Biostratigraphy and Regional Relations of the Mississippian Leadville Limestone in the San Juan Mountains, Southwestern Colorado

GEOLOGICAL SURVEY PROFESSIONAL PAPER 985

Biostratigraphy and Regional Relations of the Mississippian Leadville Limestone in the San Juan Mountains, Southwestern Colorado

By AUGUSTUS K. ARMSTRONG *and* BERNARD L. MAMET

GEOLOGICAL SURVEY PROFESSIONAL PAPER 985

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1976

UNITED STATES DEPARTMENT OF THE INTERIOR

THOMAS S. KLEPPE, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, ***Director***

Library of Congress Cataloging in Publication Data

Armstrong, Augustus K.
Biostratigraphy and regional relations of the Mississippian Leadville limestone in the San Juan Mountains, southwestern Colorado.

(Geological Survey Professional Paper 985)
Bibliography: p. 24-25.
Supt. of Docs. no. I 19.16:985
1. Geology, Stratigraphic–Mississippian. 2. Geology–Colorado–San Juan Mountains. I. Mamet, Bernard L., joint author. II. Title: Biostratigraphy and regional relations of the Mississippian Leadville limestone... II. Series: United States Geological Survey Professional Paper 985.
QE672.A68 551.7'51'0978838 76-608257

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock Number 024-001-02910-3

CONTENTS

ILLUSTRATIONS

[Plates 1 and 2 follow references. Plate 3 is in pocket]

BIOSTRATIGRAPHY AND REGIONAL RELATIONS OF THE MISSISSIPPIAN LEADVILLE LIMESTONE IN THE SAN JUAN MOUNTAINS, SOUTHWESTERN COLORADO

By Augustus K. Armstrong and Bernard L. Mamet

ABSTRACT

In the San Juan Mountains, southwestern Colorado and adjacent areas, the Leadville Limestone, of Mississippian age, disconformably overlies the Ouray Limestone of Late Devonian (Famennian) age. Generally the Leadville Limestone can be divided into two parts. The lower part, 2–50 m thick, is unfossiliferous dolomite and lime mudstone of uncertain age that were deposited in a subtidal to supratidal environment. Overlying these is 2–26 m of pellet-echinoderm-ooid-foraminifer packstone-wackestone that contains a microfossil assemblage of zone 9, which is Osagean, late Tournaisian age. This fossiliferous limestone was deposited in open, shallow marine water.

A regional unconformity and pre-Pennsylvanian erosion surface at the top of the Leadville Limestone represent a stratigraphic hiatus encompassing Meramecian, Chesterian, and probably part of early Morrowan time. The lowest beds of the overlying Pennsylvanian Molas Formation were deposited on the Leadville Limestone as a residuum composed of nonmarine mudstone, solution-rounded limestone, and chert.

A major marine transgression occurred in zone 9, late Osage time, in northern Arizona, southern Colorado, New Mexico, and southern Utah. The crinoid-foraminifer limestone of the Leadville Limestone of the San Juan Mountains is part of a once extensive carbonate cover. Open-marine carbonate rocks that are time-stratigraphic equivalents of the Leadville include to the west the Mooney Falls Member of the Redwall Limestone of the Grand Canyon, Ariz., and to the south the Ladron Member of the Kelly Limestone of west-central New Mexico. The Espiritu Santo Formation, to the southeast in north-central New Mexico, is a subtidal-supratidal facies of zone 9 of the Leadville Limestone.

INTRODUCTION

The field studies (fig. 1) for this report were done in 1965 and 1966 in southern Colorado. The sections in the Nacimiento Mountains and north-central New Mexico were sampled in 1965, 1966, 1972, and 1973. The Mississippian outcrops of west-central New Mexico were sampled in 1956, 1970, and 1973.

The stratigraphic sections were measured with a Jacobs staff and tape. Lithologic samples were collected at 1- to 3-m intervals. The lithologic samples were made into thin sections for petrographic and microfossil study.

The primary objectives of this study were to date the Leadville Limestone in the San Juan Mountains and the hiatus that separates the Mississippian rocks from the Devonian Ouray Limestone. The regional stratigraphic relations of the Leadville Limestone of the San Juan Mountains to other Mississippian rocks of the region are shown by correlation charts and regional paleogeographic maps.

Durham's (1962) carbonate rock classification is used in this report.

We wish to express our appreciation to Dr. Frank Kottlowski, Director of the New Mexico Bureau of Mines and Mineral Resources, who suggested this study in 1964 and who supported the field studies in New Mexico in 1965. We acknowledge with pleasure the help and encouragement given us in this study by U.S. Geological Survey geologists J. Thomas Dutro, Jr., and William J. Sando. We are indebted to Dutro for the identification of the Devonian brachiopods and to John W. Huddle for the conodont data.

PREVIOUS STUDIES

The Leadville Limestone was named by Eldridge (Emmons and Eldridge, 1894) for outcrops in the Leadville mining district of Lake County, Colorado.

Spencer (1900) designated the type locality of the Ouray Limestone, at the junction of Canyon Creek with the Uncompahgre River just south of Ouray, in the San Juan Mountains, Colo. The name was originally applied to beds in which only Devonian fossils were then known. Girty (1903) found that the megafossils from the upper part of the Ouray Limestone of the San Juan Mountains were of Early Mississippian age and were similar to faunas from the type Leadville Limestone at Leadville and to the Madison Limestone of Yellowstone National Park.

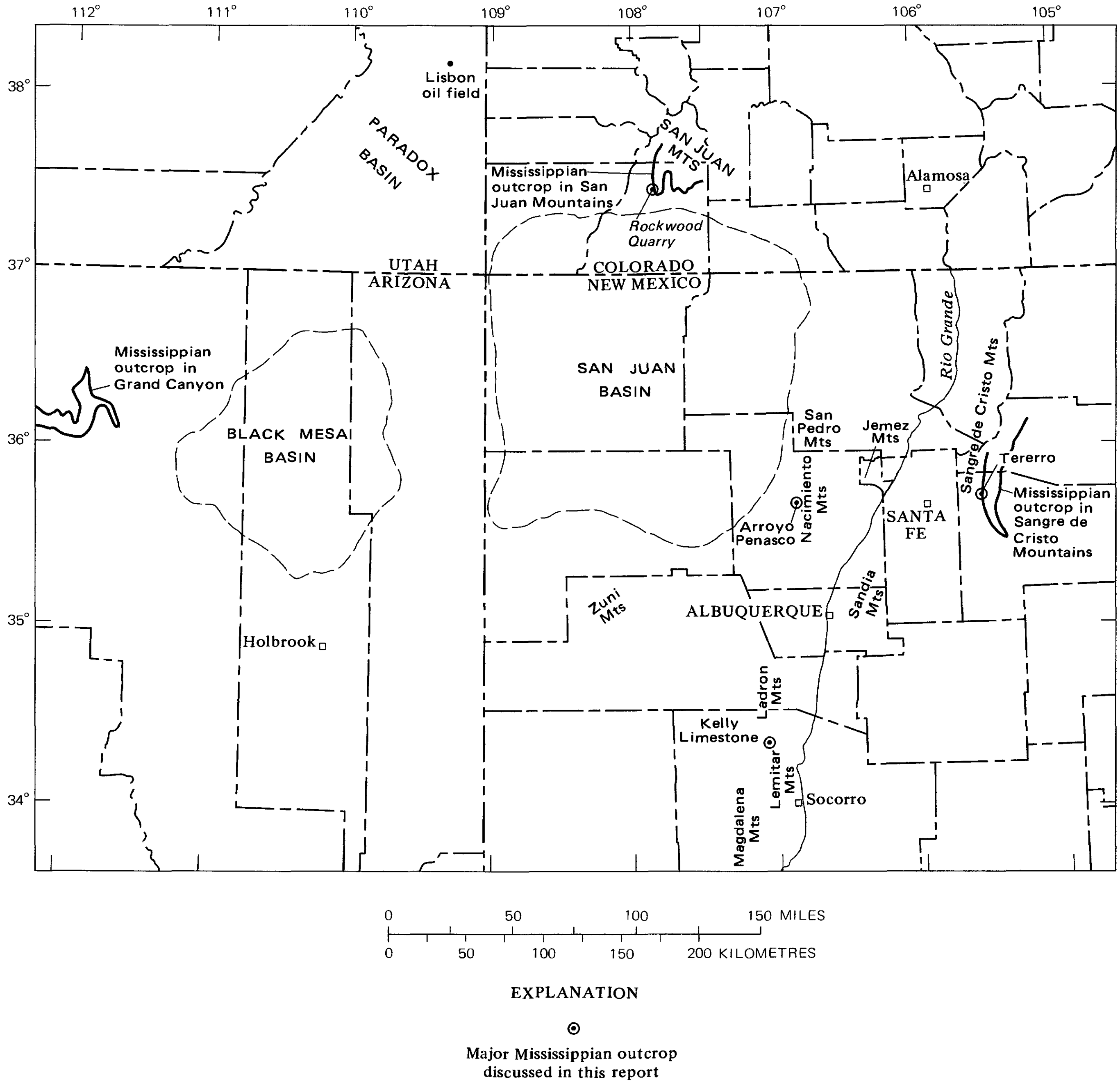


FIGURE 1.—Location of major Mississippian rock outcrops and localities discussed in this report.

Kindle (1909) described the Upper Devonian fauna from the Ouray Limestone and recognized a Mississippian fauna in the upper part of the formation. Kirk (1931) restricted the Ouray Limestone to the lower part of what had previously been called Ouray to that part that is Upper Devonian and assigned the Mississippian part of the original Ouray Limestone to the Leadville Limestone. Bass (1944), Wood, Kelley, and MacAlpin (1948), and Steven, Schmitt, Sheridan, and Williams (1969) used the term Leadville Limestone for Mississippian rocks and restricted the Ouray Limestone to Devonian rocks of the San Juan Mountains.

Armstrong (1955, 1958b) considered the Leadville Limestone at Piedra River and Rockwood Quarry in the San Juan Mountains to be Kinderhookian on the basis of microfossil evidence.

