratum noted in eastern New Mexico."

This statement probably refers to the fusulinid-bearing strata that have since been included in the Fresnal and Keller group (Thompson, 1942) or the Holder formation (Pray, 1952) of Virgilian age. In the same account, Baker (1920, p. 110) makes reference 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 shaly sands and fossiliferous limestones."

Darton (1926, p. 834) was the first geologist to question in print the stratigraphic position of the ammonoid-bearing strata near Tularosa. He also discusses the nature of the contact between the Magdalena and Abo formations. His statement follows:

> "The Abo-Magdalena contact is an unconformity with time hiatus of considerable length, but at most localities without noticeable deformation. Generally it is marked by sharp breaks of sediments, local conglomerates, and some channeling, but in places there is uncertainty as to the precise plane of separation, especially where red, sandy members are present in the supposed top member of the Magdalena group."

In a footnote Darton continues:

> "The fossils reported by Böse 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."

Two years later, Darton (1928, p. 20) states that:

> "In most places the Abo formation appears to lie unconformably on the Magdalena group, but the nature, duration and extent of the hiatus are not known."

In 1932 Penn made a systematic paleontologic study of a number of faunas that were collected from several localities in the northern part of the Sacramento Mountains. Although a few measured stratigraphic sections were included, no detailed field investigations were made. In his unpublished report Penn (1932, p. 32) concludes about the Magdalena-Abo contact in the northern Sacramento Mountains:

> "The contact between the Abo formation and Magdalena limestone is well exposed in numerous localities, in the area studied, where the two are accordant, although they are separated by an erosional surface. The erosional surface at the top of the Magdalena group shows a relief which may amount in some places to as much as fifty feet."

Penn continues (1932, p. 33):

> "The base of the Abo in every locality studied is a conglomerate member, which varies considerably but is always present and nowhere more than 50' thick."

Penn (1932, p. 1) also discusses a fauna that was collected by Beede and himself in the vicinity of Tularosa in a "red sandy series which is included in the Abo formation." The fauna is principally a

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* Insertion by author

molluscan and brachiopod fauna and is supposed to be typically upper Pennsylvanian in age. However, it seems that Penn (1932, p. 66) includes zones, equivalent to the Wolfcampian, in the Pennsylvanian System. He states:

> "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). With presently accepted usages, the faunas would be lower Permian in age.

A. K. Miller (1932, pp. 59-93) restudied the fauna collected by Böse east of Tularosa and confirmed the upper Pennsylvanian aspect of the ammonoids. Miller regards the sandstones and shales at Tularosa as the time-equivalent of the upper part of the lower Cisco Series. The Cisco Series correspond to the Virgilian of other areas (Moore, et al, 1944, chart 6). However, Miller doubts whether all units of the Abo formation to which Darton assigned a Permian age are correlative with the type section located in Abo Canyon, 100 miles north-northwest of Tularosa. Miller thinks that the beds near Tularosa belong to a different formation (Miller, 1932, p. 61), or at least to a different zone of the Abo formation.

Moore (1940, p. 309) states that P. B. King agrees with Miller's conclusion that the ammonoid-bearing beds near Tularosa do not belong to the Abo formation. In 1942, King (1942, p. 676) writes that the ammonoid collection from east of Tularosa probably came from the upper part of the Magdalena group. As to the contact relationships between the Magdalena and Abo formations in the Sacramento Mountains, King and Read (King, 1942, p. 675) state the following:

> "In the Sacramento, San Andres and other mountains of southern New Mexico, the usual limestone and other marine sediments of the Magdalena pass upward into several hundred feet of interbedded limestone, 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 it is 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."

King and Read continue:

> "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*, where the Abo lies on the upturned beds of the main part of the Magdalena, with the upper beds missing."

However, 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 non-marine Abo formation. This

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*Approximately 9 miles south of the junction of La Luz and Fresnal Canyons.

is the first statement to the effect that the basal Abo formation might be younger than the base of the Permian System.

Also in 1942, in a separate report, Thompson discussed more specifically the area of the northern Sacramento Mountains where he recognized lower Permian fusulinid-bearing strata. Thompson (1942, p. 82) states the following:

> "In Fresnal 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) states 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 rocks 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. In 1946, these Wolfcampian strata were given three different names: the Red Tanks member of the Madera limestone in the Lucero uplift (Kelley and Wood, 1946); the Aqua Torres formation in the Los Pinos Mountains (Stark and Dapples, 1946, p. 1154); and the Bursum formation (Wilpolt, et al, 1946) in the Los Pinos Mountains. The name, Bursum formation, is preferred by the New Mexico Bureau of Mines and Mineral Resources and was also adopted by E. Russell 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 Mountain area, which included the lower Permian beds in Fresnal Canyon. In 1949, Pray said the following, as quoted by E. Russell Lloyd (1949, pp. 32-33), about 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."

A few years 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) discussed in the section "Recommendations for Further Investigations" the area that is located north of his area of study and that extends from La Luz Canyon on the south to a point three miles north of Tularosa. Pray states the following:

> "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."

It should be recognized that the earlier workers lacked the field evidence to support their interpretations. One objective of this investigation was to resolve the earlier stratigraphic problems and settle these conflicting statements by a detailed field study at a scale greater than two inches to a mile to obtain definite evidence to support the conclusions.

In 1952, Pray treated some of the structural features that occur in the northern part of the Sacramento Mountains. He demonstrated convincingly the late Cenozoic fault-block origin of the Sacramento Mountains. (Pray, 1952, pp. 306-322). He also discussed the pre-Abo and post-Abo deformation, evidence of which is present in the northern parts of the Sacramento Mountains and he concluded (Pray, 1952, 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 (1952, p. 344) treated more specifically a prominent fault feature, the Fresnal fault, that occurs near Fresnal Canyon, in the southeastern part of the area of present study (Figure 4), and he indicated both pre-Abo and post-Abo movements on this fault.

He further states (Pray, 1952, p. 343):

> "An isolated exposure of deformed Pennsylvanian strata north of La Luz Canyon suggests that the Fresnal fault continues as a buried structural feature at least for an additional two miles."

A detailed field study on a scale larger than two inches to a mile might result in a more detailed knowledge of the exact sequence of events of this structurally complex area and afford a better understanding of the relation between sedimentary and tectonic processes in the northern part of the Sacramento Mountains.

II. STRATIGRAPHY

INTRODUCTION

PENNSYLVANIAN-PERMIAN BOUNDARY

General Statement

The boundaries of the recognized geologic systems were placed originally at structural, lithologic or paleontologic breaks in the geologic columns of the regions where they were first studied. The structural criteria, in particular, were used as a basis for the division of the geologic column and regional stratigraphic correlation. Such a division of the time-scale assumes the world-wide and periodic recurrence of diastrophic events, which theory to date is still strongly supported by many geologists. However, a number of geologists have always seriously questioned the validity of this theory. More recently, Gilluly (1949) presented evidence that deformation appears to take place almost continuously within the earth's crust, but with different intensity at different places and is not a spasmodic or episodic process that occurs contemporaneously in many parts of the world. If this view is correct, diastrophism is not the ultimate basis of correlation, and even relatively widespread unconformities can be expected to be represented by a thick sedimentary section in other regions. Where unconformities originally defined the systemic break in the geologic column, the problem now is to determine the position of the system boundary in an unbroken sequence of time-equivalent strata. It will be shown that in the part of the Sacramento Mountains investigated by the writer the Pennsylvanian-Permian boundary is locally a marked angular unconformity, locally a disconformity and locally represented by essentially continuous deposition.

As was indicated by Tomlinson (1940, p. 349), lithologic criteria are commonly of small importance in the selection of systemic boundaries. Most distinguishable kinds of sedimentary rock are not restricted to one geologic system. Tomlinson (1940, p. 356) further states that a time-boundary, regardless of other factors, should be drawn at that point in the column where the most significant and extensive paleontologic changes take place.

Although Tomlinson's recommendation is followed in this report for lack of better means of correlation, its limitations ought to be recognized. The writer believes that if the paleontologic record were complete, probably only gradual evolutionary changes would be observed and that the time-boundaries in the geologic record would have to be arbitrarily defined. One problem connected with this is caused by the migration of faunas, which results in time differences between the same faunal changes in different regions (Arkell, 1933, Figure 1). However, within a small area and the present incomplete record, a horizon of significant paleontologic change is usually marked by a break in the succession of strata or by an environmental change; both reflect change of conditions which usually have as an underlying cause the tectonics of the area.

Paleontology

The family of the Fusulinidae has a range that coincides with the Pennsylvanian and Permian Periods. On the basis of predominance of certain generic fusulinid groups, the total time interval of these periods can be subdivided into certain zones, each of which is characterized by a certain fusulinid genus. For example, the Missourian and Virgilian are characterized by the zone of *Triticites*, the Wolfcampian by the zone of *Pseudoschwagerina* (Thompson, 1948, p. 4). The occurrence of not one but several new fusulinid genera makes the zone of *Pseudoschwagerina* particularly useful in identifying the lower limit of the Permian. The appearance of the genera *Schwagerina*, *Pseudoschwagerina* and *Paraschwagerina* represents a great evolutional outburst above the hiatus at the base of the Wolfcamp formation. Their distribution becomes world-wide (Dunbar in Moore, 1940, p. 324). The faunal break above the zone of *Pseudoschwagerina* is much less distinct. The genus *Parafusulina*, from the zone of the same name, evolves gradually from the genus *Schwagerina*.

The Pennsylvanian strata of Missourian and Virgilian age are characterized by various species of the genus *Triticites*, with none of the genera that are diagnostic for the Wolfcampian. As might be expected, the genus *Triticites* holds over into the zone of *Pseudoschwagerina* and gradually dies out. The zone of *Triticites* is equally recognizable in other parts of the world. Within the zone of *Triticites* a certain evolutionary trend of species rank is recognized. The early species of *Triticites* are all small and slender and have relatively thin walls (Missourian). Gibbous forms develop in the lower Virgilian and in the upper part of the Virgilian, *Triticites ventricosus* develops much larger than any previous forms (Dunbar, 1940, p. 269).

Other fossil groups have been used to determine the Pennsylvanian-Permian boundary, but have generally not been accepted as widely.

Pennsylvanian-Permian Boundary in Other Regions

Russia*

The type section of the Permian System was assigned by Murchison in 1841 to a series of sandstones and conglomerates overlying the Carboniferous limestone of northern Russia. Later detailed work found this clastic series to be a facies of the upper Carboniferous limestones, with a different stratigraphic position in different parts of the region. Since then, the position of the lower limit of the type Permian has been a subject of controversy. Most Russian geologists chose the base of the Permian at the top of the Sakmarian or the top of the *Pseudoschwagerina* zone. However, according to Dunbar (1940), the base of the Sakmarian would form a more natural lower limit to the Permian System. It marks the beginning of the rapid evolution of the Uralian geosyncline.

Western Europe*

In western Europe the base of the Permian has always been drawn at the base of the "Rotliegendes", the European red beds. As the "Rotliegendes" is in part equivalent to the marine beds of the *Pseudoschwagerina* zone, and the underlying Carboniferous beds are not younger than lowermost Stephanian (lower Virgilian), the base of the Permian System when placed at the base of the *Pseudoschwagerina* zone, accords best with previous usage.

North America

Adams et al (1939, pp. 1673-81) proposed the Wolfcampian Series, comprising the beds of the "restricted" Wolfcamp

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* The following paragraphs are summarized from Dunbar's review of the type Permian section in Russia and its comparison with other areas.

formation in the Glass Mountains of West Texas (King, 1937, p. 94) as the lowermost division in the Permian System. According to Moore (1940, p. 316) the Wolfcamp formation contains, along with the genus Pseudoschwagerina, the genera Schwagerina, Paraschwagerina and advanced forms of the genus Triticites; also the ammonoids Artinskia and Properrinites.

Detailed discussions on the determination of the Pennsylvanian-Permian boundary in north central Texas (Cheney, 1940, pp. 65-118) and the Mid-Continent region (Moore, 1940, pp. 298-307) bring out that the presence of the genus Pseudoschwagerina, although diagnostic, is not essential for a Permian age of the containing strata. In many areas, the genus Pseudoschwagerina is absent, or occurs considerably higher in the section than the genus Schwagerina, which is then considered diagnostic for the Permian.

These criteria are generally accepted in North America and are adopted for this report.

STRATIGRAPHIC NOMENCLATURE

The lack of uniformity displayed by the Pennsylvanian and lower Permian strata in large parts of New Mexico, resulted in many stratigraphic terms for rock units of approximately the same age in different areas. Furthermore, the boundaries of the rock-units were not always clearly defined, and the indiscriminate usage of time-rock and rock terms has added to the confused status of the stratigraphic nomenclature in New Mexico. Thus, it is necessary to review briefly and define the history of some of these terms. The usage of this report is indicated on Figure 3.

Time-Rock Units

The Pennsylvanian was originally defined by H. S. Williams in 1891 as the term for the "Coal Measures" (Willmarth, 1925, pp. 72-73) and had series rank as the upper part of the Carboniferous System. However, most North American geologists have used it with period or system rank, and in 1953 the United States Geological Survey officially adopted systemic or period rank for the Pennsylvanian in North America. 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 as defined on the basis of fusulinids.

The series names used by the New Mexico Bureau of Mines and Mineral Resources (Lloyd, 1949, p. 16 and p. 34) for subdivisions of the Pennsylvanian and Permian Systems will be 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 usage of the 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 and a sharply defined formal subdivision of the series into stages.

Thompson (1942) classified the Pennsylvanian rocks in New Mexico into eight groups and fifteen formations. These lithologic units are only recognizable near the type areas and hence not applicable in regional correlation. However, the diagnostic fusulinid content proved the usefulness of Thompson's divisions for regional

THIS REPORT Northern Sacramento Mountains				PRAY 1952 Sacramento Mountains	THOMPSON 1942 New Mexico
System	Series	Group	Formation	Formation	Group*
PERMIAN	Guadalupian	Manzano group	San Andres	San Andres	
PERMIAN	Guadalupian	Manzano group	Glorieta (?)	Glorieta (?)	
PERMIAN	Leonardian	Manzano group	Yeso	Yeso	
PERMIAN	Wolfcampian	Manzano group	Abo	Abo: Upper tongue of Abo Pendejo tongue of Hueco ls Lower tongue of Abo	
PERMIAN	Wolfcampian	Magdalena group	Laborcita	Bursum	Un-named limestone
PENNSYLVANIAN	Virgilian	Magdalena group	Holder	Holder	Fresnal
PENNSYLVANIAN	Virgilian	Magdalena group	Holder	Holder	Keller
PENNSYLVANIAN	Missourian	Magdalena group	Beeman	Beeman	Hansonburg
PENNSYLVANIAN	Missourian	Magdalena group	Beeman	Beeman	Veredas
PENNSYLVANIAN	Desmoinesian	Magdalena group	Gobbler	Gobbler Bug Scuffle limestone member	Bolander
PENNSYLVANIAN	Desmoinesian	Magdalena group	Gobbler	Gobbler	Armendaris

Figure 3. Classification of rock units of portions of the Pennsylvanian and Permian Systems.

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

time correlation. The terms "Fresnal group" and "Keller group" have therefore only meaning as stages of the Virgilian in a time-rock classification and will be used in that sense 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 established on the basis of 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 uses the "Bursum" in a time-rock sense as a stage. The name, Bursum formation, is therefore also abandoned in this report.

Rock Units

Gordon (1907, p. 506) proposed the name, Magdalena group, for a rock unit, largely composed of marine limestones and sandstones, between the Kelly limestone of Mississippian age and the Manzano series in the Magdalena Mountains of central New Mexico. Herrick (1900, p. 4) had previously named as the Manzano series a section of red beds and associated strata in the Manzano Range of central New Mexico. Gordon (1907, p. 4) changed the name from Manzano series to Manzano group. The strata of the Magdalena and Manzano groups crop out over extensive areas in central and southern New Mexico and are regarded to be largely Pennsylvanian and Permian in age. Many stratigraphers considered 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, pp. 21-24) careful review of the term, and he therefore decided to abandon the term, Magdalena. De Ford and Lloyd (1942, p. 534), for different reasons, essentially agree with Thompson. Their statement follows:

> "The term Magdalena has long been synonymous with the Pennsylvanian of New Mexico. Most petroleum geologists follow this usage. To the editors (De Ford and Lloyd)*, therefore, it seems inexpedient that King, partly at the suggestion of C. B. Read, has expanded the term Magdalena so as to cross a systemic boundary and include beds of Wolfcamp age. Read's 'upper unit of the Magdalena' is commonly assigned to the Abo."

R. E. King (1945, p. 21) recommends that the term, Magdalena, "a relic of an antiquated type of stratigraphic nomenclature", be permanently abandoned. Bates et al (1947, p. 17) rejects the name on grounds of "redundancy of stratigraphic nomenclature." Both Lloyd (1949) and Pray (1952) decided against the use of the term, Magdalena, because of the stratigraphic confusion surrounding the term.

However, as paleontologic criteria are used for establishing time boundaries and lithologic criteria for the distinction of

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* Insertion by author.

rock units, the contacts of rock units will very frequently not coincide with time boundaries. Thus, the writer feels that the name, Magdalena, can be maintained, notwithstanding the possibly lower Permian age of certain Magdalena beds in some parts of New Mexico, as long as the unit only includes strata occurring between the Kelly limestone and the base of the Manzano group. In the area of 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.

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. Thus, 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 this report, the predominantly marine strata between the top of the Holder formation and the base of the Abo formation have been designated as the Laborcita formation. The lower part of this unit was formerly named the Bursum formation. Although the Laborcita formation forms a distinctly 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. Therefore, the author deems it necessary to group certainly the Holder and Laborcita formations together in a unit of higher rank. In this report, the Holder and Laborcita formations together with the underlying Gobbler and Beeman formations are treated as subdivisions of the Magdalena group. This effectively contrasts the largely marine character of the sediments of the Magdalena group with those of the overlying non-marine red beds of the Abo formation.

PENNSYLVANIAN SYSTEM

In most areas in central and southern New Mexico, the Pennsylvanian System is several thousand feet thick and is largely composed 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 make it difficult to distinguish rock divisions that can be mapped over a wide geographic area. Pray (1952) in his study of the Pennsylvanian System of the Sacramento Mountains introduced a threefold division, which can be applied throughout the entire area. The maximum thickness of the Pennsylvanian section in the Sacramento Mountains is about 3,000 feet, but commonly, where the upper part has been eroded, the thickness amounts to about 2,000 feet.

The lowermost unit of the Pennsylvanian System recognized by Pray is the Gobbler formation, composed largely in the lower part of shale, argillaceous limestone and very coarse-grained quartz sandstone.* The upper part consists of either massive beds of gray cherty limestone or of calcareous sandstone and shale. The Gobbler formation ranges in thickness from about 1,200 to 1,600

*Grade scale according to Wentworth (1922) used in this report.

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, the southern extent of the area of investigation. The age of the Gobbler formation ranges from Atokan to the lower part of the Missourian Series.

The Beeman formation overlies the Gobbler. It ranges from about 350 to 450 feet in thickness and is composed of shale and thin-bedded,* argillaceous limestone and feldspathic sandstone in most of the area along the western part of the Sacramento Mountain escarpment. This 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 Mountain escarpment, limestones are predominant in the Beeman formation. The age ranges from lower through upper Missourian. In many parts of the central and southern Sacramanto 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. It is composed largely of white, non-cherty limestone interbedded with sandstone, conglomerate and red and gray shale. The base of the Holder formation is defined by

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* Terminology according to McKee and Weir (1953) used in this report.

the base of numerous discontinuous bioherms, 50 to 100 feet thick. In the northern part of the area, where the section is complete, the top of the formation is formed by the base of the Laborcita formation. All of the Holder formation is Virgilian in age. The upper two-thirds were termed the Fresnal group by Thompson and as these strata form an important part of the writer's problem, they are discussed below in more detail.

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 author suggests a slight revision of this definitions 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. However, 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$\frac{1}{4}$NW$\frac{1}{4}$ 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 proposed by 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* 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. The top of this section forms the base of the overlying Laborcita formation. North of La Luz Canyon along the frontal escarpment of the Sacramento Mountains, no post-Holder, pre-Laborcita erosion has been observed. It is therefore inferred in this report that the 900 foot thick section of the Holder formation is representative for the northern part of the Sacramento Mountains. This figure has been adopted for the construction of the structure sections (Plate 3).

In most of the map area (Plates 1 and 2 and Figure 4) only the upper part of the Holder formation is exposed. Therefore, the following discussion is largely devoted to the upper part of the Holder that was originally discussed by Thompson as the "Fresnal group." Thompson's 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 road bed in the fourth major arroyo about six-tenths of a mile northwest of the junction of the roads in La Luz and Fresnal Canyons. The top of the section is in the road cut in the second arroyo, one-tenth of a mile from the road junction. At the type locality the "Fresnal group" is 530 feet thick. (Thompson, 1942, p. 73).

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* This section is located near the southernmost boundary of the map area of this report.

Areal Distribution

The strata of the Holder formation are widespread in the area of the Sacramento Mountains. According to Pray (1952, p. 209) the Holder formation is largely located along the fringe of the Tularosa Basin in the north and south end of the Sacramento Mountains. In the central area "it occurs as isolated resistant caps on many of the high ridges at the west front of the mountains." In the eastern part the beds of the Holder are absent, cut out by 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 one mile northeast of La Luz. From this canyon northwestward to the mouth of Domingo Canyon, a distance of about 4-1/2 miles, the Holder formation forms the lower part of the frontal escarpment (Figure 4). It extends about three-quarters of a mile upstream along Laborcita Canyon and its tributary canyons. The upper part of the Holder formation is exposed in a few erosional windows through the overlying Abo formation in 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, which includes the Holder formation, varies more markedly geographically than the lithology of any of the other Pennsylvanian Series. The variations become especially marked in the Fresnal group part of the Holder formation. Pray's report (1952,

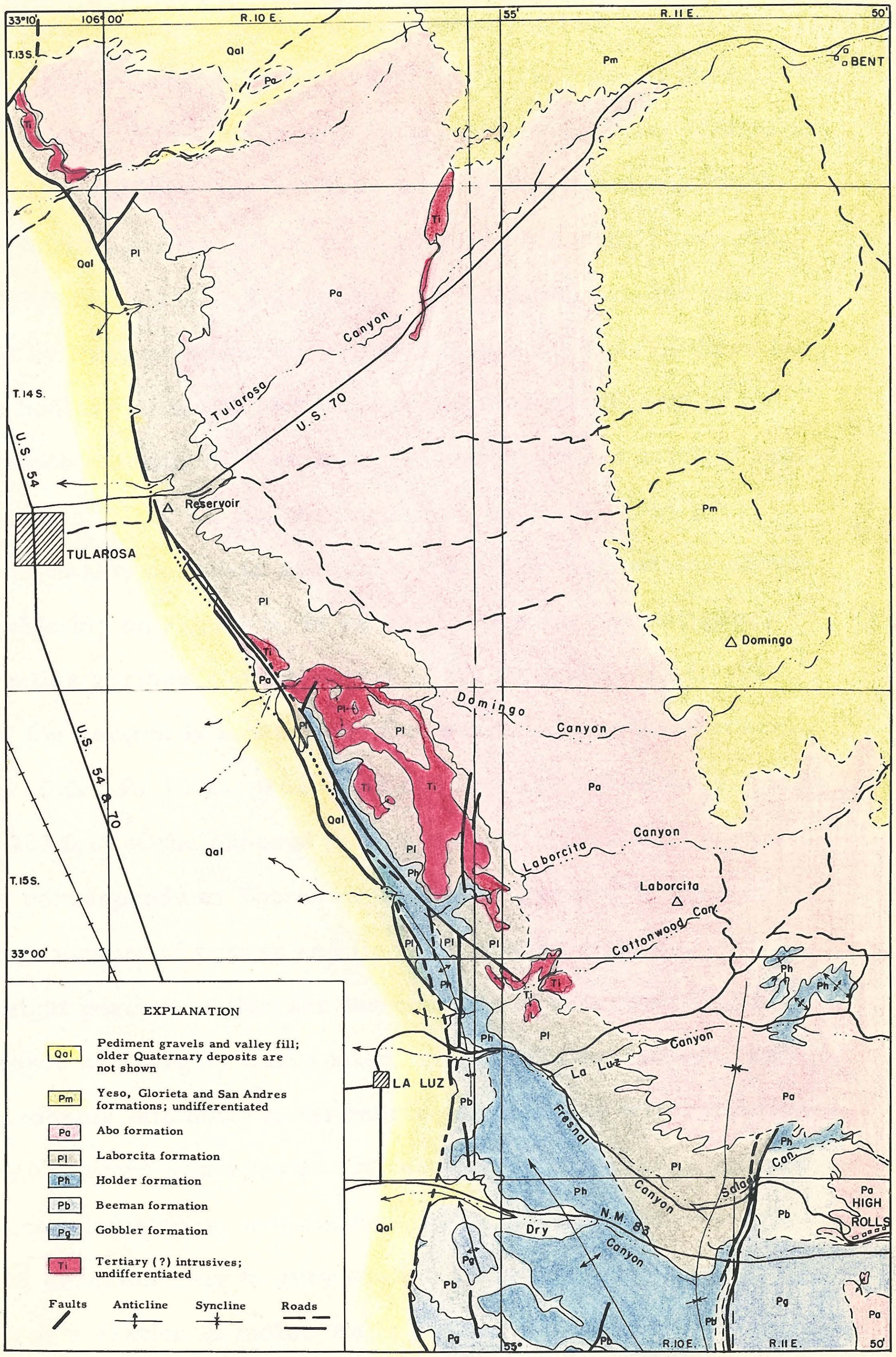

Fig. 4 GEOLOGIC MAP OF THE NORTHERN SACRAMENTO MOUNTAINS

(generalized from plates 1 and 2; area south of 33°00' after Pray, modified by C. Otte)

Scale in Miles

0 1 2 3 4

p. 187) includes a graphic log of the entire 900 foot section that has been assigned to the Holder formation. The base of the formation in most of the Sacramento Mountains contains many lenticular bodies of essentially massive limestone, with a maximum thickness of about 100 feet. They are considered biohermal accumulations (Plumley, 1953). The base of the Holder formation was mapped by Pray as a horizon coinciding with the base of these lenticular bodies. Although bioherms occur throughout most of the Sacramento Mountains, they have not been observed north of sec. 3, T. 16 S., R. 10 E. and thus are not found in the map area.

A nearly complete section of the Holder formation, shown by graphic log on Figure 5, 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 center of sec. 24, T. 15 S., R. 10 E. The basal 100 feet are not exposed. The lower 300 feet of the exposed part of the section, which approximately corresponds to Thompson's "Keller group", is marked by the large amount of coarse and fine terrigenous clastics. Only about eight percent of this section consists of limestone. The sandstones are largely well sorted, calcareous sandstones, and were probably laid down under marine or brackish water conditions. About 20 percent of the lower 300 feet consists of sandstones and pebble conglomerates, and the remainder is composed of poorly exposed greenish gray to gray shales. This is in marked contrast with Pray's section in Indian Wells Canyon (1952, p. 187) where almost half of the lower 300 to 400 feet consists of limestone.

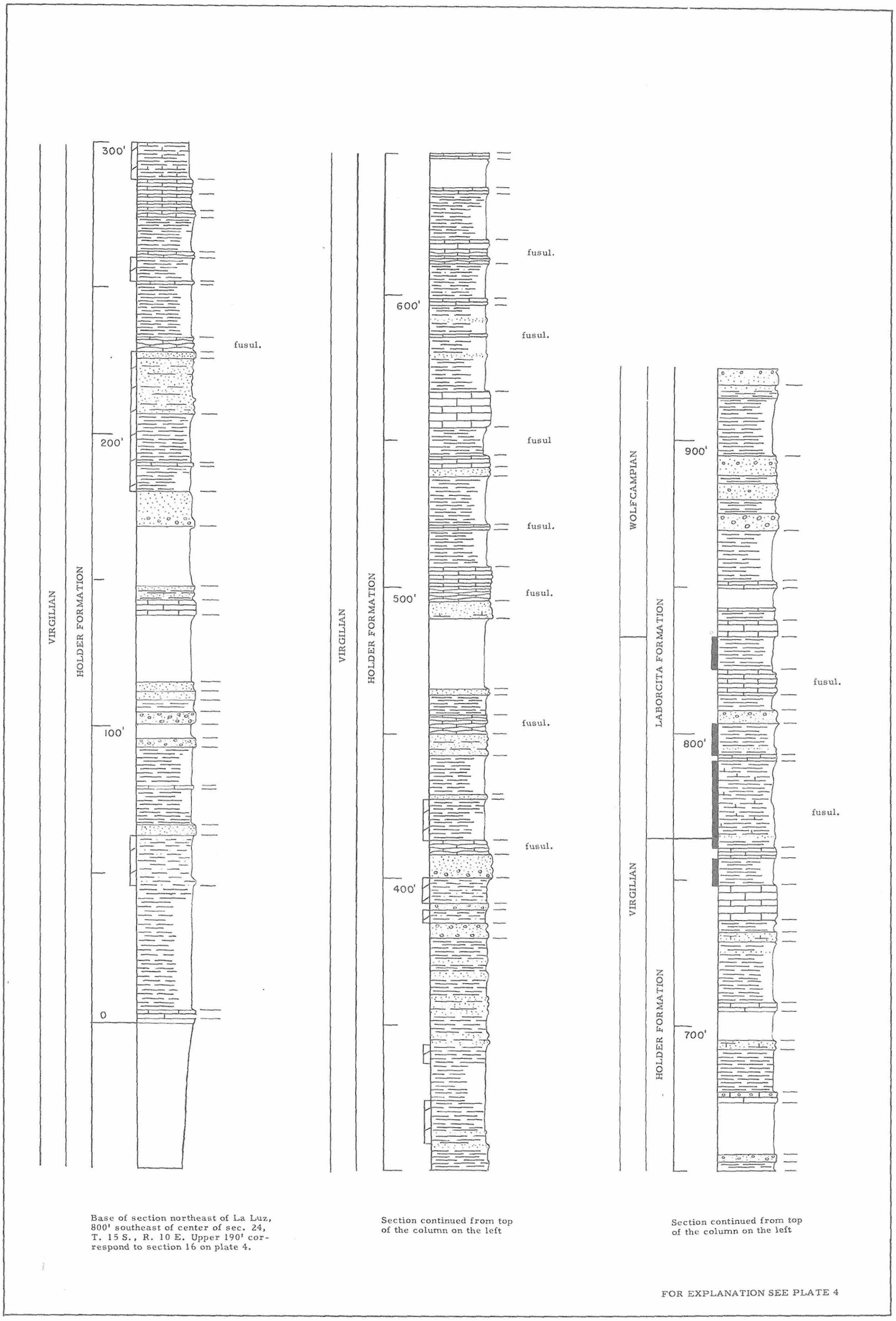

Fig. 5 STRATIGRAPHIC SECTION (38) OF THE HOLDER FORMATION

The top part of the section in the La Luz anticline does not differ very much from Thompson's description of the "Fresnal group" in La Luz Canyon. In Thompson's section, 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 four feet. Only three limestone beds are over ten feet in thickness. The total accumulative thickness of the limestones in the "Fresnal group" is about 160 feet, or 30 percent of the section, compared with about 90 feet or 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, which occur very locally, are generally closely associated with the massive limestone beds and are probably intraformational in origin. 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 "Fresnal group" and 70 percent in La Luz anticline). They suggest near-shore deposition with alternating reducing and oxidizing conditions. A reduction in the total amount of red shale is especially noticeable in the upper portion of the section toward the northwest. Features indicating cyclical deposition have been observed and Pray (1952, p. 213) describes 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 (1952, p. 209) reports 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. This lensing might, to a large extent, account for the reduction in thickness of the Holder formation to about 400 feet.

An overturned anticline in upper Pennsylvanian rocks occurs at the north side of Salada Canyon in SW$\frac{1}{4}$ 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* as middle Fresnal age, occur stratigraphically 210 feet higher in the section, in strata that are unconformably overlain by the Laborcita formation. From these determinations it appears that the lower part of the Holder formation thins perhaps 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 on the structure sections (Plate 3), is therefore due partly to primary differences in section thickness and partly to later erosion 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 portions of sections 22, 23 and 27, T. 15 S., R. 11 E. In a few places fusulinid limestones occur interbedded with gray shales and

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*Personal communication.

pebble conglomerates. On the basis of a late Virgilian age of the fusulinids, the outcropping strata have been correlated with the Holder formation. However, some massive limestone beds with abundant chert and large amounts of green sandstone indicate that these units possibly 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 classes of 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 conditions. The fluctuations of the sea level probably exposed the near-shore mud banks to the oxidizing conditions of the atmosphere, preserving the original red color of the terrigenous clays and silts. Under reducing conditions, which might have prevailed on the bottom of the ocean, the original red shales probably became green in color.

Elsewhere, evidence of cyclic repetition of certain lithologic sequences indicates advance and retreat of the sea, with each cycle representing a marine invasion. The intraformational limestone conglomerates might have been caused by local emergence of the depositional area, or else erosion at the wave-base level without emergence of the strata above sea level. In both instances, diastems of very limited extent occur.

The cross-bedding in the sandstones indicate shallow water conditions. Locally, a brackish water environment might 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 towards 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 is everywhere in contact with the underlying Beeman formation. The two formations appear to be parallel, and evidence of a persistent erosional surface at the contact has not been observed. The upper contact of the Holder formation is mostly with the Laborcita formation in the map area. In the southeastern part, the Holder formation is in direct contact with the Abo formation and the contact is an angular unconformity. In the western part of the area where the Holder and Laborcita formations are in contact, the two formations are essentially parallel. In Fresnal Canyon, south of the junction of Fresnal and La Luz Canyon, the upper contact is considered a disconformity, or slight angular unconformity, separating fusulinid-bearing strata from the non-fossiliferous, possibly brackish water beds of the Laborcita formation.

