

Paleozoic Stratigraphy of the Southern Part of the Mule Mountains, Arizona

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By PHILIP T. HAYES *and* EDWIN R. LANDIS

CONTRIBUTIONS TO GENERAL GEOLOGY

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ILLUSTRATION

PLATE 1. Columnar sections of Paleozoic rock units..... In pocket

CONTRIBUTIONS TO GENERAL GEOLOGY

PALEOZOIC STRATIGRAPHY OF THE SOUTHERN PART OF THE MULE MOUNTAINS, ARIZONA

By PHILIP T. HAYES and EDWIN R. LANDIS

ABSTRACT

The Bolsa Quartzite, the Abrigo Limestone, the Martin Limestone, the Escabrosa Limestone, and the Naco Group, all of Paleozoic age, were named for exposures in the Mule Mountains. Type sections or principal reference sections for the pre-Pennsylvanian formations are described in detail for the first time.

The Bolsa Quartzite, 344 feet thick at its type section in the Mule Mountains, is of Middle Cambrian age and represents near-shore deposition in a sea transgressing from the southwest. The marine Abrigo Limestone of Middle and Late Cambrian age conformably overlies the Bolsa. It is 713 feet thick at its type section, where it is subdivided into four members. The Martin Limestone, whose disconformable basal contact is here revised slightly from earlier usage, is 460 feet thick at its type section and 405 feet thick at its principal reference section. The Martin represents marine deposition during Late Devonian time. The marine Escabrosa Limestone of Mississippian age is informally divided into two members at its principal reference section where it is 735 feet thick. Only the three lower formations of the Naco Group are present in the Mule Mountains. These are the Horquilla Limestone of Middle and Late Pennsylvanian age, 1,221 feet thick where measured in the Naco Hills; the Earp Formation of Late Pennsylvanian and Early Permian age, 350 to 595 feet thick; and the Colina Limestone of Early Permian age, at least 495 feet thick. The Horquilla and Colina consist dominantly of marine limestone whereas the Earp contains a high percentage of red beds probably also deposited in a shallow marine environment.

INTRODUCTION

PURPOSE AND SCOPE OF REPORT

This report is based on stratigraphic data gathered while we mapped the geology of the southern part of the Mule Mountains in Cochise County, Ariz. (pl. 1). It is recommended that the geologic map (Hayes and Landis, 1964) be used as a companion publication. The report contains much more detailed descriptions of type and reference

sections of Paleozoic rocks of the area than have been published previously. Eight columnar sections are presented on plate 1. Three of these are presented as selected stratigraphic sections on pages F32-F41. Included also are interpretations of conditions of deposition, age, and regional correlations of the various rock units.

PRESENT WORK AND ACKNOWLEDGMENTS

Fieldwork for the present study, including geologic mapping (Hayes and Landis, 1964), was done by Hayes and Landis during 2 months in the spring and 2 months in the fall of 1960, and was completed by Hayes during an additional 2 months in the spring of 1961. Curt Teichert assisted in the study of Devonian rocks for 3 days in the fall of 1960, and Robert B. Raup aided in the measurement of a stratigraphic section in 1961. All stratigraphic sections were measured with an Abney hand level mounted on a Jacobs staff, supplemented by steel tape.

Office work on Paleozoic rocks included the study of more than 100 thin sections that were prepared by M. M. Cochran and by N. D. Taylor. James Thomas determined lime and magnesia content of 132 samples of carbonate rock by the versenate method. Paleontologic work was done by several U.S. Geological Survey paleontologists who are credited within the report.

We are grateful to the Phelps-Dodge Corp. and the many individual property owners in the area who freely granted access to their property.

EXPLANATION OF TERMS USED

Many rock names, as well as some of the parameters employed in describing rock characteristics, are used so variably that it is desirable to define some of the terms used in this report.

Rock names.—Nouns used as rock names are kept to a minimum. For the most part, only the simplest terms such as limestone, dolomite, sandstone, and siltstone are used and these need no definition. Adjectives rather than restricting nouns are mostly used to further describe the rock types. Names in this report that may need definition are marl, quartzite, and hornfels. "Marl" as used here is a rock consisting of between one-third and two-thirds each of clay minerals and finely divided carbonate. "Quartzite" describes a sandstone, consisting predominantly of quartz, that has been recrystallized to such an extent that when broken, the rock fractures across rather than around individual sand grains. "Hornfels" is mudstone or claystone that has been very mildly metamorphosed but which shows no schistosity.

Carbonate rock descriptions.—The carbonate rock classification of Leighton and Pendexter (1962) is used herein because it is easily

adaptable to both field and laboratory, is descriptive rather than genetic, utilizes well-known adjectives for the most part, and avoids the use of complicated new nouns for carbonate rocks of slightly different textures. Inasmuch as the terms of Leighton and Pendexter are largely self-explanatory and their grain-size classification conforms closely to the well-known Wentworth (1922) scale, their classification is not described here.

Quartzose and siliceous.—In this report, “quartzose” describes a rock in which the detrital grains consist mostly of quartz, whereas “siliceous” refers to one whose cementing material consists dominantly of quartz. “Quartzose” thus implies the presence of allogenic quartz, whereas “siliceous” implies the presence of authigenic quartz.

Bedding thicknesses.—Thicknesses of beds usually are given in feet or inches. Terms such as “thin bedded” and “thick bedded” are used here to mean relatively thin bedded or relatively thick bedded as compared to bedding in adjacent rock units.

Rock colors.—Rock-color names conform approximately to those in the “Rock-Color Chart” (Goddard, 1948). In general, rock colors are given for both fresh fractures and weathered surfaces, but where fresh and weathered surfaces have very nearly the same color, only one color name is given.

GEOLOGIC SETTING

GEOLOGIC STRUCTURE

The Mule Mountains have been described as a large faulted and intruded northwest-trending anticline (Ransome, 1904). Parallel or coincident with the anticlinal axis is the Dividend fault (Ransome, 1904, p. 85; Hayes and Landis, 1964), along which major movement took place after deposition of the Paleozoic rocks and before intrusion of the Juniper Flat Granite of Jurassic age. Vertical displacement on the fault was probably as great as 5,000 feet. On the upthrown block northeast of the Dividend fault, the Paleozoic rocks were removed by pre-Cretaceous erosion, and Cretaceous rocks there rest on Precambrian rocks and on the Juniper Flat Granite.

On the downthrown block southwest of the Dividend fault, the surface rocks are mainly Precambrian and Paleozoic rocks that have been intricately faulted and intruded by satellite dikes of the Juniper Flat Granite and later intrusive bodies. Most of the faults involving the Paleozoic rocks in the southwest part of the Mule Mountains trend either northwest or northeast and are older than the Juniper Flat Granite. The faulting is of such magnitude and complexity that stratigraphic horizons cannot be traced far laterally. There are few well-exposed stratigraphic sections of as much as several hundred feet that are not faulted.

PRE-PALEOZOIC ROCKS

Rocks older than Paleozoic in the southern part of the Mule Mountains are mostly assigned to the Pinal Schist, named by Ransome (1903, p. 23) for exposures in the Pinal Mountains about 135 miles north-northwest of the Mule Mountains. Two small masses of hornblende-quartz diorite that intruded the Pinal Schist on the west side of the Mule Mountains were assigned a Precambrian age by Gilluly (1956, p. 11-12).

The Pinal Schist is not as resistant to erosion as the overlying Cambrian Bolsa Quartzite or the Juniper Flat Granite, which are most commonly in contact with it. The Pinal consists of an unknown thickness of drab yellowish-gray, light-olive-gray, greenish-gray, and pale-yellowish-brown, imperfectly foliated fine-grained quartz-muscovite schist and subordinate amounts of quartz-muscovite-chlorite schist, quartz-muscovite-albite schist, and slightly schistose micaceous quartzite. The Pinal probably was formed by the regional metamorphism of a thick series of impure arenaceous geosynclinal sediments.

Sedimentary rocks of the Apache Group of Precambrian age, which are present between the Pinal Schist and Cambrian rocks in the Little Dragoon Mountains (Enlows, 1941, p. 249; Cooper and Silver, 1964) about 40 miles to the north, are not now present at the surface in the Mule Mountains. Whether or not they were once there is unknown.

POST-PALEOZOIC ROCKS

Post-Paleozoic rock units in the southern part of the Mule Mountains include the Juniper Flat Granite of Jurassic age, the formations of the Bisbee Group of Early Cretaceous age, intermediate to acidic intrusive rocks of presumed Tertiary age, and unconsolidated or poorly consolidated alluvial deposits of late Tertiary and Quaternary age.

The Juniper Flat Granite is intrusive into late Paleozoic rocks (Gilluly, 1956, p. 54; Hayes and Landis, 1964) and is unconformably overlain by the Bisbee Group; thus it can be dated geologically as probably Triassic or Jurassic. The potassium-argon and rubidium-strontium ages of biotite samples from the Juniper Flat are 163 and 177 (average) million years, respectively (Creasey and Kistler, 1962, p. 1); these figures indicate an Early Jurassic age.

The Bisbee Group, subdivided into the Glance Conglomerate, Morita Formation, Mural Limestone, and Cintura Formation, overlies all older rocks with pronounced unconformity; local relief is measurable in hundreds of feet (Ransome, 1904, p. 57-58; Hayes and Landis,

1964). The Bisbee Group is assigned an Early Cretaceous age on the basis of fossils mainly from the Mural Limestone and stratigraphically adjacent rocks (Stanton, in Ransome, 1904, p. 70; Stoyanow, 1949).

Small dikes of intermediate composition are intrusive into the Bisbee Group in the southeastern part of the Mule Mountains (Hayes and Landis, 1964) and are assumed to be of Tertiary age. Rhyolite porphyry, which intruded upper Paleozoic rocks near the west edge of the Mule Mountains (Gilluly, 1956, p. 105; Hayes and Landis, 1964), is lithologically very similar to rhyolite porphyry mapped near Tombstone (12 miles to the north) by Gilluly (1956, p. 105). Biotite samples from the rhyolite near Tombstone has since been dated by the potassium-argon method as 63 million years old by Creasey and Kistler (1962, p. 1).

There is no evidence in the Mule Mountains of sedimentary or volcanic rocks of post-Paleozoic and pre-Cretaceous age such as are known to be present about 20 miles to the west in the Huachuca Mountains (Hayes, Simons, and Raup, 1964). Similarly, no upper Cretaceous or lower Tertiary volcanic or sedimentary rocks are in the Mule Mountains, though rocks of these ages are in many other ranges in southern Arizona and northern Sonora.

CAMBRIAN SYSTEM

BOLSA QUARTZITE

NAME AND TYPE SECTION

The Bolsa Quartzite was named by Ransome (1904, p. 28) for incomplete exposures of the formation in Bolsa Canyon on the southwest side of Escabrosa Ridge in the present study area. A section described as typical for the Bolsa Quartzite was measured by Ransome (1904, p. 29 and pl. 6A) where, or very near where, the formation is exposed in Spring Canyon in NW $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 7, T. 23 S., R. 24 E. The lower part of stratigraphic section 6 of the present report (pl. 1) is a remeasurement of that type section.

LITHOLOGY

The Bolsa Quartzite, although strongly jointed, is one of the more erosion-resistant rock units of the Mule Mountains and is markedly more resistant than the underlying Pinal Schist or the overlying Abrigo Limestone. As a result, it typically crops out as a cliff above a slope of its own debris or forms rugged blocky hills and ridges.

The Bolsa consists almost entirely of very resistant, evenly bedded yellowish- to reddish-brown-weathering grayish-red to pinkish-gray siliceous sandstone made up of rounded to subrounded grains. Shaly

siltstone partings of similar color and generally less than 1 inch thick are present at several horizons in the upper two-thirds of the formation.