Knight and Baars (1957) accepted Stainbrook's (1947) conclusion that the fauna of the Percha Shale of southern New Mexico was Early Mississippian and similar to the Ouray Limestone fauna, which they considered also to be Early Mississippian. They therefore concluded, because the Ouray fauna was both Devonian and Mississippian and the contact between the Ouray and Leadville Limestones showed gradational aspects, that the Ouray Limestone was transitional both stratigraphically and faunally with the overlying Leadville Limestone. However, they did note that the Ouray fauna is distinct from the Leadville fauna. With the Leadville Limestone of Kinderhookian and Osagean age directly overlying the Ouray Limestone, the time available for the development of any major unconformity at the top of the Ouray was limited. Knight and Baars (1957, p. 2280) recognized two new members in the Leadville Limestone—the Beta Member for its lower dolomitic facies and the Alpha Member for its upper limestone facies—from the subsurface of the Paradox basin of Utah to the outcrops in the San Juan Mountains.

Knight and Baars (1957) gave a detailed account of the regional aspect of the Leadville Limestone and considered it Kinderhookian.

Parker (1961) considered the Leadville Limestone of southwestern Colorado to be Kinderhookian and early Osagean. Merrill and Winar (1958) show the Leadville Limestone of the San Juan Mountains as Osagean and early Meramecian.

Parker and Roberts (1963) published a detailed study of the Leadville Limestone of the San Juan Mountains and in the subsurface of the Paradox, Black Mesa, and San Juan basins of the Four Corners region. They suggested that the subdivision of the Leadville Limestone in the San Juan Mountains, based on changes from dolomite, below, to limestone, above (the Beta and Alpha Members of Knight and Baars, 1957), be abandoned. Their subsurface studies indicated very complex patterns of dolomitization that affected the Mississippian limestone of the region, and these patterns were not related to specific horizons over broad geographic regions.

In a series of papers Baars (1965, 1966) and Baars and See (1968) developed the concept of pre-Pennsylvanian positive areas in the Paradox basin of Utah and the San Juan Mountains of southwestern Colorado. Baars and See (1968, p. 333) suggested the following sequence of events (pl. 3).

> The Grenadier highlands, a northwest-trending graben-faulted anticline involving all pre-Pennsylvanian rocks is exposed in the core of the San Juan Mountains near Silverton, Colo. The feature was formed before Late Cambrian time when younger Precambrian quartzites were extensively downfaulted into juxtaposition with the older Precambrian basement complex. The quartzites emerged topographically high and supplied local talus to Ignacio deposits (Late Cambrian) adjacent to the faults. Ignacio rocks do not cover the fault block, but thicken and become finer grained away from the feature.
>
> As the Late Devonian seas advanced, the McCracken Sandstone Member of the Elbert Formation was deposited along the flanks of the structural feature, but apparently did not cross it. The upper Elbert intertidal dolomites were the first sediments to be deposited across the faulted fold where they lie directly on Precambrian quartzites. Latest Devonian or earliest Mississippian stromatolitic dolomites of the Ouray Formation overlie Elbert strata on the flanks of the old feature, and equivalent normal marine limestones are locally present within the downfaulted block.
>
> The Early Mississippian Leadville Formation thins abruptly onto the flanks of the graben-faulted anticline, where the lithologic aspect is one of stromatolitic dolomite formed in an intertidal zone. Within the graben, Leadville strata are thin or missing except as remnants in the overlying Molas regolith, suggesting that intense post-Leadville weathering removed those rocks across the regionally high structure. A small horst is present within the large graben where Pennsylvanian sedimentary rocks rest directly on upturned Precambrian quartzites. The graben was again downfaulted at some undetermined post-Desmoinesian time, for Middle Pennslyvanian beds are now in fault contact with Precambrian rocks along the flanking fauls.
>
> A similar ancient fault block south of Ouray, Colo., [the Sneffels horst] extends northwestward into the subsurface of the eastern Paradox basin. This feature parallels the nearby Uncompahgre uplift and may be genetically related to it.

STRATIGRAPHIC SECTIONS

ROCKWOOD QUARRY SECTIONS 65A–12A AND 66C–4

The excellent exposures at and adjacent to Rockwood Quarry in the southern San Juan Mountains are easily accessible (figs 2, 3). The carbonate rocks of both the Devonian Ouray Limestone and the Mississippian Leadville Limestone have not been extensively dolomitized here as is common elsewhere in the San Juan Mountains. Also the boundary between the Ouray and Leadville Limestones can be easily located by lithologic differences. It cannot be defined by paleontologic methods.

The Leadville Limestone at Rockwood Quarry is 34.8 m thick (figs. 3, 4) and has a sharp lithologic contact with the underlying Ouray Limestone. The Ouray Limestone 5 m below the contact is massive, brown to gray dolomite composed of 50-μm hypidiotopic dolomite rhombs. Above this is a 2-m-thick bed of crinoid-bryozoan-brachiopod packstone from which a brachiopod fauna was collected. The brachiopods were identified by J. Thomas Dutro, Jr. (written commun., 1973) (USGS 9206–SD):

echinoderm debris, indet.
Schizophoria australis Kindle
Schuchertella coloradoensis Kindle
Leioproductus coloradoensis (Kindle)
Paurorhyncha endlichi (Meek)
rhynchonellid, undet.
Cyrtospirifer cf. *C. whitneyi* (Hall)
Cyrtospirifer? *animasensis* (Girty)
Cyrtospirifer sp.
Syringospira prima (Kindle)
reticulariid, indet.
bellerophontid gastropod, indet.

FIGURE 2.—Outcrop of Mississippian Leadville Limestone, north end of Rockwood Quarry, southwestern Colorado. View is to the west from U.S. Highway 550. Prominent notch at base of the Leadville Limestone is the contact with Devonian Ouray Limestone. The high trees on the center and left of the photograph are on the shaly and arenaceous carbonate beds of the Devonian Elbert Formation. Massive outcrop in the center of the photograph is the Upper Cambrian Ignacio Quartzite. Rubble slope covers the Precambrian-Cambrian contact.

Dutro stated, "This is the fauna described from the Rockwood quarry by Kindle (1909), it is of probable mid-Famennian age." Above the brachiopod beds composed of echinoderm-brachiopod packstone is a 0.6-m-thick lime mudstone overlain by a 1.7-m-thick bed (figs. 3, 4) of breccialike material composed of silt- to boulder-size lime mudstone and wackestone. The matrix between the clasts is filled by calcite, argillaceous calcite, reddish-brown-gray iron-rich shale, and shale clasts. This unit has a very irregular contact with the underlying beds and a regular contact with the overlying beds. The thickness of this breccia varies, and 1–2 km north of Rockwood Quarry it is represented by

FIGURE 3.—Leadville Limestone just north of Rockwood Quarry. Red shale and limestone band in lower part of Leadville Limestone is just above the breccia zone.

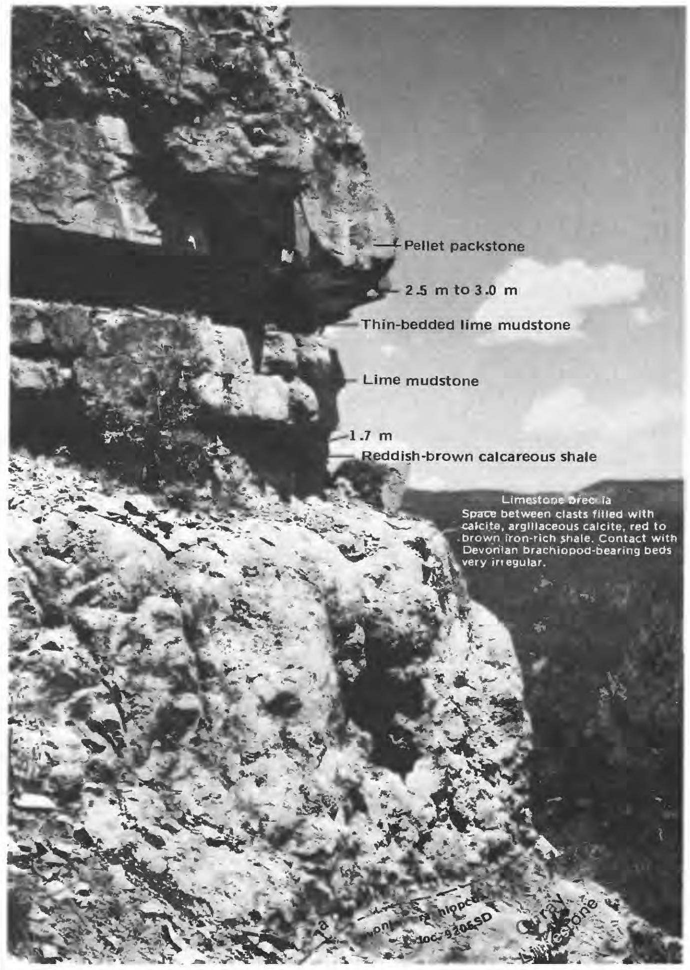


FIGURE 4.—Limestone breccia and red shale and limestone band at base of Leadville Limestone.

what appears to be an interformational conglomerate 0.5–1 m thick. At about 3.5–4 m above the base of the Leadville Limestone is a 0.5- to 0.7-m-thick fine-grained brownish-gray dolomite with laminations 20 mm to 2 cm thick; subrounded intraformational clasts are a few millimetres to 3 cm in size. Birdseye structures and low-relief stromatolites are common, with some bioturbation. These features clearly indicate deposition in an intertidal-supratidal environment. From about 4.2 to 20 m above the base, the Leadville Limestone contains lime mudstone and pellet packstone with minor interbeds of dolomite composed of hypidiotopic, 10- to 30-μm dolomite rhombs. From 20 to 33 m, the unit is composed of crossbedded massive, ooid-foraminifer-echinoderm-brachiopod packstone and grainstone. From 33 to 35.3 m crinoid wackestone predominates. The top of the Leadville Limestone is an erosion surface marked by extensive solution activity, terra rossa clay, and large rounded cobbles and boulders of limestone and chert in the basal beds of the Molas Formation.

MICROFOSSILS, ALGAE, AND FORAMINIFERS

Sample number 65A–12A + 18; 3 m below the top of the Ouray Limestone. USGS loc. M1180.
Kamaena sp.
Kamaena itkillikensis Mamet and Rudloff
Age: Late Devonian or Mississippian.

Sample number 66C–4 + 130; 1 m above base of Leadville Limestone. USGS loc. M1181.
Calcisphaera laevis Williamson
Parathurammina sp.
Vicinesphaera sp.
Age: Late Devonian or Mississippian.