In the exposures along State Highway 83, about three-quarters of a mile west of the tunnel area east of the synclinal axis, 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 on the structure sections HH' through NN' (Plate 3) the contact between the Holder and Laborcita formations becomes a more marked angular unconformity toward the east, cutting out the top part of the Holder formation.* In the upper part of La Luz Canyon, in sections 22 and 27, T. 15 S., R. 11 E., about 60 feet of conglomerate and shale, that are considered to be equivalent to the Laborcita formation, overlie with distinct angular unconformity the eroded upper part of the Holder formation (Plate 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 lenticular pebbly conglomerate unit of a maximum thickness of six feet. This horizon has been mapped as key bed 5 (Plates 2 and 4), but only persists for 800 feet northwest along the strike. Farther north the upper contact of the Holder formation is marked by a phantom horizon, mapped at a position 30 feet above key bed 4. The contact between the Holder and the 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

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*By oral communication of L. C. Pray, Dr. L. M. Cline, of the University of Wisconsin, noticed a slight convergence between the Holder and Laborcita formations in Fresnal Canyon southward on the west flank of the syncline. In the distance of 2 miles from Thompson's type section of the "Fresnal group" to State Highway 83, about 100 feet of the upper strata of the Holder formation appear to be cut out by the basal member of the Laborcita formation.

obvious physical unconformity", must represent only a diastemic break of very local extent. It is significant that in this area the lithofacies of the two formations near the contact are 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 particularly 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 Appendix I, might yield important results for investigations of the Pennsylvanian-Permian boundary in other areas.

Fusulinids are abundant and have been studied by Thompson and others. Thompson (1942, p. 74) recognized at least 20 fusulinid-bearing strata in the fossiliferous type section of the "Fresnal group". Both the Missourian and Virgilian Series form a part of the *Triticites* Zone. Dunbar (1940, p. 269) remarks that the early species of *Triticites* are all small and slender and have relatively thin walls. Gibbous forms, such as *Triticites plummeri*, appear first in the lower Virgilian. In the upper part of the Virgilian Series the much larger *Triticites ventricosus* are common.

The fusulinids of the "Fresnal group" are highly developed forms of the genus Triticites. Fifty feet below the top, the large obese species like Triticites ventricosus var. sacramentoensis Needham, Triticites ventricosus Meek & Hayden, and Triticites consobrinus Galloway and Ryniker, have been identified (King et al, 1949, p. 62). Thompson (1942, p. 74) states 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 are also considered to be of Virgilian age. Thus, a very complete part of the upper Pennsylvanian System 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, pl. 4), which is the horizon mapped as the base of the Holder formation.

Correlation and Regional Relationships

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

"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). On the basis of subsurface information, it appears 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). The Virgilian marked a widespread advance of the sea in the New Mexico area. In some areas the late Virgilian sea persisted through the duration of the Pennsylvanian System, 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, appears never to have been deposited.

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 towards the development of more or less separate, but not isolated, basins of deposition, mainly west of the proposed Pedernal Landmass. The presence in some areas of the red bed facies of the Bruton formation (lower Fresnal stage), that 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 as far as Albuquerque in the north, Silver City in the west and near Las Cruces in the south. 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).

On the basis of fusulinids, the upper Fresnal stage appears to be present in an area including the San Andres Mountains, Robledo Mountains and Sacramento Mountains west of the Pedernal Landmass (Thompson, 1942, p. 68 and 74). The zone of *Triticites ventricosus* (upper Fresnal) has also been reported from the southern Los Pinos Mountains (Wilpolt et al, 1946). It feathers out towards the Joyita Hills in the west, where the Abo formation is in direct contact with beds older than Missourian. Thompson (1942, p. 74) reports a Fresnal section over 1,000 feet thick in the San Andres Mountains. The area of the northern Sacramento Mountains, the Tularosa Basin and possibly including the San Andres Mountains, appears to have been part of one large marine basin that received sediments throughout Virgilian and even early Wolfcampian time. Read and Wood (1947, Figure 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 on the northwestern edge of the Permian Basin, which, in southeastern New Mexico and west Texas, contains the thickest known succession of marine Permian strata in the world (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 widely adopted and is followed in this report. However, the United States Geological Survey (King, 1942, pp. 548-549, King and Knight, 1945) still classes the Wolfcampian as Permian (?).

The deposition of much of the Permian section was greatly affected by the growth of barrier reefs, as was first pointed out by Lloyd (1929). Three major facies can be recognized on the basis of the position of deposition with respect to the growing barrier reefs; the back-reef or lagoonal facies, the actual reef facies and the seaward or pontic facies. The Sacramento Mountain escarpment is located in the back-reef area and lies from 50 to 100 miles northwest of the closest major reef masses. (Pray, 1952, p. 220).

The Permian strata of the Sacramento Mountains range in age from early Wolfcampian to Guadalupian. This study involves mainly the strata of Wolfcampian age, which occur here in two distinctly different facies. The lower predominantly marine facies is termed the Laborcita formation and the upper non-marine facies comprises the Abo formation. As the Permian reefs largely developed during Leonardian and Guadalupian time, the term, back-reef facies, is of significance only in reference to the younger Permian strata. These are, according to the classification used by Pray (1952, Figure 35a), from oldest to youngest, the Yeso, Glorieta (?) and San Andres formations, as indicated on Figure 3.

LABORCITA FORMATION

In 1942, Thompson (p. 82) described a series of strata overlying the upper Virgilian beds in La Luz Canyon. These beds, composed of red and gray shale, sandstone, conglomerate and a few limestones, contained fusulinids of early Wolfcampian age in the upper portion. Beds of similar age occurring in the central part of New Mexico directly below the non-marine Abo formation received three different names in 1946. Kelley and Wood (1946) introduced the name, 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, 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 Bursum formation, which term was widely adopted by the geologists of the New Mexico Bureau of Mines and Mineral Resources. 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 the northern end of the Sacramento Mountains.

The evidence resulting from the writer's detailed field studies necessitates a revision of the nomenclature of these strata, despite the undesirability of adding a new formation name to the already confusing number of names for rock-units of Pennsylvanian and early Permian age in New Mexico. In the Sacramento Mountains, the "transition beds" consist largely of a marine sequence of fossiliferous gray shales, limestones and sandstones, whereas in central New Mexico the Bursum formation is predominantly composed of red beds which occur interbedded with a few thin, fusulinid-bearing limestones. Furthermore, the lower part of the "transition series", which is non-fossiliferous in La Luz Canyon, contains several zones of fusulinids two miles to the north, indicating a late Virgilian age. The use of the name, Bursum formation, at least for the lower portion of the "transition" series, is therefore not valid.

An alternative suggestion changing the definition of the underlying Holder formation to include the upper Virgilian part of the "transition beds" and thereby restricting the name, Bursum formation, to the remaining lower Wolfcampian portion is not feasible, in view of the unconformity at the base of the "transition beds" in the area southeast of La Luz Canyon.

The term, Laborcita formation, is proposed 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 terrestrial clastics. The base of the type section is located 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 is derived. The top of the type section is about one 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 1.

To illustrate the very abrupt lithofacies changes of the Laborcita formation, 34 stratigraphic sections measured throughout the entire exposed part of the unit are plotted graphically on Plate 4.

Areal Distribution

The Laborcita formation crops out as a narrow, 17 mile long strip through the entire length of the map area (Figure 4). 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, for a distance of about five miles. From Cottonwood Canyon northward to Domingo Canyon for four miles, the lower portion of the Laborcita formation forms 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 eight miles.

A few conglomerate beds of the Laborcita formation that are exposed through windows in the overlying Abo formation, are located three 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 formally recognized in that area.

Lithology

General Features

The Laborcita formation is composed of widely different sedimentary rock types. As a formation, it truly reflects the changing conditions of a predominantly marine to a predominantly terrestrial environment of deposition. Thin-bedded, argillaceous limestones grade into thick-bedded limestones and occur interbedded with gray, green and red, commonly calcareous mudstones and shales. Pure quartz sandstones, feldspathic sandstones, arkoses and subgraywackes are present; sandstones grade into conglomerates with clasts of varying composition and size. Except for the shaly intervals, the 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 do not extend laterally more than a few hundred yards and lens out or grade laterally into a different rock type. Calcareous shales grade into nodular limestones and/or thick-bedded limestones. Limestone conglomerates may grade into thick-bedded limestone beds in one direction and into chert pebble conglomerates in the opposite direction. A few beds, however, appear with relatively greater persistence and are continuous for several miles.

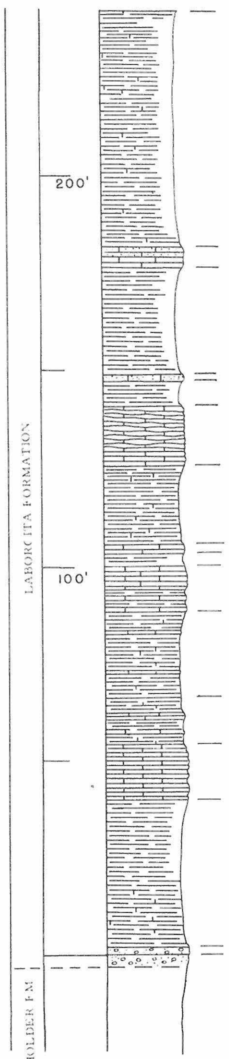
The abruptly changing lithofacies cause sections, only a few hundred feet apart, to differ considerably. Therefore, it is practically impossible to distinguish subdivisions in the Laborcita formation that could be recognized over much of the map area. In the field, horizons formed by the base of many locally recognizable rock units were mapped, and detailed stratigraphic sections were measured and described throughout the area. The more persistent of the rock units were used to correlate the many measured stratigraphic sections, and the relative stratigraphic position of previously known and newly discovered fossil occurrences was determined accurately.

In an attempt to portray the abrupt facies variations in the Laborcita formation, graphic logs of 34 of the correlated sections are plotted on Plate 4 at a scale of 50 feet equal 1 inch. The mapped horizons are numbered consecutively upward in the section according to their relative stratigraphic position. The stratigraphic position of a fossil locality not along the line of a measured section is indicated with respect to the nearest measured 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 location of all measured sections on Plate 4 are recorded on the geologic maps (Plates 1 and 2). Different base lines have been used for plotting the graphic logs on the correlation diagram. Marker horizons 42, 37, 53 and 55 were used respectively from right to left on the diagram.

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

Local Features

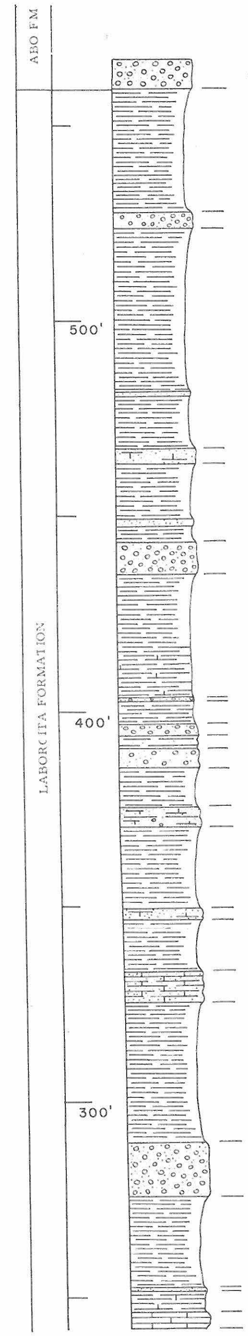
From south to north, the deposits of the Laborcita formation exhibit a gradual transition from a non-marine red bed facies to a largely marine facies of interbedded limestones and shales. The deposits also indicate a gradual emergence of the area and a transition from marine to non-marine environments upward in the section. For the purpose of discussion, the long narrow strip of outcrops of the Laborcita formation can be broadly subdivided into three areas. The southern area, which extends from a point one-quarter mile south of State Highway 83 to La Luz Canyon for a distance of three miles, includes most of the red bed facies of the Laborcita formation (Figure 4). The central area extends from La Luz Canyon to Domingo Canyon for a distance of six 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, for a distance of eight miles, forms the northern area and involves here only the upper half of the largely marine Laborcita formation. The basal portion of the Laborcita formation is no longer exposed north of Domingo Canyon because of the presence of an igneous sill near the mouth of Domingo Canyon.



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	26'	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 1 1/2 miles and towards 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., northeast of road. Section measured toward ENE, in and south of arroyo.

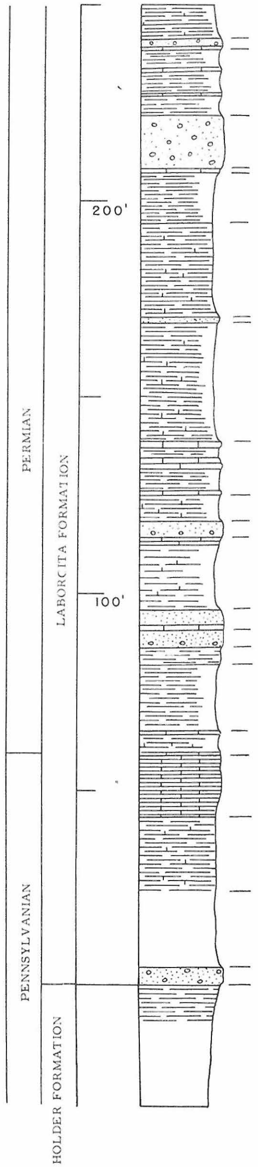


40	7'	Conglomerate; pebbles, cobbles and boulders of quartzite (50%), limestone and chert.
39	32'	Poorly exposed; largely red mudstone.
38	4'	Conglomerate; pebbles of limestone (50%), chert and quartzite.
37	56'	Poorly exposed; largely red mudstone.
36	4'	Sandstone, quartz, light brownish gray, medium grained, calcareous; cross-bedded.
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 2600' 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 the top of the column to the left.

P.L.5

STRATIGRAPHIC SECTION OF THE LABORCITA FORMATION (SECTION 7 AND 6) IN FRESNAL CANYON.

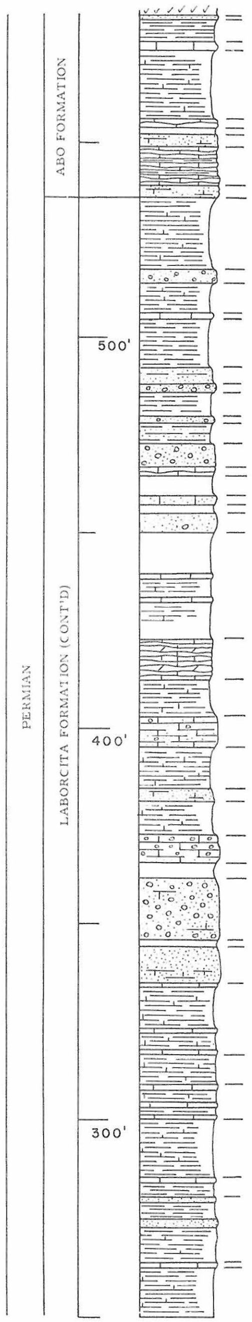


21	3'	Limestone, medium gray; grades upward into sandy limestone conglomerate.
20	16'	Poorly exposed; largely greenish yellow claystone with minor interbedded dark silty limestone, fossiliferous.
19	14'	Conglomerate, sandy, pebbles and cobbles of limestone and chert.
		Overlying section measured N. 20 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; non-red.
11	4'	Conglomerate, granules and pebbles of limestone; grades upward into calcareous, medium grained quartz sandstone.
10	18'	Largely covered, probably yellowish claystone.
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 road junction from La Luz and Fresnal Canyons. Section measured up arroyo toward NE.

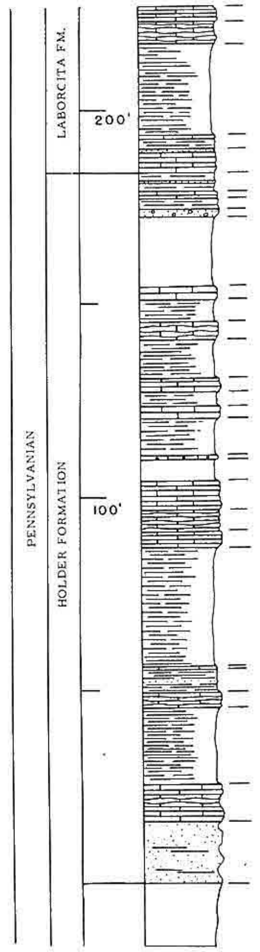


		Intrusive rocks.
66	1'	Sandstone; very resistant.
65	6'	Mudstone, dark greenish gray.
64	2'	Limestone, grayish red.
63	18'	Poorly exposed, largely red mudstone; limestone nodules.
62	2'	Limestone, light brownish gray, argillaceous, undulatory bedding.
61	2'	Covered.
60	3'	Sandstone, dark red, medium 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 in 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' southeast of center of SE 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'	Limestone, medium gray, argillaceous; slightly nodular.
45	5'	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 southeast 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 calcareous, medium gray, silty shale. Abundant fusulinids (Schwagerina). Fossil locality 11-F-2.
26	15'	Poorly exposed; largely non-resistant olive gray calcareous shale.
25	5'	Shale, olive gray, calcareous; capped by 6" argillaceous limestone. Abundant brachiopods, gastropods, pelecypods. 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 non-resistant, olive gray, very calcareous shale.

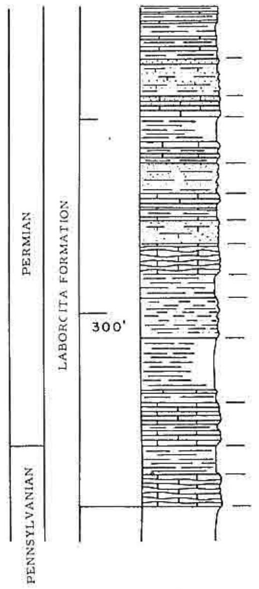
Section continued from the top of the column to the left.

STRATIGRAPHIC SECTION OF THE LABORCITA FORMATION IN LA LUZ CANYON (SECTIONS 11 AND 12)
(largely summarized from a section measured by L. C. Pray)

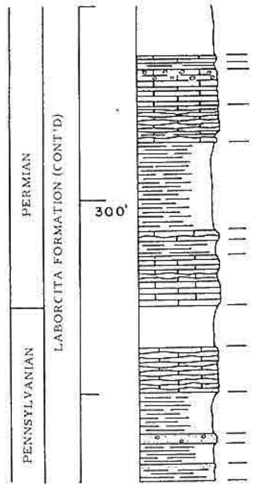
P.L.6



30	4'	Limestone, grayish red; algae; massive.
29	6'	Limestone, grayish red, argillaceous, nodular to undulatory bedding. Abundant fusulinids; 18-F-3.
28	23'	Poorly exposed; largely red mudstone.
27	4'	Shale and argillaceous limestone interbedded. Abundant fusulinids in top layer; 18-F-2.
26	6'	Limestone, greenish gray, sandy, well bedded; grades upward into medium grained, olive gray quartz sandstone.
		Contact of Laborcita formation projected to base of unit 26 (see Correlation Chart). Contact appears to be gradational. No significant difference in lithology on either side of contact.
25	5'	Mudstone, dusky red with sandstone layer.
24	2'	Limestone, medium light gray, silty; algae in top part.
23	2'	Covered.
22	2'	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; 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 cross-bedded.
		Base of measured section in bottom of Laborcita Canyon, 700' SE of center of sec. 13, T. 15 S., R. 10 E. at north side of canyon. (Section 18).

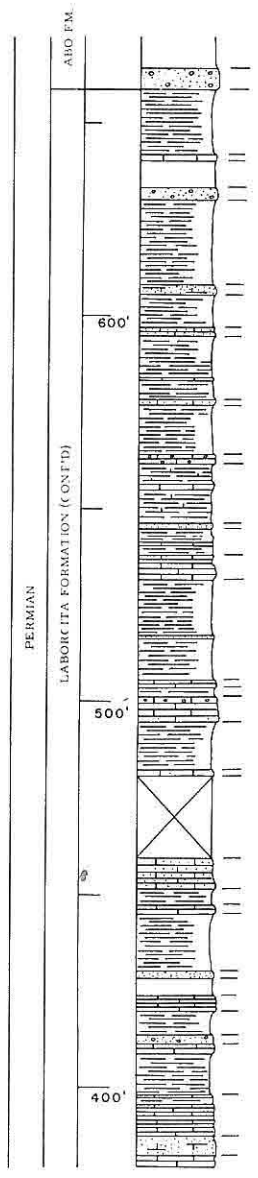


47	16'	Limestone, dark bluish gray, argillaceous, sublithographic; interbedded with shale
46	10'	Sandstone, yellowish gray, very fine grained, calcareous; interbedded with thin limestone layers
45	5'	Limestone, medium gray, very sandy, granules of chert
44	12'	Poorly exposed; shale and greenish gray 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; 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 NE 1/4 Sec 13, T. 15 S., R 10 E, 1700' along strike of unit 35 of previous section toward NNE (horizon 8 of correlation chart). (Section 20).



		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.); 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, algal debris, massive; 6' from bottom a 3' argillaceous zone with undulatory bedding. Abundant fusulinids (Schwagerina sp.); 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; 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.

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

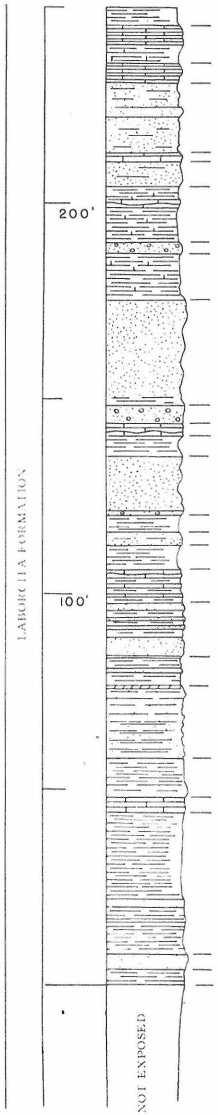


83	5'	Conglomerate, dark yellowish brown, pebbles of quartzite, chert and some limestone in sandstone matrix.
82	18'	Poorly exposed, red mudstone.
81	1'	Limestone, pale yellowish brown, argillaceous.
80	7'	Covered.
79	3'	Conglomerate, pebbles of limestone and chert.
78	22'	Covered; red mudstone
77	3'	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 south (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 Sections 19 and 20). Base of overlying section 19 near center of SE 1/4 SE 1/4 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

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

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

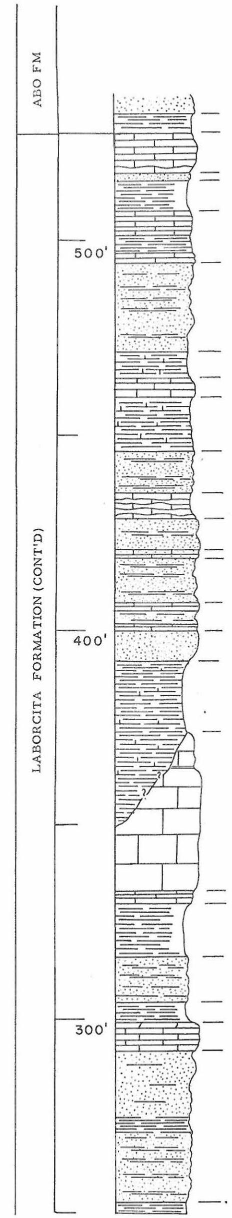
PL. 7



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 and 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, non-red.
13	15'	Arkose, gray olive green, very coarse grained, well sorted; conglomeratic (quartzite, chert, limestone) at base; petrified wood.
12	4'	Covered; non-red shale and sandstone.
11	4'	Sandstone, pale brown, very coarse grained; feldspathic; plant remains.
10	6'	Covered; non-red shale.
9	6'	Limestone, medium gray, argillaceous, slightly nodular bedding (algae in top 3'); interbedded with non-exposed 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 1/4, SE 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 north on the Stratigraphic Correlation Chart, occurs approximately 450' below horizon 32 (unit 2).

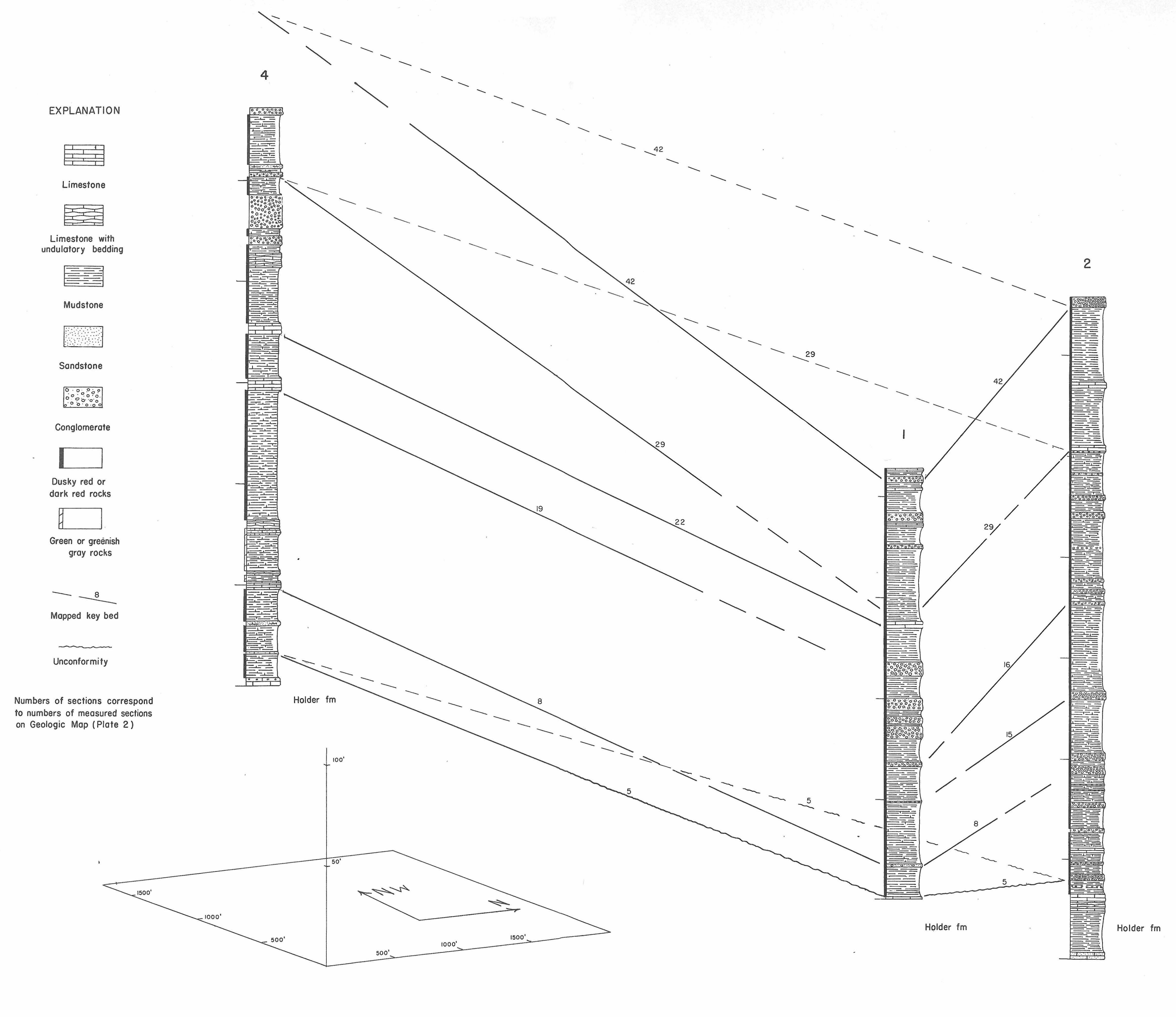


51		Arkose, dusky red, coarse grained; minor cross-bedding.
50	5'	Shale, light olive gray, non-calcareous. Plant leaf impressions.
49	14'	Limestone, light gray, very fine crystalline, massive; basal 2' nodular argillaceous. Fossiliferous (brachiopods, fusulinids, algae).
48	2'	Arkose, greenish gray, 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 cross-bedded.
34	18'	Shale, medium dark gray, calcareous, fissile; top 1' interbedded with argillaceous limestone. Fossiliferous (pelecypods, brachiopods, gastropods); 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; 29-F-1, 30-F-1.
32	3'	Limestone, medium gray, very fine crystalline; irregularly bedded; lower 1' brown weathering dolomitic limestone.
31	14'	Covered; probably shale, non-red.
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.

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

P.L. 8

STRATIGRAPHIC SECTION OF THE LABORCITA FORMATION 3/4 MILE NORTH OF TULAROSA CANYON (SECTIONS 29 & 30).



ISOMETRIC DIAGRAM OF THE SOUTHERNMOST PART OF THE LABORCITA FORMATION

Furthermore, the progressive northward decrease in displacement on the boundary fault system, as far north as Tularosa Canyon, causes younger strata to form the frontal escarpment. For the area between Tularosa Canyon and a point five miles to the north, the displacement appears to be relatively uniform and the same portion of the section is continuously exposed. The few isolated outcrops of the Laborcita formation about three miles east of the junction of La Luz and Fresnal Canyons are discussed under the "Upper La Luz Canyon Area".

Southern Area

The southern area, extending between a point one-quarter of a mile south of State Highway 83 and La Luz Canyon, comprises most of the red bed facies of the Laborcita formation. The rock units of this part of the map area are shown diagrammatically by the graphic logs of sections 1 to 10 on the correlation diagram of Plate 4. Sections 7 and 6 are considered representative of the southern non-marine facies of the Laborcita formation and have been described in detail and shown graphically on plate 5. The base of this composite section is in the creek bottom, 1-1/4 miles southeast of the road junction of 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, that occur largely in the lower portion of the section, and sandstones and pebble and cobble conglomerates that are mainly restricted to the upper portion. The sandstones are relatively resistant, predominantly medium-grained, well-sorted, calcareous quartz sandstones. The conglomerate clasts consist of limestone, chert and quartzite, with the quartzite increasing in amount upward in the section.

The Laborcita formation extends southeastward of measured sections 7 and 6 for two miles and thins abruptly in that direction. As is indicated on Plate 4, the lower 430 feet of the measured section below horizon 42 is equivalent to a 200 foot thick red bed sequence two miles farther south. The limestones, which are very persistent in that part of the section, also lens out. Limestone pebble and cobble conglomerates constitute about 20 percent of section 1 on Plate 4, as compared to less than 10 percent of conglomerates and sandstones in the section two miles to the northwest. The marked facies changes within a short lateral distance are illustrated diagrammatically on Plate 9, where three sections, 1, 2 and 4, which are located on the geologic map, (Plate 2), are plotted in an isometric diagram. The increase in thickness between sections 1 and 2 takes place principally in the interval of strata between horizons 5 and 16. Over a lateral distance of about 1500 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 the abrupt wedging in the basal portion is visible on Figure 6.

The conglomerates of the Laborcita formation in this southernmost part of the map area are interformational in origin as compared to some of the intraformational conglomerates of the Laborcita formation near La Luz Canyon and the underlying Holder formation.

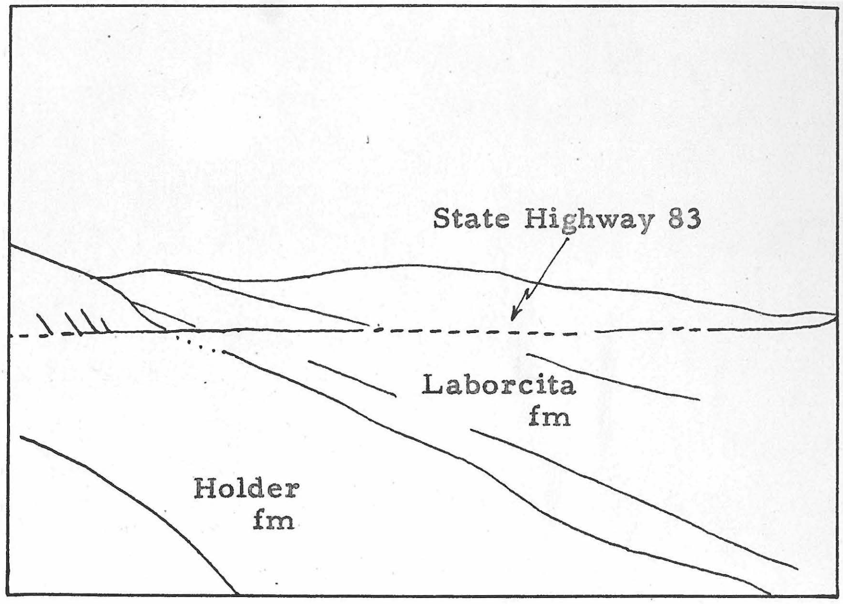


Figure 6. Angular onlap of the basal part of the Laborcita formation on the Holder formation. Note wedging in the lower portion of the Laborcita formation. Viewed toward southwest from a point north of State Highway 83, near center of SW1/4 NW1/4 sec. 6, T. 16 S., R. 11 E.