The texture and composition of the sandstone change rather systematically from coarser grained and feldspathic near the base of the formation to finer grained and more quartzose at the top. Changes in bedding are less systematic. In the lower part, the sandstone is coarse to very coarse grained and many beds contain abundant granules. Rounded pebbles of quartz and quartzite are common near the base of the formation and, locally, small well-rounded cobbles of quartz as much as 4 inches in diameter are present just above the basal contact. Sandstone in the middle part of the formation is dominantly medium grained, and tends to be fine to very fine grained in the upper part. Some siltstone beds occur within a few feet of the top of the Bolsa.

Feldspar grains make up 5 to 15 percent of the clastic part of the sandstone in the lower two-thirds of the formation. Clasts of quartzite, schist, and various opaque minerals may also comprise as much as 5 percent of some beds in that part of the formation. Quartz grains, which make up the remainder of the clastic part of the rock, are virtually the sole constituent in the upper 100 feet or so of the unit.

Thicknesses of beds separated by distinct parting planes are variable within the Bolsa Quartzite. Most beds range from $\frac{1}{2}$ to 5 feet and average about 2 feet in thickness, but beds near the middle of the formation and in the uppermost part are generally thinner. Nearly all the Bolsa is distinctly laminated, the laminae ranging from 0.1 to 1 inch in thickness. The laminae are made apparent by very minor differences in color and texture. Parallel lamination is present throughout the formation, but sweeping cross-laminae are also common in the basal two-thirds of the formation and are especially conspicuous in the middle third.

Thin-section examination of five samples of Bolsa Quartzite reveals that the detrital grains of the sandstone are cemented by quartz overgrowths in optical continuity with the grains; thus, intergranular porosity is negligible. Hematite and limonite are disseminated throughout much of the quartz cement and often incompletely coat the detrital grains. Orthoclase and microcline make up most of the feldspar grains, but minor amounts of plagioclase are present in all samples studied.

THICKNESS

The thickness of the Bolsa Quartzite in Spring Canyon on the northeast slope of Mount Martin (stratigraphic section 6) is 344 feet. Ransome (1904, p. 29) reported 430 feet of Bolsa at or very near the

same locality. The reason for this disparity is not apparent. The formation, where completely preserved within the southern part of the Mule Mountains, is probably nowhere less than about 300 feet thick nor more than about 450 feet thick.

CONTACTS

The Bolsa Quartzite overlies the Pinal Schist with an unconformable contact of low relief. In many places the contact is covered by talus of the Bolsa, but where it is exposed it is sharp and easily recognized; there is no difficulty in distinguishing the strongly foliated rocks of the Pinal from the evenly bedded silicified sandstone of the Bolsa.

The Bolsa is conformably overlain by the Abrigo Limestone.

AGE AND CORRELATION

No fossils have ever been found in the Bolsa Quartzite in the Mule Mountains, to our knowledge. However, because of the upward transition of Bolsa into beds of late Middle Cambrian age in the lower part of the Abrigo Formation, Ransome (1904, p. 30) assigned a Middle Cambrian age to the Bolsa. On the basis of later work and regional considerations, Stoyanow (1936, p. 482) and Lochman-Balk (1956, p. 539) concurred with the assignment of a Middle Cambrian age to the Bolsa of the Bisbee district. That age was accepted also by Gilluly (1956, p. 15) for the Bolsa in the nearby Tombstone district.

The Bolsa Quartzite once may have been lithologically continuous with the probable homotaxial equivalent, but younger, Bliss Sandstone of southern New Mexico, as suggested by Kelley and Silver (1952, p. 55-56), Lochman-Balk (1956, p. 539-544), and Sabins (1957, p. 471-472). Mulchay and Velasco (1954, p. 630) have correlated the Bolsa with the similar Capote Quartzite of the Cananea district, about 35 miles to the southwest in Sonora, Mexico. Farther to the southwest, near Caborca, Sonora, rocks generally equivalent in age to the Bolsa are included in the Los Arroyos and El Tren Formations (Cooper and Arellano, 1956a, p. 34-36), far above the basal Lower Cambrian units in that area.

CONDITIONS OF DEPOSITION

The Bolsa Quartzite represents shallow-water near-shore deposition in a sea transgressing, apparently from the southwest, over a peneplain carved on Precambrian rocks. The upward decrease in grain size, feldspar content, and cross-lamination all indicate an increasing depth of water and greater distance from source area as Bolsa deposition progressed. The general lack of clay minerals in the matrix of the Bolsa sandstones, and of schist pebbles near the base, as well as the

relatively high percentage of rounded and subrounded quartz grains, suggests that much of the Bolsa may represent reworked sediment derived from upper Precambrian sedimentary rocks such as those that are present in the Apache Group to the north but which are no longer preserved in the present report area. It is equally possible that much of the quartz and feldspar was derived from not too distant older Precambrian granitic terranes. As Ransome (1904, p. 30) and Gilluly (1956, p. 15) have suggested, some of the quartz pebbles near the base of the Bolsa may have been derived from quartz veins in the underlying Pinal Schist.

ABRIGO LIMESTONE

NAME AND TYPE SECTION

The Abrigo Limestone was named by Ransome (1904, p. 30) from Abrigo Canyon in the southern part of the Mule Mountains where part of the formation is well exposed. Stoyanow (1936, p. 467-471) proposed that the Abrigo of the Bisbee area be restricted to the middle part of the original Abrigo as established by Ransome. The lower part of the original Abrigo was called the Cochise Formation by Stoyanow, and the upper part the Copper Queen Limestone. The base of the restricted Abrigo was marked by the lowest occurrence of two fossil species. This distinction does not constitute a usable field mapping datum, so the Cochise Formation is not recognized here. The Copper Queen, although distinctive in the Mule Mountains, has not been recognized elsewhere. It is here proposed that Stoyanow's Copper Queen Limestone, whose type area is the Copper Queen mining area of Bisbee, be considered as an upper member of the Abrigo Limestone.

The only exposure of the entire Abrigo is on the opposite side of Escabrosa Ridge from Abrigo Canyon, on the north slope of Mount Martin. The section exposed there was measured by Ransome (1904, p. 31) and is regarded as the type section. The middle part of stratigraphic section 6 of the present report (p. F38; pl. 1), measured in SW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 7, T. 23 S., R. 24 E., is a remeasurement of that section.

LITHOLOGY

For purposes of description it is convenient to divide the Abrigo Limestone of the Mule Mountains into four lithologic members: a basal shaly member, a ribbed limestone member, a sandy member, and, at the top, the Copper Queen Limestone Member.

For the most part the Abrigo is exposed in gentle slopes and on rounded hills, but the thicker limestone beds of the Copper Queen Limestone Member form rounded ledges, and, just east of Black Gap,

sandstone and dolomite of the sandy member are silicified and form a prominent ledge.

Shaly member.—The shaly member is 252 feet thick at the type locality of the Abrigo Limestone. A little more than one-third of the rock in the member is made up of light-olive-gray to grayish-orange-pink-weathering claystone, most of which exhibits contorted laminae and a crude shaly fissility. Some of the claystone is less shaly and is very calcareous. Most of the remainder of the shaly member is made up of laminated light-gray- to grayish-orange-pink-weathering medium-gray limestone. Most of this limestone consists of $\frac{1}{4}$ - to $\frac{1}{2}$ -inch laminae of relatively pure micritic limestone alternating with equally thick laminae of slightly more resistant silty and argillaceous micritic-detrital limestone conglomerate whose granule- and pebble-sized intraclasts are made up of micritic limestone. The remaining limestone consists dominantly of laminated silty micritic-skeletal limestone that contains about one-third siliceous limestone in crinkly laminae 0.1 to 0.6 inch thick. On the outcrop these siliceous laminae are generally rusty brown to tan and stand out in relief from the non-siliceous limestone. A minor amount of laminated micritic-pellet limestone is in the member. In the basal 10 feet of the member there are a few very thin beds of siliceous siltstone like that in the upper part of the underlying Bolsa Quartzite.

Ribbed limestone member.—Conformably overlying the basal shaly member of the Abrigo Limestone is a ribbed limestone member composed of interbedded limestone and limestone edgewise conglomerate both of which are interlaminated with variable amounts of more resistant light-brown-weathering siliceous limestone and silty limestone in $\frac{1}{4}$ - to $\frac{1}{2}$ -inch crinkly laminae. The member is 201 feet thick at the Abrigo type section on Mount Martin. More than half the member is light-gray-weathering medium-gray silty laminated micritic-skeletal limestone. Most of the rest of the member consists of mottled-light-gray to light-olive-gray-weathering mottled-grayish-orange-pink to medium-light-gray, partially recrystallized detrital-micritic limestone and micritic-detrital limestone edgewise conglomerate. The detrital particles in the detrital-micritic limestone and in the edgewise conglomerate are intraclasts of micritic limestone. Glauconite, partially altered to hematite, rims some of the clasts in the detrital-micritic limestone.

Sandy member.—The sandy member of the Abrigo Limestone, typified by glauconitic cross-laminated sandstone and dolomite and a little marl, is apparently about 166 feet thick in the Mount Martin section where it is slightly faulted and very poorly exposed. The same general thickness for the member is maintained elsewhere in the area

where exposures are better. The following description of the member is based on observations throughout the mountains rather than on the Abrigo type section: The member is marked at the base by a 35- to 50-foot-thick slope-forming unit of interlaminated calcareous sandstone and limestone in irregular 1- to 3-inch-thick beds. The laminae are 0.1-0.6 inches thick. The sandstone laminae are made up of light-olive-gray and brownish-gray, fine to very fine grained glauconitic quartz sand cemented by calcite; the limestone laminae are made up of olive-gray, partially recrystallized glauconitic micritic limestone. The rock is pale to moderate yellowish brown on the outcrop. The remainder of the member consists dominantly of interbedded cross-laminated mottled light-brown and olive-gray sandy dolomite and cross-laminated olive-gray dolomite-cemented glauconitic quartz sandstone. Locally present are interbeds of dolomitic marl and partially recrystallized detrital-micritic-pellet dolomitic limestone which contains minor amounts of glauconite around recrystallized ovoid pellets.

Copper Queen Limestone Member.—In the type section of the Abrigo Limestone, the Copper Queen Limestone Member is about 94 feet thick whereas at Black Gap (stratigraphic section 7) it is absent altogether. The member is made up of thin-bedded laminated medium-gray to pinkish-gray limestone in the type section. The basal 25 feet of the member is medium to coarse crystalline and contains laminae of brown-weathering medium-gray siliceous limestone; the next 15 feet forms the base of a prominent rounded ledge and consists of partially recrystallized detrital-micritic limestone containing sandy laminae; the next 30 feet forms the upper part of a ledge and consists of stylolitic laminated detrital-micritic limestone whose detrital fragments consist of sparry calcite and micrite; and the top 24 feet, which is rather poorly exposed, contains laminae of argillaceous limestone and a few thin beds of chert.

The upper contact of the Abrigo Limestone as described here is about 70 feet below that used by Ransome (1904, p. 32), who used the top of a bed of pure white quartzite. Our reasons for revising the contact are explained on pages F15-F17.

THICKNESS

The thickness of the Abrigo Limestone was measured only on the northeast slope of Mount Martin (stratigraphic section 6) where it is about 713 feet thick. That thickness agrees closely with the 770 feet reported by Ransome (1904, p. 31) at the same locality, inasmuch as we are using an upper contact about 70 feet below that used by Ransome. At Black Gap (stratigraphic section 7) where the Copper Queen Limestone Member is missing, the Abrigo may be as much as

100 feet thinner than at Mount Martin. Gilluly (1956, p. 20) reported thicknesses ranging from 749 to 844 feet for the Abrigo at several localities farther north in Cochise County.

CONTACTS

The contact between the Abrigo Limestone and the underlying Bolsa Quartzite is conformable and gradational, but nevertheless is generally rather sharply defined as the horizon at which dominant silicified siltstone and sandstone below gives way to a 40- to 50-foot-thick unit of thinly interbedded claystone and argillaceous limestone that has minor siliceous siltstone in the basal 10 feet. The contact can be determined from a distance as approximately at the top of a ledgy brown cliff-forming unit below a yellowish-brown slope-forming unit.