Sample number 65A–12A + 41; 4.6 m above base of the Leadville Limestone. USGS loc. M1182.
Calcisphaera sp.
Kamaena sp.
Parathurammina sp.
Proninella sp.
Vicinesphaera sp.
Age: Late Devonian or Mississippian.

Sample number 65A–12A + 95; 21 m above base. USGS loc. M1183.
Calcisphaera laevis Williamson
"*Globoendothyra*" *trachida* (Zeller)
Inflatoendothyra sp.
Kamaena sp.
Latiendothyra sp.
Latiendothyra of the group *L. parakosvensis* (Lipina).
Medioendothyra sp.
"*Nostocites*" sp.
Palaeoberesella sp.
Septabrunsiina sp.
Septabrunsiina parakvainica Skipp, Holcomb, and Gutschick
Septaglomospiranella sp.
Septatournayella sp.
Septatournayella aff. *S. pseudocamerata* (Lipina *in* Lebedeva)
Spinoendothyra paracostifera (Lipina)
Spinoendothyra spinosa (Chernysheva)
Spinoendothyra tenuiseptata (Lipina)
Tournayella sp.
Vicinesphaera sp.
Age: Zone 9, late Tournaisian.

Sample number 65A–12A + 105; 24.1 m above base. USGS loc. M1184.
Kamaena sp.
Proninella sp.
Septabrunsiina sp.
Septaglomospiranella sp.
Spinoendothyra sp.
Tournayella sp.
Age: Zone 9, Late Tournaisian.

Sample number 65A–12A + 115; 27 m above base. USGS loc. M1185.
Calcisphaera sp.
Earlandia sp.
Kamaena sp.
Latiendothyra sp.
Palaeoberesella sp.
Septabrunsiina sp.
Septaglomospiranella sp.
Septatournayella sp.
Spinoendothyra sp.
Spinotournayella sp.
Vicinesphaera sp.
Age: Zone 9, late Tournaisian.

Sample number 65A–12A + 125; 30.2 m above base. USGS loc. M1186.
Calcisphaera sp.
Earlandia sp.
Kamaena sp.
Latiendothyra sp.
Septabrunsiina sp.
Septatournayella sp.
Spinoendothyra sp.
Tournayella sp.
Age: Zone 9, late Tournaisian.

CONODONTS

Samples were collected from the lower part of the Leadville Limestone at Rockwood Quarry in 1973 for conodonts. The samples were sent to John W. Huddle who reported that the samples from 9.8, 10, 11.6, 12.8, 13.7, and 17.1 m above the base of Leadville Limestone did not contain conodonts (written commun., 1974). Two samples contained conodonts.

73C–12A+50; about 7.5 m above the base of the Leadville Limestone. (USGS 25447–PC).

	Number of specimens
Falcodus sp.	1
Hindeodella sp.	2

73C–12A+36; about 2 m above base of Leadville Limestone. Limestone cobbles in red shale. (USGS 25448–PC)

	Number of specimens
Apathognathus? sp.	1
Hindeodella sp.	1
H. sp.	1
Neoprioniodus sp.	1
bar fragments	---

All of the species reported are bar-type conodonts and not very useful in correlation. All the genera occur in the Devonian and Mississippian.

I examined a collection that I made in 1969 with Poole, Sandberg, and Uyeno from the top of the bed you place at the top of the Ouray Limestone. Neither Sandberg nor I are ready to commit ourselves on the age of the bed but we think it is Late Devonian, probably *Polygnathus styriacus* Zone or somewhat younger. There are some new species and perhaps a new genus in the fauna. It has not been described.

COALBANK HILL SECTION 66C–1

The Coalbank Hill section 66C–1 is the same as Baars' (1966, 1968) Mill Creek Lodge section and Merrill and Winar's (1958) Coalbank Hill section. The outcrop is well exposed in a roadcut 2.1 km north of the Mill Creek Lodge on U.S. Highway 550 (pl. 3).

The contact between the Ouray and Leadville Limestones was picked at the top of the gray to tan-gray dolomite composed of 0.5- to 1-mm dolomite rhombs, with thin 0.5-cm yellowish-green shale partings. The upper 1.5 m of this dolomite has vugs as much as 2 cm in diameter that are filled with gray to light-green shale. The overlying dolomite, arbitrarily assigned by lithology to the Leadville Limestone, is pale yellowish orange to olive gray having weakly developed lamination and intraformation clasts. The dolomite is composed of 30- to 100-μm rhombs. The dolomite from 0 to 8.2 above the base contains no recognizable mega- or microfossils. The rocks from 0 to 8.2 m we consider, provisionally on the basis of lithologic characteristics, to be basal Leadville Limestone. Merrill and Winar (1958), on the basis of insoluble residue, considered this dolomite to be the Ouray Formation. The rocks between 8.2 and 20.4 m have been strongly affected by solution activity, have chaotic bedding and collapse structure, and are filled by a reddish-brown matrix of shale and silt. The limestone is gradational at its base with nearly solid limestone that is only slightly affected by solution activity. The limestone in this unit is primarily crinoid packstone with microfossils of zone 9, Osagean age.

The crinoid limestone of this unit was included by Merrill and Winar (1958) in their Coalbank Hill Member of the Molas Formation. As these rocks represent a post-Leadville vadose-weathering zone, it may be correct to consider them as the basal member of the Molas Formation, but for purposes of regional correlation and rock type distribution, we consider them to be a highly altered part of the Leadville Limestone.

MICROFOSSILS

Sample number 66C–1 + 165; 15.8 m above the base of the Leadville Limestone. USGS loc. M1187.

Earlandia sp.
Kamaena sp.
Septaglomospiranella dainae Lipina
Age: Zone 9, late Tournaisian.

Sample number 66C–1 + 175; 18.9 m above the base. USGS loc. M1188.

Kamaena sp.

MOLAS CREEK SECTION 66C–2 AND MOLAS LAKE SECTION 66C–2B

The Molas Creek and the Molas Lake sections were measured about 1 km apart. The Molas Creek section was measured along Molas Creek (pl. 3, figs. 5, 6) which drains Molas Lake, 0.5 km south of Molas Lake. This section exposes rocks from the Cambrian Ignacio Quartzite to the Molas Formation. The Molas Lake section was measured along the roadcut on the north shore of Molas Lake (fig. 7) where the upper crinoidal facies of the Leadville Limestone and the contact with the overlying Molas Formation are well exposed.

The contact between the Ouray Limestone and the Leadville Limestone was picked at the top of a massive

FIGURE 5.—Leadville Limestone at the Molas Creek section (66C–2). The steep cliffs are formed by dolomite.

FIGURE 6.—Top of the Leadville Limestone at the Molas Creek section (66C–2). The Leadville here has been strongly affected by pre-Pennsylvanian vadose weathering and is now rounded limestone boulders and terra rossa soil.

FIGURE 7.—Large solution-rounded boulder of Leadville Limestone showing cavities with terra rossa clay. Top of Leadville Limestone Molas Lake section 66C–2B.

2.8-m-thick light-gray chert bed. The Ouray Limestone below the chert bed is massive, yellowish-gray to light-olive-gray dolomite composed of 80-μm rhombs. The Leadville Limestone, above the chert bed, is yellowish-gray, massive, laminated dolomite with chert pseudomorphs of gypsum at 10.7 m above the base (pl. 1, fig. 1). The uniform dolomite from 0 to 20 m above the base is composed of hypidiotopic dolomite rhombs in the 40- to 100-μm size. The fine-grained dolomite, lamination, and chert pseudomorphs all suggest that the rocks in the interval between 0 and 20 m were deposited in an intertidal to supratidal environment.

The contact between Leadville dolomite and underlying Ouray dolomite is difficult to pick because of the lack of fossils in either formation and the similar types of dolomite in both. Baars (1965, p. 134) did not pick a boundary and lumped the strata into a Leadville-Ouray Formation at this outcrop.

Resting directly on the massive Leadville dolomite (fig. 5) is 3 m of foraminifer-algal-pellet packstone of zone 9, Osagean age. A covered interval exists between 20.6 and 27.5 m where a large remnant of the upper Leadville Limestone is found within the Molas Formation regolith. This remnant is bryozoan-crinoid-coral-brachiopod packstone that has been subjected to extensive vadose weathering (fig. 6).

The Molas Lake section contains an excellent exposure of the crinoidal facies of the Leadville Limestone and the Molas Formation. The base of the section is at water level at the edge of the lake. The Leadville Limestone from 0 to 6 m above the base is lump to pellet-brachiopod-foraminifer packstone and grainstone. The section is covered from 6 to 13 m and is a crinoid packstone-wackestone from 13 to 26 m. The highest 10 m has been strongly affected by post-Leadville vadose weathering and solution activity (fig. 7).

MICROFOSSILS

Sample number 66C–2 + 176; 21.6 m above the base of the Leadville Limestone. USGS loc. M1189.
Calcisphaera laevis Williamson
Inflatoendothyra sp.
Kamaena sp.
Latiendothyra sp.
Latiendothyra of the group *L. parakosvensis* (Lipina)
"*Nostocites*" sp.
Parathurammina sp.
Proninella sp.
Radiosphaera sp.
Septabrunsiina sp.
Septabrunsiina parakrainica Skipp, Holcomb, and Gutschick
Septaglomospiranella dainae Lipina
Spinoendothyra sp.
Spinoendothyra spinosa (Chernysheva)
Tournayella sp.
Vicinesphaera sp.
Age: Zone 9, late Tournaisian.

Sample number 66C–2B + 0; 0.0 m above base of section. USGS loc. M1190.
Spinoendothyra sp.
Spinoendothyra spinosa (Chernysheva)
Age: Zone 9, late Tournaisian.

Sample number 66C–2B + 5; 1.5 m above base of section. USGS loc. M1191.
Calcisphaera sp.
Calcisphaera laevis Williamson
Kamaena sp.
"*Globoendothyra*" *trachida* (Zeller)
Palaeoberesella sp.
Proninella sp.
Septabrunsiina sp.
Septabrunsiina parakrainica Skipp, Holcomb, and Gutschick
Septaglomospiranella sp.
Spinoendothyra sp.
Spinoendothrya spinosa (Chernysheva)
Spinotournayella sp.
Spinotournayella tumula (Zeller)
Age: Zone 9, late Tournaisian.