Limestones, which were distinctly derived from a Pennsylvanian source, predominate in the conglomerate clasts. Brachiopods, horn corals and fusulinids are present in the pebbles and cobbles, and on the basis of lithology and color, the rocks appear to have been largely derived from the upper part of the Holder formation. Chert and quartzite occur in minor amounts in the conglomerates. The increasing coarseness and thickness of the conglomerate beds toward the southeast and east suggest a source for the clastic sediments 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 for a distance of six miles from La Luz Canyon to Domingo Canyon and comprises the area of the predominantly marine Laborcita formation. This facies of the Laborcita formation is composed of red and gray mudstones, interbedded with limestones and sandstones. The various rock units of the central area are shown graphically on Plate 4, sections 11 to 24.

Detailed description and a graphic log of the portion of the Laborcita formation that overlies Thompson's type section of the "Fresnal group" near the junction of La Luz and Fresnal Canyons are given on Plate 6. This measured section appears as sections

11 and 12 on the correlation diagram of Plate 4. The lower section is summarized from Pray (Pray, 1952, pl. 17). Because of the writer's revision of the base of the Abo formation, the 200 feet of red beds that overlie Pray's section of the Bursum formation are also included in the Laborcita formation. The total thickness of the section at this point is 536 feet, essentially the same as the measured section 1-1/2 miles to the south. In La Luz Canyon only the top 160 feet consists of red beds, in contrast to the section in the south, where red beds constitute three-fourths of the section. The red beds in La Luz Canyon are largely composed of red mudstones, interbedded with calcareous quartz sandstones and quartzite pebble conglomerates. Of the underlying 370 feet, which correspond to Pray's Bursum formation, about two-thirds consist 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 7 and 9 on Plate 4 illustrates the abrupt lithofacies changes between the southern and central area. Within three-quarters of a mile, a probably non-marine red bed sequence grades into a series of gray limestones, shales and sandstones of predominantly marine or brackish water origin.

The type section of the Laborcita formation in this report is located near the mouth of Laborcita Canyon. A detailed description of this section, which is also shown graphically by sections 18, 19 and 20 on the correlation diagram, is indicated on Plate 7.

Although about 20 feet of the section is eliminated as a result of an igneous intrusion, it was considered to be the most representative section of the marine Laborcita facies. Furthermore, the upper and lower contacts are well exposed.

The Laborcita formation is approximately 480 feet thick at the type locality. About one-third of this section is composed of red mudstones which occur through the entire unit. 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 limestones in the section in La Luz Canyon. Coarse clastics appear to decrease from La Luz to Laborcita Canyon. Quartz sandstones and conglomerates form about eight 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 this section, which permits the determination of the Pennsylvanian-Permian boundary within narrow limits. The fusulinids are also significant as indicators of more open marine conditions. The many limestones, consisting mainly of coarse bioclastic debris, also indicate marine conditions. The rocks in Laborcita Canyon appear to have been deposited in a predominantly marine environment, with the possible exception of the top 110 feet of this section which is mainly composed of red mudstones. Thus, 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 with repeated fluctuations throughout the deposition of the lower two-thirds of the Laborcita formation.

A very rapid lithofacies change from west to east has been observed in the portion of the Laborcita formation that is exposed in the vicinity of the Laborcita Canyon and its tributary canyons. 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 many red shale intervals as compared with the type section. The limestone content is considerably less and coarse clastics predominate. It appears, therefore, that the change from marine to non-marine conditions takes place toward the east as well as south-southeast.

At the mouth of Laborcita Canyon the upper part of the Holder formation and the lower part of the Laborcita formation cannot be distinguished on a lithologic basis, as is demonstrated by section 18 on Plate 4. No persistent erosional break was observed near the contact, and the absence of a persistent lithologic marker indicates that the contact between the Holder and Laborcita formation is probably gradational in this part of the map area. From a point half way between Cottonwood and Laborcita Canyons the contact was traced northward for a distance of 3-1/2 miles as a phantom horizon, 30 feet stratigraphically above a persistent limestone marker. From Laborcita Canyon to Domingo Canyon, the almost identical 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 on Plate 4 illustrate the persistent limestone markers and the relative uniformity of the lithofacies.

Certain lithologic sequences appear in cyclical repetition at both sides of the contact. Although laterally uniform, open marine conditions prevailed in this area, many fluctuations in sea level must have occurred repeatedly. These conditions of deposition persisted throughout late Pennsylvanian and early Permian time, which is the main reason for grouping the Holder and Laborcita formations together in the Magdalena group.

Northern Area

The northern area extends for approximately eight miles from Domingo Canyon to a point about five miles north of Tularosa, and includes all outcrops of the Laborcita formation north of Domingo Canyon. A slightly discordant igneous sill near the mouth of Domingo Canyon forms a natural geologic 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 about 200 feet, intruded successively younger strata toward the southeast and east, as is shown on Plates 1 and 4, and prevents the underlying lower portion of the Laborcita formation from being exposed 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 that are included in the Laborcita formation of the northern area are shown by the graphic logs of measured sections 25 to 34 on the correlation diagram of Plate 4. In this area, the lithofacies is considerably more uniform than in the southern area, the structure is much less complex, and a few carefully chosen marker beds readily established a framework for correlation of the various 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, which involves all strata between marker bed 49 and the top of marker bed 55 is incorporated into 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 is readily noted on Plate 4. In the northern area, the Laborcita formation consists predominantly of coarse and fine terrigenous clastics, 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 very persistent.

Details of the sequence of Laborcita strata in the northern area are illustrated by the stratigraphic section on 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. A few gypsiferous siltstone zones that are several inches thick are noted in about two places associated with greenish gray siltstones, and occur in very porous aggregates.

The increase of the coarse clastic content is the most marked feature in this section, in comparison with 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, Figure 66) due to the presence of a "paste-like" 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 the remaining 39 percent is composed of matrix material. Because of the absence of rock fragments, this rock is considered to be 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 sandstones are in general more continuous laterally than those in the southern part of the area. The increase in feldspar content is particularly marked, in contrast to the more lenticular, but also purer quartz sandstones in the south. 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 cross-bedding, with the cross-beds dipping west. On the basis of the lateral continuity of the thin sandstones and siltstones, 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 clastics of unusual lateral persistence. This sequence occurs approximately in the center of the measured section between horizons 39 and 51, as noted on Plate 4. It is largely composed of red and green arkoses and red mudstones, and is about 150 feet thick. The corresponding interval to this sequence in the central and southern areas consists entirely of red beds and is about 100 feet thick. The difference in thickness between these two broad areas is caused by a 45 foot thick, coarse-grained, greenish-gray, calcareous sandstone bed, which is indicated on section 26, Plate 4, as underlying horizon 48. The unit is very lenticular and markedly cross-bedded, with the foreset beds dipping east (Figure 7). The

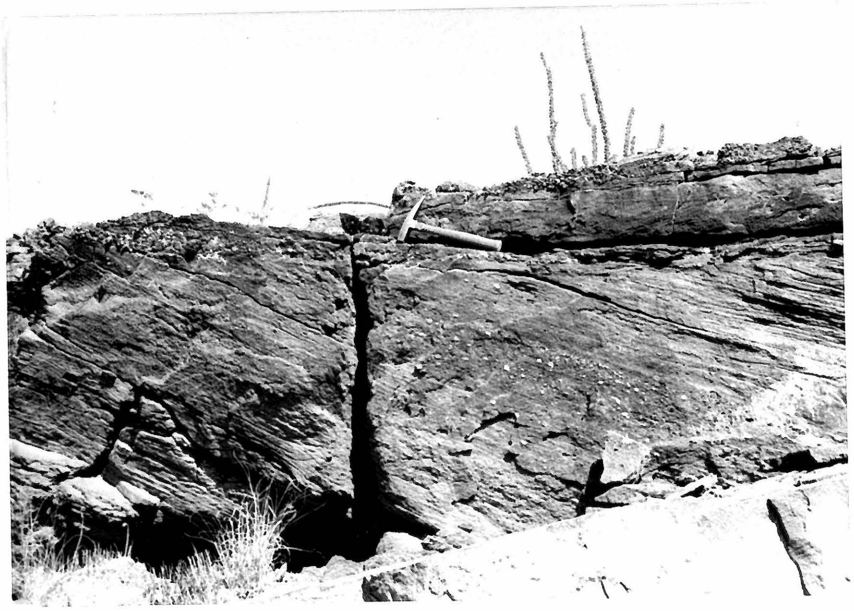


Figure 7. Cross-bedded sandstone and conglomerate of the Laborcita formation near mouth of Domingo Canyon in SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 34, T. 14 S., R. 10 E. View looking north.

laterally persistent red color of the interval between horizons 39 and 51 is interpreted to indicate a widespread emergence of large parts of the map area and deposition under alluvial plain and possibly near-shore marine conditions.

The limestones of the northern area, particularly in the lower part of the section, are commonly dark gray and argillaceous. Locally, they contain round algal structures about three inches in diameter, that show a laminated structure. Two limestone members, units 28 and 33, are laterally very persistent and have been mapped as marker beds 51 and 52 (Figure 8). They extend for 7 and 4-1/2 miles,

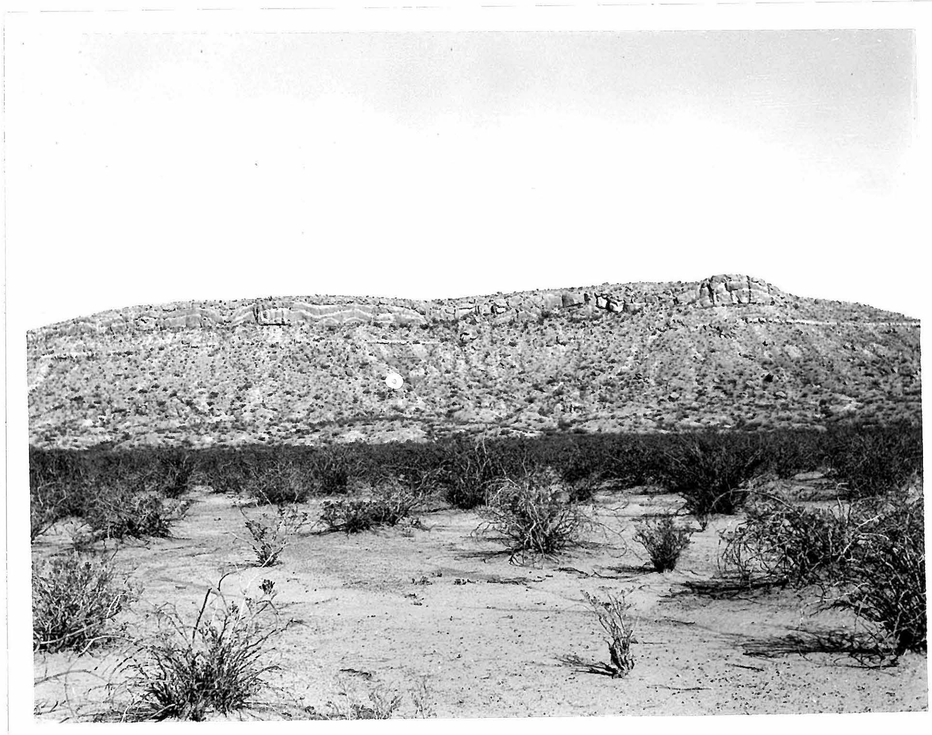


Figure 8. Algal reefs and overlying detrital limestone layers form resistant ledge on crest of frontal escarpment north of Tularosa. The thin continuous lower band is dolomitic limestone (bed 51, Plate 4).

respectively, and are locally dolomitized, which is very distinctive as a result of the rusty brown color.

A persistent, massive limestone ledge about 60 feet thick is conspicuously exposed on the crest of the frontal escarpment from a point northeast of Tularosa for a distance of about three miles (Figure 8). Detailed field and petrologic studies, that are discussed in detail in Appendix II, revealed that this limestone ledge of relatively uniform thickness is composed of two parts, a lower part that consists of a series of mound-like bodies of massive accretionary limestone, and an upper part that consists of detrital limestone.

The mound-like bodies, that occur in the lower part, average about 35 feet in thickness, but are as much as 60 feet thick in places. The flanks of these structures dip locally as much as 35 degrees. On the basis of various lines of evidence the mounds can be interpreted as reefs. The slightly dolomitized limestone unit 33 of Plate 8 forms the base of the reef masses wherever they occur. Field evidence indicates that the structures are equivalent to a few feet of strata in the off-reef facies, and grew above the level of contemporaneous sedimentation. The low content of fine terrigenous clastics suggests a development into the zone of water agitation. The lack of real rough-water deposits and reef-flank deposits is, however, suggestive of growth not far above wave-base. A filamentous alga was the principal framework-building and cement-binding organism. The reefs also contain substantial quantities of bioclastic debris that occurs largely in small pockets and was derived from different types of organisms, such as brachiopods, fusulinids, crinoids and unidentifiable algae.

The upper part of the resistant ledge consists of a coarse-grained detrital limestone that reaches locally a thickness of about 60 feet. It is restricted to the reef area where it caps the massive limestone structures and is composed of fragments of tubular algae, crinoids, brachiopods and fusulinids. The detrital limestone is considered a post-reef deposit, and probably the reef structures continued to have a topographic expression on the sea floor and continued to affect the sedimentation and marine life in post-reef time, thereby restricting the formation of the detrital limestone. These deposits were also laid down above wave-base, as is suggested by the low content of fine terrigenous clastics. The time-equivalent deposits of the reef facies and post-reef detrital limestone facies reached a thickness of six feet in the off-reef areas.

The zone of reef development was probably 1/4 to 3/4 mile wide and probably did not extend much beyond the area of present exposure, which is about three miles long. It is believed that the organic structures developed under optimum growth conditions on the gently sloping, relatively stable sea floor that bordered the lower Permian landmass to the east and southeast. Water depth, temperature and currents are inferred to have been favorable for reef 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, that are exposed through windows in the Abo formation, are located about three 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. (Figure 4 and Plate 2).

The field evidence indicates that a sequence of limestone and conglomerate beds is overlain with an angular discordance of about 15 degrees by a quartzite cobble conglomerate that forms the base of the Abo formation. A few limestones, that occur interbedded with several pebble conglomerate layers of varying composition, contain locally abundant fusulinids. Identification of the fusulinids by Thompson showed an "upper Fresnal" age for these strata, that are therefore correlated with the Holder formation. This correlation might be questioned for the Pennsylvanian strata exposed in sec. 23 and northern part of sec. 22, T. 15 S., R. 11 E. (Plate 2), and these beds might be equivalent to 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 is firmly established, a few pebble and cobble conglomerate beds and interbedded shale overlie, in a few places, the upper Pennsylvanian strata with a marked angular discordance of as much as 40 degrees. The conglomerates consist mainly of limestone, chert and quartzite and are markedly different from the overlying quartzite cobble conglomerate of the Abo formation. Thus, the conglomerates and the interbedded non-exposed intervals, which form a wedge-shaped unit about 60 feet thick, are bound on either side by angular unconformities. Because of the stratigraphic position, this 60 foot interval is correlated with the Laborcita formation farther west, where 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 of 530 feet in thickness grade within a lateral distance of three miles into 60 feet of conglomerates and shales.

Two miles due south of the Upper La Luz Canyon area, near Salada Canyon, the Laborcita formation also lenses out into the unconformity at the base of the Abo formation, and similar conditions are inferred for the area north of the Upper La Luz Canyon area, as is indicated on FF' of Plate 3. Deposition of the Laborcita formation occurred from east to west and possibly from southeast to northwest. Therefore, the writer believes that the nearly north-northwest orientation of the correlation diagram on Plate 4 is in part along the strike of deposition of the Laborcita formation, which might 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 (Plate 4).

Marker Beds*

The relatively more persistent marker beds are discussed in an attempt to illustrate in detail some of the abrupt lithofacies changes in the Laborcita formation. As the marker beds represent

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*"Marker Beds" have been designated "key beds" in the explanations of Plates 1 to 4. The term, "marker bed" is preferred by the writer and will be used in the manuscript. The same number has been applied for both a marker bed and the mapped horizon at its base. Generally, the usage of the term will readily tell which meaning is implied.

essentially time lines, they indicate the distribution of the various depositional environments that were present at any given time in the different parts of the map area.

The marker beds can be divided into two broad groups on the basis of geographic location. The area south of Domingo Canyon, which includes the central and southern areas of the previous section, comprises the marker beds of the uppermost part of the Holder and the entire Laborcita formation. The northern area includes only the marker beds of the upper portion of the Laborcita and the lowermost Abo formation (Plate 4). In each subdivision the individual marker beds are discussed in ascending order from oldest to youngest. The lateral lithologic variation, continuity and approximate geographic extent of the marker beds are best illustrated by Plate 4, and have been shown diagrammatically on Figure 9.

Southern and Central Areas

No. 4

A medium gray, resistant, fragmental limestone layer persists for about 3-3/4 miles, extending northward from a point 1/2 mile north of Cottonwood Canyon to Domingo Canyon, where it is last observable. This limestone member is locally as much as 25 feet thick, but averages about 10 feet. It is commonly a massive cliff-former. Northward, it grades into a nodular limestone. The limestone is largely composed of coarse organic detritus.

No. 5

The base of the Laborcita formation in La Luz Canyon in section 11

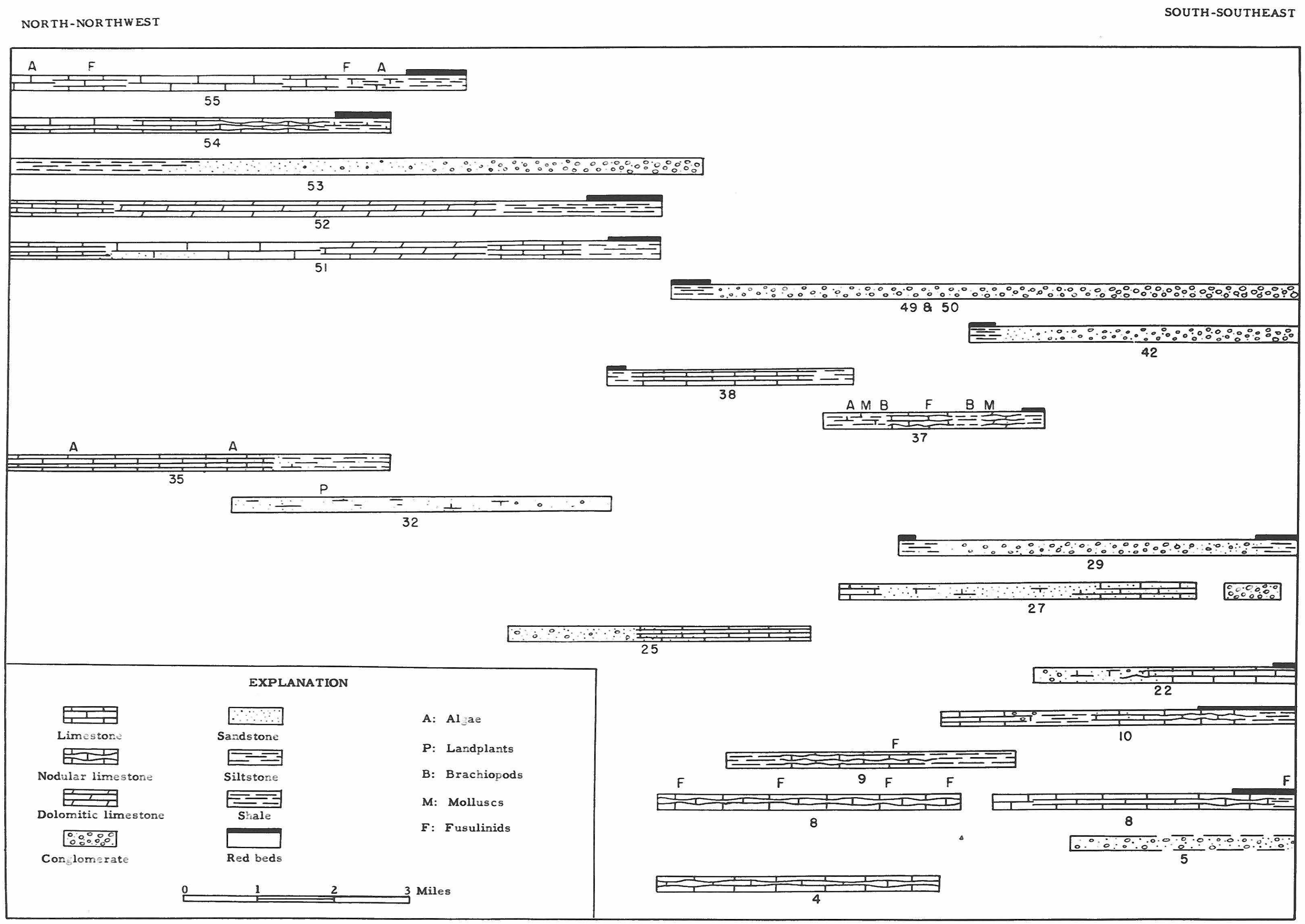

Figure 9. LATERAL VARIATION DIAGRAM OF IMPORTANT MARKER BEDS

(Plate 4) is marked by a sandstone and conglomerate layer about four feet thick which is indicated as marker bed 5. Pebbles in this layer consist of limestone and chert. The limestone contains Pennsylvanian fossils. The conglomerate, that does not persist as a continuous layer toward the southeast, was recognized in many places at the same stratigraphic position, overlying fusulinid-bearing nodular limestones and shales of the Holder formation. It extends for a distance of about three miles in Fresnal Canyon. 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 thinly bedded, medium dark gray, silty limestone layer, 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 layers remain very persistent and are easily recognizable for about two miles between sections 5 and 11 south of La Luz Canyon. The limestone varies only slightly in thickness. In the locality of section 7, the shales contain many plant fossils and a few coaly layers. Southeast of section 5, within one-third of a mile, the dark gray shales grade into red mudstones with abundant fusulinids which, according to Thompson*, might be of late Virgilian age. The limestones show evidence of

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* Personal communication

undulatory bedding toward the southeast and gradually lens out. Northwest of section 11, within about one-quarter of a mile, the limestone becomes more massive and is light medium gray in color, 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 in that direction. Beyond that point it appears to grade into shale and is no longer exposed.

A medium gray, slightly nodular, fusulinid-bearing limestone occurs in section 16, about half a mile south of Laborcita Canyon. With little change in both lithology and fossil content, this bed was recognized for about 3-1/2 miles and was traced from Cottonwood Canyon in the southeast toward Domingo Canyon in the northwest. This bed appears to occupy the same stratigraphic position as the thin-bedded argillaceous limestone layer 8, and therefore was also designated by that number. Because of complex structural relationships in the vicinity of Cottonwood Canyon, it is not known whether these beds grade into each other.

No. 9

Marker bed 9 has been traced for about one mile and has been observed in measured sections 16, 17, 18 and 20 in the vicinity of Laborcita Canyon. It is described in section 18 as unit 37. This medium gray, resistant limestone layer consists mostly of bioclastic debris and is about 12 feet thick. Fusulinids of early Wolfcampian age occur in a three foot thick, argillaceous, nodular limestone interval six feet above the base. This is the lowest limestone unit in the Laborcita formation with Permian fusulinids, and the Pennsylvanian-Permian boundary has been located at the base of the marker bed, thus coinciding with horizon 9. Bed 9 grades laterally into dark gray shale, and to the north the Pennsylvanian-Permian boundary has been determined as a phantom horizon about 15 feet above the base of bed 8. Southeast of La Luz Canyon, the stratigraphic position of the boundary approximately corresponds to the top of the thin-bedded carbonaceous limestone of bed 8 (Plate 4).

No. 10

The base of an argillaceous, very fine-grained, medium gray, non-fossiliferous, five foot thick limestone bed has been mapped as horizon 10 in the area of Fresnal Canyon. It extends for 1-3/4 miles between sections 4 and 9. Toward the southeast, the limestone becomes nodular and is interbedded with red shales, and gradually dies 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 layer, about 20 feet thick, extends for about half a mile north of Cottonwood Canyon and occurs at the level of horizon 10, 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. Markedly cross-bedded calcareous quartz sandstone with pebbles of limestone gradually grades toward the southeast into a four foot thick fragmental limestone layer, that is largely composed of bioclastic debris. Pebbles of chert and limestone are scattered throughout. In the vicinity of section 1, the limestone is very argillaceous, fine-grained and grayish-red in color.

No. 25

Marker bed 25 is a thin-bedded, medium gray, argillaceous limestone in section 22 about one mile north of Laborcita Canyon, and extends northward for four 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 markedly cross-bedded sandstone containing pebbles of limestone and chert. It is no longer observable 1-1/4 miles north of Domingo Canyon.

No. 27

A calcareous quartz sandstone about 10 feet thick has been traced as bed 27 for about six miles, from a point about three miles southeast of La Luz Canyon to about three-quarters of a mile north of Laborcita Canyon. Its thickness remains relatively uniform throughout. In the vicinity of Laborcita Canyon where it is last observable it grades into a very sandy limestone. Toward the southeast, about one mile south of La Luz Canyon, the sandstone grades into a medium gray, very sandy limestone. A very 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 five 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. Its lower contact is very irregular, as can be easily observed with respect to the underlying sandstone marker 27, and shows evidence of scour-and-fill structures. Locally it cuts down below the level of bed 27 and contains reworked material of this layer. Detailed tracing of bed 29 toward the southeast revealed that it 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 quartzite cobble conglomerate layer 29 and has been mapped as bed 37. This medium gray argillaceous limestone has nodular to undulatory bedding. It 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 is composed of coarse bioclastic debris of unidentifiable algae. The limestone grades southeastward, within half a mile of Cottonwood Canyon, into a fossiliferous black shale zone 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 with number 37. The dolomitic limestone grades southeastward into a red, non-fossiliferous mudstone. From Laborcita Canyon northward to the location of section 19, a distance of one-quarter mile, the fusulinid limestone grades into a dark silty limestone containing brachiopods and pelecypods, and then into an arenaceous shale containing small leaf-like algae. Beyond this point, the bed lenses out.

No. 38

Marker bed 38 is a dark, four foot thick, bluish-gray, fine-grained argillaceous limestone, that forms an excellent marker bed in the vicinity of Domingo Canyon. It was traced for about three 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 one 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 is traced into a dark gray, poorly exposed shale.

No. 42

A very persistent conglomerate bed, about nine feet thick, has been mapped as bed 42 for four 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 toward the southeast. No large amount of channeling has been observed at the base of this unit.

No. 49

A quartzite pebble and cobble conglomerate has been mapped as marker bed 49 from the extreme southern end of the area to a point as far north as Domingo Canyon, a distance of about 8-1/2 miles. The thickness of the conglomerates ranges from a few feet to as much as 15 feet. North of Cottonwood Canyon, the amount of limestone and chert increases with respect to the quartzite. Where the conglomerate is coarser, as in the southern part of the map area, the pebble and cobbles consist almost entirely of quartzite. It 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 (Plate 4). Locally, the bed shows evidence of scour-and-fill structures. Clasts about two feet in size, and probably 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 49 is considered the base of the Abo formation in the southern half of the map area. The absence of marine beds in the Abo section overlying this conglomerate in that part of the area is added support of this interpretation.

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 (Plate 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 recognized as bed 32, from Domingo Canyon northward for about 4-1/2 miles. This resistant layer is about four 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, it 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 shows cross-bedding. In a few places it contains plant fossils, but no marine fossils have been noted.

No. 35

A medium gray argillaceous limestone was traced northward as bed 35 from one mile northeast of Tularosa for four miles to where it is no longer exposed. The limestone is about three feet thick and contains dark gray limestone concretions that are interpreted to be 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 formed by a laterally very persistent, medium gray, very thick-bedded limestone. This layer is about ten feet thick, and extends from half a mile north of Domingo Canyon for 7-1/2 miles to the north, where it is no longer exposed. The limestone is largely a coarse detrital limestone, which shows characteristic rusty-brown dolomitization in the vicinity of Tularosa Canyon, between sections 28 and 29, for a distance of two miles. 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 on 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 three feet, extends for 4-1/2 miles in the vicinity of Tularosa Canyon.

Toward the south, it is known to extend for two more miles, where it grades into gray shale and then red mudstone, as is indicated on sections 27 and 25. Toward the north, it grades into a six foot thick, medium gray, detrital limestone layer, which consists mainly of unidentifiable algal fragments.

No. 53

A conglomerate layer has been recognized from Domingo Canyon northward for a distance of 7-1/2 miles as marker bed 53. Between Domingo and Tularosa Canyons it consists predominantly of cobbles of quartzite. Feldspar porphyry constitute about five 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 Canyons.

No. 54

Marker bed 54 is a resistant, medium gray, very fine-grained, brown-weathering limestone in the northernmost two miles of the map area. In section 33, it is about eight feet thick, very sandy at the base, and grades near section 34 into a 15 foot limestone ledge that is very thick-bedded at the top and consists of coarse bioclastic debris. Between sections 33 and 30, a distance of 2-1/4 miles, it grades southward into a very nodular sandy and argillaceous limestone, which occurs interbedded with red shale. Farther south, it is known to grade into red calcareous shale.

No. 55

A thick-bedded, medium light gray limestone, which is about 12 feet thick, forms marker bed 55. It has been traced from Tularosa Canyon northward for five miles. In the northern part of the area the bed contains locally abundant fusulinids and grades laterally into a limestone that is marked by medium dark gray algal nodules which are about one inch in size. South of Tularosa Canyon within half a mile, the thick-bedded limestone grades into a very silty limestone and then into a medium dark gray calcareous siltstone. This siltstone contains abundant irregular leaf-like algae and some fusulinids. Farther south, the bed grades into red mudstones overlying marker bed 53, and it can no longer be distinguished as a separate horizon. In the area north of Tularosa bed 55 is overlain by the main mass of Abo red beds, and the top of this unit marks the top of the Laborcita formation in that area.

Conditions of Deposition

The conditions that prevailed during the deposition of the Laborcita formation are discussed in this section which is subdivided into three parts. The first concerns sedimentary facies and treats eight different rock types that are considered to indicate certain restricted environmental conditions. In an attempt not to duplicate the previous discussions on local features and marker beds in the section on "Lithology", only the more prominent features of the various rock types essential to the discussion of sedimentary facies will be emphasized. Lateral and vertical rock sequences or cyclothems are discussed in the second portion of this section. The third portion outlines briefly the depositional history of the Laborcita formation as it is known in the northern Sacramento Mountains.

Sedimentary Facies

Conglomerates

Conglomerates are one of the most useful rock types in the area both for marker beds and interpretation of conditions of deposition. Most conglomerates in the map area are poorly sorted, wedge-shaped deposits that commonly exhibit evidence of scour-and-fill structures at their base. The composition of clasts and matrix ranges widely. In general, four different types can be distinguished in the mapped area.

Pebble and cobble conglomerates, largely composed of various types of limestone, some with diagnostic Pennsylvanian fossils and with minor amounts of chert, occur mainly in the vicinity of State Highway 83 in the southernmost part of the map area, as is shown on Plates 4 and 9. These deposits reach locally a thickness of 20 feet, are wedge-shaped 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 the process of removal by solution with resultant accumulation of only the insoluble parts, such as chert. However, the association with red beds is indicative of a warm, relatively humid climate (Van Houten, 1948, p. 2116), and the writer believes, therefore, 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, wedge-shaped nature, absence of marine fossils in the matrix and poor sorting is 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 to become more gentle, allowing finer materials to be deposited. The steeper parts of the area of aggradation are considered by the writer to represent a piedmont environment. The term, alluvial plain environment, is applied to the more gentle portions and is probably a surface of very low relief in the map area. Rapid erosion of the limestone terrain and rapid burial after relatively short transport is compatible with the proposed piedmont environment of the limestone conglomerates.

Conglomerates that are more continuous than the limestone conglomerates and 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 as much as 20 feet. These conglomerates, such as beds 29, 42, 49 and 53 (Plate 4), are predominantly composed of cobbles of quartzite; limestone and chert are generally present in minor quantities, but locally they might form as much as 50 percent of the clasts. Commonly, the conglomerates grade laterally into quartz-rich sandstones. These conglomerates are interpreted to have been deposited in a piedmont environment, principally because of their lack of marine fossils in the matrix, dominance of cobble-sized clasts, irregular thickness and channel features at the base. The lateral persistence of these conglomerates is possibly caused by either deposition near the broad base of an alluvial fan or several coalescing alluvial fans, that form a continuous apron of waste at the base of an area undergoing erosion.

Locally, it has been noted that these conglomerates consist entirely of quartzite cobbles. This phenomenon is attributed to selective sorting according to size which removed the smaller size particles, composed mainly of limestone and chert, leaving the conglomerate richer in quartzite. This is suggested by some observed lateral transitions, such as beds 29 and 49, from quartzite cobble conglomerate into pebble conglomerate of quartzite and limestone and granule conglomerate of chert and limestone. These relatively more continuous conglomerates were possibly deposited under conditions of less rapid burial than the interformational limestone conglomerates, as suggested by the better and more complete sorting in a lateral direction and the smaller size of the limestone clasts.

Some conglomerates of the area are probably marine. The thin conglomerates, such as marker beds 13 and 21 on Plate 4, that are about 10 feet thick, grade laterally within less than a mile into calcareous quartz sandstones. These conglomerates occur interbedded with marine shales and limestones, and are indicative of either short periods of emergence and alluvial plain conditions, or might have been deposited under partially deltaic marine conditions.

A few limestone conglomerates in the area, that apparently occur in close association with massive marine limestones, such as bed 10, have been tentatively interpreted as intraformational conglomerates. The clasts of these conglomerates are of pebble size and appear to be composed of one type limestone. Temporary withdrawal of the marine waters, mud cracking and subsequent flooding of the mud-cracked layers might explain their formation. However, the short lateral extent of most of these conglomerates and the generally well-rounded shape of the pebbles might suggest transporting agents that were locally more active, such as streams.