The Abrigo is overlain disconformably by the Martin Limestone of Devonian age.

AGE AND CORRELATION

The Abrigo Limestone is of Middle and Late Cambrian age. Ransome (1904, p. 33; 1916, p. 146) considered the formation to be of Middle Cambrian age, but Stoyanow (1936, p. 466-471) demonstrated that a large part of it is Late Cambrian. Fossils collected by Josiah Bridge, R. S. Cannon, Jr., and W. H. Hass in 1938 from the Abrigo type section on Mount Martin were reported on by A. R. Palmer (in Gilluly, 1956, p. 23) who identified both Middle and Upper Cambrian fauna. The fossils identified by Palmer are listed below and, based on examination of the field notes of Bridge, are keyed to the Mount Martin section of the Abrigo as remeasured during the present investigation (stratigraphic section 6).

Fauna, by zones, in Mount Martin section (p. F37 and pl. 1)

[Numbers are those assigned to the U.S. Geological Survey's collections. Brachiopods and problematica are marked with an asterisk]

Late Cambrian (Franconia age):

Ptychaspis zone:

USGS 651-CO (probably from unit 4):

"Aagnostus" parilis Hall

Drumaspis sp.

Ellipsocephaloides? sp.

Maladia sp.

Pseudagnostus sp.

Prosaukia? sp.

Wilbernia sp.

**Billingsella* sp.

Late Cambrian (Dresbach age) :

Crepicephalus zone :

USGS 650-CO (probably from unit 6) :

Coosella sp.*Coosia* cf. *C. connata* (Walcott)*Crepicephalus* sp.*Tricrepicephalus* sp.**Kinsabia* sp.

USGS 649-CO (probably from unit 8) :

Coosella sp.*Crepicephalus* sp.*Kormagnostus* cf. *K. simplex* Resser*Meteoraspis* cf. *M. borealis* Lochman*Tricrepicephalus* cf. *T. coria* (Walcott)*Tricrepicephalus* cf. *T. texana* (Shumard)*Cedaria* zone :

USGS 648-CO (from near top of unit 11) :

Cedarina cf. *C. cordillerae* (Howell and Duncan)*Kormagnostus* cf. *K. simplex* Resser*Meteoraspis* cf. *M. borealis* Lochman*Semnocephalus centralis* (Whitfield)

USGS 647-CO (from unit 11) :

Albansia? cf. *A.? montanensis* (Howell and Duncan)*Cedarina* cf. *C. cordillerae* (Howell and Duncan)*Coosella* sp.*Meteoraspis* cf. *M. borealis* Lochman**Kinsabia* sp.

USGS 646-CO (from unit 11) :

Ankoura? sp.*Kingstonia* sp.

Middle Cambrian :

USGS 645-CO (from near base of unit 11) :

Eldoradia sp.

USGS 644-CO (from unit 12) :

Bolaspidella sp.

USGS 643-CO (probably from unit 13) :

Bolaspidella sp.*Ehmania* sp.

The listed fossils from the Mount Martin section indicate that the shaly member of the Abrigo Limestone is Middle Cambrian age. The boundary between the Middle and Upper Cambrian is low in the ribbed limestone member. The boundary between the Dresbachian and Franconian Stages of the Upper Cambrian is probably in the upper part of the sandy member, and hence the Copper Queen Limestone Member is probably entirely of Franconia age. No post-Franconia fossils have been found in the Abrigo.

Elsewhere in the Mule Mountains, several small collections of brachiopods and trilobites from the Abrigo Limestone were taken from the upper part of the sandy member and from the Copper Queen

Limestone Member. These collections, which were examined by A. R. Palmer (written commun., 1961), confirm a Franconia age for the Copper Queen Limestone Member and the uppermost part of the underlying sandy member.

In southwestern New Mexico, the Bliss Sandstone, whose lower part is of Franconia age (Flower, 1953, p. 2055) and thus probably equivalent in age to the upper part of the Abrigo, rests directly on Precambrian rocks. Rocks equivalent in age to the lower part of the Abrigo apparently were not deposited there. The Abrigo is known definitely only as far west as the Patagonia Mountains (F. S. Simons, oral commun., 1963), about 40 miles distant, but to the northwest has been identified as far as 150 miles distant in the Vekol Mountains (McClymonds, 1959, p. 77-78). To the southwest about 35 miles, near Cananea, Sonora, Mexico, the Esperanza Limestone is considered to be an equivalent of the Abrigo (Mulchay and Velasco, 1954, p. 630).

CONDITIONS OF DEPOSITION

The Abrigo Limestone represents deposition in somewhat deeper water and farther seaward than the transgressive sands preserved as the Bolsa Quartzite. The generally thin laminations and fine texture of most of the sediments in all but the sandy member of the Abrigo and the common presence of glauconite probably indicate slow deposition in quiet water of moderate depth, but the common intraformational and edgewise limestone conglomerates, also present, seem to indicate that the bottom sediments were occasionally agitated either by storm waves or by strong currents. The somewhat coarser sediments and dominant cross-lamination of the sandy member may indicate deposition in a temporarily shallower water environment that prevailed during a minor regressive-transgressive pulse near the end of Abrigo time.

The fact that the Abrigo is thinner and sandier northward and eastward from the Mule Mountains suggests a source area in those directions.

PRE-LATE DEVONIAN UNCONFORMITY

The unconformity between the Abrigo and Martin Limestones is one of low relief. Although the top of the Abrigo apparently is of Franconia age everywhere within the report area, lithologic evidence indicates local removal of the Copper Queen Limestone Member of the Abrigo before deposition of the Martin. Regionally, there is distinct evidence of erosion on top of the Abrigo. Rocks of Franconia and latest Dresbach age at the top of the Abrigo are missing altogether beneath the Martin Limestone in French Joe Canyon in the

Whetstone Mountains about 35 miles to the northwest (A. R. Palmer, written commun., 1964).

In the Mule Mountains, the unconformity represents latest Late Cambrian, Ordovician, Silurian, Early Devonian, and all or most of Middle Devonian time. Whether rocks of any of these ages were ever present in the Mule Mountains is unknown. Epis and Gilbert (1957, p. 2228) described several hundred feet of marine limestone identified as the Lower Ordovician El Paso Limestone conformably overlying Cambrian rocks in the southern Swisshelm Mountains, about 25 miles northeast of the Mule Mountains. It seems reasonable, therefore, to expect that the El Paso once extended across the area of the present Mule Mountains. Rocks of Middle Ordovician age, however, are not present within hundreds of miles of the Mule Mountains and probably were never deposited there. The nearest known exposures of Upper Ordovician rocks are in the Peloncillo Mountains (Gillerman, 1958, p. 24), about 80 miles to the northeast, and the nearest Silurian rocks are in the vicinity of Silver City, N. Mex. (Pratt and Jones, 1961, p. 490) about 135 miles to the northeast. In those areas, there is apparently no indication of nearby shorelines, so it is quite possible that Upper Ordovician and (or) Silurian rocks once covered the area of the present Mule Mountains but were subsequently removed, probably during Early and Middle Devonian time.

DEVONIAN SYSTEM

MARTIN LIMESTONE

NAME AND TYPE SECTION

The Martin Limestone was named by Ransome (1904, p. 33) for its complete exposures on the north slope of Mount Martin in the southern part of the Mule Mountains. The upper part of stratigraphic section 6 of the present report (p. F37; pl. 1) was measured in $SE\frac{1}{4}SE\frac{1}{4}$ sec. 7 and in $NE\frac{1}{4}NE\frac{1}{4}$ sec. 18, T. 23 S., R. 24 E., and is a remeasurement of the type section of the Martin. Inasmuch as the type section of the Martin is not well exposed, a much better section, here designated as the principal reference section (stratigraphic section 3, p. F34; pl. 1), was measured in $SW\frac{1}{4}SE\frac{1}{4}$ sec. 9, T. 23 S., R. 22 E.

LITHOLOGY

The Martin Limestone is generally weakly resistant to erosion and typically crops out in slopes beneath cliffs of the overlying Escabrosa Limestone. Some limestone and dolomite beds in the middle and upper parts of the Martin, however, form thin but locally conspicuous ledges.

Although no attempt was made to subdivide the Martin into either

formal or informal members in the southern part of the Mule Mountains, it is convenient, for descriptive purposes, to consider the Martin as consisting of three parts: a sandy and dolomitic lower part, a fossiliferous middle part, and an unfossiliferous and dolomitic upper part.

The lower part, 50–100 feet thick, consists dominantly of olive-gray-weathering sandy and silty dolomite and subordinate calcareous or dolomitic siltstone and sandstone. Poorly exposed dolomitic marl is locally present, as is medium- to coarse-grained quartzose sandstone.

The middle part, generally more than 200 feet thick, consists of variably bedded medium- to dark-gray limestone and poorly exposed marl and calcareous siltstone. Most of the limestone is abundantly fossiliferous and is characterized by a variety of silicified colonial corals and brachiopods of the genus *Atrypa*. Under the microscope nearly all the limestone shows a micritic-skeletal or skeletal-micritic fabric. Limestone from higher in the middle part tends to be dolomitic throughout the Mule Mountains and most of the middle part has been dolomitized south and east of Black Gap, but is still recognizable by virtue of the silicified corals and brachiopods.

The top 50–100 feet of the Martin Limestone in most places is covered by debris from the overlying Escabrosa Limestone, but seems to consist dominantly of thin-bedded medium- to light-gray and pinkish-gray, fine- to medium-grained unfossiliferous dolomite.

THICKNESS

At its type locality on the northeast slope of Mount Martin (stratigraphic section 6), the Martin Limestone is 460 feet thick. This thickness includes 72 feet of beds at the base that Ransome (1904, p. 37) did not include in his measurement (340 ft) of the formation at about the same locality. In a section measured 4 miles west of the type section near the west edge of the Mule Mountains (stratigraphic section 3), the Martin is about 405 feet thick. In a third section measured about 4 miles southeast of the type section near Black Gap (stratigraphic section 7), where the middle part of the Martin seems to be relatively thin, a thickness of 289 feet was measured. These thicknesses are all slightly greater than those reported by Gilluly (1956, p. 29). At least some of the difference is attributable to the fact that we place the basal contact somewhat lower than did Gilluly.

CONTACTS

Revision of lower contact.—The contact between the Martin Limestone and the underlying Abrigo Limestone at their type section on Mount Martin (stratigraphic section 6) is here placed 70 feet lower

than Ransome's (1904, p. 32) contact on the basis of lithologic correlation with fossiliferous beds in stratigraphic section 3, measured in the western part of the Mule Mountains.

Stratigraphic section 3, measured about 4 miles west of the Mount Martin section, contains a light-colored cliff-forming limestone and dolomite unit about 33 feet thick that is overlain by 11 feet of soft-weathering thin-bedded cherty dolomite. These rocks are underlain by a partly exposed slope of brown-weathering sandy dolomite and are correlated unhesitatingly with the Copper Queen Limestone Member of the Abrigo Formation as recognized in the Mount Martin section. Stoyanow (1936, p. 470-471) found the brachiopod *Billingsella coloradoensis* near the base of the Copper Queen at Mount Martin, and near the base of the Copper Queen at stratigraphic section 3 we found trilobites representing the genera *Saratogia* and *Ptychaspis* (identified by A. R. Palmer, written commun., 1961). These fossils are typical of the Franconian Stage of the Upper Cambrian (A. R. Palmer, written commun., 1961).

The basal rocks assigned to the Martin in section 3 (unit 43) are 12 feet of poorly exposed beds that yielded no fossils but are not unlike rock in the overlying unit that contains *Platyrachella* and *Grammysia*? (see p. F18) of definite Devonian age. The rock in which these fossils were found (unit 42) is brown-weathering, partially cross-laminated, somewhat sandy dolomite that may correlate with the silty dolomite noted at Mount Martin (unit 15 of the Martin Limestone).