Sample number 66C–2B + 20; 6.1 m above base of section. USGS loc. M1192.
Calcisphaera sp.
Kamaena sp.
Parathurammina sp.

Pronineila sp.
Vicinesphaera sp.
Age: Zone 9, late Tournaisian.

OURAY SECTION 66C–5

The Elbert Formation, Ouray Limestone, and Leadville Limestone are magnificently exposed west of the town of Ouray (pl. 3; fig. 8).

The Precambrian Uncompahgre Formation is overlain with an angular unconformity by the Elbert Formation, 11.5 m thick, above which is the Ouray Formation, 14.6 m thick. The Ouray is a pale-olive-gray calcareous dolomite composed of 30- to 50-μm dolomite rhombs that have been calcified (dedolomitized) on their margins.

Kindle (1909, p. 7) reported, from beds that are now recognized to embrace both the Ouray and Leadville Limestones as defined by Bass (1944) and Steven, Schmitt, Sheridan, and Williams (1969), that "Although no fossils were found by me in the lower part of the Ouray limestone at Ouray, its position and lithologic characteristics clearly show its identity with beds holding a Devonian fauna at localities both to the south and north." Baars (1965, 1968) did not find any fossils in the type section of the Ouray Limestone. Our studies also failed to find any fossils in the beds we assigned to the Ouray Limestone. The boundary between the Ouray and Leadville Limestones was chosen at the base of a 1.2-m-thick bed of 1- to 2-cm rounded to angular pebbles of dolomite in a dolomite matrix. The very fine grained dolomite is composed of 5-μm dolomite rhombs. The matrix contains some silt-size quartz grains. Some of the material may be broken and reworked algal mats as indicated by the laminations. The dolomite-pebble conglomerate is overlain by almost 1.5 m of fine-grained dolomite in 4- to 6-cm-thick beds with thin gray shale partings.

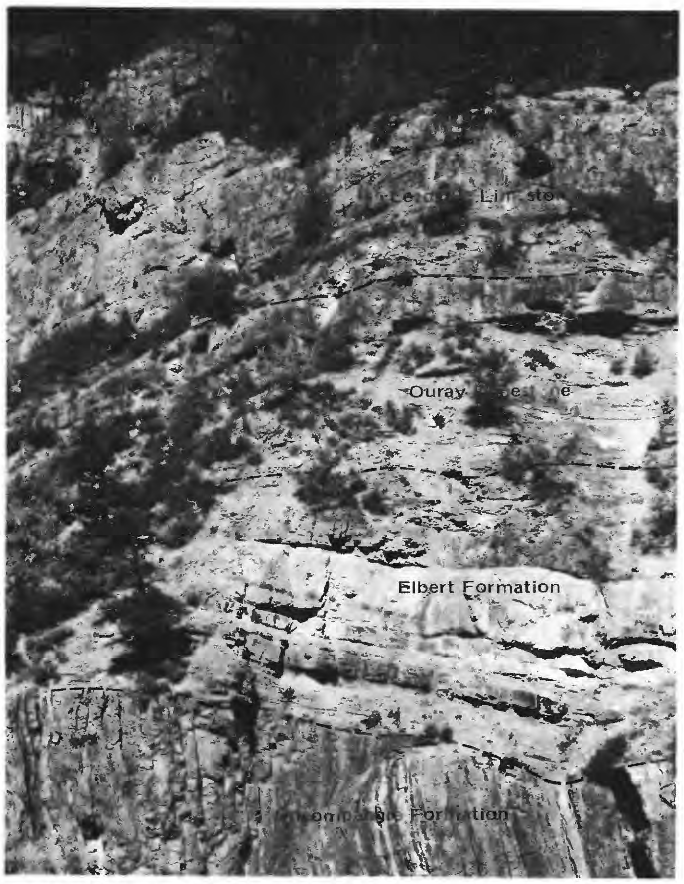


FIGURE 8.—Angular unconformity between nearly horizontal Elbert Formation and Precambrian Uncompahgre Formation in Box Canyon near Ouray, Colo.

A thick-bedded massive unit composed of 10- to 15-μm hypidiotopic dolomite occurs at 2.5 m above the base of the Leadville Limestone. Sedimentary structures are weakly developed stromatolites, intraformational lithoclasts, and lamination, which indicate deposition in an intertidal environment. At 5.8–7.6 m the dolomite is replaced by ostracode-pellet lime mudstone. A fine-grained gray dolomite is present from 7.6 to 13.7 m, and from 13.7 to 20.7 m is a limestone composed of neomorphic calcite crystals in the 10- to 30-μm size. The unit was probably deposited as lime mud. A lime mud lump to pellet lime mudstone is present from 20.7 to 29.6 m. A massive-bedded gray crinoid-bryozoan-ooid-foraminifer packstone and wackestone is present from 29.6 to 38.4 m (pl. 2, figs. 1, 2, 3; pl. 1, fig. 6). Crinoid packstone and grainstone comprise the highest beds from 38.4 to 65.2 m.

The contact of the Leadville Limestone with the overlying Molas Formation is sharp. The crinoid limestone shows little evidence of vadose weathering or solution activity. The basal beds of the Molas Formation are pale-brown to pale-gray chert pebble conglomerate, with clay and calcite cement, which grades upward into pale-brown poorly bedded shale.

MICROFOSSILS

Sample number 66C–5 + 115; 8.8 m above the base of the Leadville Limestone. USGS loc. M1193.
Calcisphaera sp.
Parathurammina sp.
Vicinesphaera sp.
Age: Late Devonian or Mississippian.

Sample number 66C–5 + 185; 30.2 m above the base. USGS loc. M1194.
Brunsia? sp.
Calcisphaera laevis Williamson
Earlandia sp.
Earlandia of the group *E. clavatula* (Howchin)

Earlandia of the group *E. elegans* (Rauzer-Chernoussova and Reitlinger)
Exvotarisella cf. *E. index* (Ehrenberg *sensu* von Möller)
Kamaena sp.
Kamaena maclareni Mamet and Rudloff
Latiendothyra sp.
Latiendothyra of the group *L. parakosvensis* (Lipina).
Palaeoberesella sp.
Proninella sp.
Septabrunsiina sp.
Septabrunsiina parakrainica Skipp, Holcomb, and Gutschick
Septaglomospiranella sp.
Septatournayella sp.
Spinoendothyra sp.
Spinoendothyra spinosa (Chernysheva).
Spinoendothyra tenuiseptata (Lipina)
Spinotournayella sp.
Age: Zone 9, late Tournaisian.

Sample number 66C–5 + 210; 37.8 m above the base. USGS loc. M1195.
Latiendothyra sp.
Septabrunsiina sp.
Septaglomospiranella sp.
Spinoendothyra sp.
Age: Zone 9, late Tournaisian.

Sample number 66C–5 + 220; 40.8 m above the base. USGS loc. M1196.
Exvotarisella index (Ehrenberg *emend* von Möller)
Kamaena sp.
Pseudoissinella sp.
Age: Zone 9, late Tournaisian.

Sample number 66C–5 + 225; 42.4 m above the base. USGS loc. M1197.
Calcisphaera laevis Williamson
Kamaena sp.
Palaeoberesella sp.
Parathurammina sp.
Age: Zone 9, late Tournaisian.

VALLECITO SECTION 66C–3

The Vallecito section (pl. 3) was measured about 0.3 km north of the Vallecito Campground. The Ignacio(?) Quartzite, Elbert Formation, and Ouray Limestone are together only 11 m thick. The Ouray Limestone is a pale-bluish-gray to light-gray argillaceous arenaceous dolomite composed of 20- to 40-μm dolomite rhombs with some silt-size quartz grains. The top of the Ouray Limestone was picked at the occurrence of a 3- to 5-cm-thick calcareous brownish-red shale. The overlying Leadville Limestone is a crinoid-brachiopod bryozoan packstone. A quartz sand crinoid packstone about 0.8 m thick occurs 19 m above the base. The section from 21 to 25.9 m is a gray limestone composed of neomorphic calcite crystals in the 0.3- to 0.5-mm size. The poorly exposed contact of the Leadville Limestone with the Molas Formation is covered in part by soil and forest. The basal beds of the Molas Formation are pebble and cobble conglomerate and maroon shale and siltstone.

MICROFOSSILS

Sample number 66C–3 + 100; 19.5 m above the base of the Leadville Limestone. USGS loc. M1198.
cf. *Atractyliopsis* sp.
Calcisphaera laevis Williamson
"*Radiosphaera*" sp.
Age: Probably zone 9, late Tournaisian.

Sample number 66C–3 + 120; 25.6 m above the base. USGS loc. M1199.
Calcisphaera laevis Williamson
Kamaena sp.
Palaeoberesella sp.
Proninella sp.
Parathurammina sp.
Vicinesphaera sp.
Age: Zone 9, late Tournaisian.

PIEDRA RIVER SECTION 65A–10

The Piedra River section is well exposed in the box canyon of the Piedra River near the junction with Davis Creek (pl. 3), San Juan Mountains, Colo. The Cambrian Ignacio(?) Quartzite and the Devonian Elbert Formation and Ouray Limestone is only about 12 m thick and rests with an angular unconformity on the Precambrian Uncompahgre Formation. The Ouray Limestone is 6 m thick and is fine-grained arenaceous brownish-gray dolomite. No micro- or megafossils were found in this unit. The contact between the Ouray and Leadville Limestones was picked at a slightly undulatory surface that is overlain by 3–5 cm of reddish-brown shale; this shale is overlain by gray lime mudstone that contains reworked chips and pebbles of the reddish-brown shale. The Leadville Limestone from 1 to 3.4 m above its base is a fine-grained cherty microdolomite composed of 10- to 15-μm dolomite rhombs. An ooid-foraminifer packstone to grainstone, from 3.5 to 6.2 m above the base, contains abundant *Spinoendothyra spinosa*. The section is from 10 to 12.5 m above the base lime mudstone and wackestone, and from 12.5 to 17.7 m it is pellet-algal-foraminifer packstone and grainstone. The section from 17.7 to 19.8 m above the base is algal wackestone. The top of the Leadville Limestone is an irregular erosion surface marked by extensive solution cavities filled by terra rossa clay from the overlying Molas Formation.