Coarse-Grained Sandstone

On the basis of grain size, the sandstones of the Laborcita formation can be classified into two broad groups, coarse-grained and fine to medium-grained sandstones, which are also indicative of certain restricted environmental conditions. 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, as is indicated on Plate 4. These sandstones contain a few scattered pebbles of chert and limestone (Figure 7), and occur interbedded with thin layers of red or green mudstone. Generally, these coarse-grained deposits are red or greenish-gray in color and show marked cross-stratification, and are noted by the absence of marine fossils. The dip of the cross-beds, which averages about 15 degrees, is predominantly toward the west, although local variations occur. The author believes that these thick sequences are evidence of fluvial deposition, and possibly represent river channel and/or deltaic deposits. The presence of the relatively unweathered feldspar suggests rapid erosion in the source areas.

Fine and Medium-Grained Sandstone

Although most sandstones of the Laborcita formation are of local extent, a few sandstone beds are relatively uniform in thickness and laterally very persistent, extending for as much as six miles. In general, these are well sorted, fine to medium-grained and do not show marked cross-bedding. Most of the sandstones are composed largely of quartz, commonly with calcareous cement. Marker bed 27, which occurs in the southern part of the map area, is of this type. This bed laterally grades into a very sandy, thin-bedded limestone (Figure 9). Others, such as bed 53, grade laterally into conglomerates. A few sandstones, such as bed 32, which are largely confined to the area north of Domingo Canyon, are classified as subgraywackes, because of the large amount of interstitial detrital material. Marine fossils are in general absent.

The laterally persistent sandstone beds probably represent thin blanket marine deposits. The relatively "clean" quartz sandstones of the southern part of the map area were possibly formed in a near-shore environment, where more turbulent water conditions resulted in a winnowing out of the fine terrigenous clastics. The blanket subgraywackes of the area north of Domingo Canyon are characterized by a "paste-like" matrix and feldspar content of about 15 percent. They 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 nodular bedding as much as four inches thick, and layers that are largely 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 nodular limestones. The nodular limestones are fine-grained, and are composed of detrital limestone particles of about 2/10-5/10 mm, packed in a very fine grained matrix. Fusulinids are most commonly found in limestones of this type and locally form about half the rock. Although these deposits occur throughout the entire Laborcita formation, they are most abundant in the central area between La Luz and Domingo Canyons, where they form a large part of the section, as is shown on Plate 4. On the basis of the occurrence of fusulinids and the bedded nature of the strata, the nodular limestones probably represent an open marine environment.

An area of active erosion is postulated east and southeast and possibly northeast of the map area, on the basis of the increasing amount of conglomerates and abrupt thinning of the Laborcita formation toward the east and southeast. Many of the nodular limestones grade laterally in the direction of this land area, into gray, green or red mudstone, which is diagrammatically shown by beds 8, 9, 10, 37 and 54 on Figure 9. These limestones, therefore, are probably deposited under relatively quiet water conditions in an area seaward from the zone of maximum deposition of terrigenous clastics.

The limestone nodules that occur commonly interbedded in red or green shales are, at the most, three inches in diameter and are sublithographic in texture. The lack of organic structures in the limestone nodules is striking, and an inorganic accumulation of these nodules in very shallow water marine conditions is inferred. Locally, these nodules are dolomitic, which supports the interpretation of an inorganic origin in a shallow water environment, as will be pointed out in the section on dolomitic limestones.

Massive Limestone

Many of the laterally persistent limestone strata that extend as much as seven miles in the Holder and Laborcita formations are either obscurely bedded, or occur in beds over one foot in thickness. These are largely detrital limestones that consist of bioclastic debris occurring in a very fine-grained matrix. The coarser particles range from 1/10-4/10 mm. The limestone appears to be formed dominantly by fragments of algae, which are no longer identifiable. Fragments of the hard parts of other, largely benthonic marine invertebrates are present in very small quantities. The average clay content of these fragmental limestones is about four percent, based on an insoluble residue determination of six typical samples. The massive, obscurely bedded limestones probably represent a seaward extension of the nodular limestones. This is suggested by the lateral transition of the nodular limestones (Figure 9) into massive limestones in a direction away from the inferred shore-line. The slightly smaller particle size of the massive limestones as compared to the nodular limestones might indicate a source of at least some of the detrital fragments from more near-shore areas. The low clay content indicates a reduced influx of fine terrigenous clastics in the zone of deposition of the massive limestones.

The massive reef limestone lenses that are about 35 feet thick and occur in the area northeast of Tularosa were formed by cement-binding and framework-building encrusting algae. They can be considered accretionary limestones as opposed to the massive obscurely bedded limestones of the detrital type. These reefs were probably formed under turbulent water conditions as is suggested by their low clay content, and were probably wave-resistant structures.

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, Figure 9), which appear to form a shoreward extension of the massive limestones. The author believes that McKee's explanation of the formation of the "rusty brown dolomites" in the Cambrian of the Grand Canyon region is applicable to these dolomitic limestones of the Sacramento Mountains. McKee (1945, p. 62) states that as a result of a marine transgression, the zone of clastic deposition shifts more toward the source area. Meanwhile, 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 clastic and pure-lime deposition. The near-shore position suggests more shallow water conditions. This might result in relatively high water temperatures, increased evaporation and salinity and carbonate precipitation, which is probably what McKee meant when he stated "that this facies is controlled by waters of fairly high concentration."

Gray and Green Mudstone

Gray and green mudstones are the dominant rock type in the Laborcita formation north of La Luz Canyon, as may be noted on Plate 4. In most places, these mudstones are distinctly calcareous and are commonly the shoreward transitions of marine limestones (Figure 9). They locally contain abundant fossils such as brachiopods, molluscs and calcareous algae, of types usually found in shallow marine water, and, therefore, these gray and green mudstones are interpreted as shallow water marine deposits. During periods of relative tectonic stability permitting deep weathering in the source areas to the northeast, east and southeast, the stream detritus will consist largely of fine terrigenous clastics. Much of this was probably 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 are interpreted as 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 (Plate 4). The red coloring in the sandstones and conglomerates is largely due to the red clays from the mudstone. This contrasts with some of the arkoses in the overlying Abo formation which locally receive their red coloring from pink orthoclase. Thin-section study of a few of the more common dark red mudstones showed that the coloring is entirely caused by the particles of clay size. The quartz fragments, although present in substantial amounts, do not affect the coloring of the rock, and no pink feldspar is present.

From various lines of evidence which are enumerated below, the author believes that the red beds are largely terrestrial deposits and that the red coloring is a result of the weathering conditions that prevailed in the source areas. Furthermore, the author believes that under terrestrial deposition the red color of the sediments will be preserved.

(1) The area east, southeast and probably to the northeast of the map area represents an area of active erosion during much of Laborcita time. Considering the Laborcita formation as a whole, the red bed facies appears to be the time-equivalent of a facies known to be marine and occurs between an area actively undergoing erosion and one of marine deposition.

(2) Certain individual marker beds grade from marine limestones or green or gray shales toward the east and southeast into red mudstones (Figure 9). 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 cross-bedding and lateral discontinuity of the beds are suggestive of fluvial deposition; the coarse-grained deposits in stream channels and the fine 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 environments, whereas oxidizing conditions required for deposition of red beds are prevalent in a subaerial environment.

Although these criteria are suggestive for the largely non-marine environment of deposition of the red shales in the map area, they fail to explain the origin of the red coloring. As the author made no detailed study of the nature and origin of the red color, some of the better known views which appear to agree with the relationships in the Sacramento Mountains are briefly summarized below.

Van Houten (1948, p. 2116) pointed out that a sufficiently warm and humid climate in the source area will produce a red soil that will be the source of the coloring matter and of much of the clastic material in the 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 bedded in red shales, and red shales containing abundant fusulinids might be explained by deposition in the littoral zone of marine waters with repeated emergence and flooding of the area, possibly associated with conditions of rapid burial. These occurrences also support the conclusion that the red color of fine sediments is caused in the source area. The subsequent loss of the red color in marine sediments is probably a diagenetic process that takes place after burial, where 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 the lithofacies of marker bed 37 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 and are illustrated on the diagram of Figure 9. These gradual changes appear to represent a gradual transition from deeper marine environments toward littoral or terrestrial environments.

Gradual changes in faunal content have been observed to correspond to the lateral lithologic sequences. This is clearly demonstrated 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 leaf-like algae.

This gradual faunal change is interpreted to be controlled largely by the depth of the marine waters, although many other factors such as temperature, water turbulence, salinity and turbidity may bring about certain changes. Similar faunal changes were observed by Elias (1937) in the Big Blue sediments of Permian age in Kansas. Elias infers a depth of 160 to 180 feet for the fusulinids, 90 to 160 feet for the calcareous brachiopods and between 75 and 110 feet for the calcareous algae. Although these figures are probably not applicable in absolute terms to the various fossil groups of the Laborcita formation, the author believes that the faunal content is certainly a key in establishing the relative depths of the various lithofacies. Therefore, the gradual transition of the lithofacies in any single 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 shore line.

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, that appear to be such large contributors to the obscurely bedded massive limestones, require sunlight for their photosynthesis. Kuenen (1950, p. 8) states that the depth of penetration of sunlight is a "few dozen meters", and Sverdrup (1942, p. 774) gives a figure of 80 meters or more, which is generally considered a maximum. Extrapolation of Elias' maximum depth figures for the various faunal zones and postulating a gradual increase in depth in a direction away from the shore line, would indicate an approximate depth of 200 feet for the zone of deposition of the massive limestones. Although the author believes that this figure is definitely a high estimate of the depth of deposition of the massive limestones, it still would be well within the limits of the depth of the euphotic zone.

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

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 on Plate 4. Pray (1952, p. 213) previously noted evidence of cyclic sequences in the Holder formation of the Sacramento Mountains.

Following the usage of Wanless and Weller (1932, p. 1003), the cyclic pattern is referred to as a cyclothem. Although the cyclothems of the Laborcita formation appear to be less perfectly developed than those of the underlying Holder formation and most sequences are probably incomplete, a complete or ideal cyclothem that is typical of the cyclic deposition of the Laborcita formation can be determined. Two types are most common and are indicated on Figure 10.

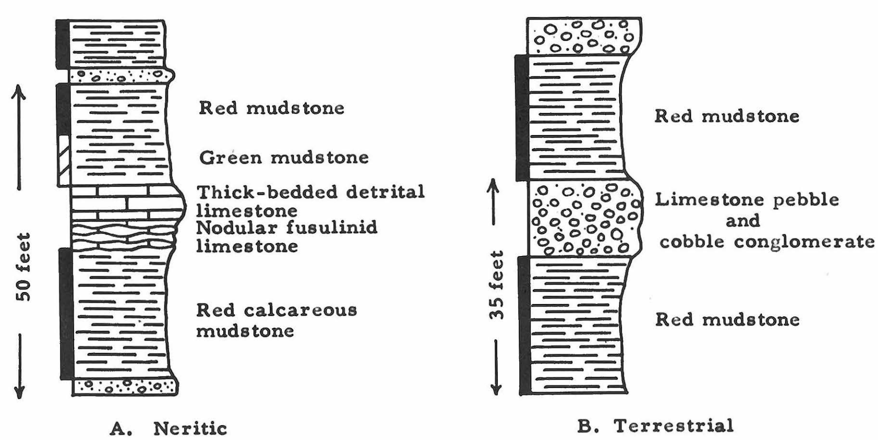

Figure 10. Cyclothems of the Laborcita formation.

The neritic cyclothem (Figure 10A) 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 gradually overlain by obscurely bedded fragmental limestone. A red or green shale will directly overlie this limestone, which 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, that might indicate a slight break of possibly diastemic nature, is commonly absent. In a few places, intraformational limestone conglomerates occur at the top of the obscurely or thick-bedded limestones. In other places, however, the entire massive limestone unit will be missing and the nodular limestones grade upward directly into red or gray shales.

It is significant that the vertical succession from sandstone to obscurely bedded limestone in each cycle is essentially the same as the succession in the lateral rock sequences. In a few places, such as marker bed 37 on Figure 9, it can be clearly demonstrated that a nodular limestone grades both laterally and upward into a thick-bedded limestone, which, on the basis of the previous discussion, indicates increasing depth of the marine waters during the deposition. Therefore, each cycle appears to represent essentially one complete marine transgression and regression. If the depth of deposition for the massive limestone is inferred at 200 feet, and if the basal thin sandstone and the red mudstone is terrestrial in origin, sea level must have fluctuated at least 200 feet during one complete cycle. A cyclothem of this type, with a dominance of marine conditions, is classed as deltaic or neritic (Wanless and Shepard, 1936). A similar sequence was reported by Wanless (1947, Figure 4, Column 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 author believes that the thin sandstone or conglomerate in the cyclothems of the Laborcita formation might represent slight diastemic breaks.

The interbedded limestone conglomerates and red shales (Figure 10 B), that occur in the southeasternmost part of the map area, are interpreted as terrestrial cyclothems (Wanless and Shepard, 1936). Each sequence averages a thickness of about 35 feet. 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 more toward the source area and as a result deposition of fine terrigenous clastics was at a minimum in the map area. The repeated fluctuations in sea level might be related to the general instability of the area, and might indicate the episodic nature of the deformation that occurred contemporaneously with the deposition of the Laborcita formation in the areas to the east and southeast. In this manner the terrestrial cyclothems in the direction of the source area might be explained by recurrent uplifts of the source area. The initial period of rapid erosion in the source area and rapid burial of the limestone conglomerates in the adjacent piedmont areas is followed each time by a period of relative stability and deep weathering in the source areas. During these relatively stable periods, the thick red shale sequences are deposited on a broad surface of low relief and low gradient, such as an alluvial plain, and maximum deposition of fine terrigenous clastics occurred in the adjacent marine basins.

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 and fine clastics, are generally active simultaneously. Therefore, 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 might be explained by relatively short periods of great carrying capacity of the streams.

Depositional History

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

First Phase

The first phase concerns deposition of the lower two-thirds of the Laborcita formation, that is, the portion between the basal contact and horizon 39 (Plate 4). For this part of the section, a gradation from non-marine conditions in the southeast and east to marine conditions toward the northwest and west is indicated. Red beds in the area south of La Luz Canyon grade into marine limestones and shales in the area between La Luz and Domingo Canyons. Locally, lagoonal or fresh water conditions might have existed, as is indicated by the occurrence of abundant plant fossils and coaly layers in certain shale zones. The section in the vicinity of La Luz Canyon is relatively rich in non-red sandstones and conglomerates, which might indicate deltaic conditions locally. In the area 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. A significant increase in the amount of non-red sandstones in this area is evident as compared to areas to the south. These changes are suggestive of a transition from Domingo Canyon northward into near-shore marine or lagoonal environments. Possible evaporative conditions are indicated by minor amounts of gypsum.

During the first phase, the basin of marine deposition probably extended west of the presently exposed part of the Laborcita formation. Terrestrial conditions of deposition for the area north of Domingo Canyon are inferred 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.

Second Phase

The second phase includes roughly the strata between horizons 39 and 49 on Plate 4. This interval consists of about 100 feet of red beds throughout the entire exposed part of the Laborcita formation. It is interpreted as a prolonged period of low emergence for that area. Deposition probably occurred on a broad alluvial plain with possibly deltaic conditions for the area north of Domingo Canyon, where red and green, coarse, cross-bedded arkoses are present in the section.

Third Phase

The interbedded marine limestones and non-marine red beds that occur between horizons 49 and 55 in the area north of Domingo Canyon, are included in the third phase. This section, which is 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 was repeatedly flooded by marine waters from the west.

Source Areas

The source of most of the clastic sediments must have been in the southeast, east and northeast. This land area is considered to be a part of the Pedernal Landmass. An increase in the amount and size of the coarse clastics toward the southeast and east indicate a source in that direction. The conglomerates in the Upper La Luz Canyon area grade westward into sandstones, shales and limestones in the section near the junction of La Luz and Fresnal Canyons. Within a distance of about three miles, the section increases in thickness from about 60 feet to about 550 feet (HH', Plate 3). This marked wedging is partly caused by post-Laborcita and pre-Abo erosion. Nonetheless, it reflects the presence of a positive area in the east with deposition toward the west. Continued erosion in late Laborcita time must have exposed large areas of pre-Cambrian quartzite in the source area, as abundant quartzite cobbles and pebbles occur in the upper part of the Laborcita formation.

The feldspar content of the subgraywackes, arkoses and feldspathic sandstones in the section north of Domingo Canyon is in marked contrast with the relatively pure quartz sandstones in the area to the south. The conglomerates in the section of the Laborcita formation north of Domingo Canyon are characterized by their content of about 30 percent of pink feldspar porphyry, which does not occur in the conglomerates farther south. Therefore, the difference in feldspar content of the coarse clastics of these two areas is largely attributed to differences in composition of the source areas from which these sediments were derived, and the area north of Domingo Canyon probably received its detritus from a feldspar-bearing source to the east or northeast.

Contact Relationships

Everywhere within the area of investigation the Laborcita formation is in contact with the underlying Holder formation. Near the junction of La Luz and Fresnal Canyon, the contact has been selected at the base of a four foot thick conglomerate layer, bed 5, which overlies directly Thompson's type section of the "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 with respect to the overlying strata and represents the best mappable contact. It occurs above inter-bedded nodular fusulinid limestones and red shales and below plant-bearing dark carbonaceous shales and limestone. The conglomerate marks essentially a change from marine to brackish water conditions. According to Dr. Cline, of the University of Wisconsin, southeast of section 11, in a distance of about 2-1/2 miles, about 100 feet of the uppermost part of the Holder formation appear to be gradually cut out by a horizon that approximately coincides with the base of conglomerate bed 5*. The contact is therefore a very slight angular unconformity in the Fresnal Canyon area.

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, nor was any evidence of an erosional discontinuity observed beyond this point. From this point northward, the base of the Laborcita formation is traced as a phantom horizon, at a position about 30 feet stratigraphically above the persistent limestone

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*Oral communication by L. C. Pray.

bed 4. The lithologic character of the strata on either side of horizon 5 is very similar in this area and no recognizable break exists in the succession of strata. Therefore, the contact is considered gradational and deposition appears to have been essentially continuous in the area north of La Luz Canyon.

The 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 area. The abrupt wedging of several beds in the Laborcita formation (Plate 9, sections 1 and 2) is partly caused by an onlap of these strata on a pre-existing anticlinal structure in the Holder formation, as is indicated on Plate 3, sections MM' and NN'.

Further evidence of a period of post-Holder and pre-Laborcita folding and faulting exists in Salada Canyon, about one mile north of State Highway 83. Faults in this area are a part of the northward extension of the Fresnal Canyon fault zone in the southeasternmost part of the map area (Plate 2). Directly west of this major fault zone, in the vicinity of Salada Canyon, the red conglomerates and shales of the Laborcita formation are essentially parallel with limestones of the Holder formation (LL', Plate 3). The occurrence of ventricose Triticites in the limestones indicates a late Fresnal age for these beds. 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* as middle Fresnal, on the basis of fusulinids. Thus, 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 are missing.

In the Upper La Luz Canyon area, three 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 30 degrees.

The localities of known angular discordance between the Holder and Laborcita formations all occur east of a line that trends northward from State Highway 83 near the Fresnal Canyon fault zone (Plate 2), and therefore, similar structural discordances are inferred in the subsurface in the area due north of the Upper La Luz Canyon area, as is indicated on Plate 3.

The lower contact of the Laborcita formation is thus an unusual example of an abrupt disappearance of an angular unconformity. The lower contact of the Laborcita formation, that appears to be gradational in the area northwest of La Luz Canyon, gradually becomes a disconformity and marked angular unconformity toward the southeast and east, within a lateral distance of three 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 Bursum formation was selected at the base of marker bed 29, which is a relatively persistent conglomerate bed. The lower contact of this bed was considered by Pray

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*Personal communication.

(1952, p. 251) to be a slight angular unconformity. This conclusion was based largely on the following:

1. Apparent continuity of this horizon with the quartzite cobble conglomerate that clearly forms the basal part of the Abo formation in the High Rolls area in the southeastern part of the map area, where it is unconformable on the underlying Pennsylvanian strata.
2. Local erosional features at the base of this unit.
3. The increase of the quartzite content in cobbles of the conglomerate as compared with conglomerates of the underlying section.

Detailed tracing of bed 29 toward the southeast revealed that it grades into a quartz sandstone 1-3/4 miles southeast of La Luz Canyon. The quartzite cobble conglomerate of the basal Abo near the High Rolls area corresponds approximately to conglomerate bed 49, that occurs stratigraphically in a position about 200 feet above bed 29. Furthermore, conglomerate bed 29 lenses out about half a mile north of Cottonwood Canyon, and north of this point, neither features indicating channeling, nor lenticular bodies of coarse clastic sediments occur at the stratigraphic position of horizon 29. The apparent change in environment of deposition which was thought to be marked by the conglomerate bed southeast of La Luz Canyon is not recognizable in the vicinity of Cottonwood Canyon, where fusulinid-bearing shales and limestones overlie the conglomerate. On the basis of this evidence, the upper contact of the Laborcita formation is selected at the base of bed 49 in the area south of Domingo Canyon, where it is considered a disconformity, and the 200 feet of strata that occur between the top of Pray's Bursum formation and the base of bed 49 are included in the Laborcita formation.

North of Domingo Canyon, where the Laborcita and Abo formations interfinger, the contact becomes gradational and is selected successively at the base of bed 53 and the top of bed 55 (Plate 4). Thus this contact, which is discussed in more detail under the Abo formation, is also an excellent example of a major unconformity that dies out within a relatively short lateral distance.

Fauna, Flora and Age

The primary emphasis of the work in the map area has been field tracing of individual horizons, in the course of which the precise stratigraphic position of some previously known fossil localities has been determined and other localities have been discovered and collected. The collections contain a wide variety of marine fossil types such as fusulinids, brachiopods, cephalopods, gastropods and pelecypods. In addition, one locality yielded abundant plant fossils. It is of paleontologic significance that in this area the age-assignments of these different fossil groups can be compared once the relative stratigraphic position of the various collecting localities is determined. It is largely for this reason that the study of these groups has been turned over to specialists in each of the four major fossil groups. The results of these studies indicate a definite conflict in age-assignments of correlative parts of the Laborcita formation. This is significant in view of similar conflicts in other parts of the United States, especially in West Texas, where the lateral continuity of strata is more difficult to determine. The detailed results and conclusions of the various specialists are given in Appendix I of this report.

The fusulinids, commonly used for the purpose of regional correlation, occur more abundantly through the Holder and Laborcita formations than any other group. For this reason, the author used the age-assignments of the fusulinids as a basis for correlation of the various formations, and for the determination of the Pennsylvanian-Permian boundary in the map area.

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 which have been indicated on section 18. Thompson* considers the fusulinids of sample 18-F-4 to be Virgilian in age. Schwagerina sp. of early Wolfcampian age occur in 18-F-5, about 29 feet higher in the section, and sample 18-F-6, another 34 feet stratigraphically higher in the section, contains a Dunbarinella sp. which is found in the Texas Wolfcampian and is definitely Permian in age. On the basis of this information, the base of the Permian is selected at the base of the limestone ledge 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 are therefore late Virgilian in age, and correspond to about 60 feet of strata in the section that overlies Thompson's type section of the Fresnal group.

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* Personal communication.

This position of the base of the Permian System 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, of the Shell Oil Company, 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*. In the vicinity of Fresnal Canyon horizon 9, which is taken as the base of the Permian, coincides approximately with the top of the carbonaceous limestone that has been mapped as bed 8.

The age of the middle portion of the Laborcita formation is definitely lower Wolfcampian. In section 11, sample 11-F-2 indicates the zone from which the Wolfcampian fusulinids were derived that are reported by Thompson (1942, p. 82) and Bowsher (King et al., 1949, p. 61).

The fusulinids collected in the area north of Tularosa aided in determining an upper age limit for the beds of the Laborcita formation. Collection 30-F-1 (section 30), that was found on the flank of an algal reef, occurs about 800 feet stratigraphically above the base of the Laborcita formation and contains Wolfcampian Schwagerina and Dunbarinella species. According to Thompson*, these forms should be correlated above the top of the type section of the Bursum formation, but they appear to be older than the fusulinids that occur

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*Personal communication.

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 stratigraphically above the base, is, according to Thompson*, 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. huecoensis, 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 represents the middle and upper part of the Wolfcampian Series, which suggests that the uppermost part of the Laborcita formation in the northern part of the map area is possibly 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.

Cooper studied the brachiopods and considers them Permian rather than Pennsylvanian in age*. His conclusions are largely based on a group study of the brachiopods that were 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

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*Personal communication.

M-3, 11-M-1, 13-M-1 and 30-M-3, which are in a position at least 250 feet stratigraphically above the base of the Laborcita formation, or about 160 feet above the base of the Permian, which was located on the basis of fusulinids.

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

Fossil plants collected by C. B. Read east of Alamogordo in the upper unit of the Magdalena group (Read in King, 1942, p. 676), were probably 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 is selected on the basis of fusulinids 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 therefore this conflicting age-assignment is not considered too significant.

Correlation and Regional Relationships

Rock units of early Wolfcampian age have been recognized

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*Personal communication.

in surface outcrops and in the subsurface in many parts of New Mexico. In central New Mexico, thin marine limestones occur interbedded with coarse conglomerates and red sandstones. This unit received the name 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 stratigraphically 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. The upper part of the Laborcita formation is younger than any Bursum beds in the state, as was shown in the previous section. The Bursum formation therefore corresponds to the middle portion of the Laborcita formation. This conclusion is supported by the absence of uppermost Virgilian strata in areas of central New Mexico and the presence of conglomerates of reworked Pennsylvanian limestone at the base of the Bursum formation.

In the Oscura Mountains where massive basal Permian fusulinid-bearing limestones overlie unconformably red beds of an early 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, Plate II) recognized a few 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, p. 68) considers of slightly younger age than earliest Wolfcampian, are probably the same limestones as indicated on 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). On Plate 13 in this report, 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. The uppermost 200 feet of the Laborcita formation in the area north of Tularosa might be the time equivalents of the Powwow conglomerate. In this report the Laborcita formation is considered to be early Wolfcampian in age.

In many places of central and southern New Mexico, the Pennsylvanian-Permian boundary is marked by either a regional disconformity or an angular discordance, as in the central and southern Sacramento Mountains and areas to the southeast. The absence of uppermost Virgilian and lowermost Wolfcampian strata indicates a period of erosion or non-deposition and wide retreat of the ocean. In a few places, such as in the area 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 (Bursum) a transgression of the sea covered many parts of central and southern New Mexico, which was followed by a period of non-deposition or formation of Abo red beds. The early Wolfcampian sea persisted in the area of the northern Sacramento Mountains and apparently retreated toward the west (Plates 3 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.

The deposition of the Hueco limestone marks a new invasion of the Wolfcampian sea, which, however, did not extend into south central and central New Mexico, where Abo type deposition continued. This tongue of the Hueco limestone is discussed in more detail 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."

It appears that the Pedernal Landmass and ancestral Sacramento Mountains 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 in color, 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 in 1943 (Needham and Bates, 1943, p. 1654). The type section of the Abo formation is located 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 regarded 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 earliest Permian in the area of the type locality to pre-Cambrian 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 in Bates et al (1947, pp. 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. However, petrified wood is locally abundant, and the beds are considered to be terrestrial in origin. Because of the distinctive coloring and similar stratigraphic position, the beds have been correlated with the Abo formation of central New Mexico.

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, Plate 18). North of Tularosa, the Abo formation has a thickness of 1400 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, its thickness increases. The Abo and overlying Yeso formations appear to be essentially parallel in the Sacramento Mountains. According to Pray (1952, Plate 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 on Plate 13 of this report.

Areal Distribution

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

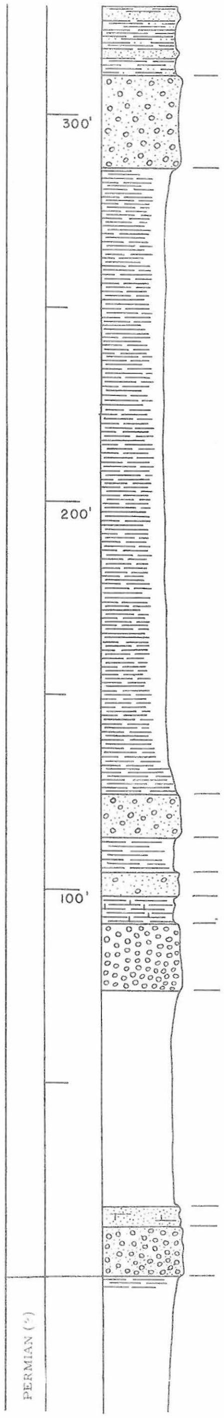
Southward from High Rolls, the outcrops of the Abo formation form a narrow band a quarter of a mile wide, according to Pray (1952, p. 235). Between High Rolls and Laborcita Canyon, in the southern part of the map area, the Abo formation underlies the eastern part of the area of investigation (Figure 4). Near Laborcita Canyon, the lower surface or bench is about three miles wide and gradually widens to about six miles in the vicinity of Tularosa, which is in part caused by the increase in thickness of the Abo formation toward the north. About five miles north of Tularosa, the Abo formation is completely covered by overlapping Quaternary gravel deposits and is no longer exposed.

Lithology

In the northern part of the Sacramento Mountains the Abo formation consists of a thick monotonous sequence of continental 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 ranges from 250 to 500 feet (Pray, 1952, Pl. 18) and thickens progressively both toward the south and the north. Generalized stratigraphic sections of the Abo formation along the length of the Sacramento escarpment are indicated on Plate 13. Measured sections 5, 6, 7 and 8 on this diagram demonstrate 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 map area can be subdivided roughly into four areas, which are, from south to north: the High Rolls area, the Upper La Luz Canyon area, the Cottonwood Canyon area and the area northeast of Tularosa. The stratigraphic sections of the last three areas have been shown in detail on Plates 10, 11 and 12, and the locations of measurement are indicated on the geologic map.

High Rolls Area

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

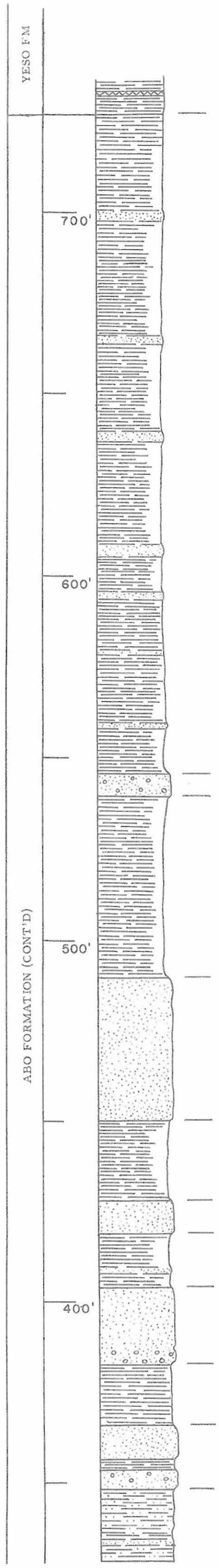


Overlying section measured towards NE from top of conglomerate at north side of road, 1300' east of point where intrusive dikes cross La Luz Canyon.

10	24'	Conglomerate; largely cobbles and boulders of quartzite; top 5' with rhyolite porphyry clasts and very coarse grained arkosic matrix.
9	161'	Poorly exposed; probably red mudstone.
8	11'	Conglomerate, quartzite cobbles and boulders.
7	9'	Poorly exposed; largely red mudstone.
6	6'	Sandstone, dark red, medium grained, cross-bedded; scattered chert pebbles.
5	7'	Mudstone, dark red, calcareous.
4	17'	Conglomerate; largely quartzite cobbles and chert pebbles.
3	56'	Covered; probably red mudstone.
2	5'	Sandstone, dark red, medium grained, calcareous.
1	13'	Conglomerate and sandstone; pebbles, largely chert, in lower 4' and quartzite at top.

Contact: The strata underlying the basal conglomerate of the Abo formation are poorly exposed. Some evidence exists for the presence of an angular unconformity between the Abo formation and the underlying beds that are considered to correlate with the beds of the Laborcita formation.

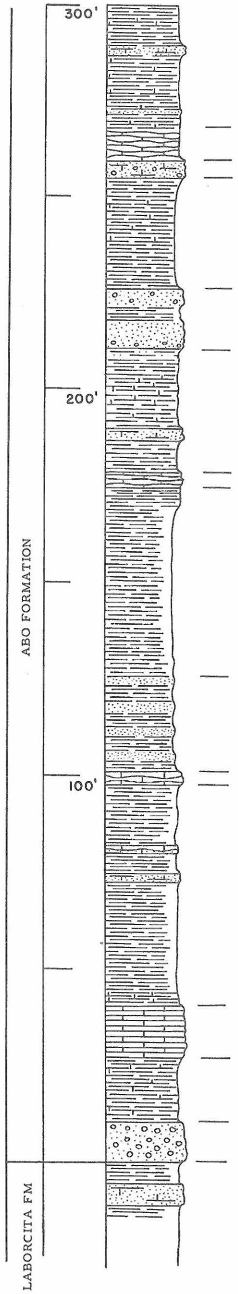
Base of Abo section near the center NE1/4NE1/4 sec. 27, T. 15 S., R. 11 E. La Luz Canyon. Section measured toward east at south side of canyon.