In his definition of the Martin and Abrigo Limestones, Ransome (1904, p. 30-42) placed the contact in the Mount Martin section on top of a bed of "pure white quartzite" which he described as a persistent stratum of variable thickness that locally grades downward into upper sandy limestones of the Abrigo. Stoyanow (1936, p. 470-471) examined the Mount Martin section and accepted the quartzite bed as the top of the Cambrian sequence. He stated that the "quartzite in places grades laterally into a sandstone in which poorly preserved brachiopods of Cambrian aspect have been found." No quartzite bed similar to that at Mount Martin is present in stratigraphic section 3. About half a mile from that section, however, in SW $\frac{1}{4}$ sec. 10, T. 23 S., R. 23 E., a sandstone bed very similar to the quartzite of Mount Martin in color, texture, and composition (it differs only in degree of silicification) is present about 18 feet above a bed correlated unquestionably with the brown-weathering sandy dolomite that yielded *Platyrachella* in stratigraphic section 3.

On the basis of lithologic correlation between our stratigraphic section 3 and the section on Mount Martin, we believe that the contact between Cambrian and Devonian rocks at Mount Martin is at the top

of the 24-foot-thick sequence of thin-bedded cherty limestone that overlies the light-colored cliff-forming limestone. This contact is about 70 feet below the top of the quartzite that formerly was believed to mark the contact. The revision of the contact seems to disregard the fact that Stoyanow (1936, p. 470-471) reported that the quartzite of Mount Martin grades laterally into sandstone in which poorly preserved brachiopods of Cambrian aspect occur; however, Stoyanow did not give any locations where the gradation occurs or where the brachiopods were found, nor were the brachiopods identified. Inasmuch as there are faults both to the northwest and southeast of the Mount Martin section, we consider it likely that the brachiopods of Cambrian aspect were found across a fault in one of the brachiopod-bearing sandstone beds beneath the upper limestone of the Abrigo.

Upper contact.—The contact between the Martin Limestone and the Escabrosa Limestone is probably disconformable; it is described on page F21.

AGE AND CORRELATION

The Martin Limestone of the Mule Mountains was considered by Williams (in Ransome, 1904, p. 42) to be of probable Middle Devonian age. Kindle (in Ransome, 1923, p. 7-8) considered it to be mostly Late Devonian, as have all later workers. The fossil fauna of the Martin in the Bisbee area was described in some detail by Williams (in Ransome, 1904, p. 35-42). Fossils collected during the present investigation from section 3 measured near Spring Creek were identified by W. A. Oliver, Jr. (written commun., 1961) and by J. T. Dutro, Jr. (written commun., 1961). Their determinations follow.

Fauna in Spring Creek section (stratigraphic section 3)

[Fossils marked with an asterisk were identified by J. T. Dutro, Jr.; all others by W. A. Oliver, Jr.]

USGS 6366-SD (from unit 13) :

Amphipora? sp.

Thamnoporoid corals

USGS 6362-SD (from unit 16) :

"*Pachyphyllum*" or "*Phillipsastraea*" sp.

Alveolites sp.

Thamnopora sp.

USGS 6361-SD (from unit 17) :

Hexagonaria sp.

"*Pachyphyllum*" sp.

Alveolites sp.

Thamnopora sp.

USGS 6365-SD (from unit 19) :

Alveolites sp.

Thamnoporoid corals

"*Pachyphyllum*" sp.

USGS 6365-SD (from unit 19)—Continued

"*Phillipsastraca*" sp.

**Nervostrophia?* sp.

**Atrypa* aff. *A. devoniana* Webster

USGS 6360-SD (from unit 23) :

"*Pachyphyllum*" sp.

**Cyrtospirifer* cf. *C. placitus* Stainbrook

**Spinatrypa* sp.

USGS 6359-SD (from unit 27) :

Cyathophylloid horn coral

**Dowvillina* sp.

USGS 6358-SD (from unit 29) :

Cyathophylloid horn corals

**Atrypa* aff. *A. devoniana* Webster

**Spinatrypa* aff. *S. trulla* (Stainbrook)

USGS 7250-SD (from unit 32) :

**Nervostrophia?* sp.

**Spinatrypa* sp.

*platyceratid gastropod, indet.

USGS 6357-SD (from unit 34) :

Macgeea sp.

Tabulophyllum? sp.

Alveolites sp.

"*Pachypora*" sp.

**Dowvillina* sp.

**Dowvillinaria?* sp.

**Atrypa* aff. *A. devoniana* Webster

**Acutatheca?* sp.

**Spinatrypa* aff. *S. trulla* (Stainbrook)

USGS 7251-SD (from unit 42) :

**Platyrachella* sp.

**Grammysia?* sp.

*Plant fragments, indet.

According to Dutro (written commun., 1961), unit 42, containing the large spiriferoid *Platyrachella*, can be correlated "with the lowermost beds of the Upper Devonian, although latest Middle Devonian is a possibility." He stated that the brachiopods in unit 34 upward through unit 19 are probably all of early Frasnian age (early Late Devonian). Oliver (written commun., 1961) assigned an early Late Devonian age to units 34 upward through unit 16 on the basis of corals. In the Spring Creek section no closely diagnostic fossils were found in the upper 180 feet of the Martin. However, a collection from within 138 feet of the top of the Martin, from unit 12 of stratigraphic section 7, east of Black Gap, contains fossils that indicate a general correlation with the Frasnian beds of the Spring Creek section (Dutro, written commun., 1961). In summary, it appears that the base of the Martin in southeastern Arizona is very nearly equivalent to the base of the Late Devonian and that the lower two-thirds to three-fourths

of the Martin is of early Late Devonian age. Whether or not the upper one-third or one-fourth of the Martin in this area contains post-Frasnian Devonian beds is unknown.

The Martin Limestone of the southern part of the Mule Mountains is nearly synchronous with the Swisshelm Formation of Epis, Gilbert, and Langenheim (1957) in the Swisshelm and Pedregosa Mountains about 25 miles northeast of the present report area. Those workers (Epis, Gilbert, and Langenheim, 1957, p. 2255) believed that the lower part of the Swisshelm, correlative with the Onate Formation of Stevenson (1945, p. 222) of central New Mexico, was older than any part of the Martin, but the discovery of *Platyrachella* near the base of the Martin in the Spring Creek section is believed by Dutro (written commun., 1961) to indicate possible correlation of the lower part of the Martin with the Onate. Most of the Martin is correlative with the Sly Gap Formation of Stevenson (1945, p. 227), but the uppermost part may be at least partially equivalent to Stevenson's Contadero Formation (1945, p. 239) and to the Percha Shale as restricted by Stevenson (1945).

Teichert (1965) divided the Martin Formation of central Arizona into the Beckers Butte Member of Early or Middle Devonian age and the Jerome Member of early Late Devonian age. Only the Jerome Member can be considered as equivalent to the Martin Limestone of the Mule Mountains.

A sequence of rocks 200–500 feet thick near Cananea, Sonora, about 40 miles to the southwest, was correlated with the Martin by Mulchay and Velasco (1954, p. 630). The Martin has been recognized also in several ranges to the west and northwest of the Mule Mountains.

CONDITIONS OF DEPOSITION

The Martin Limestone of the Mule Mountains almost certainly represents the deposits of a shallow shelf sea. The cross-laminated dolomite and lenticular sandstone beds of the lower part of the formation may represent the transgressive phase of deposition in that sea. Huddle and Dobrovolny (1952, p. 83) summarized existing knowledge of the Martin in east-central Arizona and suggested that the Martin was deposited in a sea that advanced from a geosyncline in Mexico. Their view is strengthened by the more recent recognition by Cooper and Arellano (1956b, p. 46–47) of a sequence at least 280 meters (920 ft) thick of Upper Devonian limestone about 20 miles west of Caborca, Sonora.

PRE-MISSISSIPPIAN DISCONFORMITY

The contact between the Martin Limestone and the overlying Escabrosa Limestone is nearly everywhere covered by debris from the

Escabrosa, but no evidence of unconformity was noted either during the present investigation or by Ransome (1904, p. 34-35). However, inasmuch as no fossils of late Late Devonian age have been found in the Martin and because the earliest Mississippian is apparently not represented in the Escabrosa, the contact between the two formations probably is a disconformity.

MISSISSIPPIAN SYSTEM

ESCABROSA LIMESTONE

NAME AND TYPE SECTION

The Escabrosa Limestone was named by Ransome (1904, p. 42) for its exposures on Escabrosa Ridge in the southern part of the Mule Mountains. Ransome (1904, p. 43) measured three sections of the Escabrosa but did not specifically designate any of them as a type section. He was aware, however, that the top of the Escabrosa is missing in one of the sections and the base is missing along a fault in another; his third section, measured "just west of Black Gap," can properly be regarded as the type section. This section was not remeasured during the present study because it seemed that post-Mississippian alteration of the limestone was excessive, but a reference section (stratigraphic section 8) was measured about three-fourths mile east of Black Gap. An excellently exposed and nearly unaltered section of the Escabrosa was measured near the west edge of the Mule Mountains in NW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 9 and SW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 4, T. 23 S., R. 23 E., and is here designated as the principal reference section (stratigraphic section 2, p. F32; pl. 1).

LITHOLOGY

The thick and massive light-colored limestone beds of the Escabrosa are very resistant and form conspicuous ledges and cliffs or prominent hills and ridges wherever the formation occurs.

Two main subdivisions of the Escabrosa Limestone are recognized in the Mule Mountains—a 600- to 650-foot-thick lower member present wherever the formation is exposed and a much thinner upper member recognized only in the western part of the mountains.

The lower member is made up of thick-bedded to massive, medium- to light-gray, crinoidal limestone that generally forms prominent ledges and cliffs 10-100 feet high separated by equally thick units of less resistant thin-bedded, commonly nodular, locally argillaceous medium- to medium-dark-gray micritic limestone. Most of the limestone has a very low magnesium content. Calcium and magnesium determinations were made of 17 samples, and of these, 15 showed only a trace of magnesium; two samples can be classified as dolomitic lime-

stone having calcite-dolomite ratios of 89:11 and 77:23. The calculated insoluble residues of the 17 samples average 2.0 percent; thin-section examination of six of these samples shows that disseminated chert constitutes nearly all of the insoluble residue. Some of the limestone is slightly argillaceous. Large nodules of chert are common in some intervals. Aside from crinoidal debris, the most conspicuous fossils are rugose corals, many of which are silicified. Scattered colonial corals are also present. The more thinly bedded, darker gray limestone units contain sparse poorly preserved brachiopods.

The upper member of the Escabrosa Limestone consists of thin-bedded medium-gray crinoidal limestone in units 5–35 feet thick separated by very poorly exposed units of about equal thickness that seem to be mostly pink- to gray-weathering nodular argillaceous and silty siliceous limestone and calcareous siltstone. Fossils, including brachiopods, bryozoans, and echinoderm remains, are moderately abundant. Five samples of limestone were analyzed for calcium and magnesium and none showed more than a trace of magnesium.

THICKNESS

The thickness of the Escabrosa Limestone was measured at two localities. About three-fourths mile east of Black Gap (stratigraphic section 8), where the upper member is apparently missing, 667 feet was measured. This thickness compares with "a thickness of a little more than 600 feet" determined by Ransome (1904, p. 43) just west of Black Gap. In stratigraphic section 2, in the west part of the Mule Mountains, about 735 feet was measured, of which 131 feet is assigned to the upper member. The upper member alone was measured across the south edge of sec. 35, T. 23 S., R. 23 E., near the south end of the Naco Hills, where it is about 66 feet thick. Variations in the thickness of the Escabrosa in the Mule Mountains probably are largely dependent on the amount of Escabrosa removed by pre-Middle Pennsylvanian erosion.

CONTACTS

The base of the Escabrosa Limestone is marked by resistant light-gray crinoidal limestone that is easily distinguished from the usually poorly exposed fine- to medium-grained dolomite near the top of the Martin Limestone. In most places the actual contact can be located only approximately because the basal limestone of the Escabrosa typically forms a resistant cliff whose base is buried by its own debris.