MICROFOSSILS

Sample numbers 65A–10 + 54 to 74 ft; within the Leadville Limestone 3.5 to 6.2 m above its base. USGS loc. M1226.

Brunsiina sp.
Calcisphaera laevis Williamson
Earlandia sp.
Eotuberitina sp.
Inflatoendothyra sp.
Issinella sp.
Kamaena sp.
Kamaena maclareni Mamet and Rudloff
Latiendothyra parakosvensis (Lipina)
Medioendothyra sp.
Parathurammina sp.
"*Polyderma*" sp.
Proninella sp.
Radiosphaera sp.
Septabrunsiina sp.
Septaglomospiranella sp.
Septatournayella sp.
Septatournayella pseudocamerata Lipina *in* Lebedeva
Spinoendothyra sp.
Spinoendothyra spinosa (Chernysheva)
Spinotournayella sp.
Tournayella sp.
Tournayella discoidea Dain

Age: Zone 9, late Tournaisian.

Sample numbers 65A–10 +85–104 ft; within the Leadville Limestone 12.5 to 18 m above its base. USGS loc. M1226.

Brunsiina sp.
Calcisphaera laevis Williamson
Earlandia sp.
Eotuberitina sp.
Inflatoendothyra sp.
Kamaena sp.
Kamaena maclareni Mamet and Rudloff
Latiendothyra sp.
Parathurammina sp.
Proninella sp.
Septabrunsiina sp.
Septaglomospiranella sp.
Spinoendothyra sp.
Spinoendothyra spinosa (Chernysheva)
Spinotournayella sp.
Tournayella sp.

Age: Zone 9, late Tournaisian.

KERBER CREEK SECTION 66C–6 AND 66C–6B

The pre-Mississippian Paleozoic section (pl. 3) in the Kerber Creek section is dissimilar to those in the central parts of the San Juan Mountains. Burbank (1932, p. 12, 13) originally applied the name Leadville Limestone to these rocks solely on the basis of lithologic correlation and stratigraphic position as compared with other Devonian and Mississippian sections in Colorado. He admitted that, with the exception of one fish tooth, no fossils were found in the Leadville Limestone of the Kerber Creek section.

Ordovician dolomite underlies the Devonian and Lower Mississippian(?) Chaffee Group. The lower 12 m of the Chaffee is gray, brown, and maroon clastic shale, sandstone, and siltstone of intertidal origin. Fish bones are abundant. These are overlain by 27.5 m of argillaceous gray to olive-gray thin-bedded dolomite with abundant birdseye structure, lithoclasts, stromatolites, and cut-and-fill structures. No fossils were found in this dolomite.

The contact between the Chaffee Formation and the Leadville Limestone (pl. 3) was picked at an undulatory surface on the argillaceous dolomite that is overlain by dark-gray massive dolomite that contains large stromatolites and intraformational clasts. The basal 30 m of the Leadville Limestone is gray slightly argillaceous dolomite. From 0 to 18 m above the base the dolomite rhombs are 5–10 μm in size; from 18 to 26 m above the base the dolomite rhombs are 10–70 μm in size; and from 26 to 30 m the dolomite is coarser grained with rhombs in the 0.1 to 0.5 mm size. The fine-grained microdolomite from 0 to 18 m preserves many of the original depositional structures and fabric. The rock was deposited as lime mud, and pelletoid structure is preserved in laminations that are abundant between 14 and 16 m above the base. Quartz sand admixtures are found at 5 m and from 18 to 20 m above the base. The environment of deposition for the lower 30 m of the Leadville Limestone is interpreted as subtidal to intertidal marine. The beds from 30 to 39.5 m above the base are siliceous-spiculitic-dolomite. The dolomite is composed of rhombs that range in size from 10 μm to 1 m at different stratigraphic levels. The microdolomite has relic pelletoid structures, and the coarser dolomite has crinoid packstone relic structures. A massive-bedded chert occurs from 39.5 to 42.7 m above the base. Relic textures and fabric within the chert suggest that it is silicified lime mudstone. The interval between 42.7 and 53.3 m above the base is covered. The siliceous and dolomitic beds in the lower 53.3 m of the Leadville Limestone contain no known mega- or microfossils, and the assignment of these beds to the Leadville Limestone is based on lithologic similarity and stratigraphic position. The sedimentary structures and microdolomite suggest that most of the beds in this interval were deposited in subtidal to intertidal environments, and this may explain the lack of fossils.

The Leadville Limestone from 53.3 to 65 m above the base is a sequence of lime mudstone, pellet packstone, and dolomite capped by 2 m of foraminifer-ooid packstone of zone 9, Osagean age. This unit is lithologically similar to the Leadville Limestone 153 km to the southwest at the box canyon of the Piedra River, San Juan Mountains. The ooid packstone is unconformably overlain by massive ferruginous coarse-grained to pebble quartz conglomerate of Pennsylvanian age.

MICROFOSSILS

Sample number 66C–6B + 321; 58.2 m above the base of the Leadville Limestone. USGS loc. M1200.

Calcisphaera laevis Williamson
Palaeocancellus sp.
Parathurammina sp.
Vicinesphaera sp.
Age: Probably Mississippian.

Sample number 66C–6B + 338; 63.4 m above the base. USGS loc. M1201.

Calcisphaera laevis Williamson
Earlandia sp.
Earlandia of the group *E. elegans* (Rauzer-Chernoussova and Reitlinger)
Earlandia of the group *E. moderata* (Malakhova)
primitive *Eoforschia* sp.
cf. *Garwoodia* sp.
Inflatoendothyra sp.
Latiendothyra sp.
"*Nostocites*" sp.
Ortonella sp.
Priscella sp.
Septabrunsiina sp.
Septabrunsiina parakrainica Skipp, Holcomb, and Gutschick
Septaglomospiranella sp.
Septatournayella sp.
Spinoendothyra sp.
Spinoendothyra spinosa (Chernysheva)
Tournayella sp.
Vicinesphaera sp.
Age: Zone 9, late Tournaisian.

MICROFOSSILS OF THE LEADVILLE LIMESTONE

The following taxa of algae and foraminifers have been recognized in the Leadville Limestone of the San Juan Mountains.

cf. *Atractyliopsis* sp.
Brunsia sp.
Calcisphaera sp.
Calcisphaera laevis Williamson
Earlandia sp.
Earlandia of the group *E. clavatula* (Howchin)
Earlandia of the group *E. elegans* (Rauzer-Chernoussova and Reitlinger)
Earlandia of the group *E. moderata* (Malakhova)
primitive *Eoforschia* sp.
Exvotarisella index (Ehrenberg *emend* von Möller)
Exvotarisella aff. *E. index* (Ehrenberg *emend* von Möller)
Inflatoendothyra sp.
Kamaena sp.
Kamaena awirsi Mamet and Roux
Kamaena maclareni Mamet and Rudloff
cf. *Garwoodia*? sp.
"*Globoendothyra*" *trachida* (Zeller)
Latiendothyra sp.
Latiendothyra of the group *L. parakosvensis* (Lipina)
"*Nostocites*" sp.
Ortonella sp.
Palaeoberesella sp.
Palaeocancellus sp.
Parathurammina sp.
Priscella sp.
Proninella sp.
Pseudoissinella sp.
"*Radiosphaera*" sp. (*Radiosphaerina*, etc.)
Septabrunsiina sp.
Septabrunsiina parakrainica Skipp, Holcomb, and Gutschick
Septaglomospiranella sp.
Septatournayella sp.
Septatournayella aff. *S. pseudocamerata* (Lipina *in* Lebedeva)
Spinoendothyra sp.
Spinoendothyra paracostifera (Lipina *in* Grozdilova and Lebedeva)
Spinoendothyra spinosa (Chernysheva)
Spinoendothyra tenuiseptata (Lipina)
Spinotournayella sp.
Spinotournayella tumula (Zeller)
Tournayella sp.
Vicinesphaera sp.

This microfauna closely resembles that reported by Skipp (in McKee and Gutschick, 1969) from the middle part of the Mooney Falls Member of the Redwall Limestone of northern Arizona and corresponds to her zone 4 ("*Endothyra spinosa* assemblage zone"). The only apparent discrepancy with the Redwall distribution is the presence of *Tournayella* in the Osagean Leadville Limestone. This is also true for most Tournaisian carbonate rocks of the American Cordillera (see Sando and others, 1969). The microfossils are indicative of zone 9 in the Mamet classification (see Mamet and Skipp, 1970b).

TUBERENDOTHYRA SKIPP IN McKEE AND GUTSCHICH 1969 AND TAXONOMIC EMENDATION OF SPINOENDOTHYRA LIPINA 1963

By Bernard L. Mamet

When Skipp erected the new taxon *Tuberendothyra* (1969), she was unaware of the publication of the Second Colloquim on the Systematics of endothyroid foraminifers (Commission of micropaleontological coordination, Academy of Sciences of the USSR, 1963) in which numerous new endothyroid taxa had been proposed. She included in *Tuberendothyra* endothyroids "with unconnected thick secondary mounds of tubercles, ridges and crests. . .some of the deposits have resorbed bases and have an apostrophe shape in cross section" (1969, p. 211). She designated as type species, *Endothyra tuberculata* Lipina which she emended. Included in the taxon were: *Plectogyra tumula* Zeller part (renamed *T. paratumula*), *Endothyra tuberculata magna* Lipina (renamed *T. safanovae*), *Chernyshinella tumulosa* Lipina, and *Endothyra tuberiformis* Durkina (which is not an Endothyridae and should be removed from the list).

However, the original diagnosis of *Spinoendothyra* (1963) stated that the discontinuous secondary deposits are "spines, hooks or tubercles (tumuli). . ." (p. 225). Thus, should *Tuberendothyra* be considered a junior synonym of *Spinoendothyra*? Both have similar morphology, the same disconnected secondary deposits throughout their whole life, and rather similar stratigraphic distribution and age.

The question is further complicated by the fact that many forms described by Skipp as *Tuberendothyra* (for example, pl. 18, figs. 14–16, pl. 19, figs. 13–19, pl. 20, figs. 21, 23, 26, 27) have spinose projections, not tumuli. Furthermore, Skipp emended Lipina's *tuberculata* to include forms with "apostrophes" and suggested that the shape was due to resorption; this is certainly not the Russian usage. Finally, Skipp believed that "*Endothyra spinosa* possesses secondary deposits as thin ridges, while the spinoendothyrids have thin, isolated, anteriorly curved projections, not parachomatical ridges."