22		Mudstone, dark red and green with abundant gypsum.
21	182'	Poorly exposed; largely red mudstone with a few arkosic layers.
20	6'	Arkose, very dark red, very coarse grained; some pebbles.
19	50'	Poorly exposed; largely red mudstone.
18	40'	Arkose, very dark red, medium to coarse grained.
17	22'	Poorly exposed; largely red mudstone.
16	9'	Arkose, very dark red, very coarse grained.
15	15'	Poorly exposed; largely red mudstone.
14	21'	Arkose, dark red, coarse grained, pebbly at bottom.
13	17'	Mudstone, very dark red.
12	18'	Arkose, very dark red, medium to very coarse grained cross-bedded; 3' mudstone break.
11	38'	Siltstone, dusky red, with fine grained purple sandstone stringers.

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

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

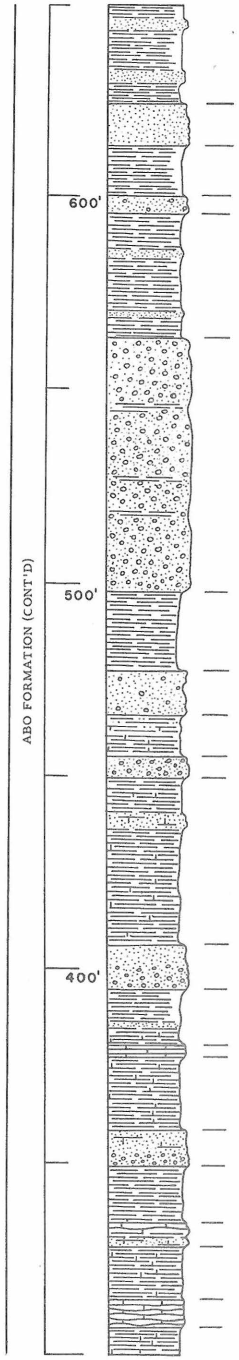


14	40'	Mudstone, dusky red, very calcareous; locally thin dark red medium grained sandstone layers.
13	10'	Limestone, brownish gray, nodular.
12	4'	Sandstone, quartz, dark red, coarse grained, calcareous; conglomeratic in places.
11	29'	Mudstone, dusky red, calcareous, with nodular limestone.
10	15'	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.

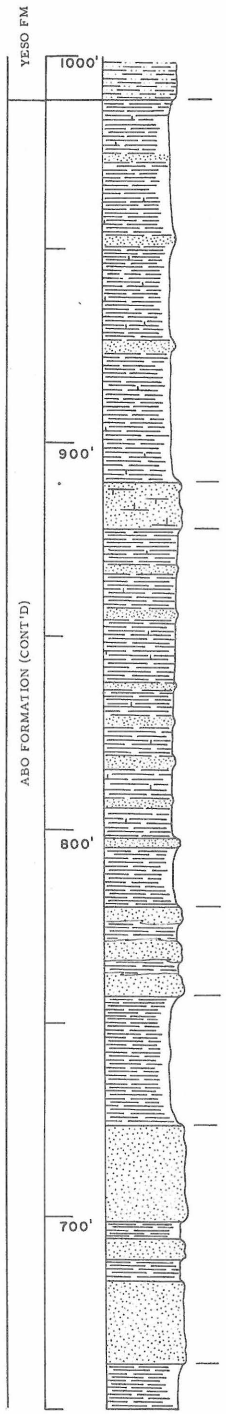
Contact: The base of a distinctive conglomerate bed is considered the base of the Abo formation. This predominantly quartzite pebble and cobble conglomerate layer has been recognized over a seven mile distance as key bed 49. No other lithologic distinctions exist between the underlying and overlying 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 SW1/4 SE1/4NE1/4 sec. 19, T. 15 S. R. 11 E. in canyon bottom just below horizon 49.



Section continued from the top of the column to the left

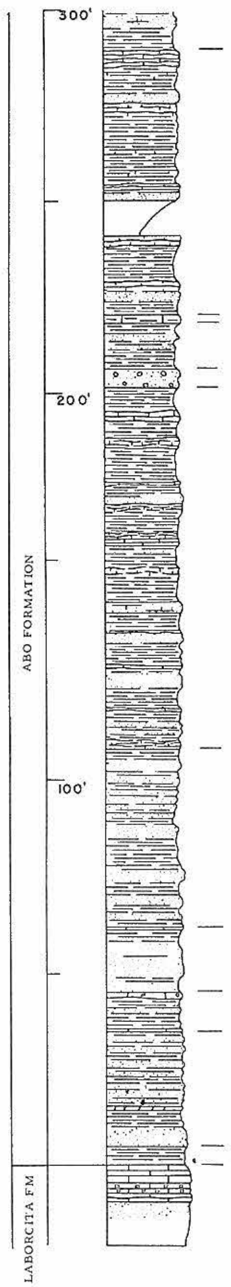
34	37'	Poorly exposed; largely red mudstone; interbedded with two medium to coarse grained, pale red, cross-bedded arkosic layers.
33	11'	Arkose, dark red, very coarse grained.
32	13'	Poorly exposed; probably red mudstone.
31	5'	Arkose, dusky red, very coarse grained with quartzite pebbles scattered 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 the top of the column to the 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 2000' north on east end of ridge starting with equivalent horizon.
35	62'	Arkose, dusky red and pale red, medium to coarse grained; strongly cross-bedded. Interbedded with poorly exposed red mudstone.

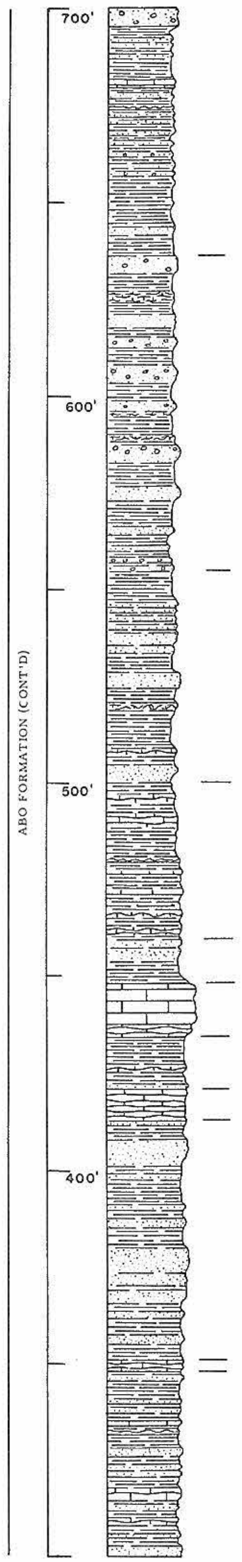
STRATIGRAPHIC SECTION OF THE ABO FORMATION NORTHEAST OF LA LUZ. (SECTION 36)



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, non-fossiliferous limestone.
2	30'	Arkose, dusky red, coarse grained, minor cross-bedding. Interbedded with dusky red mudstone (20%).
1	6'	Shale, light olive gray, non-calcareous. Plant leaf impressions.

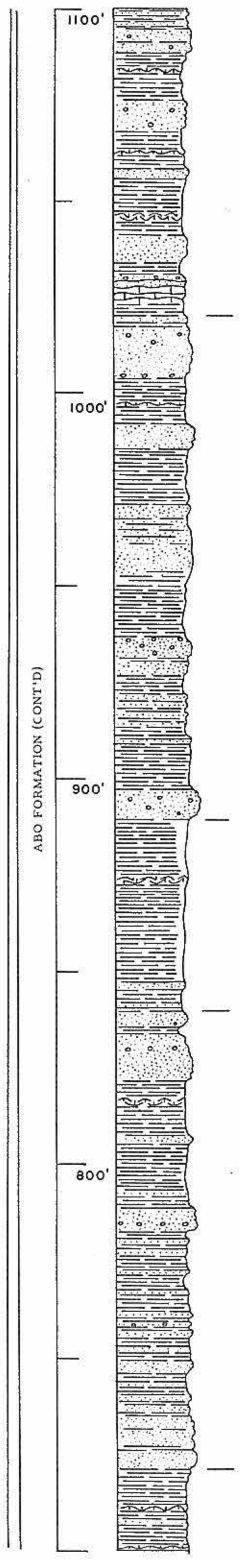
Contact: Gradational. The underlying limestone ledge contains fusulinids (Schwagerina and Dunbarinella) when traced to north and south and is considered to be the top of the Laborcita formation in the Sacramento Mountains.

Base of section is located in SW1/4NE1/4NE1/4 sec. 9, T. 14 S., R. 10 E. at top of horizon 55, approximately 2 1/2 miles north of the Tularosa Reservoir.



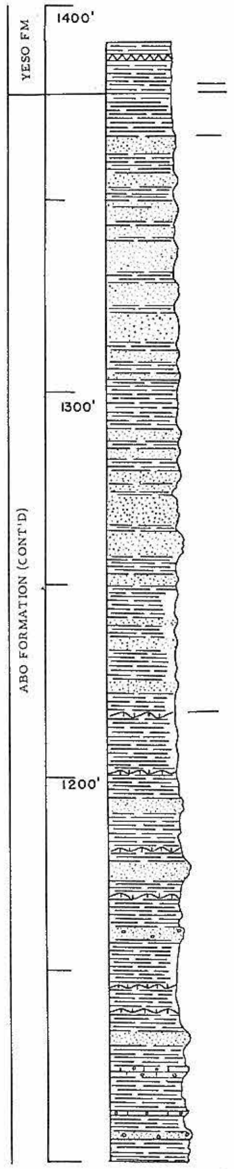
21	86'	Mudstone, dark reddish brown and very coarse dusky red arkose, locally conglomerate. Minor amounts of gray argillaceous nodular limestone.
20	83'	Conglomerate and very coarse arkose; pebbles and cobbles; 65% rhyolite porphyry and remainder quartzite. Interbedded with dusky red mudstone.
19	56'	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 non-fossiliferous. 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 and locally cross-bedded. Dusky red mudstone interbedded.
12	3'	Limestone, grayish red, argillaceous and sandy. Slightly nodular.
11	55'	Arkose, dusky red, cross-bedded. Interbedded with dark red mudstone and medium gray argillaceous limestone beds.

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

Section continued from the top of the column to the left

Measured by C. Otte and L. C. Pray

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

Horizon 50 occurs about 10 feet higher stratigraphically than the base of bed 49, which is also a quartzite cobble conglomerate and 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 located about 2-1/2 miles north of the High Rolls section. The base of the La Luz Canyon section, which is shown in detail on Plate 10, is near the center NE$\frac{1}{4}$NE$\frac{1}{4}$ 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, commonly lens out abruptly and show marked cross-bedding and scour-and-fill structures at the base. The part of the Abo formation shown on Figure 11, which corresponds to unit 11 on Plate 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 Abo section west of the area of Pennsylvanian outcrops in the upper part of La Luz Canyon. This was determined by detailed tracing of units 1 and 4 of Plate 10 from east to west in La Luz Canyon. The thicker western section contains thin argillaceous limestone layers and zones with limestone nodules, which are absent in the thinner eastern section.

Figure 11. Interbedded dark red mudstones and arkoses of the Abo formation. Note lenticularity of the units. Road cut on south side of La Luz Canyon, SE$\frac{1}{4}$NW$\frac{1}{4}$sec. 25, T. 15 S., R. 11 E.

Cottonwood Canyon Area

A stratigraphic section, that is almost 1,000 feet thick, was measured in Cottonwood Canyon northeast of La Luz, and is shown in detail on Plate 11. Two-thirds of the section is composed of 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 the dark red mudstones.

Near the middle of the section, a 66 foot thick zone of quartzite cobble conglomerate, that contains about 10 percent of feldspar porphyry in an arkosic matrix, forms a distinctive and resistant ledge. It is indicated as unit 29 on Plate 11 and is correlated with unit 10 on Plate 10. The base of this bed, that could not be mapped much north of Cottonwood Canyon, 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 arkoses and a scarcity of feldspathic sandstones and feldspar-bearing igneous rocks, such as granite and feldspar porphyry, in the conglomerates (Plates 10 and 11). The sandstones in this part of the section are commonly very calcareous quartz sandstones. In this Cottonwood Canyon section, the minor amounts of non-fossiliferous, grayish-red, very argillaceous limestone are restricted to the lower portion 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 1400 feet. Details of the Abo section measured here by L. C. Pray and the writer are shown on Plate 12. The uppermost 250 feet of the underlying Laborcita formation, above horizon 49, correspond to Abo beds in the southern part of the area (Plate 13). Between Cottonwood and Tularosa Canyons, a distance of about ten miles, the increase in thickness of the stratigraphic sections overlying bed 49 amounts therefore 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.

Discussion of Rock Types

Conglomerates

The conglomerates of the Abo formation are marked by the predominance of quartzite. In many places almost pure quartzite cobble conglomerates occur in the lower part of the Abo formation. Although quartzite pebbles and cobbles have been observed also 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 monolithologic 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 on Figure 12. Rhyolite porphyry pebbles occur in conglomerates and arkoses only in the upper portion of the Abo formation in the southern part of the map area. In the section measured north of Tularosa small amounts of rhyolite porphyry and granite pebbles are contained in the conglomerates throughout the entire Laborcita and Abo formations, indicating that the Abo formation of the southern and northern portions of the map area received at least some of its clastic material from different source areas.

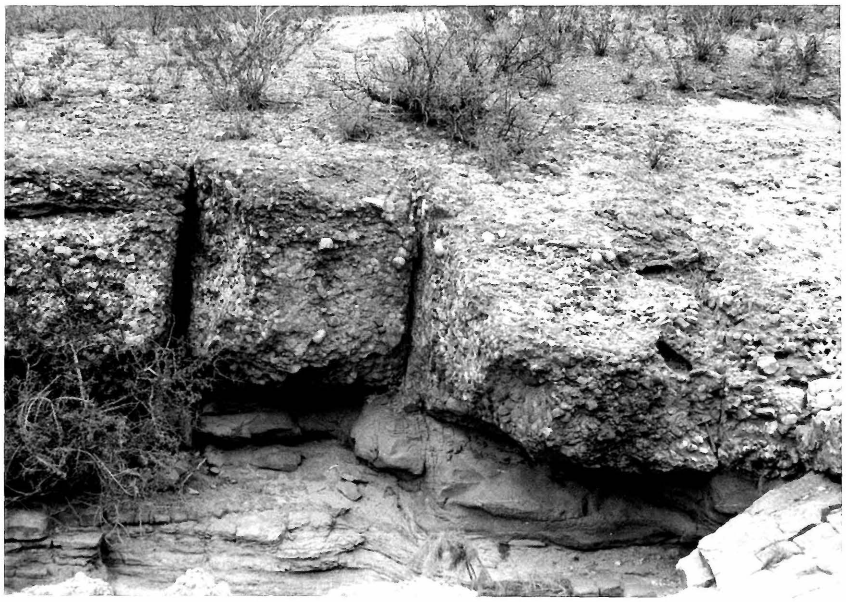


Figure 12. Basal Abo quartzite pebble and cobble conglomerate (bed 53) overlying greenish siltstones of the Laborcita formation one-quarter mile north of Domingo Canyon.

Arkoses and Sandstones

The arkoses are generally very coarse-grained, cross-bedded and of very short lateral extent. The feldspar locally forms more than half of the arkose and consists largely of pink orthoclase. The grains are angular to subangular and commonly are as much as 4 mm. in size. The arkoses have a calcareous matrix. Two modes of typical arkoses are listed below:

	Unit 19, Plate 13	Unit 21, Plate 13
Feldspar	40%	49%
Quartz	35%	40%
Calcite	15%	5%
Matrix, undiff.	10%	6%

Both fresh and weathered feldspars have been observed. The feldspar content of the arkoses appears to decrease with the grade size, and the finer grained rocks are generally composed of feldspathic or quartz sandstones. Study in thin section of a few Abo siltstones and arkoses indicated that the rock color is caused by the dark red clays of the matrix.

Mudstones

The dark red to dusky red mudstones form about two-thirds of the entire Abo formation. The total amounts appear to decrease toward the north. Although it is the dominant rock type, it is less conspicuous than any of the other rocks because of its non-resistant nature. In many places it is calcareous and becomes very silty.

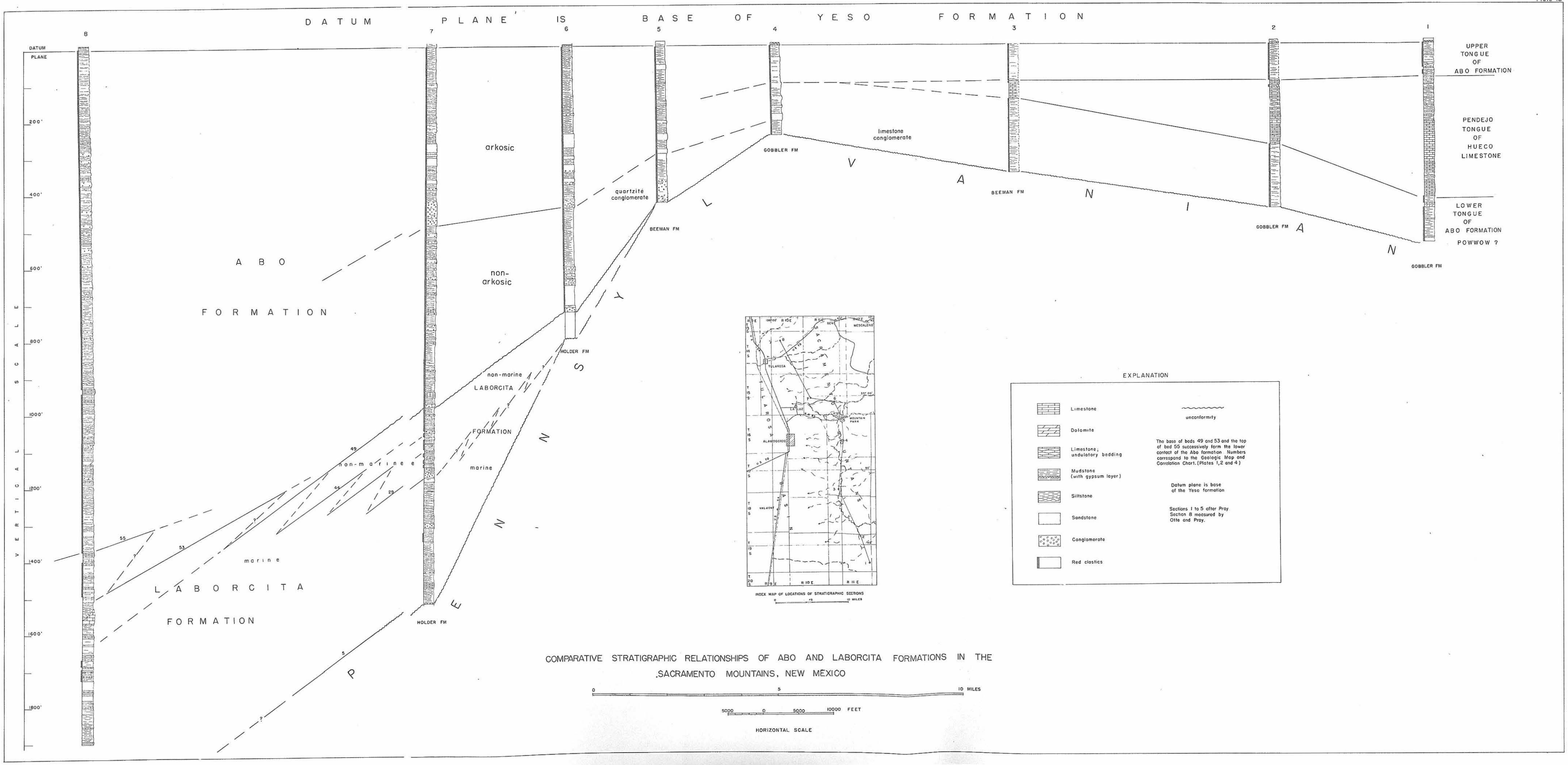
Limestones

Limestone beds or zones of limestone nodules are commonly restricted to the lower part of the Abo formation. More massive limestone ledges occur only in the Abo section that is exposed in the vicinity of Tularosa. The limestones that occur in the Abo formation are characterized by a high clay content as compared with the limestones of the underlying Laborcita formation. In one instance the insoluble residue of a 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 four percent of the Laborcita limestones. The reddish color of many of the limestones and limestone nodules is probably caused by the content of the red clays.

A few of the argillaceous limestone layers that occur 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 four miles. In thin section these limestones show remains of invertebrate shells, and therefore these limestones are probably deposited in a shallow water marine environment, although a fresh-water origin cannot be ruled out. The grayish-red, dense, argillaceous limestones with undulatory bedding and the nodular limestones are interpreted to be shoreward extensions of the thin-bedded argillaceous limestones. The lack of any organic structures in the limestone nodules that are, at the most, several inches in diameter, is striking, and an inorganic accumulation of these nodules appears to be reasonable. Locally, these nodules are dolomitic, which supports this interpretation.

Local Correlation

The considerable difference in thickness between the sections of the Abo formation in the central and northern part of the Sacramento Mountains is mainly caused by the addition of strata in the basal portion of the Abo formation toward the northwest, as is shown on Plate 13. The Abo formation that overlies with angular unconformity rocks of Pennsylvanian or older age south of High Rolls 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 (Plate 10) in La Luz Canyon and the uppermost 500 feet in section 36 (Plate 11) in Cottonwood Canyon. The twofold division of the Abo formation in this southern area is not as distinct in the Tularosa area, as the massive conglomerate



COMPARATIVE STRATIGRAPHIC RELATIONSHIPS OF ABO AND LABORCITA FORMATIONS IN THE SACRAMENTO MOUNTAINS, NEW MEXICO that marks the base of the upper member can be traced only for about a mile north of Cottonwood Canyon. Furthermore, arkoses occur through the Laborcita and entire Abo sections near Tularosa, and are not 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 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 (Plate 13).

The lower portion of the Abo formation in the northern Sacramento Mountains, 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 five miles to the south (Pray, 1952, Pl. 18). The unconformity at the base of this conglomerate dies out to the northwest and corresponds to the Laborcita formation. These stratigraphic relationships are shown on Plate 13. A great many diastemic breaks at the base or within coarse clastic units of the Abo formation undoubtedly occur in the southern part of the map area. Those local erosional breaks are probably time-equivalents of strata farther to the northwest; for example, conglomerate bed 53, which does not appear south of Domingo Canyon.

Conditions of Deposition

Environment

The Abo formation of the northernmost Sacramento Mountains was deposited largely under continental conditions. Abundant petrified wood, lack of marine fossils, discontinuous nature of the beds, evidence of channel fillings and cross-bedding and the dark red color are all factors to suggest the terrestrial origin of most of the Abo beds.

Laterally extensive pebble and cobble quartzite conglomerates are largely restricted to the Abo formation in the area south of Tularosa Canyon. Particularly noteworthy are the beds that define 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 coarse nature of most of the conglomerates indicates that they were deposited on a surface of appreciable gradient, not far from an area undergoing active erosion. However, the relatively great lateral extent of as much as eight miles of some of these beds suggests deposition near the broad base of an alluvial fan, which in general had a relatively more gentle gradient. This sheet nature of the conglomerates might be explained also by a number of coalescing fans, forming a continuous apron of waste in the piedmont area.

The markedly cross-bedded, discontinuous, coarse sandstones and arkoses characterize an alluvial plain environment, and are probably the channel deposits of continuously shifting streams. Thin, very lenticular conglomerate beds are commonly associated with these deposits. The dark red mudstones and siltstones probably indicate fluvial deposition on broad flood plains. Under such conditions, the prevailing oxidizing conditions in the piedmont and alluvial plain environments will tend to preserve the red color of the source area detritus. The formation of red beds was given in more detail in the Laborcita formation. Raindrop impressions and mudcracks are notably lacking among the sedimentary features of the Abo formation in the northern Sacramento Mountains. This might be attributed to the absence of the type of sediments, such as fine sands, in which these features commonly occur, and appear to be better preserved.

Depositional History

The lower part of the Abo formation in the map area was largely deposited northwest and west of the present central part of the Sacramento Mountains, as that part of the Abo section thickens markedly, grades into finer grained sediments and contains more limestones in those directions. The presence of limestone beds and zones of limestone nodules in the western and northern part of the map area probably suggests an environment of broad alluvial plains, with 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 Abo section in the northern Sacramento Mountains do not extend much south of the High Rolls area, and a pre-Cambrian source area toward the east 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, as indicated by the abundant presence of feldspar in that section as compared to the Abo section in the south. Both areas of provenance might be considered to form parts of the Pedernal Landmass which locally must have formed mountains of considerable height.

The upper part of the Abo formation in the northern Sacramento Mountains, that has been correlated with the Abo formation in the central part of the escarpment, appears to be of relatively uniform thickness. It 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, ill-sorted arkoses, in association with conglomerate lenses with much granitic or rhyolite porphyry debris, are the products of violent erosion of the pre-Cambrian source areas and accumulation of the detritus as stream channel deposits in piedmont and alluvial plain environments. Conditions of rapid burial probably prevailed for these coarse sediments.

The thick sequences of red mudstones interbedded with coarse irregular bodies of arkose probably indicate recurrent uplift in the source areas and periods of deep weathering and soil formation alternating with periods of rapid erosion. Pray (1952) showed that the deposition of the Abo formation in the central part of the Sacramento Mountains was in part contemporaneous with the later stages of folding, which is direct 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 non-erosional interval in a distance of 10 miles.

In most of the Sacramento Mountain 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 Sacramento 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 in the vicinity of Salada Canyon in sec. 34, T. 15 S., R. 11 E., where folding and normal faulting preceded the deposition of the Abo beds (Plate 3). Evidence indicates that the pre-Abo erosion surface was a surface of low relief in the Sacramento Mountains. (Pray, 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 by the base of the coarse quartzite cobble conglomerate beds 50 and 49, respectively. Where these beds form the contact, it is considered a disconformity. The non-marine 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 these beds on the basis of this disconformity and the marked increase of quartzite content of the conglomerates.

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

The Abo formation above the unconformity is younger than bed 49 (Plate 13), and is of late early Wolfcampian age on the basis of fusulinids in this zone in the area north of Tularosa. Inasmuch as upper Virgilian strata are locally present below the unconformity, e.g. just north of Salada Canyon NE$\frac{1}{4}$ sec. 34, T. 15 S, R. 11 E, the major period of deformation in the Sacramento Mountain area must have taken place between late Virgilian and late early Wolfcampian time. That interval coincides with the deposition of the Laborcita formation in the northern Sacramento Mountains where the Abo formation is essentially parallel with the underlying beds.

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

Fauna and Flora

According to Pray (1952, p. 252) gastropods have been observed in the Pendejo tongue of the Hueco limestone in the Sacramento

Mountains (Plate 13), but these have not been studied in detail. The more continuous and massive limestone ledges in the Abo section near Tularosa contain unidentifiable fragments of invertebrate fossils. They appear to be remains of pelecypods and gastropods, but are undiagnostic for either marine or fresh water origin. The invertebrate fossils from previously known fossil localities in "questionable" Abo strata in the Sacramento Mountains are now all included in the Laborcita formation.

No vertebrate remains have been 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, Plate 18) has very clearly demonstrated that the Abo formation in the central part of the Sacramento Mountains is directly equivalent to much of the Hueco limestone of western Texas. The threefold division of the Abo formation in the central and southern part of the escarpment can be directly correlated with the Hueco limestone as it is currently defined (King and Knight, 1945). The lower tongue of the Abo formation grades into the Powwow conglomerate; the Pendejo tongue of the Abo formation 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. Thus, the age of the Abo formation will largely be dependent upon the age determination of the Hueco limestone.

King and Knight (1945)* assigned a Wolfcampian age to most of the Hueco limestone, with a possibly Leonardian age for some of the upper part. The direct correlation of the Hueco limestone with the type Wolfcampian Series in the Glass Mountains is made difficult by the dissimilarities in lithologies and associated faunas. The Wolfcampian at the type locality is predominantly composed of shale, with interbedded limestones and sandstones, a lithology almost identical to the Laborcita formation. The fusulinids and ammonoids in the Hueco limestone and the Wolfcampian in the Glass Mountains are closely similar, but pelecypods, gastropods and possibly brachiopods appear to be very different. The lowest of the three divisions of the Hueco limestone contains a fusulinid assemblage that shows the strongest affinities to the type Wolfcampian. Very few fusulinids have been collected from the middle division of the Hueco limestone. Some collections consist of Wolfcampian species, others are Leonardian. The brachiopods that have been described from the middle and upper divisions of the Hueco limestone include some species that occur in the type Wolfcampian, but also many that occur in the Leonardian of the Glass Mountains. However, the exact relationships between the Wolfcampian and Leonardian Series at the type section are somewhat in doubt, as has recently been suggested by others, which might contribute to the difficulty in correlation.

According to Lloyd (1949, p. 31), the limestones above the Powwow conglomerate, which is the limestone of the lower division, do not contain the lowermost Wolfcampian fusulinids. He considers

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*Following paragraph largely summarized from King and Knight (1945).

the Hueco limestone to be late Wolfcampian, or possibly middle and late Wolfcampian. On the basis of the stratigraphic information gathered in the Sacramento Mountains, the fusulinid identifications by Thompson and the data from King and Knight (1945), the author considers the Laborcita formation to be of early Wolfcampian age. The Powwow conglomerate is then, very late early Wolfcampian, as fusulinids in the Tularosa area, 200 feet stratigraphically below the top of the Laborcita formation (30-F-1), are older than those of the Powwow conglomerate*, and Schwagerina 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. 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 comprise the upper Wolfcampian. The remainder of the upper division of the Hueco limestone is possibly Leonardian in age. The regional correlation of the Abo formation and Hueco limestone is indicated on Figure 13.

The lower non-arkosic member of the Abo formation of the northern Sacramento Mountains, which includes the intertonguing portion of the Abo and Laborcita formation, thins abruptly toward the south, and correlates with the lower 100 feet of the High Rolls Abo section (Plate 13), that contains the quartzite cobble conglomerates. This entire lower part of the Abo formation is considered

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*Personal communication by M. L. Thompson.

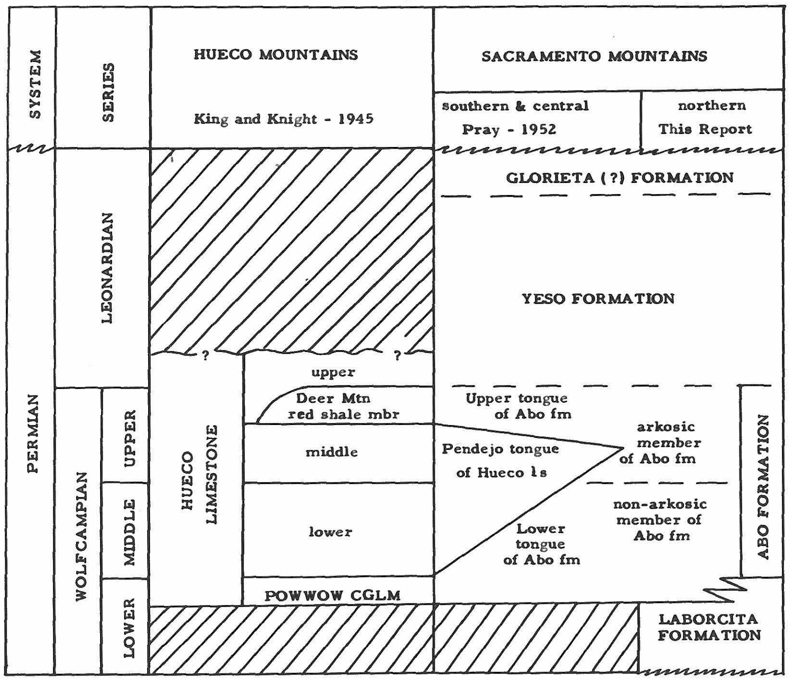

Figure 13. Age and regional correlation of Abo formation of the Sacramento Mountains.

to represent the late early and middle Wolfcampian. The upper part of the Abo formation, which comprises the arkosic member of the southern part of the map area, is of relatively more uniform thickness. It is considered to form the upper Wolfcampian and is probably 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. Many local unconformities must occur within the coarse clastic members of the Abo formation and Pow-wow conglomerate, in order to be the depositional time-equivalents of much thicker fine clastic and limestone units in other areas.

Pray (1952, p. 255) indicated that the evidence from the flora conflicts with the Wolfcampian age of the Abo formation. Read has identified plants of the Supaia floral assemblage from the southern extension of the Abo between the Sacramento Mountains and the Hueco Mountains (King, 1942, p. 690). These probably came from the upper tongue of the Abo formation. The Supaia assemblage is indicated by King (1942, Plate 2) as Leonardian. The Walchia 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 the same age as the vertebrates in the upper part of the Wichita group of central Texas, which is Leonardian in age (King, 1942, Plate 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 of 2100 feet 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 pre-Cambrian to early Permian. In the subsurface, east of the crest of the Sacramento Mountains, the Abo formation is interpreted to rest on the pre-Cambrian 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) considers 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 therefore, are not the time-equivalent of the Abo formation west of the Pedernal Landmass.

YESO FORMATION*

The Yeso formation was originally defined by Lee (1909, p. 12) and applied to a 100-2,000 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, pp. 1657-61) 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 this area of study it extends from northeast of Tularosa southward to Laborcita Canyon along the eastern boundary (Figure 4). R. C. Northup and L. C. Pray (Pray, 1952, Plate 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 1200 feet of the Yeso formation, 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

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*As the emphasis of this investigation is on the late Pennsylvanian and early Permian stratigraphy of the northern Sacramento Mountains, little time was devoted to a study of the strata overlying the Abo formation in the vicinity of the map area. The following brief discussions of the Yeso and younger Permian strata are largely summarized from L. C. Pray's work in 1952.

is pale red, pink, yellowish or gray, but in general contrasts sharply with the dusky red of the underlying Abo beds. 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 distribution and nature of the deposits comprising the Yeso formation in the Sacramento Mountains suggest deposition in a broad area lying between a source of clastic materials to the north and the open sea to the south and southeast. At times, circulation of the normal marine waters was restricted, probably by reef development in the southeastern part of the state, leading to deposition of the evaporites in the shoreward areas and deposition of carbonates closer to the reef and open sea. The uniformity in thickness of the Yeso formation and general similarity of lithology over broad areas indicates that deposition in most of the area of the Yeso formation took place on a stable shelf.