The contact between the Escabrosa Limestone and the overlying Horquilla Limestone is readily recognizable where the upper member

of the Escabrosa is present. Where the upper member is missing, however, and light-gray limestone of the Horquilla rests directly on light-gray limestone of the Escabrosa, the contact may be rather difficult to place with precision. Generally the Horquilla is thinner bedded, is finer grained, and is more likely to contain pink to rusty siliceous stringers. Fusulinids are a certain indication of the Horquilla. Other fossil groups are less diagnostic, but in general, crinoids and corals are more common in the Escabrosa, whereas brachiopods and bryozoans are more common in the Horquilla.

AGE AND CORRELATION

The lower member of the Escabrosa Limestone of the Mule Mountains can be correlated on both lithologic and paleontologic bases with the Escabrosa Limestone of the Tombstone area, but correlation of the upper member of the Escabrosa is less certain. In a summary of his own and earlier work on fossil collections from the Escabrosa, Williams (in Gilluly, Cooper, and Williams, 1954, p. 12) considered the formation to be of Kinderhook and Osage age (Early Mississippian) with the possibility that in a few places, including the Mule Mountains, beds of post-Osage and probably pre-Chester age might be present. The upper member of the Escabrosa Limestone, apparently present only in the western part of the Mule Mountains, bears some lithologic resemblance to the Black Prince Limestone of areas to the north (Gilluly, Cooper and Williams, 1954, p. 13). Williams (*in* Gilluly, Cooper, and Williams, 1954, p. 15) thought the Black Prince to be of late Osage or early Meramec age, but saw evidence in one collection that beds of Pennsylvanian age might be included locally in the formation. Nations (1963) has presented evidence to show that Mississippian faunal elements in the Black Prince are reworked and that the formation is, in fact, of Morrow (Early Pennsylvanian) age.

Nine fossil collections from the Escabrosa Limestone made during the present investigation are recorded below. Collections 19623-PC through 19626-PC, 19764-PC, and 19765-PC were examined by W. J. Sando (written commun., 1961), and collections 19781-PC through 19783-PC by Helen Duncan and J. T. Dutro, Jr., (written commun., 1964).

USGS 19623-PC (from unit 43 of stratigraphic section 2) :

Syringopora aff. *S. surcularia* Girty

USGS 19624-PC (from unit 41 of stratigraphic section 2) :

Vesiculophyllum sp.

USGS 19625-PC (collected in NE $\frac{1}{4}$ sec. 8, T. 23 S., R. 23 E., from lower part of upper member) :

Fenestrate bryozoa, indet.

Perditocardina sp.

Echinoderm remains, indet.

USGS 19626 PC (collected in SW $\frac{1}{4}$ sec. 4, T. 23 S., R. 23 E., from bed correlated in field with unit 22 of stratigraphic section 2) :

Dipterophyllum glans (White)
Homalophyllites cf. *H. calceolus* (White)
Rhipidomella aff. *R. jerseyensis* Weller
 Echinoderm remains, indet.

USGS 19764-PC (from unit 18 of stratigraphic section 8) :

Michelinia sp.
Vesiculophyllum sp.
Syringopora sp.
 Lithostrotionoid coral

USGS 19765-PC (from unit 19 of stratigraphic section 8) :

Syringopora surcularia Girty

USGS 19781-PC (collected in NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 8, T. 23 S., R. 23 E., from middle part of upper member) :

Cladochonus cf. *C. beecheri* (Grabau)
 Pelmatozoan material, indet.
 Echinoid spine, indet.
Dichotrypa sp.
Leioclema cf. *L. punctatum* (Hall)
 Trepostomatous bryozoan debris, indet.
Fenestella spp.
Hemitrypa? sp.
 Rhomboporoid bryozoans, indet.
 Productoid brachiopod, indet.
Tetracamera cf. *T. subcuneata* (Hall)
 Rhynchonelloid fragment, indet.
Spirifer aff. *S. tenuicostatus* Hall
Composita? sp.
Punctospirifer? sp.

USGS 19782-PC (collected in NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 2, T. 24 S., R. 23 E., from middle part of upper member) :

Cladochonus cf. *C. beecheri* (Grabau)
Amplexus, probably 2 spp.
Siphonodendron sp.
 Pelmatozoan debris, indet.
 Worm tubes, indet.
Dichotrypa sp.
Leioclema cf. *L. punctatum* (Hall)
Fenestella spp.
Hemitrypa sp.
Polypora sp.
 Rhomboporoid bryozoans, indet.
 Productoid fragment (large, "P." *viminalis*-type)
 Rhynchonelloid fragment, indet.
Spirifer aff. *S. pellaensis* Weller
Composita cf. *C. trinuclea* (Hall)
Cleiothyridina? sp.
Punctospirifer sp.
Dielsma sp.
Girtyella sp.
 "Cranaena" sp.

USGS 19783-PC (from 46-48 feet below top of Escabrosa Limestone in stratigraphic section 5) :

Cladochonus cf. *C. beecheri* (Grabau)

Amplexizaphrentis? sp. indet.

Siphonodendron sp.

Pelmatzoan debris

Dichotrypa sp.

Leioclema cf. *L. punctatum* (Hall)

Fenestella spp.

Hemitrypa sp.

?*Worthenopora spinosa* Ulrich

Spirifers sp. (like that in 19781-PC)

According to W. J. Sando (written commun., 1961), four of the small collections from the lower member of the Escabrosa of the Mule Mountains contain long-ranging forms that suggest an Early Mississippian age. One collection (19626-PC) of more definite Osage age came from a bed in the upper part of the lower member which we believe to be the same as unit 22 of stratigraphic section 2. This collection suggests that no more than 100 feet of beds at the top of the lower member of the Escabrosa is of post-Osage age; perhaps none is.

The small collection (19625-PC) from the lower part of the upper member of the Escabrosa contains fossils reported by W. J. Sando (written commun., 1961) as of probable Meramec age. The collections (19781-PC through 19783-PC) made higher in the upper member of the Escabrosa also indicate an early Late Mississippian age according to Helen Duncan and J. T. Dutro, Jr. (written commun., 1964). These paleontologists stated that the fauna is not similar to the fauna of Morrow aspect described by Nations (1963) from the Black Prince Limestone of the type area, but that it may be equivalent to the uppermost unit of the Escabrosa as interpreted by him. Duncan and Dutro further suggested that the upper member of the Escabrosa of the Mule Mountains is equivalent to the uppermost part of the Hachita Formation of Armstrong (1962, p. 10). There is little lithologic similarity between the upper member of the Escabrosa in the Mule Mountains and the type section of Armstrong's Hachita Formation in the Chiricahua Mountains, 55 miles to the northeast.

Armstrong (1962, p. 12) reported that "Beds considered to be the equivalent of the Black Prince Limestone have been found in the hills south of Bisbee near Warren." We are not able to determine from his report just where those beds are nor why they were considered to be equivalent to the Black Prince.

Huddle and Dobrovolsky (1952, p. 86) stated that in central Arizona the Escabrosa Limestone can be traced into the Redwall Limestone, which is exposed widely in central and northern Arizona.

CONDITIONS OF DEPOSITION

The shallow-water marine fossils of the Escabrosa, the nearly pure limestone that makes up most of the formation, and the widespread distribution of the Escabrosa and its correlatives in southeastern Arizona and adjacent areas indicate that the formation was deposited in clear water of an extensive but shallow sea.

PENNSYLVANIAN AND PERMIAN SYSTEMS**NACO GROUP**

The Naco Limestone was named by Ransome (1904, p. 44) for the Naco Hills in the southwestern part of the Mule Mountains. Rocks equivalent to the Naco at the type section as well as to younger Permian rocks were subsequently referred to the Naco Limestone over a wide area in southeastern Arizona. On the basis of work in central Cochise County, north of the present report area, Gilluly, Cooper, and Williams (1954, p. 16) elevated the expanded Naco to group status. Only the three lower formations of the Naco Group—the Horquilla Limestone, the Earp Formation, and the Colina Limestone—are exposed in the southern part of the Mule Mountains.

HORQUILLA LIMESTONE**NAME**

The Horquilla Limestone was named and originally described by Gilluly, Cooper, and Williams (1954, p. 16) for exposures on Horquilla Peak in the Tombstone Hills, a few miles northwest of the Mule Mountains.

LITHOLOGY

The Horquilla Limestone consists mostly of resistant ledges of limestone separated by thinner units of less resistant thin-bedded limestone and siltstone. It thus crops out in most places on steep ledgy slopes or forms irregular ridges.

In the Naco Hills the Horquilla can be divided into three informal lithologic members. These members cannot be distinguished with certainty elsewhere in the Mule Mountains but are described separately below.

Lower member.—The lower member of the Horquilla, about 600 feet thick in the Naco Hills, consists dominantly of resistant medium- to light-gray-weathering medium-light-gray to light-brownish-gray limestone mostly in beds 1–5 feet thick. Irregularly shaped light-brown-weathering chert nodules are common in many beds. The more common fossil types include fusulinids, brachiopods, bryozoans, and crinoid columnals. Solitary corals and colonial corals are occasionally

observed. The dominant textures of the limestone are skeletal, skeletal-micritic, micritic-skeletal, and micritic. Analyses for calcium and magnesium were made of eight samples of limestone: seven had calculated calcite:dolomite ratios of 100:0 and one of 92:8.

About one-third of the volume of the lower member consists of less resistant pale-red to light-pinkish-gray silty to argillaceous, limestone to calcareous dolomite that occurs mostly in beds less than 1 foot thick. Calcite:dolomite ratios were computed for two analyzed samples of this hed-hued carbonate rock; these ratios were 40:60 and 51:49.

Middle member.—The middle member of the Horquilla, about 180 feet thick in the Naco Hills, is less resistant to erosion than either the upper or lower members and is generally rather poorly exposed in slopes or saddles. Limestone makes up about two-thirds of the member and siltstone the remainder.

The limestone ranges from pale red and pinkish gray to light gray and light brownish gray on fresh fracture. Much of it is rather silty. Textures vary through various combinations of skeletal and micritic. Small irregular chert nodules occur in some beds. Most beds are less than 1 foot thick, but a few are as much as 5 feet thick. Calcite:dolomite ratios of two samples are 93:7 and 100:0.

Siltstone in the middle member is mostly very poorly exposed; it is pale red and strongly calcareous, and occurs in beds less than 6 inches thick.

Upper member.—The upper member of the Horquilla, about 440 feet thick in the Naco Hills, consists dominantly of limestone. About half of the member consists of medium-light-gray to light-brownish-gray limestone very similar to that of the lower member, and about one-fourth consists of limestone similar to that in the middle member. The remainder of the upper member consists of about equal amounts of siltstone like that in the middle member and pinkish-gray micritic-pellet dolomitic limestone in beds 4 inches to 3 feet thick. A sample of this dolomitic limestone has a calcite:dolomite ratio of 80:20.

THICKNESS

The measured thickness of the Horquilla Limestone in the Naco Hills (stratigraphic section 5, pl. 1) is 1,221 feet. Although several small faults were crossed by the line of section, we are fairly confident that beds were matched properly on opposite sides of the faults and that the measurement is reasonably accurate. Harold L. Wanless (cited by Kottlowski, 1960, p. 111-112) also measured the Horquilla in the Naco Hills and reported a thickness of about 1,240 feet. Kottlowski (1960, p. 111-112), for reasons that are not clear, assigned the top 190 feet of the Horquilla as mapped by us in the Naco Hills to the overlying Earp Formation and therefore reported the Horquilla to be

1,050 feet thick there. In the type section of the Horquilla Limestone, about 20 miles north-northwest of the Naco Hills, Gilluly, Cooper, and Williams (1954, p. 16-17) measured 999 feet of the formation and believed that probably 50-200 feet of beds at the top of the Horquilla is missing there.