It appears, however, that the distinction between *Tuberendothyra* and *Spinoendothyra* is feasible and useful in stratigraphy, if both genera are redefined as follows.

GENUS TUBERENDOTHYRA SKIPP IN McKEE AND GUTSCHICK 1969 EMENDED

Diagnosis.–Test free, irregularly discoidal, slightly compressed laterally. Proloculus followed by an irregularly coiled spirotheca. Deviation of the coiling axis constant. Chambers irregular, subglobular. Septa irregular, anteriorly directed. Number of chambers in the last coil ranging from 6 to 10. Secondary deposits as discrete discontinuous tubercles present in all the chambers. No continuous floor thickening. Irregular septal thickenings. Wall calcareous secreted, a single layered microcrystalline tectum. Aperture, a low slit at the base of the apertural face.

Type of the genus.–*Endothyra tuberculata* Lipina 1948. Akad. Nauk SSSR Geol. Inst. Trudy, v. 62, no. 19, p. 253, pl. 9, figs. 1–2.

Taxa included in the genus.—

1955 ?*crassitheca* Lipina
1955 *magna* Lipina (OBJ, preoccupied by 1948 *magna* Rauzer-Chernoussova)
1969 *sofonovae* new name for *magna* Skipp *in* McKee and Gutschick
1957 *superlata* Malakhova
1957 "*tumula*" Zeller (part)
1959 ?*turbida* Durkina

Stratigraphic distribution and range.—Cosmopolitan in the Northern Hemisphere (Eurasia, North Africa, North America).

Appears at the top of zone 7 where it is scarce, abounds in zone 8, and disappears in the late Tournaisian (zone 9).

Usually present in pellet-algae or in pellet-calcisphere grainstone and packstone. Absent in crinoid-bryozoan grainstone or in encrinite.

GENUS SPINOENDOTHYRA LIPINA 1963 EMENDED

Diagnosis.—Test free, irregularly discoidal, compressed laterally. Proloculus followed by an irregularly coiled spirotheca. Deviation of the coiling axis constant or by sudden changes. Chambers irregular, subglobular to subquadratic. Septa irregular, anteriorly directed. Number of chambers in the last coil ranging from 7 to 11, exceptionally 6 to 12. Secondary deposits as discrete, disconnected spines, present in all the chambers. No continuous floor thickenings. No ridges. Wall calcareous secreted, a single layered microcrystalline tectum, showing some differentiation in the most evolved forms. Aperture a low slit at the base of the apertural face.

Type of the genus.—*Endothyra costifera* Lipina in Grozdilova and Lebedeva (1954). (VNIGRI, v. 81, p. 86, pl. 10, fig. 15.)

Taxa included in the genus.—

1954 *accurata* Vdovenko
1956 ?*analoga* Malakhova
1956 *apta* Malakhova
1956 *bellicosta* Malakhova
1960 *brevivoluta* Lipina

1954 ?*calmiussi* Vdovenko
1956 *concava* Malakhova
1956 *corona* Malakhova
1954 *costifera* Lipina *in* Grozdilova and Lebedeva
1967 *hirsuta* Conil and Lys
1956 *mammata* Malakhova
1954 *media* Vdovenko (OBJ, preoccupied 1928 *media* Warthin)
1963 ?*morroensis* McKay and Green
1955 *multicamerata* Lipina
1954 *paracostifera* Lipina *in* Grozdilova and Lebedeva
1969 *paraspinosa* Skipp *in* McKee and Gutschick
1969 *paratumula* Skipp *in* McKee and Gutschick (part)
1954 ?*paraukrainica* Lipina *in* Grozdilova and Lebedeva
1960 ?*piluginensis* Lipina
1964 plagia Conil and Lys (OBJ, infrasubspecific)
1955 *recta* Lipina
1961 *speciosa* Shlykova
1940 *spinosa* Chernysheva
1954 *tenuiseptata* Lipina *in* Lebedeva
1960 *volgensis* Lipina

Stratigraphic distribution and range.— Cosmopolitan in the Northern Hemisphere (Eurasia, North Africa, North America). In North America widespread in the Cordillera and much scarcer in the midcontinent.

Occurs for the first time in zone 8, very abundant in zone 9, disappears slowly in early Viséan time.

Usually present in pellet-algae or pellet-calcisphere grainstone or packstone. Absent in crinoid-bryozoan grainstone or in encrinite.

Remarks.—If our interpretation is correct, *Tuberendothyra* is the most evolved known latiendothyrid and is the ancestral form from which *Spinoendothyra* is derived. Spinoendothyrids, by resorption of their projections, will give the *Inflatoendothyra* and are therefore the ancestral forms from which the dainellids are derived at the zone 9–10 junction.

CONTACT BETWEEN DEVONIAN AND MISSISSIPPIAN ROCKS

Kindle (1909, p. 7–8) reported "no trace of the Ouray fauna above the base of the large quarry south of Rockwood, although it is abundant a few feet below the floor of the quarry. . . In the section at the quarry. . . 5–10 feet of drab or rusty shale and shaly limestone separate the Devonian and Carboniferous beds. . . but this convenient lithologic boundary marker of the two horizons is not recognizable in some of the other nearby sections."

Knight and Baars (1957) believed that the typical Ouray Limestone fauna has both Devonian and Mississippian aspects and that the contact is gradational with the overlying Leadville Limestone. They suggested that the Ouray Limestone is transitional between the Upper Devonian Elbert Formation and the Lower Mississippian Leadville Limestone.

The boundary between the Ouray Limestone and the Leadville Limestone as yet cannot be dated by paleontologic methods at Rockwood Quarry or elsewhere in the San Juan Mountains. We have chosen the contact (pl 3; fig. 3, 4) at a marked lithologic break; it is the same contact as picked by Kindle (1909). The Ouray Limestone, 7 m below the contact, is brown to gray massive dolomite that is overlain by a 2-m-thick bed of crinoid-bryozoan-brachiopod packstone that contains a brachiopod fauna identified as Late Devonian, probably mid-Famennian (see p. 4). A 5- to 10-cm-thick shale parting is overlain by a 2.1-m-thick bed of pellet-bryozoan-pelecypod-packstone that contains, in addition to Late Devonian brachiopods, the algal species *Kamaena awirsi* Mamet and Roux and the incertae sedis *Proninella* sp. and *Parathurammina* sp. John Huddle also reports a Late Devonian condodont fauna from the top of this bed (see p. 5).

No diagnostic conodonts or other microfossils were found from 2 to 17.1 m above the base of the Leadville Limestone at Rockwood Quarry.

The lowest diagnostic foraminifers found are at 21 m above the base. The carbonate strata in the Leadville Limestone at Rockwood Quarry from 0 to 21 m above the base are considered to be Mississippian on the basis of microfacies.

Nor can the contact between the Ouray and Leadville be picked with accuracy in the other measured sections of the Leadville Limestone discussed in this report. The Ouray Limestone at most localities is a fine-grained dolomite with sedimentary structures suggesting subtidal-intertidal deposition, and the basal beds of the Leadville Limestone are a similar rock type deposited in a similar environment. Both dolomites are devoid of diagnostic fossils. The lithologic criteria used in these sections to differentiate the Ouray from the Leadville are: (1) a change in color of the dolomite from brownish gray in the Ouray to gray or light gray in the Leadville; (2) a marked decrease in argillaceous material in the Leadville; (3) the occurrence of intraformational conglomerates in the Leadville; (4) strongly developed stromatolites, laminations, and thin-bedded maroon shale in the Leadville; and (5) evidence of vadose weathering beneath the shale, on a supposed Devonian surface.

The Coalbank Hill section, 66C–1, has 8.5 m of fine-grained dolomite that we assign on lithologic grounds to the Leadville Limestone. These beds were assigned by Merrill and Winar (1958, fig. 4) to the Ouray Limestone on the basis of differences in insoluble residue between the two formations. Baars (1966, 1968) did not try to separate these dolomites and considered the unit as Leadville-Ouray, undifferentiated.

A similar problem exists in the Molas Lake section 66C–2B. The Ouray section, 66C–5, contains 5.5 m of unfossiliferous dolomite at its base that we assign to the Leadville Limestone (pl. 2).

Burbank (1932), in the Kerber Creek region of the Bonanza mining district in the extreme northeastern part of the San Juan Mountains, separated his Chaffee Formation from the Leadville Limestone on lithologic evidence. The limestone member of the Chaffee is about 27.5–31 m thick and is thin-bedded argillaceous dolomite that weathers a grayish orange. Burbank's (1932) definition of the base of the Leadville Limestone is used in this report. It is argillaceous lime mudstone with lithoclasts and stromatolites, overlain by 40 m of black massive dolomite and black nodular chert, none of which contains recognizable fossils. The assignment of the Leadville to the Mississippian(?) and Mississippian is based solely on stratigraphic position and lithologic correlation with other Mississippian sections in Colorado. Burbank did not find any diagnostic Mississippian fossils. Our study found microfossils, which indicate zone 9, only in the upper 2.5 m of the section.

CONTACT BETWEEN MISSISSIPPIAN AND PENNSYLVANIAN ROCKS

A regional unconformity at the top of the Leadville Limestone represents at least Meramecian, Chesterian, and probably early Morrowan time. Meramecian and possibly lower Chesterian strata may have been present in the San Juan Mountains above the Osagean beds but were possibly removed by the regional uplift and subsequent erosion that occurred in Chesterian and Early Pennsylvanian time. In the San Juan Mountains, the Molas Formation is 15–30 m thick and overlies the Leadville Limestone. Merrill and Winar (1958) published a detailed study of the Molas and associated formations. They divided the Molas Formation into three parts: Coalbank Hill, Middle, and Upper Members. Their lowest unit, the Coalbank Hill Member, was formed as a residual deposit of nonmarine mudstone and siltstone containing solution-rounded limestone, dolomite, and chert fragments. It accumulated as a result of uplift, erosion, and solution of Devonian and Mississippian carbonate rocks that occurred during Late Mississippian and Early Pennsylvanian time.