Everywhere in the Sacramento Mountains, the Yeso formation overlies the red beds of the Abo formation. In the map area the lower contact has been mapped for about 12 miles from Laborcita Canyon to a point about two miles north of Tularosa Canyon. The contact is locally poorly exposed as a result of slump features in the basal part of the Yeso formation. Furthermore, for a total distance of about six miles the contact is hidden under a cover of 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 the strata more characteristic of the Yeso formation. The upper part of the Abo formation consists largely of dark red mudstone interbedded with coarse arkose, which locally grades upward into a zone of interbedded red and green mudstone layers one or two 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.

GLORIETA (?) AND SAN ANDRES FORMATIONS

East of the map area, the Yeso formation is overlain by the Glorieta (?) and San Andres formations which form the youngest Paleozoic strata in the Sacramento Mountains.

The Glorieta (?) formation in the Sacramento Mountains consists dominantly of gray and olive gray limestone and dolomite, with minor beds of white to yellow-gray, calcareous, fine to medium grained, well sorted quartz sandstone. The formation ranges in thickness from 121 feet at the southern end of the escarpment to about 60 feet in the northern Sacramento Mountains. The contact of the Yeso and Glorieta (?) formations is interpreted as gradational, indicating a change in the type of deposition. The site of deposition continued to be a stable shelf area, but the circulation of marine waters in the Sacramento Mountain area apparently was not sufficiently restricted to produce evaporite deposits. The beds of sandstone may represent regressions of the seas toward the south, and clastic sediments could be transported farther to the south. The age of the Glorieta sandstone is considered by Lloyd (1949, pp. 20-22) to be either very late Leonardian or very early Guadalupian.

The San Andres is the youngest Paleozoic formation of the Sacramento Mountains and forms the crest of the range. Gray limestones form most of the San Andres formation in the Sacramento Mountains. Dolomitic limestone constitute about 10 percent of the observed sections and dolomite is very uncommon. The upper part of the formation has been eroded from the crest of the Sacramento Mountains. The thickness in the subsurface to the east is about 1400 feet, but only a few hundred feet of the San Andres formation remain at most places along the crest. The uniformity and widespread distribution of the San Andres formation indicates deposition on a stable shelf, and the rock types and fauna present indicate deposition from seas of normal salinity. The virtual absence of clastic material and the known distribution of the formation suggests that the land areas were far to the north. The age of the San Andres is considered to be early Guadalupian.

MESOZOIC STRATA

Sedimentary strata of Mesozoic age have not been observed in the Sacramento Mountains, but information from adjacent areas suggests that they were present at one time. The development of the present erosion surface in the western Sacramento Mountains that defines the top of the San Andres formation probably caused the removal of the Mesozoic and upper part of the San Andres strata. For the purpose of outlining the post-Paleozoic geologic history of the northern Sacramento Mountains, these units are briefly mentioned below.

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 more recently discussed by Allen and Jones (1952, p. 1320). R. F. Schmalz* observed the same strata in the Phillips Hills about 25 miles north-northwest of Tularosa. He reports that limestones of the San Andres formation underlie 159 feet of Triassic (?) Bernal orange red mudstone and 185 feet of maroon and green mudstones that are 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

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*Personal communication.

section. Rocks of Jurassic or early Cretaceous age are not known from these two areas. Upper Cretaceous Dakota sandstone, Mancos shale and Mesa Verde sandstone, shale and coal have been observed in the Phillips Hills section, but individual thicknesses are not definitely determined. This upper Cretaceous section reaches a thickness of about 1500 feet, as compared to about 1000 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 pyroclastics.

III. IGNEOUS ROCKS

Sills and dikes of igneous rocks occur in many parts of the northern Sacramento Mountains. As they comprise about five per-cent of the map area, they have not been studied in detail. Because of greater resistance to erosion than the surrounding sediments, the sills and dikes are commonly conspicuously exposed. On the basis of mineralogical composition, essentially three rock types are recognized, which are listed in Table I.

TABLE I

Rock Name	Principal Feldspar		Dimensions		Form and Structural Configuration
	Type	Amount	Average Thickness	Maximum length	
Quartz albitite	Albite	80°/o	50-100'	4 mi.	Sills; laccoliths; locally discordant
Andesite porphyry	Andesine	70°/o	5-20'	2 mi.	Sills; concordant
Felsite	Albite	60°/o	1-15'	3-1/2 mi.	Dikes

The structural configuration of the igneous rocks locally strongly influenced the nature of the exposures of the Laborcita formation. It is therefore used as a basis of classification of the igneous rocks in this report. The intrusives are probably all of Tertiary age.

SILLS

The sills in the area are essentially 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 usually form thin, very tabular sheets. The fine-grained intrusives of more acidic composition cut in a few places across the sedimentary strata, where they form more discordant bodies.

QUARTZ-ALBITITE

Fine-grained intrusive, quartz-albitite rocks probably form three-fourths of the igneous rocks in the map area. These fine-grained intrusives reach a thickness of 200 feet in many places and largely occur in the Laborcita formation. In the La Luz Canyon area some are intruded into the lowermost units of the Abo formation. Locally the uppermost resistant ledge of the frontal escarpment is formed by the tabular masses that are nearly parallel with the underlying and overlying strata (Figure 14). Toward the east and southeast the quartz albitite cuts slightly across the bedding planes and intruded successively younger strata, as a study of Plate 4 shows particularly. However, it is tabular in its general shape and can be considered a sill.

Lath-shaped albite (An 5-10) crystals, that range from 1/6 to 1/4 mm, form 80 percent of the rock. Quartz occurs in amounts up to about 15 percent. Locally, biotite is relatively abundant in amounts up to 20 percent, but generally it is present in small

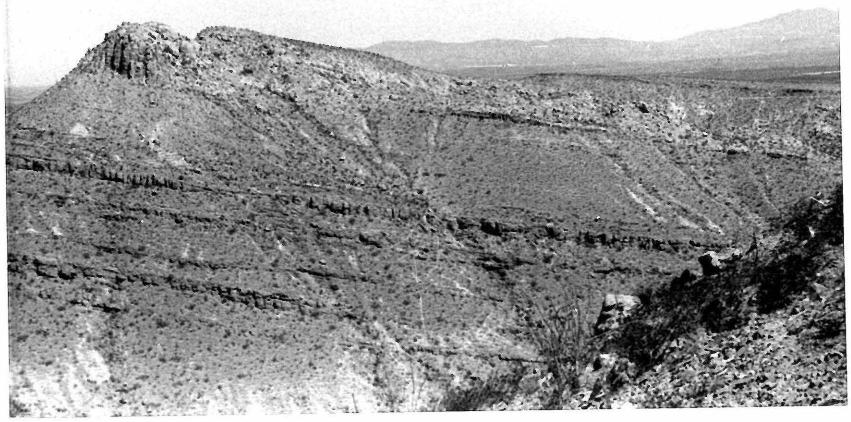

Figure 14. Fine-grained acidic intrusive forms resistant ledge on frontal escarpment. One mile south of Domingo Canyon looking north.

quantities, and is commonly chloritized. Orthoclase has not been recognized. A similar rock type was discussed by Johannsen (1932, Vol. II, p. 375), who named it a quartz-albitite. Drag features occur locally in the sedimentary beds near the contact with the intrusive. This suggests that the magma must have been relatively viscous during the intrusion, which might be attributed to its more acidic composition. In NW $\frac{1}{4}$ sec. 19, T. 15 S., R. 11 E., tight folds in the fusulinid-bearing limestone bed 37 are caused by the quartz-albitite intrusive, which is in this locality distinctly laccolithic in shape. The shales and thin sandstone beds underlying this intrusive appear to be undisturbed (GG', Plate 3).

ANDESITE PORPHYRY

Although variations in composition exist, the dark colored, thin, very tabular sills are generally made up of an andesite porphyry. Examination in thin section of a representative sample indicates that a micro-crystalline groundmass, which probably consists mostly of feldspar and small quantities of quartz, constitutes about 50 percent of the rock. Plagioclase phenocrysts, that range in size from 2 mm to 10 mm, form about 35 percent of the rock. The plagioclase feldspar appears to be andesine, although extensive alteration, largely to calcite, sericite and kaolinite, prevents accurate determination. Hornblende is the major mafic mineral and commonly forms 15 percent of the rock. The hornblende phenocrysts are between 1-2 mm in size and are decomposed to epidote and chlorite. Magnetite is the most abundant accessory mineral.

The thickness of the andesite porphyries ranges from a few to several tens of feet. Very thin sills were, in general, not mapped so that the andesite porphyry is actually more abundant than appears from 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 four miles north of Tularosa. The other crops out continuously for a distance of about four miles near the Abo-Yeso contact.

DIKES

Intrusive dikes form very distinctive, narrow linear features in the map area and some extend for a distance of at least 3-1/2 miles. They are commonly about 1 to 15 feet wide and are vertical or dip steeply. Because of their greater resistance to erosion, they form conspicuous topographic features as in Figure 15.

Figure 15. Intrusive dike at south side of La Luz Canyon. NE$\frac{1}{4}$ sec. 26, T. 15 S., R. 11 E.

Most observed dikes occur in the mudstones and arkoses of the Laborcita and Abo formations; at least in the present erosion pattern the dikes 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 colored and all appear to be of similar acidic to intermediate composition. The two parallel dikes that cross La Luz Canyon in sec. 26, T. 15 S., R. 11 E., were sampled and examined in thin section. Small laths of albite, that range from 1/8 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, in amounts up to about 10 percent, from the dark mineral content. Calcite is locally abundant and forms the remainder of the rock. Quartz and potash feldspar have not been recognized. Megascopically the dike rocks and the andesite porphyry appear to be more alike, 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. A sill of quartz-albitite cuts across a dike of more intermediate composition and is clearly the younger.

AGE

The igneous rocks are all presumed to be related to a major period of igneous activity that is 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.

A basic dike swarm and larger siliceous bodies in the Capitan Quadrangle (Allen and Jones, 1952), about 40 miles northeast of the map area, are dated as middle Tertiary. The intrusives of the northern Sacramento Mountains appear to be similar in composition to these intrusives of the Capitan region. Furthermore, the dikes of both areas have the same general trend, which suggests the presence of a parallel joint system of regional extent prior to the intrusion of the dikes.

In view of the uncertainties, the igneous rocks of the northern Sacramento Mountains are considered in this report Tertiary (?).

IV. GEOLOGIC STRUCTURE

GENERAL DISCUSSION

The Sacramento Mountains* form a part of the boundary between the Basin and Range province in the west and the Great Plains province in the east. The range is essentially a block that has been uplifted along a fault zone with respect to the Tularosa Basin on the west and tilted eastward. The western portion 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 one or two degrees eastward, in which direction they can be traced with 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 6500 feet in the central part of the escarpment (Pray, 1952, p. 321) and decreases both toward the south and north. According to Pray (1952, p. 302):

> "South of the Sacramento Mountains, the frontal fault system either dies out, or continues with only a fraction of the displacement known to the north, as faulting is but a minor feature in the region east of Oro Grande and along the western edge of Otero Mesa."

The fault, which defines the frontal escarpment of the northern Sacramento Mountains, is abruptly terminated by eastward-trending structural features at a point about five miles north of Tularosa. The 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

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* The following paragraph on regional structural features is summarized from Pray (1952, p. 301).

Mountains. King (1942) interprets the western escarpments of the Sacramento Mountains and Sierra Blanca to be the product of en-echelon faulting. Structurally the Sierra Blanca is different from the Sacramento Mountains and represents a structural basin rather than a high tilted block.

The uplift of the Sacramento Mountains, however, is the result of 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. A late Pennsylvanian and early Permian period of deformation appears to be restricted to the southeastern part of the map area. This deformation is hereafter referred to as the pre-Abo deformation. Evidence of post-Abo gentle folding is 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 cannot be dated more closely. However, one of these folds is truncated by the boundary fault zone, which indicates a period of deformation prior to late Cenozoic time. The numerous high-angle normal faults that occur in the map area in the vicinity of the boundary fault zone are probably 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, which are treated in order of decreasing age.

PRE-ABO DEFORMATION

The major angular unconformity 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 appears to be restricted to the southeastern part of the map area where it is recognized east of a line that extends northward from a point 1-1/2 miles west of High Rolls to La Luz Canyon (Plate 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 formation in the southeastern part of the map area, as a result of pre-Abo, high-angle, normal faulting (Plate 2). Between Fresnal Canyon and Salada Canyon displacement occurred on a system of two essentially parallel faults. On each fault the western side is downthrown. The western fault is called the Salada Canyon fault and was mapped for about 1-1/2 miles from Salada Canyon to Fresnal Box Canyon but might extend farther south. The Fresnal Canyon fault is the eastern fault and is continuously exposed for about five miles between Salada Canyon and Arcente Canyon to the south and has been mapped by Pray (1952). The author 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 reactivated in post-Abo time.

Salada Canyon Fault

Several periods of movement occurred along the Salada Canyon fault; some in late Pennsylvanian and some in early Permian time. It can be proven that post-Holder, pre-Laborcita displacements took place at the north end, in the canyon one-third of a mile north of Salada Canyon (Plate 2). Here, the Salada Canyon fault appears to offset strata of the Holder formation about 200 feet, whereas these strata are overlain by undisturbed beds of the Laborcita formation.

Between Salada and Fresnal Box Canyon 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', Plate 3). This indicates post-Abo movement on this system of parallel faults, although as much as half the difference in elevation might be the result of folding. If the presence of a 350 foot thick section of Holder and/or Laborcita strata is inferred overlying the Beeman formation in the fault zone between the Salada Canyon and Fresnal Canyon fault, the base of the Abo formation in the fault zone occurs at the same elevation as the base of the Abo on the High Rolls block (MM', Plate 3). An estimate of 350 feet of post-Beeman and pre-Abo strata in the fault zone is not excessive, considering at least a thickness of about 850 feet for the corresponding section directly west of the Salada Canyon fault. Therefore, the post-Abo movement on this system of parallel faults is interpreted to have occurred mainly on the Salada Canyon fault. The truncation of the lower part of the Laborcita formation by the Salada Canyon fault might possibly be the result of this post-Abo movement. According to Pray (1952, p. 334), later uplift since the deposition of the Abo formation is also noticeable in the area south of Fresnal Box Canyon. The post-Abo movement appears to die out toward the north in the vicinity of Salada Canyon.

Fresnal Canyon Fault

The Fresnal Canyon fault has been mapped by Pray (1952) for about five miles from Arcente Canyon in the south to Salada Canyon, and evidence indicates that the fault continues as a buried structural feature for an additional two miles to La Luz Canyon (Plate 2).

In the canyon one-third of a mile north of Salada Canyon, the Fresnal Canyon fault appears to offset strata of the Laborcita formation that occur on the downthrown side of the fault (Plate 2). These are overlain by the undisturbed strata of the Abo formation. On the upthrown or eastern side of the fault, the Abo formation is in depositional contact with beds of the upper Holder formation, which indicates about a 400 foot movement on this fault in post-Laborcita, pre-Abo time in this area. The displacement increases toward the south. In the vicinity of Fresnal Box Canyon, the Abo formation overlies strata of the Beeman and Gobbler formation and the displacement is about 1,000 feet (MM , Plate 3). This indicates that the major amount of displacement on the system of parallel faults occurred on the

Fresnal Canyon fault, as here the total stratigraphic separation on both the Salada Canyon and Fresnal Canyon fault is about 1,600 feet. According to Pray (1952, p. 334), this amount of displacement decreases again southward, and the fault dies out in the vicinity of Arcente Canyon.

A north-trending high-angle fault that occurs in La Luz Canyon in a few isolated exposures of deformed Pennsylvanian strata about two miles north of Salada Canyon might be a northward extension of the Fresnal Canyon fault. Although this is a structurally complex area and not clearly understood, it appears that the strata east of this fault are stratigraphically older than the strata on the west, indicating an upthrown eastern block. Locally the strata on the eastern block correlate with the Beeman formation, and west of the fault they belong to the upper part of the Holder formation. More recent displacement, however, which offsets the basal strata of the Abo formation, indicates a downward component for the eastern block (Plate 2).

FOLDS

The folds that are the result of pre-Abo deformation appear to be restricted to the southeastern part of the map area, where they generally occur in a zone that extends northward for about three miles from Salada Canyon to about one mile north of La Luz Canyon (Plate 2).

A number of small, asymmetric, plunging folds are located in the fault zone between the Salada Canyon and Fresnal Canyon fault in the vicinity of Salada Canyon. The folds occur en-echelon and the average spacing on the northwest-trending axial planes is about 1,000 feet. A very sharply overturned anticline occurs at the north side of

Salada Canyon (Figure 16). The axial plane dips approximately 45 degrees toward the east and the fold plunges very steeply toward the northwest. Toward the northeast, en-echelon with this anticline,

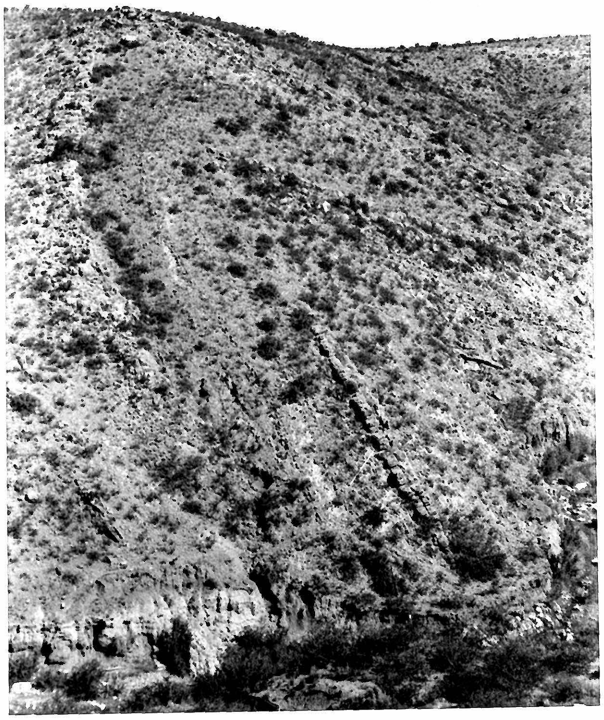

Figure 16. Overturned anticline in upper Pennsylvanian strata. Uppermost gray limestone bed contains fusulinids of middle Fresnal age. The beds in the core are Missourian in age. Salada Canyon looking north.

red beds of the Laborcita formation are folded in a plunging syncline and overlie with angular unconformity the underlying beds of the Holder formation of middle Fresnal age* (Structure section LL , Plate 3).

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* Fusulinid identification by M. L. Thompson.

The strata of the Abo formation appear to be unaffected by the folding. This indicates that some deformation occurred in post-Holder and pre-Laborcita time, but the formation of the sharply folded structures occurred largely in post-Laborcita, pre-Abo time. This fold deformation is therefore essentially 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 essentially parallel faults. This feature might be compared with the formation of drag folds in the incompetent bed on a limb of a fold as a result of slippage along the bedding planes.

In the vicinity of La Lúz 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 1-1/2 square miles, about eight separate en-echelon folds were observed. The western limb of the anticlines commonly dips 30 to 50 degrees toward the southwest. The dip of the eastern flank is very shallow and is commonly less than 10 degrees. The average plunge on the fold axis is about five degrees. A few folds are doubly plunging structures.

Strata that have been correlated with the Laborcita formation overlie with angular unconformity strata of the upper Holder formation. The strata of the Laborcita formation are folded along the same structural axes, but are overlain by the relatively undisturbed Abo strata. This indicates several periods of folding during late Virgilian and early Wolfcampian time. The folds in the La Luz Canyon area might have been formed in the same way as the folds in the Salada Canyon area to the south, although in La Luz Canyon the presence of a system of parallel faults cannot be demonstrated. Further evidence in support of this interpretation is the fact that the folds of both areas appear to be of the same age.

POST-ABO DEFORMATION

Evidence of post-Abo crustal deformation is present in the map area south of Laborcita Canyon. In this area three gently folded structures, the La Luz anticline, the Dry Canyon syncline and the Maruchi Canyon arch, are believed to be a result of the post-Abo deformation. Both the Dry Canyon syncline and the Maruchi Canyon arch occur in strata of the Abo formation. 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 surficial deposits of Quaternary age. According to Pray (1952, p. 346), strata as young as the San Andres formation are gently folded in other parts of the Sacramento Mountain escarpment, which indicates a possible post-San Andres age for this deformation. The truncation of the La Luz anticline by the boundary fault zone, and the occurrence of numerous, unfolded, small, high-angle faults of probable late Cenozoic age, that offset the strata of the La Luz anticline, indicates a development prior to late Cenozoic time. In the Phillips Hills area, about 25 miles north of Tularosa, R. F. Schmalz* discovered evidence for early Tertiary folding, and the post-Abo folding in the northern Sacramento Mountains might possibly be of the same age.

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*Personal communication.

La Luz Anticline

In the map area, the La Luz anticline is located near the front of the escarpment and extends for about two miles from La Luz Canyon to Laborcita Canyon. (Plates 1, 2 and 3). This symmetrical fold trends approximately north-northwest, and plunges northward about 10 degrees in the vicinity of Laborcita Canyon, where it appears to be truncated by the boundary fault. The limbs of this anticline show dips of about 30 degrees. The present depth of erosion indicates that beds at least as young as the Laborcita formation are affected by the folding. As the strata 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 probably formed after the deposition of the Abo formation. This structural feature might be a northward continuation of the anticline mapped by Pray (1952, p. 340) for about six 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 and extends for about four 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 (Plate 2), especially in the proximity of the Fresnal Canyon fault zone. The average dip of the western limb is about four degrees. Because of the reversal of plunge of the axis in the map area, several structural basins are formed along the length of the syncline. The plunge is generally about two or three degrees.

South of State Highway 83, the Dry Canyon syncline was mapped by Pray (1952) for a distance of eight 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 that was 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 in the west limb of this fold (Plates 2 and 3). The angular discordance at the base of the Laborcita formation in the east limb of this syncline was probably caused by general uplift or drag of the strata along the Fresnal Canyon fault zone in post-Holder, pre-Laborcita time. Therefore, in the map area the development of the Dry Canyon syncline occurred largely after deposition of the Abo formation.

Maruchi Canyon Arch

About three 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', Plate 3). This structure is about half a mile wide and is a part of the narrow deformed belt that extends northward for about four miles from Fresnal Box Canyon to La Luz Canyon and that includes the Fresnal Canyon fault zone. Apparently, portions of this belt were deformed in post-Abo time (Plates 2 and 3). The Maruchi Canyon arch is named for a tributary of La Luz Canyon. The erosion of the basal Abo beds from the higher portions of the structure exposes locally 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. Here the regional dip of the Abo and Yeso strata is one or two degrees to the east and these strata are seemingly unaffected by the post-Abo deformation.

CENOZOIC DEFORMATION

Pray (1952, p. 306) stated that the Sacramento Mountains are the result of mountain-forming activity that occurred during late Cenozoic time, and discussed in detail the fault versus the fold origin of the Sacramento Mountain escarpment. Most of the features that were presented by Pray as evidence in support of the fault hypothesis were observed in the northern part of the Sacramento Mountains. These features, such as piedmont scarps; step faults; numerous small high-angle normal faults near the frontal escarpment; isolated gravel cappings adjacent to the mountain front; truncation of internal structure, and fault drag are briefly described in the following section on the boundary structural features. 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 the Sierra Blanca are discussed separately.

BOUNDARY STRUCTURAL FEATURES

Piedmont Scarps

The fringe between the mountains and the Tularosa Basin is locally marked by scarps up to 20 feet high and about two 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 base of the escarpment and separate alluvium on the west from bed rock on the east. In the area between Laborcita and Domingo Canyons, where the scarps occur 1,500 feet west of the base of the mountain escarpment (Plate 1), the area east of the piedmont scarp is essentially a pediment with a thin alluvial cover.

Step Faults

Between Cottonwood and Tularosa Canyons two normal faults near the frontal escarpment can be interpreted as step faults (Plates 1 and 2). The faults dip steeply toward the west with an angle of about 70 degrees, and the west side is downthrown with a dominant dip-slip component of 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 seven miles by a narrow zone of fault drag about 100 feet wide (Figure 17). These two step faults merge with the frontal fault near Tularosa Canyon, and farther to the north the escarpment appears to be 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, and are replaced by numerous high-angle normal faults. These faults are in general nearly vertical. The displacement appears to be largely dip-slip and averages about 100 feet. Locally, however, 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 period of post-Abo deformation (FF' and GG' on Plate 3). A few affect the Tertiary (?) intrusive

Figure 17. Fault drag on step fault near frontal escarpment about two miles south of Domingo Canyon.

rocks and associated features. The author considers most of the small-scale faulting in the area near the frontal escarpment to be contemporaneous and believes it to be 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 might have created special stress conditions during the period of Basin and Range faulting resulting in the relatively great abundance of minor faults in that area.

Gravel Cappings

A few isolated ridges near the frontal escarpment (Plate 2) in the vicinity of Tularosa are capped by gravel deposits that occur one to two hundred feet above the level of present drainage. They are considered to be remnants of 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), and lowering of the base level of erosion can therefore not account for the dissection of the older erosion surfaces. The raised position of the older gravels above the present level of erosion is good evidence of the relative uplift of the mountain block with respect to the valley block. As these gravel cappings occur on a flat unwarped surface near the frontal escarpment, the uplift was probably caused by faulting rather than folding.

Truncation of Internal Structure

In the map area, the north-northwest-trending frontal escarpment appears to intersect 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 Mountain escarpment.

Fault Drag

Between Laborcita and Tularosa Canyons, the strata in the zone bounded by the piedmont scarps in the west and the step faults in the east dip dominantly toward the west (structure sections CC' and DD' on Plate 3). This zone, which is locally as much as 1500 feet wide, is interpreted as large-scale fault drag along the major boundary fault.

These various lines of evidence have 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 4300 feet and north of Tularosa, at 3800 feet. These displacements are based on the following assumptions:

1. The thickness of the alluvium of the Tularosa Basin is 1000 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 formations in the Sacramento Mountains is one or two degrees to the east. In the relatively undeformed parts of the northern Sacramento Mountains, such as in the area north of Laborcita Canyon, it was noticed that 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 and 30 degrees have been recorded. This gradual steepening of the strata generally occurs within a zone about half a mile wide (Plates 1 and 3). The feature is common along the Sacramento Mountain escarpment, where it was noted by Pray (1952).

No satisfactory explanation has been advanced to explain this feature. The author 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 might be called reverse drag, in contrast to normal drag that would be oriented in the opposite direction.

TRUNCATION OF THE BOUNDARY FAULT

Along the northernmost edge of the map area (Plate 1) the strike of the strata of the Abo formation turns sharply from the north toward the northwest, and the dip increases toward the northeast. This may be a part of a major east or northeast-trending fault that is largely buried under the recent gravel deposits farther to the north. About five 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, different in trend and possibly in type from those prevailing along the Sacramento Mountain escarpment. The occurrence of dissected pediment gravels and of piedmont scarps is evidence of recent uplift of the Sacramento Mountain block along the boundary fault. These movements are no doubt younger than both the structural development of the Sierra Blanca and the subsidence of the Sacramento Mountain block, that is inferred in order to explain the feature of reverse drag.

V. QUATERNARY GEOLOGY

Sediments of Quaternary age form surface deposits in a large part of the map area, where they obscure the bedrock geology. Because of the emphasis of this study on the Wolfcampian stratigraphy, relatively little time was devoted to the differentiation of the various Quaternary sediments. Although the few reconnaissance observations helped to interpret the more recent geologic and topographic development of the northern part of the Sacramento Mountain escarpment, many problems remain untouched and require more detailed investigation.

Four general groups of Quaternary deposits have been distinguished on the geologic maps. They are, listed 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 very similar, their differentiation is based primarily on the relative position of the 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 abundantly 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 ridges in the interstream areas are capped by conspicuous light colored limestone gravels. Not all the gravel cappings occur on the same level and roughly two surfaces of deposition can be distinguished.

The highest of the gravel deposits is very widespread, can be recognized throughout the entire map area, and is referred to as the older gravel deposits.

The base of the older gravels in the southern part of the area is generally 200 to 300 feet above the present level of the stream bottoms. This amount decreases northward so that in the vicinity of Tularosa Canyon, this distance ranges between 50 and 150 feet. The surface on which these gravels are deposited was recognized and referred to by Pray (1952, p. 294) as the Laborcita terrace. The older gravels are composed almost entirely of cobbles and boulders of light colored, gray, fossiliferous limestones probably derived from the San Andres formation. The maximum observed thickness of the gravel deposit is 56 feet, but commonly does not exceed 20 feet.

These high, isolated cappings are remnants of a thin continuous sheet of gravel deposits that extended with a westerly dip of about three to four degrees from the steep mountain front in the east to the Tularosa Basin in the west. The slope decreases also toward Tularosa. The surface on which these gravels rest as a thin veneer is interpreted as a pediment. It truncates the underlying Abo beds and was probably formed during the retreat of the mountain front toward the east near to 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 Quaternary deposits that have been designated as the younger gravel deposits are much less sharply defined than the older gravel deposits. They are composed largely of pebbles and cobbles of San Andres limestone. The gravels form cappings on isolated interstream areas and stream terraces and occur about 50-100 feet below the older gravel deposits.

The younger gravels were mainly recognized 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. Both toward the west and north a general convergence of the older and younger erosion surfaces appears to take place. North of Tularosa Canyon the younger surface is no longer recognizable.

The younger gravel deposits are probably fluviatile gravels that occur 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 later period of erosion, however, was not long enough to obliterate the earlier erosion surface covered by the older gravels. It was succeeded by the third and last period of major uplift that 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 largely composed of limestone 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 major 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. No doubt, future study with the aid of reliable topographic maps will establish separate map units for these surface deposits.

The younger gravel deposits grade imperceptibly into reworked gravels toward the west and on the geologic map (Plate 1) the contact between these two units was somewhat arbitrarily chosen. 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 have not been differentiated and are classed as Quaternary alluvium for mapping convenience.

In the area between Laborcita and Tularosa Canyon surficial deposits, that form 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 eight square miles (Plate 1). The alluvium is generally composed of flat-lying silts, sands and thin gravels of light gray or pink color. The flat surface, on which the thin alluvial veneer occurs, is topographically slightly higher than the surface of the Tularosa Basin that borders 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 (Plate 1).

Recent gravel deposits rest as a thin layer on the truncated Abo and Yeso beds along the northern edge of the map area (Plate 1). The surface, on which these gravels appear to be in transit, rises gently toward the steep east-trending mountain front and is interpreted as a pediment. A surface with a similar thin discontinuous gravel cover, that extends as a narrow strip with a maximum width of 1500 feet east of the major boundary fault at the base of the frontal escarpment between Laborcita and Domingo Canyons, is considered also a pediment (Plate 1).

The valley alluvium and the pediment gravels and surfaces are in the process of dissection, and 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 described above were developed. This suggests a tectonic origin rather than change in base level for the formation of the surfaces. Climatic changes may have been of significance also.

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 1000 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). Furthermore, the San Andres formation appears in surface outcrops about 25 miles north of the map area. Therefore, the depth of the alluvium near La Luz is estimated at about 1,000 feet, and is inferred to decrease gradually in thickness northward. At the northern end of the map area (Plate 3) it is estimated at about 500 feet. Tertiary as well as Quaternary alluvium is present in the Tularosa Basin (Pray, 1952, p. 298).

Stream terraces can be recognized along Tularosa Canyon at different levels. The highest one is about 50 feet above the present stream bottom. They 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.

VI. GEOLOGIC HISTORY

The chronologic sequences of sedimentation, structural events, igneous activity, and recent history in the northern Sacramento Mountains and evidence in support of the interpretation has been discussed in preceding sections of this report. This section is devoted to a summary in chronologic order of the major geologic events that can be interpreted to have occurred in this area since Virgilian time.

1. Deposition in a marine environment of about 900 feet of interbedded limestone, sandstones and shales during most of Virgilian time. This sequence of beds, which contains a rich invertebrate fauna, is designated as the Holder formation. Its thickness decreases toward the east and south toward the central part of the Sacramento Mountains. Much of the clastic material in the section was derived from a positive area to the northeast, the "Pedernal Landmass". Reef masses, about 100 feet thick, form locally the base of the Holder formation and were probably 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 is an indication of increasing tectonic instability during late Virgilian time in this area.

2. In late Virgilian time, the first evidence of deformation in the Sacramento Mountains. In the northern Sacramento Mountains deformation by faulting and related subsidiary folding 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 resulting in non-deposition or slight erosion. The intensity of the deformation appears to diminish 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 under laterally abruptly changing conditions northwest and west of the rising central and eastern part of the Sacramento Mountains. The fault zone in the southeastern part of the map area separates approximately the areas of denudation and deposition. Deposition of conglomerates and red mudstones occurred in alluvial fans and broad flood plains adjacent to, and on the flanks of the rising landmass. These beds thicken considerably toward the northwest and west, where the terrestrial environment grades into a dominantly marine environment within three 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. They reflect 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 resulting in deposition of red mudstones and sandstones of the upper one-third of the Laborcita formation over the entire area of the northern Sacramento Mountains.
5. Recurrent faulting and subsidiary folding in the zone between La Luz Canyon and State Highway 83, probably accompanied by a general downward tilt of the area northwest of Domingo Canyon.
6. Removal of strata of the Laborcita formation from the eastern, or upthrown block of the Fresnal Canyon fault zone in the southeastern part of the map area.
7. Late early Wolfcampian deposition of the lowermost Abo beds in piedmont and alluvial plain environments. Within and east of the Fresnal Canyon fault zone, the Abo formation overlies folded and faulted Pennsylvanian and lower Permian strata of the Holder and Laborcita formation. 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 shelf area. In this area deposition was essentially continuous from Laborcita into Abo time but shifted from predominantly marine to terrestrial conditions.
8. Final retreat of marine waters at the end of early Wolfcampian time toward the west and northwest.