CONTACTS

The disconformable contact between the Horquilla Limestone and the underlying Escabrosa Limestone is described on page F21; the transitional contact between the Horquilla and the overlying Earp Formation is described on page F28.

CONDITIONS OF DEPOSITION

The fossil fauna and sedimentary features of the Horquilla indicate that the formation was deposited in quiet waters of a shallow sea. The subordinate amounts of silt and sand in the formation probably are second- or third-cycle terrigenous sediments possibly derived from some island landmass in that sea.

EARP FORMATION

NAME

The Earp Formation was named by Gilluly, Cooper, and Williams (1954, p. 18) from exposures on Earp Hill, about 1 mile north of the Mule Mountains.

LITHOLOGY

The Earp Formation is generally weakly resistant to erosion and underlies gentle slopes or topographic saddles between the much more resistant Horquilla and Colina Limestones respectively below and above it. It does, however, contain a few resistant limestone beds that form locally conspicuous, but thin, ledges.

The Earp consists mostly of pale-red, grayish-red, or pale-reddish-brown generally calcareous siltstone and silty micritic limestone commonly in beds less than 1 foot thick. There are also minor amounts of similarly colored silty and calcareous mudstone and very small amounts of very fine grained sandstone. Some of the limestone, especially in the uppermost part of the formation, is medium light gray, brownish gray, or olive gray, and is in beds 1-5 feet thick. Much of this thicker bedded limestone is micritic-skeletal or skeletal-micritic. A conspicuous bed of olive-gray foraminiferal limestone usually can be found near the base of the formation. Near the middle of the formation, a thin unit of conglomerate composed of rounded siltstone, limestone, and chert pebbles can be found at some localities.

On the basis of lithology, the Earp Formation could be mistaken for the much thinner middle member of the Horquilla Limestone.

However, the proportion of limestone to siltstone and mudstone appears to be greater in the middle member of the Horquilla than in the Earp, and we have not observed either foraminiferal limestone or pebble conglomerate in the middle member of the Horquilla.

THICKNESS

The Earp Formation thins noticeably from northwest to southeast in the Mule Mountains. In the type section of the Earp Formation, about 1 mile north of the northwest corner of the mountains, Gilluly, Cooper, and Williams (1954, p. 20) reported a thickness of 595 feet. We measured a thickness of 537 feet at the west edge of the mountains, about 9 miles south of the type locality (stratigraphic section 1, pl. 1); 404 feet in the Naco Hills about 7 miles farther southeast (stratigraphic section 4); and 350 feet about $5\frac{1}{2}$ miles east-northeast of the Naco Hills, in SE $\frac{1}{4}$ sec. 16, T. 23 S., R. 24 E.

Our measurement of 404 feet in the Naco Hills differs from Kottowski's (1960, p. 112) reported 735-foot thickness for the formation in the same area. Kottowski, who was reporting on a section measured by Harold R. Wanless, included about 190 feet of beds in the Earp that Wanless assigned to the underlying Horquilla Limestone, but this difference cannot explain all the discrepancy.

CONTACTS

The Earp Formation is conformable with the underlying Horquilla Limestone and with the overlying Colina Limestone. Both the contacts used in mapping in the southern part of the Mule Mountains (Hayes and Landis, 1964) are arbitrary but fairly sharp. Whereas the upper part of the Horquilla is made up of an alternating sequence of slightly dominant resistant gray limestone and soft-weathering red-hued rocks, the basal part of the Earp contains very little resistant limestone. The upper part of the Earp contains considerable resistant limestone interbedded with red-hued clastic rocks, but the basal part of the Colina Limestone is almost devoid of red-hued clastic rocks.

CONDITIONS OF DEPOSITION

The Earp Formation was deposited in the same shallow sea in which the Horquilla and Colina Limestones were deposited, but during an increased influx of second- or third-cycle terrigenous sediment. The northward thickening of the formation suggests that this terrigenous sediment was probably derived from some landmass to the north.

COLINA LIMESTONE**NAME**

The Colina Limestone, originally described by Gilluly, Cooper, and Williams (1954, p. 23), takes its name from Colina Ridge, a few miles northwest of the Mule Mountains.

LITHOLOGY

The Colina Limestone is made up almost exclusively of relatively thick-bedded limestone, and thus is one of the more resistant formations in the Mule Mountains.

Most of the limestone in the Colina is strongly calcitic. Of 15 samples analyzed by versenate titration for calcium and magnesium content, 12 samples proved to be limestone, 2 dolomitic limestone, and 1 calcareous dolomite. Insoluble residues make up only a small percentage of the rock and generally consist of quartz silt and disseminated chert. Chert in the form of light-brown-weathering irregular nodules and fossil replacements is common, but not abundant, throughout most of the formation. Most of the limestone in the Colina has a micritic texture, but some detrital-micritic, detrital-skeletal-micritic, and micritic-skeletal limestone is also present. Most of the limestone in the Colina is light olive gray or light brownish gray on fresh fracture, and medium light gray on weathered surfaces. A little limestone is brownish or reddish gray. Most of the Colina Limestone is in beds 1-5 feet thick, but beds thicker than 5 feet are common in the middle part of the formation. There are a few beds less than 1 foot thick. The most abundant fossils are gastropods, bryozoans, echinoid spines, and brachiopods.

THICKNESS

In the southern part of the Mule Mountains, the Colina Limestone is unconformably overlain by Mesozoic or Cenozoic deposits, and its complete original thickness is nowhere preserved. The greatest amount apparently is preserved in the Naco Hills where about 495 feet of the formation was measured (stratigraphic section 4, pl. 1). At its type locality on Colina Ridge, about 18 miles to the north, where it is conformably overlain by the Epitaph Dolomite, the Colina Limestone is 633 feet thick (Gilluly, Cooper, and Williams, 1954, p. 24).

CONTACTS

The Colina Limestone conformably overlies the Earp Formation. The contact is arbitrarily placed where relatively thick bedded light-gray-weathering limestone becomes dominant over soft-weathering red-hued impure limestone and clastic rocks.

In the southern part of the Mule Mountains the Colina is unconformably overlain by the Glance Conglomerate of Early Cretaceous age or by alluvial deposits of late Cenozoic age.

CONDITIONS OF DEPOSITION

The lithologic characteristics and the contained fossils indicate that the Colina Limestone was deposited in quiet waters of a shallow sea.

AGE OF THE NACO GROUP IN THE MULE MOUNTAINS

The fossils, age, and correlation of the Naco Group in the nearby Tombstone area were discussed in detail by Gilluly, Cooper, and Williams (1954). The few megafossils collected during the present investigation, which were examined by E. L. Yochelson and J. T. Dutro, Jr. (written commun., 1961), confirm their conclusions on the age of the Naco Group but add very little to the detail. Fusulinids, however, were not reported on from the Tombstone area, whereas we collected them from many localities in the report area. Fusulinids from eight horizons were of value in substantiating or refining the age assignments previously made. The following identifications and comments are those of R. C. Douglass (written commun., 1960, 1961); numbers at left are USGS collection numbers:

f-21968 (from 3 ft above base of Colina Limestone in SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 22, T. 23 S., R. 24 E.):

Climacammina sp.

Triticites sp. aff. *T. ventricosus* (Meek and Hayden)

This sample suggests Early Permian age.

f-21969 (from unit 34 of stratigraphic section 1, 64 ft above base of Earp Formation):

Climacammina sp.

Bradyina sp.

Triticites spp.

This sample is of late Pennsylvanian age, Virgil equivalent.

f-21778 (from top of highest bed in Horquilla Limestone in stratigraphic section 4):

Triticites sp.

Age suggested: Late Pennsylvanian (Virgil).

f-21774 (from base of unit 26 of stratigraphic section 5, from a quarter of a mile east of line of section measurement; 796 ft above base of Horquilla Limestone):

Triticites sp. small, elongate form.

Age suggested: Late Pennsylvanian (Missouri).

f-21866 (from 5 ft below top of unit 39 of stratigraphic section 5, from 200 yds east of line of section measurement; 597 ft above base of Horquilla Limestone):

Bradyina sp.

Millerellids

Wedekindellina sp.

Age suggested: Middle Pennsylvanian (Des Moines).

f-21771 (from position of unit 48 of stratigraphic section 5, from 300 yds east of line of section measurement; about 340 ft above base of Horquilla Limestone):

Fusulina sp.

Wedekindellina sp.

Age suggested: Middle Pennsylvanian (Des Moines).

f-21864 (from unit 55 of stratigraphic section 5 from 300 yds east of line of section measurement; about 240 ft above base of Horquilla Limestone):

Millerellids

Fusulinella sp.

Age suggested: Middle Pennsylvanian (late Atoka).

f-21967 (from 5 ft above base of Horquilla Limestone in SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 22, T. 23 S., R. 24 E.):

Millerella sp.

Fusulinella sp.

This sample represents Middle Pennsylvanian age, late Atoka equivalent.

Horquilla Limestone.—Collection f-21967, which indicates a late Atoka age for the basal few feet of the Horquilla Limestone, and collection f-21778 from the top of the Horquilla, which suggests a Virgil age, substantiate Williams' (in Gilluly, Cooper, and Williams, 1954, p. 34) post-Morrow to middle Late Pennsylvanian age assignment for the formation. The boundary between Atoka and Des Moines age equivalents is bracketed by collections f-21771 and f-21864 and can be placed very near the middle of the lower member of the Horquilla. The boundary between Middle and Upper Pennsylvanian rocks is between the positions of collections f-21866 and f-21774, or probably somewhere in the middle member of the Horquilla. The division between Missouri and Virgil equivalents cannot be placed closer than between the positions of collections f-21774 and f-21778, or somewhere in the upper member of the Horquilla.

Earp Formation.—The Earp Formation of the Mule Mountains ranges in age from Late Pennsylvanian to Early Permian. Collections f-21778 and f-21969 indicate that at least the basal 64 feet of the formation at stratigraphic section 1 is Late Pennsylvanian (Virgil equivalent), and a collection of megafossils examined by E. L. Yochelson (written commun., 1961) indicates that at least the top 100 feet is Early Permian (Wolfcamp equivalent). The boundary between Pennsylvanian and Permian rocks thus lies somewhere in the middle 360 feet of the Earp in the southwestern part of the Mule Mountains. These collections confirm, in a general way, Williams' suggestions (in Gilluly, Cooper, and Williams, 1954, p. 38) for the age of the Earp at its type locality.

Colina Limestone.—The age of the Colina Limestone in the Naco Hills is Early Permian. A Wolfcamp age for the base of the formation is indicated by collection f-21968, and according to E. L. Yochelson and J. T. Dutro, Jr. (written commun., 1961) an Early Permian

age is indicated for collections 19695-PC, 19696-PC, 19697-PC, and 19698-PC made from about 250 to 300 feet above the base of Colina in secs. 22, 23, and 27, T. 23 S., R. 23 E. Williams (in Gilluly, Cooper, and Williams, 1954, p. 41) considered the Colina to be Wolfcamp and Leonard (?) in age.

SELECTED STRATIGRAPHIC SECTIONS

Escabrosa Limestone on east-facing slope of hill north of Little Dry Canyon

[Section 2, pl. 1. Base of section is in NW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 9; top of section is in SW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 4, T. 23 S., R. 23 E.]