The contacts between the Leadville Limestone and Molas Formation in the Rockwood Quarry (65A–12A), Coalbank Hill (66C–1), Molas Creek (66C–2), and Molas Lake (66C–2B) sections are well exposed and typical. At these locations the contact between Merrill and Winar's (1958) Coalbank Hill Member of the Molas Formation and limestone of the underlying formation is unconformable and gradational. Red mud and silt from the Coalbank Hill Member have sifted into openings in the limestone below. The solution of the limestone and development of the mantle apparently progressed downward with time.

Definition of the contact between the Molas Formation and the Leadville Limestone is difficult. Merrill and Winar (1958, p. 2116) included most of the crinoid limestone from 7 to 20.4 m above the base of our Leadville Limestone at the Coalbank Hill section (66C–1) (pl. 3) in their type section for the Coalbank Hill Member. They (p. 2115, fig. 4) showed no Coalbank Hill Member in the Molas Lake section, 66A–2B, and located the contact as we indicate in our plate 3. The contact between the Leadville Limestone and the Molas Formation at the Ouray section 66C–5 is very sharp, with little evidence of solution activity in the limestone.

The Molas Formation is absent from the Kerber Creek section (66C–6B) in the northeast San Juan Mountains where ferruginous pebble quartz conglomerate and bedded black shale of the Pennsylvanian Kerber Formation unconformably overlie the Leadville Limestone.

CORRELATION OF THE LEADVILLE LIMESTONE IN THE SAN JUAN MOUNTAINS

Baars (1966) and Baars and See (1968) developed, for the San Juan Mountains area, an ancient tectonic framework in which the Grenadier highland and the Sneffels horst (pl. 3) were active before the Late Cambrian Ignacio Quartzite was deposited. These highlands created peninsular features that extended into the Cambrian sea. The positive topographic relief on the structural horsts persisted into Late Devonian time. They believed that downfaulting adjacent to the Grenadier highland was renewed during deposition of the Devonian Ouray Limestone.

Baars (1966, p. 2103) believed that "crinoidal bioherms and stromatolitic dolomites occur in the Early Mississippian Leadville Limestone along the structurally high parts of these paleotectonic features, but no deeper-water sedimentary rocks were found in the ancient grabens. Renewed movement along the ancient faults occurred in post Mississippian time."

The only rocks that are definitely known to be Mississippian, and can be separated from the Ouray carbonate rocks without question, are the crinoid-pellet-foraminifer limestone that occurs above the dolomite.

The dolomite beneath the crinoid limestone appears to represent intertidal-subtidal environments and contain no recognizable microfossils, and thus it may well be a part of the Ouray Limestone. Our studies indicate, for the San Juan Mountains region, only weak residual bottom topographic influence on the distribution of Mississippian fossiliferous carbonate facies.

The supposed Mississippian dolomites at the Coalbank Hill and Molas Creek sections were correlated by Baars (1965; 1966, fig. 14) with his lower member of the Leadville Limestone in the subsurface of the eastern Paradox basin. According to Baars, cores from the subsurface of the eastern Paradox basin, in the Lisbon oil field 430 km to the west, have yielded a microfauna of Kinderhookian age from the lower member. In the subsurface, Baars recognized an intraformational disconformity between his dolomitic lower member and his predominantly limestone upper member.

We have assigned the unfossiliferous dolomite above the Ouray Limestone and beneath the fossiliferous Mississippian beds to the Leadville Limestone. It is best developed in the Coalbank Hill and Molas Creek sections (pl. 3). The Kerber Creek section, 150 km northeast of the Piedra River section, contains a 39.5-m-thick sequence of thin- to medium-bedded argillaceous gray unfossiliferous dolomite. The interval is assigned to the Leadville Limestone on the basis of stratigraphic position and lithology.

Parts of Baars and See's (1968, pl. 1) detailed Mississippian facies and paleogeographic analysis for the San Juan Mountains region is open to question as it is based on the unfossiliferous dolomite beneath the Molas Formation adjacent to and across the Grenadier highland.

Reconstruction of the regional facies distribution of the Leadville Limestone in the San Juan Mountains is complicated by the strong tectonic activity that occurred at the end of Leadville deposition and continued into Pennsylvanian time. This resulted in differential uplift and uneven removal of the fossiliferous crinoidal facies of the Leadville Limestone over large areas, and its complete removal over the Uncompahgre uplift.

It is evident that the fossiliferous pellet-mud-lump-crinoid-ooid wackestone and packstone in the upper parts of the Leadville Limestone represent a regional transgression of zone 9, late Osagean age.

The crinoidal carbonate rocks and associated rock types represent sedimentation on a shallow shelf with localized areas of lime mud accumulation or ooid sands developed in shoaling waters. No evidence of crinoidal bioherms was found in outcrops of the Leadville Limestone of this area.

The present thickness or isopach distribution of the fossiliferous crinoidal beds of the Leadville Limestone in the San Juan Mountains appears to reflect the extent of Late Mississippian and Pennsylvanian erosion and may not be directly related to the original thickness at the end of Early Mississippian time.

REGIONAL CORRELATIONS AND PALEOGEOGRAPHY

REDWALL LIMESTONE, GRAND CANYON, ARIZONA

Parker and Roberts (1963) correlated the Leadville Limestone of the San Juan Mountains and the subsurface of the San Juan and Paradox basins with the Redwall Limestone of the Grand Canyon region of Arizona. They considered the lower half of our Leadville Limestone at Rockwood Quarry to be equivalent to McKee's (1963) Thunder Springs Member and the upper part equivalent to the Mooney Falls Member. Their correlations were based on analysis of subsurface electric logs from eastern Arizona and Utah.

McKee and Gutschick's (1969, fig. 26) monograph of the lithology and paleontology of the Redwall Limestone indicates that the Mooney Falls Member represents the maximum eastward transgression of the Redwall Limestone. Mamet's microfossil study in this report of the Leadville Limestone of the San Juan Mountains shows the Leadville Limestone to be equivalent to the middle part of the Mooney Falls Member of the Redwall Limestone of northern Arizona. Numerous oil tests drilled in the Black Mesa basin of Arizona and the Paradox basin of Utah show continuous Mississippian carbonate beds in the subsurface from the east end of the Grand Canyon to the outcrops in the San Juan Mountains (Parker and Roberts, 1963, figs. 12–15).

ARROYO PENASCO GROUP, NORTH-CENTRAL NEW MEXICO

A detailed account of the Arroyo Penasco Group, its lithology, microfossils, and geologic history can be found in Armstrong and Mamet (1974). The following description is, in part, abstracted from that report.

The Arroyo Penasco Group includes two formations, the Espiritu Santo Formation and the overlying Tererro Formation. Its basal unit, the Del Padre Sandstone Member of the Espiritu Santo Formation (Sutherland, 1963), 0.5–15 m thick, is composed of quartz conglomerate, sandstone, siltstone, and thin shale (fig. 9). The Del Padre interfingers with carbonate rocks in the Espiritu Santo and should be considered as the basal unit of a normal transgression; thus it is probably late Tournaisian. It rests unconformably on Precambrian rocks.

A similar unit is present at the base of the transgressive late Tournaisian (zone 8) Caloso Member of the Kelly Limestone (Armstrong, 1958a, b) in west-central New Mexico.

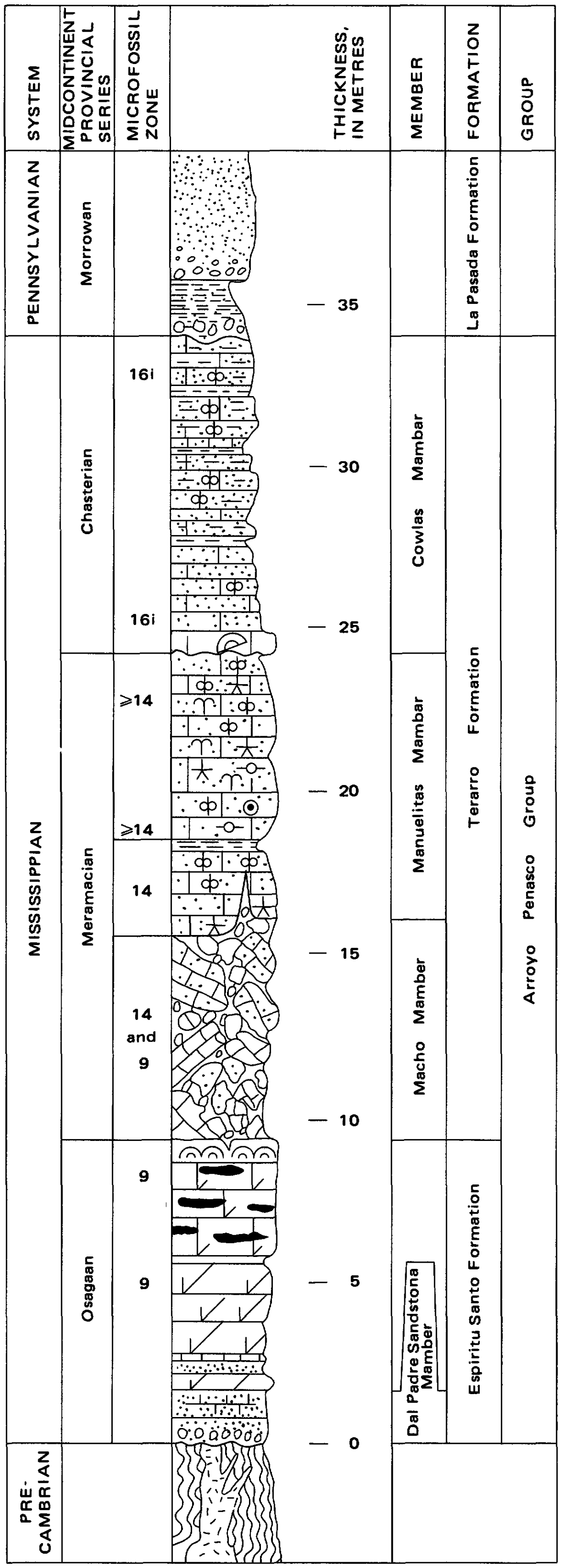


FIGURE 9.—The Mississippian Arroyo Penasco Group at Tererro, west side of the Pecos River, Sangre de Cristo Mountains. N. Mex.