9. During middle Wolfcampian time deposition of red mudstones, conglomerates and non-feldspar-bearing sandstones of the Abo formation in piedmont and alluvial-plain environments in the area between High Rolls and Cottonwood Canyon. Contemporaneous deposition of a thicker, more feldspathic section toward the northwest in the vicinity of Tularosa, with an area of provenance toward east and northeast.
10. During late Wolfcampian time deposition of coarse arkoses, conglomerates and red mudstones of the Abo formation 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 must have locally formed mountains of considerable magnitude.
11. Near the beginning of the Leonardian epoch a gradual major northward advance of the sea and general marine deposition of 1300 feet of limestones, shales, gypsum and sandstones of the Yeso formation.
12. At the end of Leonardian time, probably shallowing of marine waters and the deposition of pure quartz sandstones of the Glorieta (?) formation.
13. Early Guadalupian deposition of a 1400 foot thick marine limestone section of the San Andres formation.
14. No record of the time interval between the early Guadalupian and the Tertiary is present in the northern Sacramento Mountains. From adjacent areas it appears that about 350 feet of

red beds were deposited during Triassic (?) time. Jurassic and early Cretaceous is a period of non-deposition or erosion. Late Cretaceous is represented by deposition of approximately 1000 feet of Dakota sandstone, Mancos shale and Mesa Verde 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 area of the Sacramento Mountains.

15. Early Tertiary gentle folding.
16. Intrusion of sills and dikes of acidic and intermediate composition probably in early or middle Tertiary.
17. Late Tertiary or early Pleistocene Basin and Range type faulting along or close to the base of the present escarpment.
18. Development of a pediment surface over a part of the northern Sacramento Mountains. This surface extends from 3 to 6 miles east of the boundary fault zone and truncates largely strata of the Abo formation.
19. Differential uplift and warping, probably in part along the frontal fault zone.
20. Dissection of older pediment surface and formation of younger terraces.
21. Renewed uplift along boundary fault zone.
22. Broad valley alluviation and recent pedimentation.
23. Minor uplift developing recent piedmont scarps and causing subsequent stream dissection of alluviated valleys and recent pediments.

VII. CONCLUSIONS

The primary purpose of this study has been to provide more detailed information about the late Pennsylvanian and early Permian stratigraphic and structural history of the northernmost Sacramento Mountains. A better understanding of the nature and sequence of geologic events in the area at that time is not only of local significance, but also contributes toward a better interpretation of the geologic record in other areas. In the course of a detailed study of this nature, many geologic features or relationships are encountered that are of more general geologic importance. In the following summary an attempt has been made to distinguish the major conclusions into two categories, the ones of local and the ones of general geologic significance.

INTERPRETATIONS OF LOCAL SIGNIFICANCE

LABORCITA FORMATION

1. The Laborcita formation is a name given in this report to all the strata that occur between the top of the Holder formation and the base of the Abo formation. 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 area where both top and bottom are exposed. Its thickness increases to about 1,000 feet toward the northwest. The lithologic and faunal character of the sedimentary deposits show that abrupt lateral transitions from open-marine conditions in the northwest to terrestrial flood-plain environments in the southeast must have occurred repeatedly within a distance of a few miles. Cyclothems of neritic

and terrestrial types are common in the area.

2. 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 appear to represent essentially continuous deposition.
3. On the basis of fusulinid identifications, the Laborcita formation is very late Virgilian and early Wolfcampian in age. The uppermost portion of the Laborcita formation 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 within the lower part of the Laborcita formation, as was determined on the basis of fusulinids.
4. The deformation that affected the central part of the Sacramento Mountain area during late Virgilian and early Wolfcampian time was essentially contemporaneous with the deposition of about 600 feet of strata of the Laborcita formation in the center of the mapped area.
5. The zone of algal reefs that was discovered in the upper part of the Laborcita formation in the area north of Tularosa is potentially of economic significance. These limestone masses show locally extreme recrystallization porosity and might form a good reservoir for the accumulation of oil.

ABO FORMATION

1. The Abo formation was recognized by all previous students of the area. Thickness of this wedge-shaped unit increases from about 500 feet near High Rolls to approximately 1400 feet north of Tularosa.

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, however, was one of essentially continuous deposition from late Pennsylvanian into 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 formed by a quartzite cobble conglomerate in the area 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).

3. The conglomerates, coarse arkoses and mudstones of the Abo formation were derived from a pre-Cambrian source area, the Pedernal Landmass, that appears to be mainly composed of igneous and metamorphic rocks, in which feldspar porphyry, pink granite and quartzite are the major rock types. It extended mainly east and northeast, and possibly southeast of the area of investigation.

4. The Abo formation appears to be in part a terrestrial facies of the Laborcita formation and was largely deposited in a piedmont and alluvial-plain environment. In general, two members can be distinguished in the Abo formation in the northern Sacramento Mountains: a lower member which is non-feldspar-bearing and contains a few limestone layers, and an upper member which is characterized by the lack of limestone and the presence of arkoses.
5. In the map area, the lowermost Abo strata correspond to the uppermost lower Wolfcampian. Pray (1952) has indicated a correlation of the Abo formation with the bulk of the Hueco limestone of Trans-Pecos Texas. On this basis, Pray considers the age of the top of the Abo formation either latest Wolfcampian or earliest Leonardian.

INTERPRETATIONS OF GENERAL GEOLOGIC SIGNIFICANCE

1. Composition of the coarse clastic fraction of conglomerates must be used with caution in interpreting areas of provenance. In this area it can be demonstrated that sorting largely by size of the coarse clastic fraction can lead to markedly different compositions. A quartzite cobble conglomerate was observed to grade into a pebble conglomerate of quartzite and limestone and granule conglomerate of limestone and chert.
2. The abrupt lateral transition from open-marine environments to terrestrial flood-plain conditions is shown by tracing of individual beds. One complete lateral succession of contemporaneous deposits was determined to be within a distance of 1-1/2 miles:

massive marine limestone, nodular argillaceous fusulinid-bearing limestone, silty limestones containing abundant shallow marine invertebrates such as molluscs and brachiopods, dolomitic limestone, green shales, and marine to non-marine red shales and other terrigenous clastics. These gradual changes appear to represent a gradual transition from deeper marine environments toward littoral or terrestrial conditions.

3. In the geologic record, red beds are commonly considered to have been deposited in a non-marine environment under predominantly oxidizing conditions. In the various sections of this report other criteria besides color have been presented as evidence for a terrestrial origin of the lower Permian red beds of the Sacramento Mountains and are summarized below.

   a) Sedimentary features, such as channeling, irregular cross-bedding, lateral discontinuity of beds are indicative of fluvial deposition.

   b) In the map area the red beds contain locally abundant petrified wood.

   c) But for few exceptions, the red beds are completely barren of marine fossils.

   d) Certain individual marker beds grade toward the east or southeast from marine limestones or green or gray shales into red mudstones. The limestones and gray or green shales contain generally marine invertebrates, whereas the red shales are barren of marine fossils.

   e) Considering the red beds as a unit, the red bed facies appears to be the time-equivalent of a facies known to be marine, such as the Laborcita formation and Hueco limestone, and occurs between an area actively undergoing erosion and one of marine deposition.

4. Cyclothems generally extend over wide areas. Under favorable conditions, cyclothems composed of distinctly different lithologic sequences, such as cyclothems of the neritic and terrestrial type,

can grade into each other within a lateral distance of three miles.

5. The cyclic repetition of certain lithologic sequences appears to reflect tectonic instability. Cyclothems might be indicators of diastrophism that is episodic in nature.

6. The writer believes that the upper part of the Holder formation and the marine facies of the Laborcita formation form one of the most complete upper Virgilian and lower Wolfcampian marine sections known in North America.

7. Major unconformities might be very local in extent. They form, therefore, a poor basis for establishing boundaries in the geologic time scale. Widespread changes in the succession of faunas are more applicable to determine period or systemic boundaries over broad areas.

8. The beds of the Holder and Laborcita formation yield locally abundant marine invertebrates of different types. In addition, the relative stratigraphic position of the various collecting localities has been determined. Therefore, this area affords an excellent opportunity for specialists to compare the age-assignments of the various fossil groups and to resolve possible conflicts in the age-assignments. For example, the goniatite localities east of Tularosa occur in beds of the Laborcita formation. Miller considers this fauna to be of early late Pennsylvanian age. However, the fauna is middle early Wolfcampian in age on the basis of detailed stratigraphic correlation with sections containing fusulinids farther south. This is significant in view of similar conflicts in age-assignments in other parts of North America, especially in West Texas, where the lateral continuity of strata is more difficult to determine.

VIII. APPENDIX I

FAUNA AND AGE OF THE LABORCITA FORMATION

INTRODUCTION

The upper Pennsylvanian and lower Permian marine beds of the northern Sacramento Mountains are rich in fossil remains of many types. Fusulinids are most abundant and occur predominantly in the light gray, nodular, argillaceous limestones. A wide assortment of brachiopods, pelecypods, gastropods, cephalopods, bryozoa, corals and algae occur, particularly in the silty limestone and calcareous siltstone facies. The faunas from these strata at a few isolated localities have been known for some time and were described by different workers (Böse 1920, Penn 1932, Miller 1932 and Girty 1939). However, to this date, no systematic faunal studies of the uppermost Pennsylvanian and lower Permian beds have been undertaken in the Sacramento Mountains. Much of the knowledge is fragmentary and appears to be contradictory.

In an effort to obtain a better understanding of some of the problems involved, A. L. Bowsher and W. T. Allen, of the United States National Museum in Washington, D. C., made extensive collections of the mega-fauna in the northern Sacramento Mountains in the summers of 1948 and 1951. Additional fossil occurrences that were discovered by the author during the course of his detailed field studies were also collected by Bowsher and Allen. During the summer of 1952, Dr. G. A. Cooper, Curator at the United States National Museum, joined Bowsher and Allen and revisited many localities in the area. The reports on the brachiopods, gastropods and cephalopods is based on the National Museum collections.

Additional megafossil collections were made in the area by Dr. Rousseau H. Flower and the author in 1952, and are in the possession of the New Mexico Bureau of Mines and Mineral Resources at Socorro. A study of this new fauna, which is largely composed of gastropods, is not yet available. The locality, number 9-M-1, occurs half a mile southeast of the junction of La Luz and Fresnal Canyons, about 150 feet above the base of the Laborcita formation, and is listed on the maps and charts of this investigation.

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

The brachiopods and gastropods of the Laborcita formation were successively examined by Cooper and Bowsher and are listed in Tables II and III. Most localities, that are indicated by one locality number in this report, were collected at different times, resulting in several accession numbers for the United States National Museum collections.

BRACHIOPODS*

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, one strong rib alternating with two to four smaller ones. The species is a compressed form with a hinge narrower than the mid-width 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.

Dictyclostus welleri R. H. King - ?=D. wolfcampensis 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. The Wolfcamp species are not like. 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.

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

	UNITED STATES NATIONAL MUSEUM LOCALITY NUMBERS													
	3378	3370	3022	3022a	3366	3379	3324	3371	3372	3374	3362	3361	3363	3294
Chonetes granulifer meekianus Girty												X		
Composita sp.													X	X
Crurithyris sp.												X		
Derbyia n. sp.												X		
Dictyoclostus americanus Dunbar				X	X	X			X	X		X		
Dictyoclostus welleri R. H. King					X		X					X		
Enteletes n. sp.												X		
Juresania nebrascensis (Owen)												X	X	
Linoproductus sp.	X	X	X	X	X						X	X	X	X
Meekella striatocostata (Cox)		X						X	X			X		
Neospirifer sp.	X						X			X	X	X		
Wellerella sp.												X	X	
Locality numbers of this report	11-M-1 (3378–3379)						13-M-1 (3324–3374)				13-M-3	M-3	30-M-3	30-M-2

TABLE II. BRACHIOPODS OF THE LABORCITA FORMATION

Linoproductus sp. - This genus does not give much help because specimens have the characteristics of L. pratteniamus 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. texana (Shumard). There are nomenclatural reasons for not using the latter name but the general run of W. osagensis don't seem typical either. This is again a type that is abundant on both sides of the line. The Bursum ones seem to have the greater angularity which is common to the Permian specimens.

In the same report, Dr. Cooper states:

> "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, I should say that they are rather Permian than Pennsylvanian, the Permian similarities resting on general appearance of the shells, the presence of a type 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. wolfcampsis (D. welleri) which seems to be a definite Lower Permian brachiopod."

GASTROPODS*

Gastropods of many types, that occur abundantly at various stratigraphic positions throughout the beds of the Laborcita formation, have been listed on Table III. The most important ones are marked. The calcareous shales and dark argillaceous limestones yielded particularly many gastropods and it appears that the occurrence is strongly dominated by the facies. Despite the locally very

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

		UNITED STATES NATIONAL MUSEUM LOCALITY NUMBERS																
		3017	3017a	3017b	3017d	3017f	3281	3283	3284	3285	3295	3297	3022	3022a	3282	3286	3293	3294
X	Ananias cf. A. marconianus (Geinitz)		a	a	r	a	c	a	a	c	c	a				r	r	a
X	Baylea n. sp.								r					r		r		
	Bellerophon n. sp. cf. B. graphicus Moore					r			r						r	c	c	
	Colpites n. sp.								r				c			r		
X	Euphemites aff. E. graffhami Moore	c				a	c	c	r	r		r	c	c				
	Girtyspira cf. G. minuta (Stevens)													a			a	
X	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		
X	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					
X	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
X	Retispira cf. R. tennilineatus (Gurley)					r			r		r		a		c	c	a	
	Retispira cf. R. textiliformis (Gurley)													r				
X	Retispira n. sp.					c			r				a	a	a	a	c	c
	Soleniseus ? n. sp.															r		
	Stegocoelia n. sp.								r			r						
X	Straparollus (Amphiscapha) muricatus (Knight)		r	c	r	a	r		a	r	r					r		
X	Taosia crenulata Girty												a	a	c	c		
X	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									
	X = Important gastropods a = abundant c = common r = rare	M-1										11-M-1					13-M-2	30-M-2
		Locality numbers of this report																

TABLE III. GASTROPODS OF THE LABORCITA FORMATION extensive collections, the overall sampling does not warrant a detailed discussion 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"* represent a single faunule assemblage. Except for a few species, Straparollus (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". Thus it appears that these gastropods are Pennsylvanian in age or at least have marked Pennsylvanian affinities."

CEPHALOPODS

Miller published in 1932 a detailed account of collections, that were derived by Böse from beds of the Laborcita formation east of Tularosa, and Miller showed that the collection was late Pennsylvanian in age. The localities were recollected in 1951 and 1952 by Bowsher and Allen in the hope of finding forms that would be more diagnostic and more definitive as to the exact age. After examining these newly collected ammonoids (locality number M-1 in this report) Miller stated the following 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

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*Read Laborcita.

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 Pennsylvanian 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 that are important for the age determination of the Laborcita formation and the interpretation of the geologic history of the area have been listed in Table IV. The collections from these localities are listed under the Invertebrate Paleontology collections of the California Institute of Technology. The most critical fusulinids have been identified by M. L. Thompson in reports to the author, dated March 18, 1952, and May 7, 1953. The remainder of the samples were examined by the author, but the lack of reference collections did not permit an accurate determination on most of these. Wherever possible, quotes from Thompson's report are given directly. In these quotes "Fresnal" is used as a stage and is late Virgilian. It corresponds 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 100 feet which is very late Virgilian in age.

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

TABLE IV. Fusulinid Localities and Corresponding Invertebrate Paleontology Collection Numbers of the California Institute of Technology.

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. This form found in Texas Wolfcampian.
28-F-1 = CIT 2020	_Schwagerina_ sp. Possibly younger than any of type sections of Bursum. Not 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 to the Bursum, are high Bursum. They should be correlated above the top of the type section of the Bursum. Rocks that seem to be of this age are rare in New Mexico. They should fit within the Powwow conglomerate-Bursum formation erosional 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 sample 2020.
13-F-1 = CIT 2012	Triticites sp. Virgilian.

MISCELLANEOUS

According to Bowsher*, 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, of the United States National Museum.

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

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*Personal communication dated July 8, 1953.

SUMMARY

On the basis of the fusulinids that are abundantly and widely distributed through the unit the Laborcita formation is very late Virgilian and early Wolfcampian in age, which usage has been followed in this report. A more detailed account of the stratigraphic implications of this age-assignment was given previously in the discussion on the Laborcita and Abo formations.

The brachiopods show, in general, more affinities to Permian than to Pennsylvanian forms. However, both the gastropods and cephalopods indicate greater affinities with Pennsylvanian forms. This conflicting result is especially surprising, when it is realized that 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.

It is significant to note that a few cephalopod and gastropod species occur in rocks of definite Permian age in other places of North America. *Gastrioceras drakei* Miller*, which is common in the collection of the Tularosa clay pit (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 one mile east of Burbank, Oklahoma. The Red Eagle limestone is definitely Wolfcampian (O'Connor and Jewett, 1952), which indicates that at least some ammonoids range stratigraphically higher than previously thought, and the Tularosa clay pit collections might also be of Permian age. *Glabrocingulum* n. sp. A occurs in the Wolfcampian

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*Personal communication from Bowsher dated July 8, 1953.

of the Colorado River Valley, Texas.

The opposing views on the ages of the faunas from the Laborcita formation cannot be reconciled with the data presently available. Much the same problem exists in the Glass Mountains area of West Texas, where Cooper is now engaged in a study of the upper Pennsylvanian and lower Permian strata and faunas. According to Cooper*, it appears that the limestones contain mostly a Permian brachiopod fauna, and the interbedded shales a Pennsylvanian fauna, which would indicate a marked ecologic control for most of the forms.

Further systematic studies of the late Pennsylvanian and early Permian faunas in the Sacramento Mountains are needed, coupled with detailed comparisons with the faunas of other areas. The similar upper Pennsylvanian and lower Permian lithofacies in the Glass Mountains and Sacramento Mountains will be very helpful for a direct comparison, as it probably indicates similar environmental conditions during deposition.

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*Oral communication.

IX. APPENDIX II

WOLFCAMPIAN REEFS OF THE NORTHERN SACRAMENTO MOUNTAINS

INTRODUCTION

Resistant, mound-like limestone bodies are exposed near the crest of the low frontal escarpment of the Sacramento Mountains northeast of Tularosa for a distance of about three miles, and are interpreted to be of reef origin. The principal requirements of reef origin were stated by Lowenstam (1950, p. 433) and Wilson (1950, p. 181), and were summarized by Plumley and Graves (1953, p. 4) as follows:

1. Large vertical dimension compared with the proportions of adjacent sedimentary rocks.
2. Lack of well-developed stratification.
3. Presence of colonial-type marine organisms that acted as framework-builders.
4. Evidence that the organic mound had wave-resistant qualities and not merely the potential.

It will be demonstrated that the mound-like bodies northeast of Tularosa satisfy the first three of these requirements, but their wave-resistant nature is somewhat in doubt. Nevertheless, these organic structures are considered reefs by the author.

The reefs occur at one horizon near the top of the Laborcita formation and are of late early Wolfcampian age. Most of these organic structures are about 35 feet high, but locally are as much as 60 feet. They are capped by several layers of detrital limestone that appears to be closely related to the reef growth. The reef limestone and overlying clastic limestone layers form commonly a resistant ledge which is a conspicuous part of the frontal escarpment. The total thickness of this ledge is about 60 feet and remains remarkably uniform, despite the thickening and thinning of the lower reef limestone unit (Figure 20).

AREAL DISTRIBUTION

The reefs occur along the frontal escarpment northeast of Tularosa. They extend northward for about three miles from a point half a mile north of Tularosa Canyon to a northeast-trending normal fault (Plate 1). The absence of any reef growth or reef-derived detritus at the base of the escarpment, about 1,000 feet farther toward the northwest, suggests that the area of reef development did not extend much north of the area of observable reefs.

In an east-west direction the reef development cannot be accurately determined because of the lack of exposures. The western extension of the reef ledge has been removed completely by erosion between the present exposures and the frontal fault zone, and if the reefs extended farther west, they are now buried beneath sediments in the Tularosa Basin west of the boundary fault. One exception exists several hundred feet south of the center of sec. 5, T. 14 S., T. 10 E., where the western extension of the reef horizon appears to be present near the base of the escarpment at the western and downdropped side of a north-trending fault. The reef zone here is less than ten feet thick, which is suggestive of an original western limit to the reef growth not far beyond this point. The extent of the reef growth in an easterly direction cannot be established satisfactorily from surface evidence because of the general eastern dip of the strata and west-dipping topographic surface. In a few places, however, where the zone can be traced to the east along the walls of major canyons, the organic mounds appear to lens out within 1,000 to 1,500 feet east of the frontal escarpment. On the basis of these findings, the author believes that the extent of the reefs is approximately from the boundary fault zone in the west to where they lens out in the east, which is a distance of about half a mile. The distribution of the reefs, therefore, indicates a general north trend, approximately parallel with the shore line of the late Laborcita sea, which is inferred to have existed a few miles to the east on the basis of regional stratigraphic evidence.

METHOD OF INVESTIGATION

In an attempt to reconstruct the depositional environment of these reefs, a detailed study of the field relations was combined with petrologic investigations in the laboratory of a well exposed, easily accessible and representative group of reefs that are located in the western half of sec. 16, T. 14 S., R. 10 E., about one mile north of Tularosa Canyon. A plane-table survey on a scale of 50 feet equal one inch, was made of part of the reef zone that is located in the SW$\frac{1}{4}$ sec. 16, T. 14 S., R. 10 E. (Plate 14). This portion of the zone of reef development, which is pictured on Figures 18 and 19, permitted determination of the field relationships between the reefs and surrounding strata. Five detailed stratigraphic sections were measured and sampled across the massive limestone ledge that occurs directly to the north in the NW$\frac{1}{4}$ sec. 16, T. 14 S., R. 10 E. Three measured sections were taken along the front of the range

(Figure 20) and two on the cliff face that extends in an east-west direction (Figure 21) opposite the reef masses of which a plane-table survey was made.

SEDIMENTARY FACIES

The sedimentary strata associated with the reef development can be classified into three major groups, the reef facies, the post-reef limestone facies and the off-reef facies. The reef facies comprises the mound-like accretionary limestone structures that form the lower part of the resistant 60 foot thick limestone ledge. The detrital limestone accumulations which cap and completely bury the actual reef horizon and which are restricted to the area of reef development are included in the post-reef limestone facies.

The off-reef facies includes the sedimentary strata that possess distinct stratification and that do not appear to be influenced by the reef growth. This facies includes strata that range in age from pre-reef to post-reef, and time-equivalents of the reef.

Reef Facies

The limestone lenses, which form the lower part of the resistant limestone layer average 35 feet in thickness, but in a few places reach a thickness of as much as 60 feet (Plate 14). A distinctive fusulinid bed about two feet thick, which occurs both on top and on the flank of this resistant limestone ledge (Plate 14), indicates that the time-equivalent strata in the off-reef facies has a maximum thickness of six feet. Therefore, the reef lenses had a large vertical dimension, as compared with the adjacent sedimentary rocks which were deposited contemporaneously, even allowing for post-depositional compaction of the off-reef strata.

The mounds have a massive structure. Fine lines, which have the appearance of stratification planes, are interpreted as growth lines of filamentous type algae. The author was unable to identify these algae. In successive growth stages, the alga appears to grow as a thin veneer or filament over the old rock surface, thereby incorporating in the structure previously and contemporaneously deposited fine organic detritus (Figure 27). The thin laminae are revealed on the surface of the fine-textured rock because of slight differences in color or grain size. Yellowish-gray, gray and pinkish bands lap over one another and occur largely in sub-horizontal bands, as is shown on Figures 22 and 23. The bands are both concave and convex upward. Thickening of the bands in the parts which are convex upward (Figure 24) is evidence in favor of an organic growth and not an inorganic sedimentary origin of these laminae. During the various growth stages, the rock must have possessed a rough surface with protruding knolls and slight depressions. In plan view, the growth banding will therefore be subconcentric, as is clearly shown on Figure 25.

Pockets of bioclastic debris, which are up to about six inches in diameter (Figure 26), occur throughout the reef mass. Thin-shelled brachiopods, foraminifera and small crinoidal fragments which were scattered in a fine-grained lime mud suggest deposition in protected pockets or, at times, during quiet-water conditions

(Figures 27 and 28). The encrusting algae prevented later removal of these fine-grained sediments under more turbulent water conditions. The filamentous algae appear to be the principal framework-builder of the reef and, in addition, formed the bulk of the reef mass.

In many places the uppermost few feet of the reef are brecciated (Figure 28) which might have been caused by wave-action during the end stages of reef development. On the geologic map (Plate 14) of the reef ledge, a very dark gray to black limestone has been distinguished as a separate mappable unit. It forms a part of the reef facies and consists almost entirely of very coarse-grained recrystallized calcite. Recrystallization has obliterated much or all of the original texture (Figure 29). This dark limestone layer, which is not present everywhere, reaches an average thickness of about five feet and seems to form a veneer over the reef structures. This layer of recrystallized limestone is interpreted to be equivalent to the zone of brecciation of other places. The localization of the recrystallization activity is probably caused by the increased porosity of the brecciated zone.

Although the recrystallization activity is not restricted to this layer, it is less dominant in other parts of the reef masses, where it appears to be centered in the places that also possess a coarser texture, such as the pockets with bioclastic debris. In many places the recrystallization follows closely the outline of laminae of fine-textured limestone (Figure 23). The recrystallized parts of the reef limestone show large cavernous type weathering (Figure 30), which seems to be caused by secondary recrystallization porosity.

The reef structures show a large scale, irregular, very thick-bedded stratification, which is clearly noticeable along the front escarpment (see left side of Figure 20). Thin, very continuous layers of shale which are about one inch thick separate these massive lenticular beds. The stratification is interpreted to indicate successive stages in the development of the reef masses. The influx of large amounts of fine clastics, which spread as a thin continuous veneer over the reef mounds during quiet-water conditions, might have temporarily halted the reef growth.

The non-carbonate content of the reef masses, which consists entirely of fine terrigenous clastics, is very low and ranges from 0.5 to 2.5 percent (an average of 1.75 percent) as was determined by insoluble residue measurements of ten samples. Inasmuch as the reef-equivalent beds in the off-reef facies consist largely of very argillaceous limestone and calcareous shale, more turbulent water conditions must have prevailed in the vicinity of the organic mounds.

Extreme rough-water deposits and reef-flank deposits that consist of coarse, poorly sorted, clastic fossil material and angular to rounded rock fragments, are considered indicative of wave-resistant reef masses (Lowenstam, 1950; Plumley and Graves, 1953). Except for the locally observed brecciation on top of the reef limestone that might indicate some strong wave-action in the final stages of reef growth, these extreme rough-water deposits are lacking in the area of study. The author believes, therefore, that these reefs did not stand far above the level of vigorous abrasion or wave-base, as this was defined by Dietz and Menard (1951, p. 2001). However, it is possible that the reef-flank deposits were present at one time west of the presently exposed areas, and are now removed by erosion. With a land area to the east and prevailing western winds, an accumulation of coarse detritus could well have occurred on the west flank.

In summary it can be stated that the massive organic mounds are the products of framework-building organisms that erected distinct topographic structures on the ocean floor. Furthermore, these structures might have been wave-resistant in later stages of their development, and therefore, they satisfy essentially the principal requirements of reef definition.

Post-Reef Limestone Facies

In contrast to the massive limestone of the reef facies, the post-reef limestone facies is characterized by bedded detrital limestones, which consist dominantly of relatively coarse organic detritus that is contained in a very fine-grained matrix. Fragments are as large as 10 mm. Tubular algae, of which Anchicodium sp. (?) has been recognized, contribute most abundantly to the rock, but fusulinids, crinoid columnals and other fossil remains are also present. The detrital facies is either reef-equivalent or post-reef in time of development. If it is a reef-equivalent deposit, the detrital limestones require the presence of uncovered parts of the reef masses which do not occur within the belt of present exposures, and which can be inferred only in the area to the west that is now removed by erosion. As the coarse clastic portions of the detrital facies do not contain recognizable reef material, this entire detrital facies is interpreted to be post-reef in development. Apparently the reef structures continued to have a topographic expression on the sea floor and thus influenced the sedimentation beyond the time of their actual growth. Probably, they were a more favorable site for marine life than the off-reef areas. The restriction of the detrital limestones to the area of reef growth and their absence in the off-reef areas, where the amount of non-carbonate fine clastics increases, supports this conclusion. The clay residue content of the various recognizable detrital limestone members is much lower, and averages 1.5 percent. Therefore, in post-reef time the water must have been sufficiently turbulent in the reef area to keep the fine terrigenous clastics in suspension, but not agitated enough to remove the coarser organic detritus. The thickness of the post-reef limestone unit varies from 0 to about 60 feet, depending upon the thickness of the underlying reef structures.

For mapping purposes four members could be distinguished in the post-reef limestone facies. These are separated generally by layers of shale a few inches thick. The lower two members form zone I and the upper two members zone II on Figures 20 and 21. In addition, a dark gray, fine-grained, carbonaceous limestone layer, about four inches thick, was recognized. This limestone bed, that consists of fine bioclastic debris (Figures 31 and 32), occurs between the actual reef limestone and the lowermost member of the post-reef detrital limestone unit. It occurs only in the depressions between the reef mounds, and was probably deposited under more quiet-water conditions than the overlying four limestone members, as is suggested by the fine texture and the slightly higher percentage of fine terrigenous clastics (4.5 percent). It could not be distinguished as a separate map unit.

First and Second Limestone Members (Zone I)

The two lower limestone members that have been distinguished are almost identical in composition and make up the bulk of the post-reef detrital limestones. In the map area, the first or lowermost member, which is mostly in direct contact with the actual reef limestone, follows closely the contours of the reef structures and attains locally dips as steep as 35 degrees on the flanks of the organic mounds (Plate 14). The medium gray dense limestone layer is mainly composed of tubular algal material, such as Anchicodium (?), fusulinids and other organic substances bedded in a fine-grained calcareous matrix (Figures 33 and 34).

The overlying second limestone member is almost identical in composition; a fine-grained portion of this rock is shown on Figure 35. About 1500 feet north of the area mapped in detail in NW $\frac{1}{4}$ sec. 16, T. 14 S., R. 10 E., the two medium gray algal limestone layers are not distinguishable as separate members and are indicated on Figures 20 and 21 as zone I. Toward the west, the members of this unit grade locally into a much coarser, breccia-type detrital limestone, which contains abundant crinoid remains (Figure 36). The sedimentary nature of zone I and the conformity to the contours of the underlying lenticular reef zone is clearly shown on Figures 37 and 38.

Third and Fourth Limestone Members (Zone II)

The third and fourth mappable members of the post-reef facies are not everywhere present. They have been grouped together as zone II on Figures 20 and 21 and appear to be restricted to the areas that formed slight depressions during deposition. The third member, which is about two feet thick, consists of coarse fragments of medium gray algal material bedded in a matrix of fine bioclastic debris. Locally the rock shows considerable recrystallization, again probably a result of larger grain size and porosity. Two samples, collected from widely separated localities, are pictured on Figures 39 and 40 and indicate the close lithologic similarity with the underlying members of zone I (Figure 36). The third member seems to be composed of reworked material, derived from the underlying algal limestones, which was deposited in very shallow depressions on top of the reef area. The coarse grain size, the low content of fine terrigenous clastics and truncation of the uppermost members of the detrital facies by the even upper surface of the massive limestone ledge, is suggestive of deposition in a turbulent zone, probably one near wave-base.

The fourth and uppermost member of the post-reef facies forms a two foot thick discontinuous layer which has been recognized only in a few places in the map area. The rock exhibits characteristics that are common to both the actual reef facies and the lower members of the post-reef facies. Sub-horizontal laminae of debris-binding algae are present, as well as the alga Anchicodium sp. (?) that was previously restricted to the post-reef detrital facies (Figures 41 and 42). The rock shows both detrital and accretionary characteristics. Because of the persistent sub-horizontal orientation of the banding, the layer is interpreted as an incipient, underdeveloped reef that possessed the potential of growing upward and becoming a wave-resistant structure. The influx of fine clastics probably terminated the growth of this layer.

Areal Distribution

The post-reef detrital limestone unit appears to be restricted to the area of reef development, and is no longer present in the areas where the reef limestone, that forms the lower part of the 60 foot thick resistant limestone ledge, lenses out completely. This is illustrated by Figure 20, Plate 4 and the structure sections on Plate 14. The abrupt thickening of the detrital limestone to as much as 60 feet occurs only within the area of reef development, where local depressions are bound on either side by reef mounds (Figure 20). These features suggest that in post-reef time the marine waters were sufficiently agitated in the reef area to keep the fine terrigenous clastics in suspension and transport the organic detritus that developed more or less "in situ" into local adjacent areas of depression (Figure 37). In the off-reef areas that are available for study, such as along the frontal escarpment and major canyon walls, the current action was not sufficiently strong, probably as a result of increased water depth, to spread the bioclastic debris over the floor of the ocean. Currents might have deposited some detritus in the area west of the frontal escarpment, but this can no longer be determined for the lack of exposures. With a shore line only a few miles to the east, submarine bottom currents might be inferred that transported material westward and swept the areas eastward and between the submarine topographic features relatively clean.