Horquilla Limestone:

	<i>Feet</i>
Limestone, micritic-skeletal, medium- to light-gray; in ledge-forming beds 2-5 ft thick separated by thin covered intervals.....	40

Escabrosa Limestone:

Upper member:

1. Covered; crystalline limestone and rusty-weathering chert in float.....	16
2. Limestone, coarse crystalline, skeletal, medium-gray; small silicified brachiopods.....	3
3. Limestone, micritic, medium-gray, laminated; rusty-weathering chert nodules in top 2 ft.....	3
4. Limestone, crinoidal, medium-gray; in beds 1-2 ft thick; fragmental brachiopods and other fossil debris; minor pink-weathering light-gray chert; forms a weak ledge.....	4
5. Covered.....	5
6. Limestone, crinoidal, medium-gray; in beds 1-3 ft thick; fragmental brachiopods and other fossil debris; nodules and lentils of pink-weathering light-gray chert; ledgy.....	10
7. Covered.....	3
8. Limestone, crinoidal, medium-gray; in one bed.....	4
9. Covered.....	8
10. Limestone, skeletal, medium-dark-gray; crinoid debris and brachiopods; thin lentil of dark-gray chert at top.....	1
11. Covered.....	19
12. Limestone, crinoidal, medium-dark-gray; contains dark-gray chert; poorly exposed in slope.....	20
13. Limestone, crinoidal, medium-dark-gray; in beds 3 in. to 3 ft thick; scattered rugose corals; nodular and bedded light-gray chert near top; forms a weak ledge.....	17
14. Covered.....	18
Total measured thickness of upper member.....	131

Lower member:

15. Limestone, crinoidal, light-gray, massive; forms top of conspicuous ledge.....	34
16. Limestone, coarse crystalline, light-gray; forms steep slope in middle of conspicuous ledge.....	17

Escabrosa Limestone on east-facing slope of hill north of Little Dry Canyon—Con.
 Escabrosa Limestone—Continued

Lower member—Continued

	<i>Feet</i>
17. Limestone, coarse crystalline, light-gray, massive; scattered small nodules of light-gray chert; forms base of conspicuous ledge -----	10
18. Limestone, argillaceous, massive; a few 2- to 6-in. thick lentils of dark-gray chert; in slope -----	29
19. Limestone, skeletal, medium-dark-gray; in beds 3 in. to 1 ft thick; abundant echinoderm debris and bryozoans; forms a ledge -----	9
20. Limestone, argillaceous, massive; in slope -----	4
21. Limestone, skeletal, medium-dark-gray; in beds 3 in. to 1 ft thick; abundant echinoderm debris and poorly preserved fenestrate bryozoans, spiriferoid brachiopods, and horn corals; forms ledge -----	5
22. Limestone, coarse crystalline, medium-light-gray; in beds 2-10 ft thick; many silicified horn corals; forms a pronounced ledge -----	38
23. Limestone, micritic, light-gray; in thin wavy beds; imperfectly exposed in slope -----	12
24. Limestone, foraminiferal, light-gray, laminated; in one bed; a prominent ledge (marker bed located on both sides of fault having 30 ft of stratigraphic throw where crossed by line of section) -----	6
25. Limestone, crinoidal, medium-dark-gray; in beds about 1 ft thick; scattered brachiopod and mollusk fragments; a ledge-former -----	13
26. Limestone, medium-grained, medium-dark-gray; in beds about 1 ft thick; abundant rusty-weathering dark-gray chert in lenticular beds; in steep slope -----	20
27. Limestone, skeletal to micritic-skeletal, medium-dark-gray to medium-gray; in beds 1 in. to 1 ft thick; crinoidal debris and fragmental spiriferoid brachiopods; scattered nodules of dark-gray chert in basal 15 ft, more abundant chert in lenticular beds above 15 ft; imperfectly exposed in slope -----	38
28. Limestone, coarse-grained, medium-light-gray; in beds about 1 ft thick; contains scattered large nodules of medium-gray chert; in slope -----	17
29. Limestone, coarse-grained, medium-light-gray; in beds 3-10 ft thick; extremely abundant rusty-weathering medium-gray chert in laminae and nodules 6-15 ft above base, moderately abundant chert above 15 ft; forms ledges at base and top, steep slope in middle -----	53
30. Limestone, micritic, light-gray, very cherty, thin-bedded; weathers pale yellowish gray; very poorly exposed in slope -----	38
31. Limestone, micritic-skeletal, medium-gray; in beds 2-10 ft thick; scattered silicified bryozoans; scattered large lenticular nodules of pale-brown-weathering light-gray chert; forms steep slope -----	23
32. Limestone, argillaceous, medium-gray; in thin wavy beds -----	25

Escabrosa Limestone on east-facing slope of hill north of Little Dry Canyon—Con.
Escabrosa Limestone—Continued

Lower member—Continued	<i>Feet</i>
33. Limestone, skeletal, dark-gray; weathers medium gray; faintly laminated; in beds 2 in. to 2 ft thick; abundant fossil debris including scattered silicified horn corals; forms ledge-----	11
34. Covered; probably limestone like that of unit 35; in dip slope-----	14
35. Limestone, micritic-skeletal, medium-gray; in beds 3-6 in. thick; in dip slope-----	5
36. Limestone, micritic-skeletal, dark-gray; weathers light gray; in beds 3 in. to 1 ft thick; scattered silicified horn corals; forms ledge-----	12
37. Limestone, argillaceous, light-medium-gray; poorly exposed in dip slope-----	27
38. Limestone, micritic-skeletal, light- to medium-gray; in beds 1-5 ft thick; several thin lenticular beds of pale-brown-weathering light-gray chert; in dip slope-----	25
39. Limestone, crinoidal, light- to medium-gray, thick-bedded to massive; abundant horn corals and undetermined colonial fossils; forms rounded ledge-----	20
40. Limestone, coarse-grained, medium-gray; in poorly exposed slope-----	8
41. Limestone, crinoidal, medium-gray; in beds 2-5 ft thick; abundant silicified corals (USGS colln. 19624-PC from 9 ft above base); a resistant ledge-----	11
42. Limestone, coarse-grained, medium-gray, thin-bedded; in slope-----	8
43. Limestone, crinoidal, light- to medium-gray, massive; scattered silicified corals in top 5 ft (USGS colln. 19623-PC from top); forms bold cliff-----	47
44. Limestone, crinoidal, medium-light-gray; mostly covered by debris from unit 43; in slope-----	25±
Total measured thickness of lower member-----	<u>604±</u>
Total measured thickness of Escabrosa Limestone-----	<u>735±</u>
Martin Limestone.	

Martin Limestone on east-facing slope of small hill north of Spring Creek

[Section 3, pl. 1. In SW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 9, T, 23 S., R. 23 E.]

Escabrosa Limestone:	<i>Feet</i>
Limestone, crinoidal, light-gray; scattered silicified horn corals and colonial corals; forms massive rounded cliff; basal 30 ft covered by debris from overlying cliff-----	65+

Martin Limestone on east-facing slope of small hill north of Spring Creek—Con.

Martin Limestone:	Feet
1. Dolomite (calcite: dolomite=10: 90), fine-grained, light-gray, thin-bedded.....	5
2. Covered	25
3. Dolomite, calcareous (calcite: dolomite=20: 80 at 4½ ft from top), fine crystalline, very light gray to pinkish-gray; weathers yellowish gray; forms prominent ledge.....	5½
4. Dolomite, calcareous (calcite: dolomite=17: 83 at 3 ft from top), fine-grained, olive-gray; contains irregularly shaped siliceous nodules; in thin beds having indistinct parting planes.....	9
5. Dolomite, fine-grained, thin-bedded; mostly covered.....	5±
6. Siltstone, dolomitic; mostly covered.....	3±
7. Limestone (calcite: dolomite=95: 5 at 10 ft from top), skeletal-micritic, olive-gray; contains some crinoidal debris and scattered silicified horn corals; forms prominent ledge.....	18
8. Siltstone, dolomitic, poorly exposed.....	36
9. Dolomite, very fine grained, olive-gray; minor chert; in one bed..	2
10. Covered	4
11. Dolomite (calcite: dolomite=7: 93), very fine grained, olive-gray; minor chert; in one bed.....	3
12. Covered	8
13. Dolomite (calcite: dolomite=5: 95 at 10 ft from top), very fine grained, olive-gray; silicified fossils (USGS colln. 6366-SD from upper part); in beds 1-4 ft thick; forms ledge.....	12
14. Siltstone, dolomitic; weathers pale yellowish brown; poorly exposed in slope.....	9±
15. Dolomite, thin-bedded; poorly exposed in slope.....	10±
16. Dolomite (calcite: dolomite=6: 94 at 5 ft from top), silty, very fine grained; laminated in part; abundant corals in upper part (USGS colln. 6362-SD from top); thin bedded in lower half; one ledge-forming bed in upper half.....	7
17. Limestone, skeletal-micritic, medium-gray; replete with colonial corals (USGS colln. 6361-SD); one 4-ft-thick ledge-forming bed at base and thinner beds at top.....	8
18. Dolomite, silty; interbedded with very dolomitic siltstone and bedded rusty-weathering chert in ½-3 in.-thick beds; unusual spherical nodules of white crystalline quartz; 1-3 in. in diameter; forms recessive ledge.....	20
19. Dolomite, slightly silty, micrograined, light-olive-gray; several lentils of laminated olive-gray, very silty, very siliceous dolomite in top 6 ft; fossiliferous at base (USGS colln. 6365-SD); slope-former	28
20. Marl and very dark gray fetid micritic-skeletal limestone; poorly exposed; in dip slope.....	5
21. Limestone (calcite: dolomite=100: 0), argillaceous, skeletal-micritic, olive-gray; scattered silicified brachiopods; in one bed..	1
22. Marl or calcareous siltstone and very dark gray thin-bedded fossiliferous limestone; mostly covered.....	14

Martin Limestone on east-facing slope of small hill north of Spring Creek—Con.

Martin Limestone—Continued

	<i>Feet</i>
23. Limestone calcite:dolomite=100:0 at 7 ft from top), slightly silty, skeletal-micritic, olive-gray; fossiliferous (USGS colln. 6360-SD from upper 10 ft); basal half in beds 1-3 in. thick; upper half is in single ledge-forming bed.....	14
24. Covered	3½
25. Limestone (calcite:dolomite=100:0), fine-grained, skeletal-micritic, partially silicified, medium-dark-gray; weathers yellowish gray; in beds 1-3 ft thick; elongate rusty-weathering chert nodules; abundant silicified fossils; ledge-former.....	6
26. Covered; probably silty dolomite or dolomitic siltstone.....	14
27. Limestone, crinoidal, dark-gray; in thin nodular beds; scattered horn corals and brachiopods (USGS colln. 6359-SD).....	3
28. Covered; probably marl.....	5
29. Limestone, skeletal, very dark gray; in beds less than 1 in. thick; very fossiliferous (USGS colln. 6358-SD); forms recessive ledge.....	2
30. Limestone, silty, yellowish-gray-weathering; in very thin beds; contains echinoderm debris.....	2
31. Covered; probably marl and argillaceous limestone.....	22
32. Limestone, dark-gray; fossiliferous (USGS colln. 7250-SD).....	1
33. Dolomite, dark-gray; weathers olive gray; forms notch in ledge.....	1
34. Limestone, dark-gray; in beds 1 in. to 1 ft thick; some interbedded marl; limestone is fossiliferous (USGS colln. 6357-SD from basal 10 ft and from top).....	16
35. Covered; probably argillaceous limestone or marl.....	20
36. Dolomite, slightly sandy, dark-gray; weathers olive gray; laminated in part; thin cherty laminae in middle; in beds 1-6 in. thick; forms recessive ledge in basal 5 ft, slope at top.....	9
37. Covered; indications of dolomite like that in unit 37.....	7
38. Dolomite, microcrystalline, dark-gray; weathers olive gray; in beds 2 in. thick.....	1
39. Covered	3
40. Dolomite (calcite:dolomite=6:94 at top) fine crystalline, medium-light-gray; weathers yellowish gray; forms recessive ledge	4
41. Dolomite (calcite:dolomite=4:96 at 2 ft from top and 5:95 at 5 ft from top), sandy medium-light-gray; in very thin beds; slope-former	8
42. Dolomite (calcite:dolomite=4:96 at top), very sandy, fine-grained, light-gray; weathers pale yellowish brown; cross-laminated in top 3 ft; basal 2 ft yields fossils when broken (USGS colln. 7251-SD); in beds 6 in. to 2 ft thick; forms rounded ledge.....	14
43. Dolomite, pale-yellowish-brown-weathering; interbedded calcareous siltstone; poorly exposed; slope-former.....	12

Total measured thickness of Martin Limestone..... 405±

Martin Limestone on east-facing slope of small hill north of Spring Creek—Con.