In the area that was mapped in detail, the distribution of the individual members of the detrital limestone unit is relatively irregular

(Plate 14), and older members appear to be truncated locally by younger members. This feature might be related to the greater thickness of the underlying reef structures (60 feet) in the map area as compared to the area to the north (35 feet) (Figures 20 and 21), which possibly resulted in a greater topographic expression on the sea floor in post-reef time. Increased water turbulence or current action probably caused removal of the organic detritus from the high areas, and relatively irregular distribution of the material on the flanks of the lower mounds.

Off-Reef Facies

The off-reef facies is characterized by the high content of coarse and fine terrigenous material and is composed of limestones, shales and sandstones. The lowest of these strata considered in this section forms the base of the reef structures and is a three foot thick dolomitic limestone layer. This bed, which extends for over a distance of 4-1/2 miles, has been mapped as horizon 52 (Plate 1). In places, the reefs are directly anchored on this limestone layer, but locally, a shale layer several feet thick separates the reef facies from the dolomitic limestone. Possibly under fairly stable marine shelf conditions, the top of this marker bed was locally swept clean by wave action, affording a favorable location for initial growth of sediment-binding algae. Continued growth, both upward and sideways, over the shale-covered areas, resulted in the relative widespread development of the reef facies.

A dark gray, argillaceous limestone layer that contains abundant fusulinids overlies the dolomitic limestone by about six feet in the off-reef area (Plate 14). This fusulinid layer has been observed to wedge out against the third member of the post-reef detrital limestone facies. In other places, similar fusulinids embedded in the same rock type, have been noticed in local depressions to overlie the uppermost fourth post-reef limestone member. This proves conclusively that the 60 feet of reef and post-reef limestone is equivalent to about six feet of strata in the off-reef area. These beds are mainly composed of argillaceous limestone and dark calcareous shales that contain small brachiopods, bryozoa (*Fenestella sp.*) and other organisms which suggests relatively quiet-water conditions.

The stratigraphic separation between the dolomitic limestone (bed 52) that forms the base of the reefs and an eight foot thick, greenish-gray, feldspathic sandstone layer (bed 53) is about 70 feet in the off-reef areas and remains relatively uniform. In the off-reef area this interval is mainly composed of a medium dark gray calcareous shale, which locally contains abundant fossils. The shale and overlying sandstone are no longer present directly above the area of reef development, but even in the vicinity of the reefs (structure sections on Plate 14) the sandstone does not show any noticeable structural effects of post-depositional differential compaction. This might be explained by inferring a slight local unconformity or diastem, which eliminated a topographic high in the shales above the massive limestone lenses, at the base of the resistant sandstone ledge. Furthermore, the amount of deposited fine terrigenous clastics was probably much less in the reef area as compared to the off-reef area, as a result of more turbulent water conditions in the vicinity of the post-reef topographic highs, which would tend to reduce the effects of differential compaction.

FAUNA AND AGE

The fossil fauna of the actual reef masses and the reef-equivalent strata in the off-reef facies is markedly poor, and contains mainly small thin-shelled brachiopods, such as Composita sp., Hustedia sp., foraminifera, bryozoa and other organisms. These were not studied in detail. A brachiopod and gastropod fauna was collected by Bowsher and Allen from the post-reef dark shale zone and occur in the collections of the United States National Museum. In this report the localities are identified by the numbers 30-M-2 and 30-M-3. Thompson identified the fusulinids that were derived from the zone that lenses out against the beds of the post-reef limestone facies. He found Wolfcampian Schwagerina and Dunbarinella sp. that are older than the Powwow conglomerate and younger than the Bursum formation, which suggests a late early Wolfcampian age for the reef structures and associated strata.

Algae form the bulk of the organic substances contributing to the development of the reef limestone and post-reef detrital limestone. Although they could not be identified, they appear to be of two general types, a filamentous alga and a loose tubular alga, possibly Anchicodium (?). Both types require further detailed investigation.

SUMMARY OF REEF DEVELOPMENT

A large number of organic mounds developed as a more or less continuous massive limestone layer on the bottom of the late Laborcita sea. This ledge extends in a north-south direction for a distance of about three miles and is about half a mile wide. The mounds average

35 feet in thickness, but locally may be as much as 60 feet. The organic structures initially developed under optimum growth conditions on the gently sloping, relatively stable sea floor that bordered a landmass to the east in late early Wolfcampian time. Water depth, temperature and currents must have been favorable for reef growth in a zone paralleling and not far removed from the ancient sea coast.

The structures show little evidence of stratification. Encrusting algae of the filamentous type are the framework-building organisms. The mounds, which are lenticular and some with height and width ratios as high as 1 to 4, grew above the level of adjacent contemporaneous sedimentation. The low content of non-carbonate material indicates their growth in the zone of water agitation, and the mounds fulfill essentially the criteria of reef definition. The lack of extreme rough-water deposits and of reef-flank deposits is suggestive for growth not far above wave-base. However, it is possible that the reef-flank deposits might have been present at one time farther west of the presently exposed areas, and are now removed by erosion. With a land area to the east and prevailing western winds, a piling-up of coarse detritus could well be expected on the west flank. The evidence of brecciation in a few places on top of the reef limestone, which appears to localize the recrystallization activity, might indicate some strong wave-action in the final stages of reef growth.

A detrital limestone unit, which reaches a thickness in places of 60 feet, is restricted to the reef area, where it caps the massive limestone structures. This detrital limestone is considered a post-reef deposit. Probably the reef structures continued in post-reef time to have a topographic expression on the sea floor and thus influenced the sedimentation and marine life. These deposits were laid down in a zone of sufficient water turbulence to keep the fine terrigenous clastics in suspension. Tubular algae form the bulk of the organic substances contributing to the post-reef detrital limestone strata.

The time-equivalent deposits of the reef facies and post-reef detrital limestone facies are represented by six feet of strata composed of very argillaceous limestones in the off-reef areas. The structural effect of the reef lenses on the overlying strata above the detrital limestone facies appears to end with the dark gray calcareous shale interval which overlies the clastic limestones.

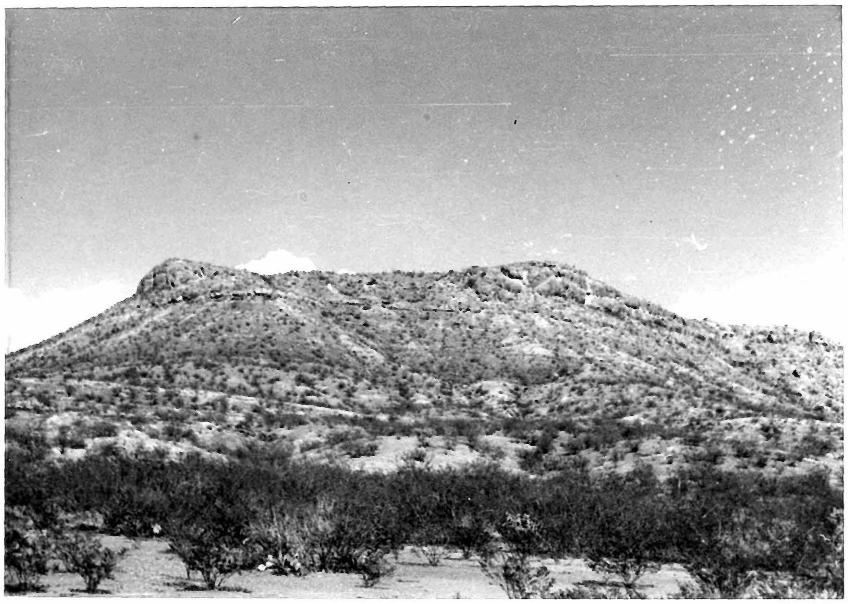

Figure 18. Frontal view of reef masses in SW 1/4, sec. 16, T. 14 S., R. 10 E., 3/4 mile north of U. S. 70, looking east.

Figure 19. View of reef masses pictured in Figure 21, looking south.

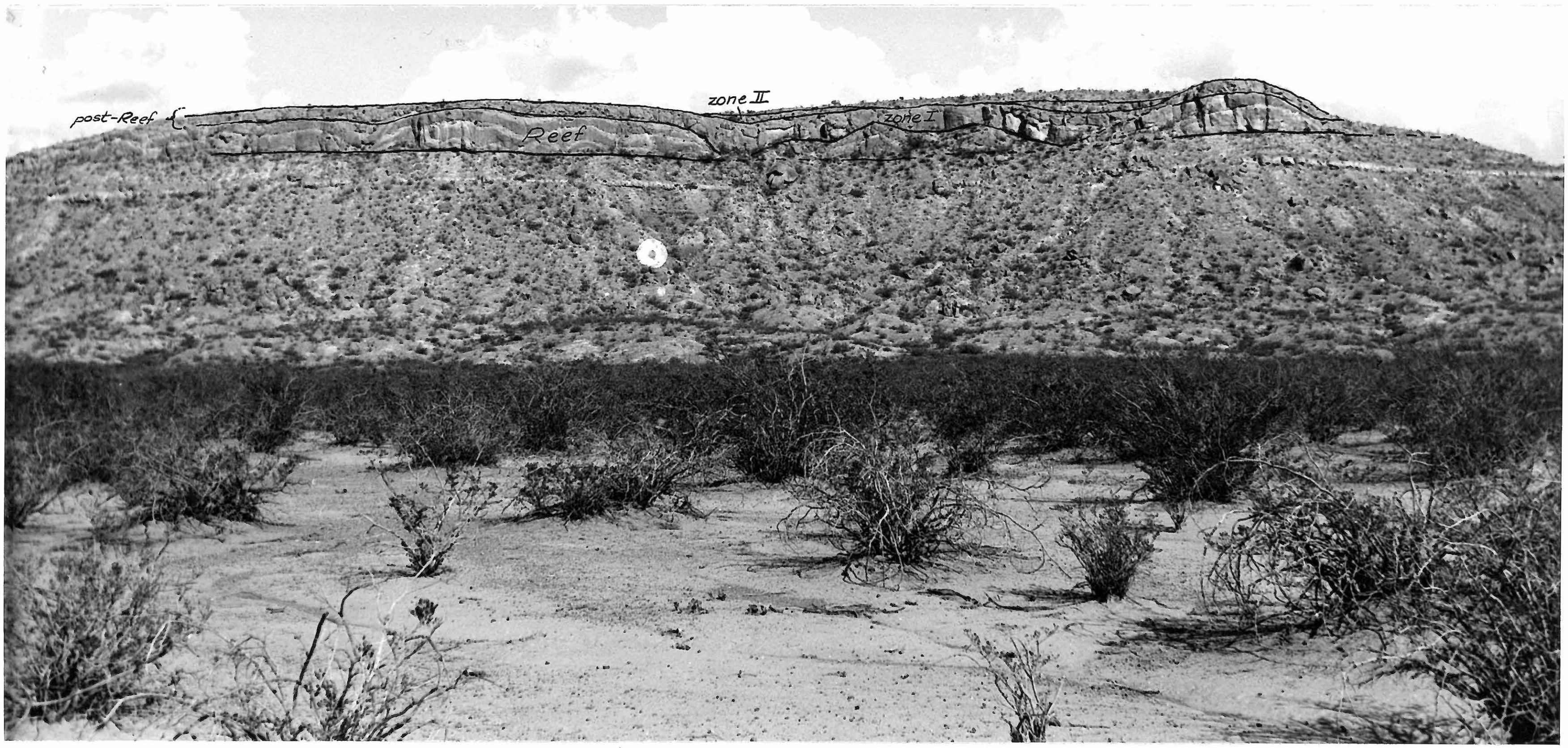

Figure 20. View of reef ledge on front escarpment in NW 1/4, sec. 16, T. 14 S., R. 10 E., looking east. Note the uniform thickness of the ledge, despite lenticular nature of the lower actual reef horizon.

Figure 21. View of reef ledge, near boundary of NW 1/4 and SW 1/4 of sec. 16, T. 14 S., R. 10 E., looking north.

Figure 22. Vertical view of reef surface showing subhorizontal banding caused by filamentous algae (light gray). The dark gray parts are recrystallized limestone.

Figure 23. Vertical view of polished rock surface showing algal laminae and replacement by recrystallized dark gray calcite. Scale in inches.

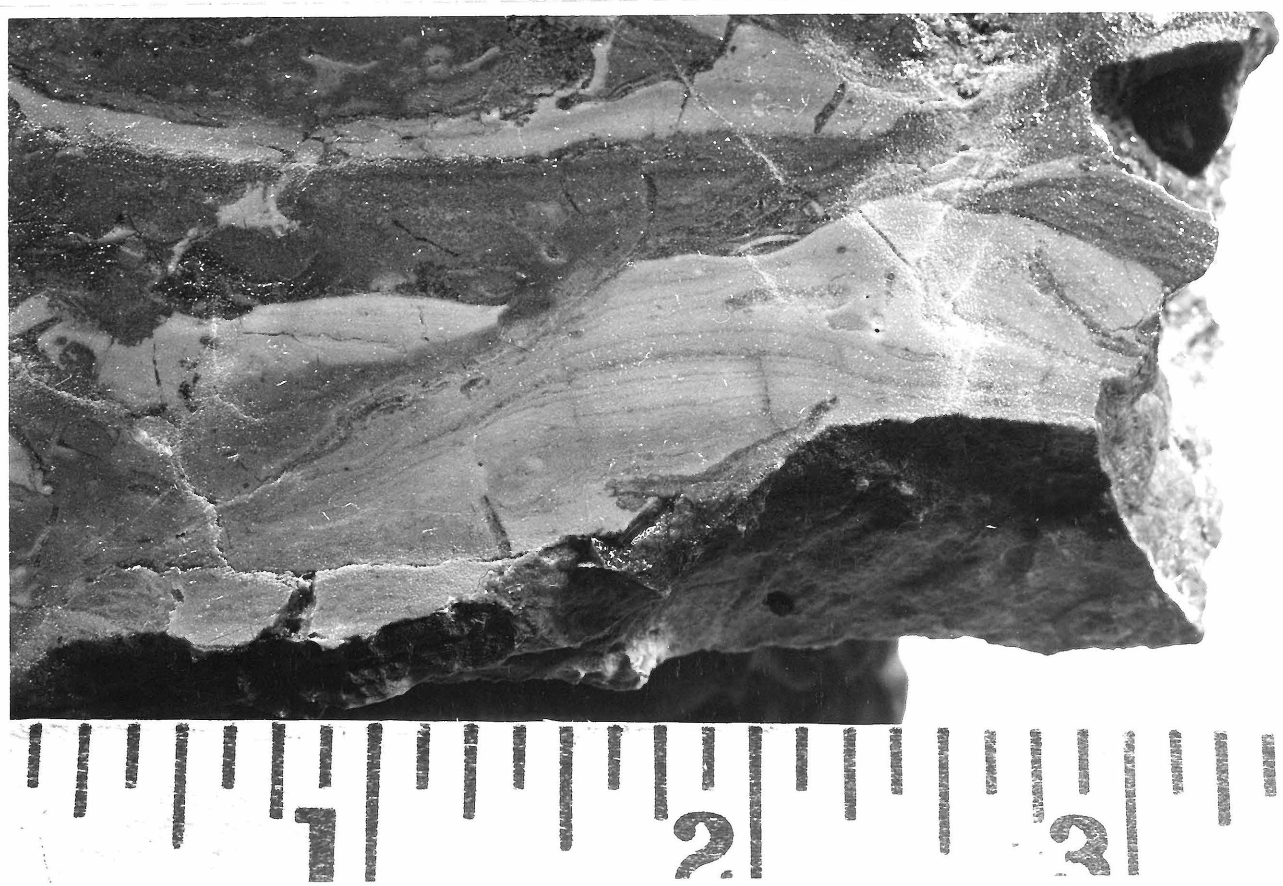

Figure 24. Close view of lower right part of surface of Figure 23. Note the thickening of banding toward the center of picture. Scale in inches.

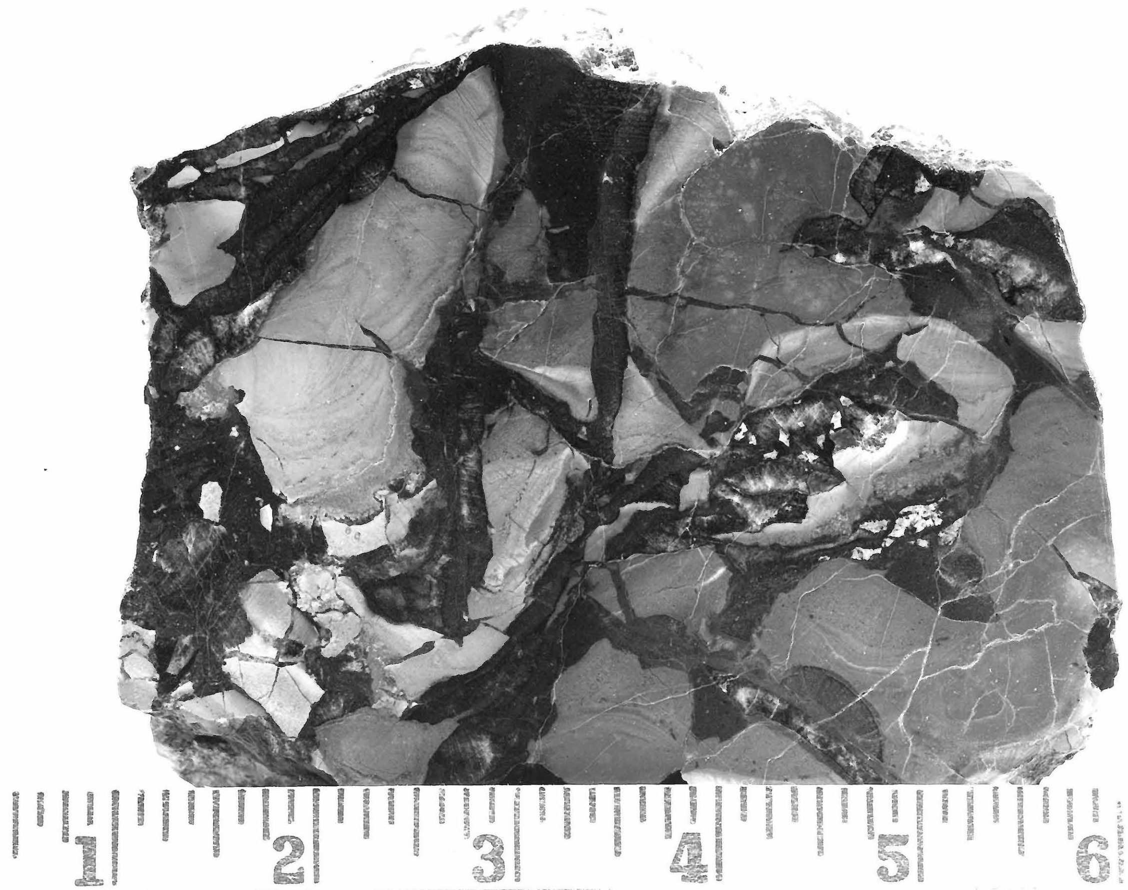

Figure 25. Polished surface of horizontal cut through rock of reef mass. Note sub-concentric banding. Scale in inches.

Figure 26. Polished surface of vertical rock cut, showing thin-shelled organisms in fine-grained matrix. Note algal banding in lower left corner. Scale in inches.

Figure 27. Photomicrograph (2X) of reef facies showing the sub-concentric banding of the algae, encrusting material of different grain size. Fine bioclastic debris occurs on the left of the picture. Note the frayed edges along margins of original limestone which is replaced by coarse calcite crystals.

Figure 28. Photomicrograph (3X) of brecciated part of reef limestone. Note small organisms in fine-grained matrix.

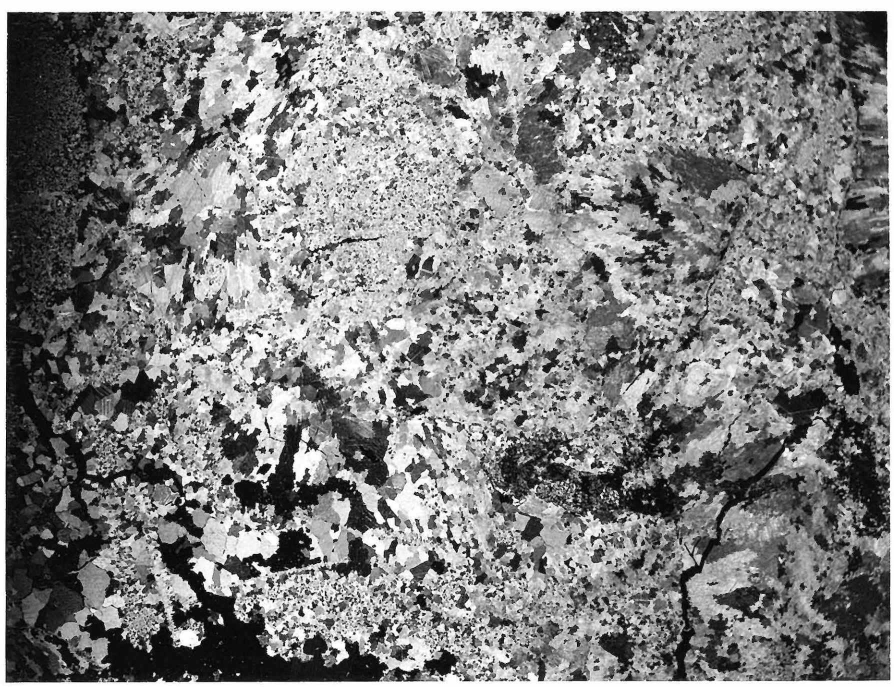

Figure 29. Photomicrograph (3X; crossed nicols) of recrystallized limestone of reef facies.

Figure 30. Cavernous weathering in recrystallized, porous parts of the reef limestone.

Figure 31. Polished surface of discontinuous dark gray fossiliferous limestone member of the post-reef facies. Scale in inches.

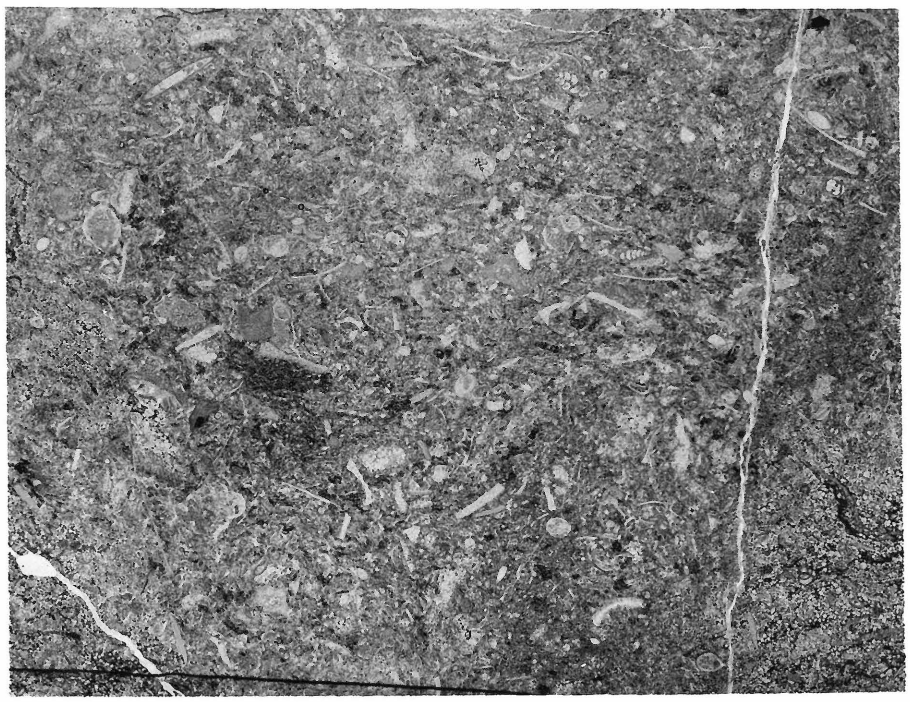

Figure 32. Photomicrograph (3X) of dark gray fossiliferous limestone.

Figure 33. Medium gray algal and fusulinid limestone. First limestone member. Scale in inches.

Figure 34. Photomicrograph (3X) of algal (<u>Anchicodium</u> sp. ?) detrital limestone. Second limestone member.

Figure 35. Fine-grained, medium gray limestone. Second limestone member. Scale in inches.

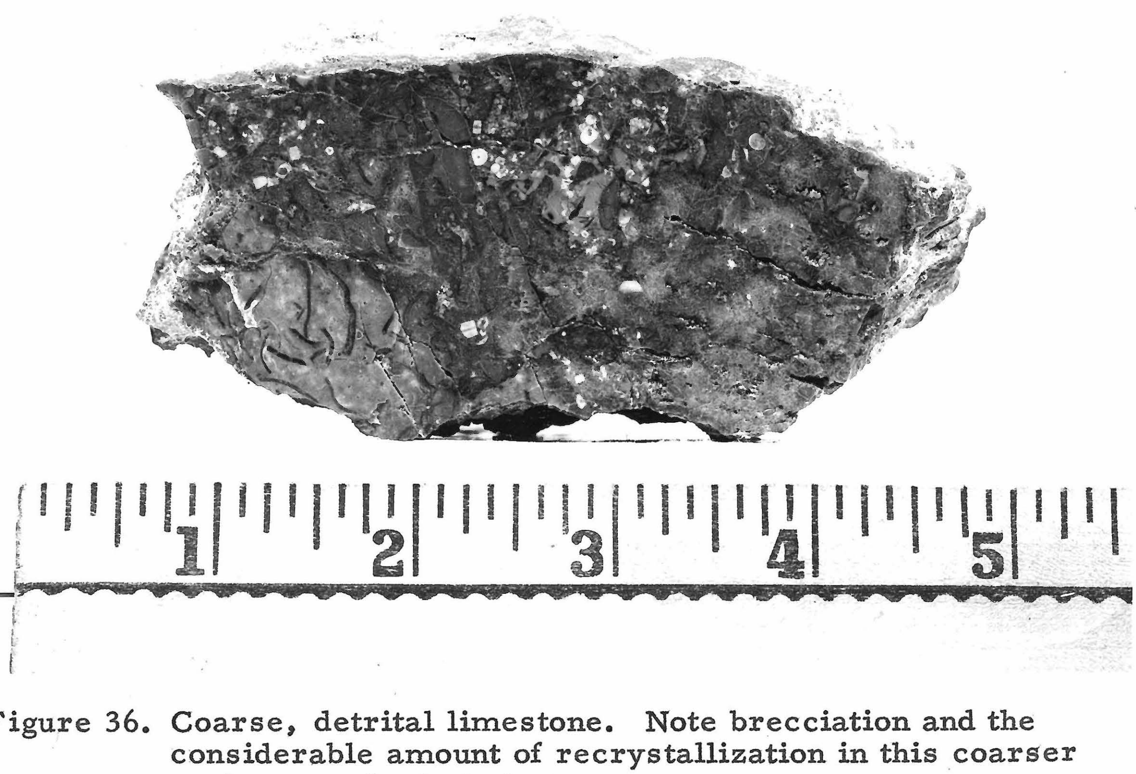

Figure 36. Coarse, detrital limestone. Note brecciation and the considerable amount of recrystallization in this coarser rock type. Scale in inches.

Figure 37. View of reef and post-reef facies looking north. Note stratification in beds of post-reef facies. NW 1/4 sec. 16, T. 14 S., R. 10 E.

Figure 38. View as Figure 37, slightly to the west.

Figure 39. Third detrital limestone member. Dark limestone is recrystallized portions. SW 1/4 sec. 16, T. 14 S., R. 10 E. Scale in inches.

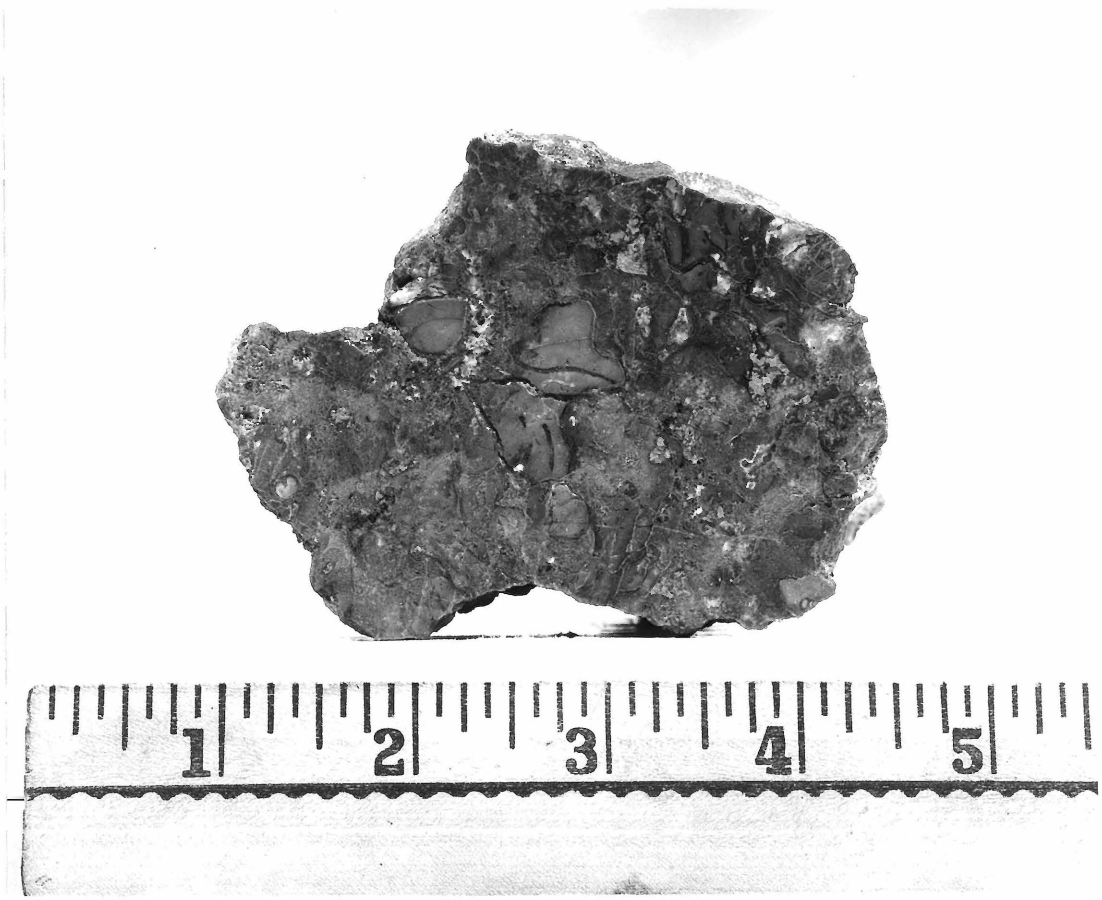

Figure 40. Third limestone member. Note similarity with rock of Figure 36.

Figure 41. Fourth limestone member. Note sub-horizontal banding by filamentous algae and _Anchicodium_ sp. (?). Dark parts are recrystallized limestone. Scale in inches.

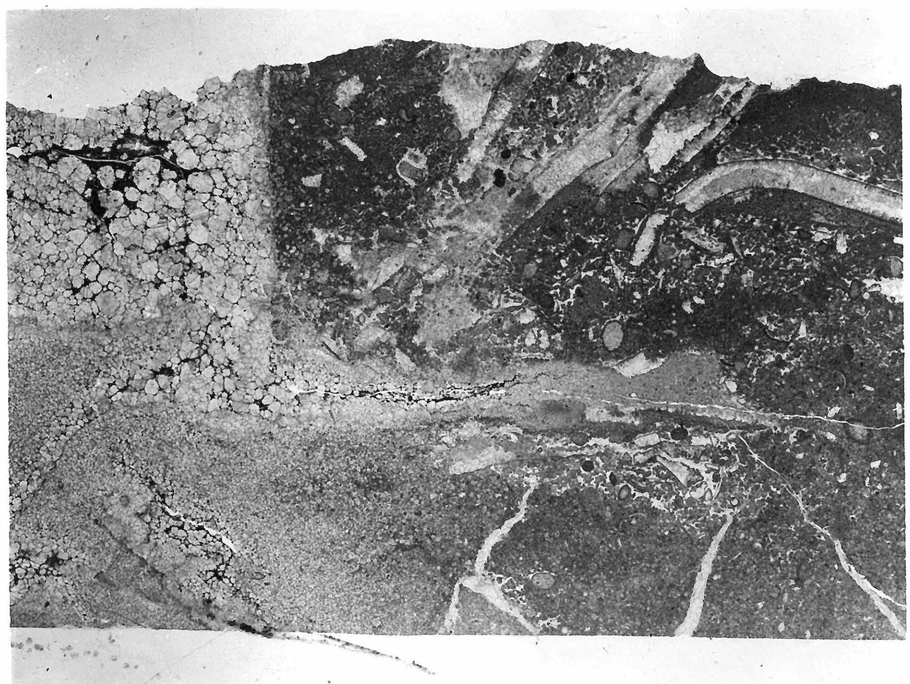

Figure 42. Photomicrograph (3X) of fourth member with Anchicodium sp. (?) in matrix of bioclastic debris. Note recrystallization on left of picture.

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