Abrigo Limestone:	<i>Feet</i>
Dolomite, fine-grained, medium-gray; weathers yellowish gray; in beds 1-6 in. thick; contains about 20 percent rusty-weathering medium-gray chert in crinkly lentils and small nodules in upper 5 ft; scattered, poorly preserved obloid brachiopods in lower part; covered in part; slope-former; overlies prominent 18-ft-thick ledge of very light gray trilobite-bearing skeletal-detrital-micritic limestone in beds 1 in. to 1 ft thick-----	21

Martin Limestone, Abrigo Limestone, and Bolsa Quartzite on north slope of Mount Martin

[Section 6, pl. 1. In SE¼ sec. 7 and NE¼NE¼ sec. 18, T. 23 S., R. 24 E.]

Escabrosa Limestone:	<i>Feet</i>
Limestone, crinoidal, very light gray; basal 40 ft is argillaceous and mostly covered in slope beneath massive resistant cliffs-----	175

Martin Limestone:

1. Dolomite, calcareous, fine- to medium-grained, pinkish-gray; weathers light olive gray; in beds 6 in. to 5 ft thick; forms resistant ledge-----	14
2. Covered -----	63
3. Limestone, dolomitic, argillaceous, fine-grained, very light gray; in slope-----	15
4. Dolomite, fine crystalline, medium-gray; numerous vugs and veins filled with white crystalline calcite; in beds 1-5 ft thick-----	40
5. Dolomite much like that in unit 4 but in thin beds and poorly exposed -----	34
6. Limestone, dolomitic (calcite:dolomite=82:18 at 20 ft from top), silty, very fine crystalline (recrystallized skeletal limestone), dark-gray; weathers medium gray; abundant brachiopods and colonial corals; in ledges of 1- to 3-ft-thick beds alternating with similar thinly bedded limestone in slopes-----	23
7. Claystone, calcareous and argillaceous limestone, alternating laminae, yellowish-gray and light-olive-gray; weathers light gray; in 1- to 4-in.-thick beds; contains abundant brachiopods; poorly exposed-----	44
8. Limestone (calcite:dolomite=100:0 at 22 ft from top), silty, partially recrystallized, micritic-skeletal; mottled light-olive-gray and medium-dark-gray; weathers medium light gray; contains fragmental fossil debris; in 1- to 5-ft-thick beds-----	29
9. Claystone, calcareous, very light gray; in 6-in.-thick beds-----	3
10. Covered; scattered float of limestone like that of unit 11 and claystone like that of unit 9-----	28
11. Limestone (calcite:dolomite=100:0 at 2 and 80 ft from top), micritic, medium-dark-gray; weathers medium gray; faintly laminated in part; in 1- to 4-in.-thick beds; scattered brachiopods; interbedded with minor light-gray yellowish-gray-weathering, partially recrystallized dolomitized argillaceous micritic-detrital limestone (calcite:dolomite=20:80 at 85 ft from top); imperfectly exposed in basal 65 ft and very poorly exposed in top 30 ft-----	95

*Martin Limestone, Abrigo Limestone, and Bolsa Quartzite on north slope of Mount Martin—Continued***Martin Limestone—Continued***Feet*

12. Sandstone, coarse-grained; granular in part; made up of poorly sorted subrounded to subangular grains of quartz cemented irregularly with silica and calcite; very pale orange; in beds 3 in. to 2 ft thick; forms resistant ledge; thins along outcrop in both directions to 8 ft or less. (This unit was considered by Ransome (1904, p. 32) as the top unit of the underlying Abrigo Limestone.)-----	12
13. Covered -----	16
14. Very poorly exposed marl and calcareous siltstone-----	16
15. Dolomite, silty, medium-grained, yellowish-gray-weathering; in crumbly ledge-----	4
16. Covered; probably mostly marl-----	24
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Total measured thickness of Martin Limestone-----	460
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Abrigo Limestone :**Copper Queen Limestone Member :**

1. Limestone (calcite: dolomite=93:7), medium-gray; weathers yellowish gray; thin bedded; numerous 5-10-mm-thick laminae of olive-gray, very argillaceous limestone and a few 3- to 6-inch-thick beds of medium-gray chert; in poorly exposed slope-----	24
2. Limestone (calcite: dolomite=100:0), pinkish-gray; weathers yellowish gray; made up of alternating laminae of micritic limestone and coarse-grained detrital-micritic limestone containing conspicuous stylolites; in beds 1 in. to 1 ft thick; forms upper part of resistant ledge-----	30
3. Limestone (calcite: dolomite=92:8), laminated; laminae are 1-10 mm thick; contains laminae ranging from light-olive-gray sandy, fine-grained detrital-micritic limestone to dark-gray micritic limestone; in beds 1 in. to 1 ft thick; forms lower part of resistant ledge-----	15
4. Limestone, coarse-grained, detrital, medium-gray; in beds 1 in. to 1 ft thick; a few laminae of brown-weathering medium-gray siliceous limestone; in steep slope below ledge; grades upward into unit 3-----	25
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Total measured thickness of Copper Queen Limestone Member-----	94
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Sandy member :

5. Sandstone, very well sorted, subrounded, very fine-grained, olive-gray, quartzose; cemented with dolomitic calcite; weathers medium light gray; interbedded with considerable similarly colored sandy dolomitic limestone; in poorly exposed slope-----	50±
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Martin Limestone, Abrigo Limestone, and Bolsa Quartzite on north slope of Mount Martin—Continued

Abrigo Limestone—Continued

Sandy member—Continued

	<i>Feet</i>
6. Limestone, dolomitic (calcite: dolomite=84:16), partially recrystallized, fine- to medium-grained, detrital-micritic-pelletal, slightly glauconitic, mottled grayish-orange; weathers mottled light olive gray; very thin beds; interbedded with considerable chalky dolomitic marl (calcite: dolomite=34:66, insoluble residue=65 percent); in very poorly exposed slope (small fault crossed by line of measurement)-----	50±
7. Marl, light-gray; considerable interbedded sandstone and limestone; sandstone is olive gray, very fine grained, glauconitic, and dolomitic; limestone is mottled olive gray, glauconitic, partially recrystallized, detrital-micritic, and dolomitic; in 2 in.- to 1-ft-thick beds; in very poorly exposed slope-----	30±
8. Sandstone interlaminated with limestone in laminae 3-12 mm thick; sandstone is light brownish gray, fine to very fine grained, glauconitic, and cemented by calcite; limestone is olive gray, very fine grained, and glauconitic; in irregular beds 1-3 in. thick; in slope-----	36
Total measured thickness of sandy member-----	<u>166±</u>

Ribbed limestone member:

9. Limestone, medium-light-gray; weathers light gray; numerous laminae about 5-10 mm thick of more resistant light-brown-weathering silty limestone; imperfectly exposed in slope---	55
10. Limestone, partially recrystallized, detrital-micritic, glauconitic, mottled grayish-orange-pink; weathers mottled light olive gray; in beds about 6 in. thick; few thin laminae of gray silty limestone; in poorly exposed slope-----	31
11. Limestone, silty, laminated, micritic-skeletal, medium-gray; weathers light gray; contains about 20 percent light-brown-weathering medium-gray siliceous limestone in laminae 5-10 mm thick; some thin beds of limestone edgewise conglomerate like that in unit 12-----	113
12. Limestone edgewise conglomerate composed of oblate and disc-shaped pebbles of light-gray to light-olive-gray micritic limestone; matrix of medium-gray, slightly silty micritic limestone; in beds about 1 ft thick-----	2
Total measured thickness of ribbed limestone member---	<u>201</u>

Shaly member:

13. Claystone, thinly laminated, light-olive-gray; weathers yellowish brown; contains laminae and a few thin interbeds of light-gray-weathering limestone-----	33
14. Limestone like that in unit 11, but less siliceous-----	25
15. Limestone (calcite: dolomite=100:0 at base), slightly argillaceous, laminated, micritic-pelletal, medium-gray; weathers light gray; grades upward into unit 14-----	5

Martin Limestone, Abrigo Limestone, and Bolsa Quartzite on north slope of Mount Martin—Continued

Abrigo Limestone—Continued

Shaly member—Continued	<i>Feet</i>
16. Limestone (calcite: dolomite=100:0 at base) like that in unit 11, but contains less siliceous limestone.....	20
17. Limestone; made up of alternating 5- to 15-mm-thick irregular laminae of softer weathering pinkish-gray-weathering light-gray micritic limestone and more resistant grayish-orange-pink-weathering medium-gray argillaceous, silty micritic-detrital limestone.....	54
18. Limestone and claystone interbedded in 2- to 3-ft thick intervals; limestone is micrograined, very light gray and is interlaminated with yellowish-brown-weathering, very light gray siliceous limestone; claystone is sericitic and yellowish brown weathering, and occurs in thin contorted laminae.....	15
19. Claystone like that in unit 18.....	7
20. Limestone, argillaceous, grayish-orange weathering; alternating in 2- to 5-ft-thick intervals with claystone and limestone like those in unit 18.....	34
21. Limestone (calcite: dolomite=100:0), micrograined, very light gray; contains about 33 percent yellowish-gray-weathering, very light gray siliceous limestone in 3- to 15-mm thick laminae.....	14
22. Claystone, calcareous, yellowish-brown-weathering; interbedded with yellowish-brown weathering noncalcareous claystone.....	35
23. Thinly interbedded yellowish-brown weathering nonfissile claystone, fissile shale, sandstone, and very argillaceous limestone; very poorly exposed.....	10
Total measured thickness of shaly member.....	252
Total measured thickness of Abrigo Limestone.....	713±

Bolsa Quartzite:

1. Siltstone to very fine-grained sandstone, mottled pink- and brown-weathering; in beds 6 in. to 1 ft thick; in poorly exposed slope.....	11
2. Siltstone to very fine grained sandstone; made up of fairly well-sorted and subrounded quartz grains cemented with silica; pinkish-gray; weathers grayish orange pink; in beds 3 in. to 5 ft thick; forms ledgy cliff.....	73
3. Sandstone, fine- to medium-grained; cemented with silica; weathers dark yellowish brown to dark reddish brown; in beds 2- to 3-ft thick; forms prominent ledge.....	5
4. Sandstone, fine- to medium-grained; cemented with silica; weathers moderate-orange-pink; in beds 1-6 in. thick; several partings of shaly siltstone; forms notch in cliff.....	13
5. Sandstone, fine- to medium-grained; made up of poorly sorted nonequant rounded grains of quartz, feldspar (about 5 percent), opaque minerals, and quartzite cemented with ferruginous silica; grayish red to pale yellowish brown; weathers dark reddish brown to dark yellow brown; in beds 4-6 ft thick; forms cliff.....	20

Martin Limestone, Abrigo Limestone, and Bolsa Quartzite on north slope of Mount Martin—Continued

Bolsa Quartzite—Continued	<i>Feet</i>
6. Sandstone, medium-grained very pale red; weathers grayish red; made up of poorly sorted nonequant subrounded grains of quartz and feldspar (about 10 percent) cemented with ferruginous silica; cross-laminated; in beds 3 in. to 3 ft thick; a few thin layers of granule conglomerate; slightly less resistant than overlying units.....	99
7. Sandstone, coarse-grained to granule and pebble conglomerate, moderate-yellowish-brown to grayish-orange-pink; made up of poorly sorted nonequant subrounded grains of quartz, feldspar (about 5 percent), and quartzite cemented with ferruginous silica; cross laminated in part; in beds 3 in. to 5 ft thick; a few very thin partings of fine-grained shaly sandstone and thinly laminated claystone, especially near top; forms ledgy cliff.....	123
Total measured thickness of Bolsa Quartzite.....	344
Pinal Schist.	

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