The remainder of the Espiritu Santo Formation consists of dolomite, dedolomite, and coarse-grained poikilotopic calcite with corroded dolomite rhombs. Where the rocks are not dolomitized, such features as stromatolitic algal mats, *Spongiostromata* mats, echinoderm wackestone, kamaenid birdseye-rich lime mudstone, and oncholitic-bothrolitic mats are recognizable. This association suggests very shallow water intertidal to supratidal carbonate sedimentation. The carbonate rocks are 26.2 m thick at the Arroyo Penasco section in the Nacimiento Mountains and 8 m thick at the type section of the Tererro Formation in the Sangre de Cristo Mountains.

The microfauna is usually destroyed or unrecognizable in the dolomite and dedolomite; however, chert usually preserves the outline of foraminiferal tests, and stratigraphically useful microfossil assemblages can be detected. The most important taxa are: abundant *Calcisphaera laevis* Williamson, *Endothyra* sensu stricto, *Latiendothyra* of the group *L. parakosvensis* (*Latiendothyra skippae* of Armstrong), *Septabrunsiina parakrainica* Skipp, Holcomb, and Gutschick, *Septatournayella pseudocamerata* Lipina *in* Lebedeva, and *Spinoendothyra spinosa* (Chernysheva). The assemblage is zone 9 and is late Tournaisian. Carbonate rocks of the Espiritu Santo Formation are an eastward and southward, more shallow water facies of the zone 9 open-marine shallow-water foraminifer packstone-wackestone beds of the Leadville Limestone of the San Juan Mountains.

The Late Mississippian Tererro Formation of the Arroyo Penasco Group is younger than the Leadville Limestone of the San Juan Mountains. The absence of Meramecian beds in the San Juan Mountains is undoubtedly due to their removal by late Chesterian and Early Pennsylvanian erosion. Meramecian carbonate rocks are present in the subsurface of the Paradox basin of southeastern Utah and the Black Mesa basin of northeastern Arizona (McKee, 1972).

The Tererro Formation includes in ascending order the Macho, Turquillo, Manuelitas, and Cowles Members. The lower 4.5 m of the Macho Member at Tererro, Pecos River, Sangre de Cristo Mountains, contains blocks of foraminifer-pellet wackestone that yield Tournaisian *Spinoendothyra* assemblages, whereas the matrix of the blocks yield Viséan *Eoendothyranopsis,* notably *Eoendothyranopsis macra* (Zeller) and *Eoendothyranopsis* of the group *E. ermakiensis* (Lebedeva). In this instance, the formation of the breccia coincides with a hiatus that spans zones 10, 11 and 12. In other sections (e.g., Turquillo), the breccia is overlain by algal mudstone that contains zone 12–13 microfossils. At all localities, the upper parts of the breccia contain collapsed blocks, derived from the overlying Turquillo Member, which contains a middle Viséan microfauna.[1]

The origin of the Macho Member, a breccia, is difficult to assess. It could have been formed by subaerial exposure after deposition of the Espiritu Santo Formation (Baltz and Read, 1960; Sutherland, 1963). Or it could be the result of dissolution by meteoric ground water of interbedded carbonate rocks and gypsum (Armstrong, 1967) during Late Mississippian and Early Pennsylvanian.

Armstrong and Mamet (1974) proposed the name Turquillo Member for a thick-bedded mudstone-wackestone, rich in foraminifers and bothrolites, that overlies either the Macho Member or, where missing, the Espiritu Santo Formation. The Turquillo Member is 2.5 m thick at the Ponce de Leon Springs section east of Taos. Elsewhere in the Sangre de Cristo Mountains it may be as much as 4.5 m thick. It is absent in the Pecos River Canyon. Foraminifers in the Turquillo Member indicate the passage of zone 12–13, which is the age equivalent of the Salem-St. Louis boundary (Armstrong and Mamet, 1974).

The Manuelitas Member (Baltz and Read, 1960) is composed of thick-bedded oolitic-bothrolitic grainstone and a silty pellet fine-grained grainstone-packstone with minor calcareous silt. The oolite ranges in thickness from 0 to 10 m. It is clearly transgressive and rests on the Espiritu Santo Formation, or in the intervening Macho or Turquillo Members of the Tererro Formation. The oolitic unit is rich in foraminifers and is a St. Louis age equivalent (zone 14). The pelletoidal facies is poorer in microfossils; most of the foraminifers are minute archaediscids.

The Cowles Member (Baltz and Read 1960), known only in the Sangre de Cristo Mountains, rests everywhere in the study region on the Manuelitas Member. The contact appears paraconformable. The top of the formation is eroded and unconformably overlain by Pennsylvanian clastic rocks in all known exposures. Its apparent thickness ranges from 0.5 to 10 m.

As in the Manuelitas Member, the Cowles microfauna is composed almost exclusively of very small, rolled, abraded, and commonly mud-filled foraminifers; these are mostly Archaediscidae with a few Endothyridae and Eostaffellidae. The presence of primitive *Neoarchaediscus* and *Zellerina* clearly indicates that the formation is younger than Meramecian and should be regarded as an early Chesterian equivalent. There is, therefore, no proof of the existence of a Ste. Genevieve fauna between the Manuelitas Member and the Cowles Member.

The Log Springs Formation (Armstrong, 1955) is only known in the Sandia, Jemez, Nacimiento, and San Pedro Mountains. The Log Springs Formation occupies a similar stratigraphic position in relation to the carbonate rocks of the Arroyo Penasco Group as the Molas Formation does to the Leadville Limestone. The Log Springs is 2–5 m thick and rests with a marked unconformity on various beds of the Arroyo Penasco Group. It contains continental clastic red beds composed of oolitic hematite, shale, arkosic sandstone, and conglomerate. It is post zone 16_{inf}, and because it is overlain with hiatus by zone 20, it must be late Chesterian. On the other hand, the Molas Formation is primarily marine in origin, well stratified, and contains Pennsylvanian Marine fossils in its upper parts (Merrill and Winar, 1958).

[1]Thus the breccia could only be formed by postburial dissolution of the gypsum. If Baltz and Read's hypothesis were correct, there would be no Turquillo blocks in the breccia.

KELLY LIMESTONE OF THE LADRON MOUNTAINS, WEST-CENTRAL NEW MEXICO

The nearest outcrop exposure of brachiopod-bearing Osagean rocks south of Rockwood Quarry is the Kelly Limestone, composed of the zone 8 Caloso Member and the zone 9 Ladron Member of the Ladron Mountains, about 310 km away. The two members have a combined thickness in excess of 25 m.

The name Kelly Limestone was applied by Gordon (1907) to Mississippian strata in the vicinity of Kelly in the Magdalena Mountains. The type section of the Kelly Limestone is defined as the outcrop on the crest of the Magdalena Mountains (NE¼SW¼ sec. 31, T. 2 S., R. 3 W.). Kelley and Silver (1952) proposed the name Caloso Formation for the Mississippian rocks of the Ladron Mountains 41 km north of Kelly. Armstrong (1955, 1958a) restricted the Caloso Formation to the lower part and the Kelly Formation to the upper part of the Mississippian section in the Lemitar, Magdelena, and Ladron Mountains. His study (1958a) of the brachiopod faunas from these two formations indicated that the Caloso Formation was probably of early Osagean age and that the Kelly Formation contained a rich brachiopod fauna of late Osagean age. The Kelly Limestone in this paper is redefined as consisting of two members, the lower, the Caloso Member (the Caloso Formation of Armstrong, 1958a, 1967), and the upper crinoidal unit, the Ladron Member. The name Kelly Limestone is restricted to west-central New Mexico, in the Lemitar, Ladron, and Magdalena Mountains and Coyote Hills. The Caloso Member unconformably overlies Precambrian metamorphic and igneous rocks. A disconformity that probably represents a short hiatus separates the Caloso Member from the Ladron Member. The Ladron Member is unconformably overlain by clastic rocks of the Pennsylvanian Sandia Formation.

CALOSO MEMBER

The Caloso Member (fig. 10) at its type locality, Caloso Arroyo in E⅓ sec. 30, T. 2 N., R. 2 W., Ladron Mountains, northern Socorro County, is 11.6 m thick. The lower 3–3.5 m is arkosic sandstone and shale. The limestone, about 6 m thick, is composed in the lower part of stromatolitic lime mudstone overlain by pellet-echinoderm-foraminifer wackestone and packstone.

The brachiopod fauna from the Caloso Member's type locality was described by Armstrong (1958a) and is *Beecheria chouteauensis* (Weller) and *Spirifer centronatus ladronensis* Armstrong. Examination by Mamet of the thin section from limestone of the Caloso Member shows that it contains a microfossil assemblage of zone 8. The Endothyridae are represented mostly by *Latiendothyra*, *Medioendothyra*, and *Tuberendothyra*.

LADRON MEMBER

The Ladron Member at its type locality in the Magdalena Mountains, NE¼SW¼, sec. 31, T. 2 S., R. 3 W., is 21.5 m thick. It is gray crinoid-bryozoan wackestone and packstone with gray nodular chert. It is unconformably overlain by shale and conglomerate of the Pennsylvanian Sandia Formation. It is separated from the underlying Caloso Member by a disconformity. In the Ladron Mountains the Ladron Member is 0 to in excess of 15 m thick. The basal 0.1–0.3 m is arenaceous lime mudstone to quartz sandstone overlain by 15 m of light-gray bryozoan-echinoderm-brachiopod wackestone and packstone.

The megafossil fauna of the Ladron Member of the Ladron Mountains was described by Armstrong (1958a) and contains the following taxa.

Brachiopoda
- *Rhipidomella* sp
- *Linoproductus* sp.
- *Chonetes* cf. *illinoisensis* Worthen
- *Tetracamera* cf. *subtrigona* (Meek and Worthen)
- *Tetracamera subcuneata* (Hall)
- *Rhynchopora persinuata* (Winchell)
- *Spirifer tenuicostatus* Hall
- *Spirifer grimesi* Hall
- *Brachythyris suborbicularis* (Hall)
- *Athyris* aff. *lamellosa* (Lèveillè)
- *Cleiothyridina hirsuta* (Hall)
- *Cleiothyridina obmaxima* (McChesney)
- *Dimegelasma neglectum* (Hall)

Blastoidea
- *Pentremites conoideus* Hall

Coelenterata
- *Zaphriphyllum casteri* Armstrong

Armstrong (1958a, p. 4), on the basis of the

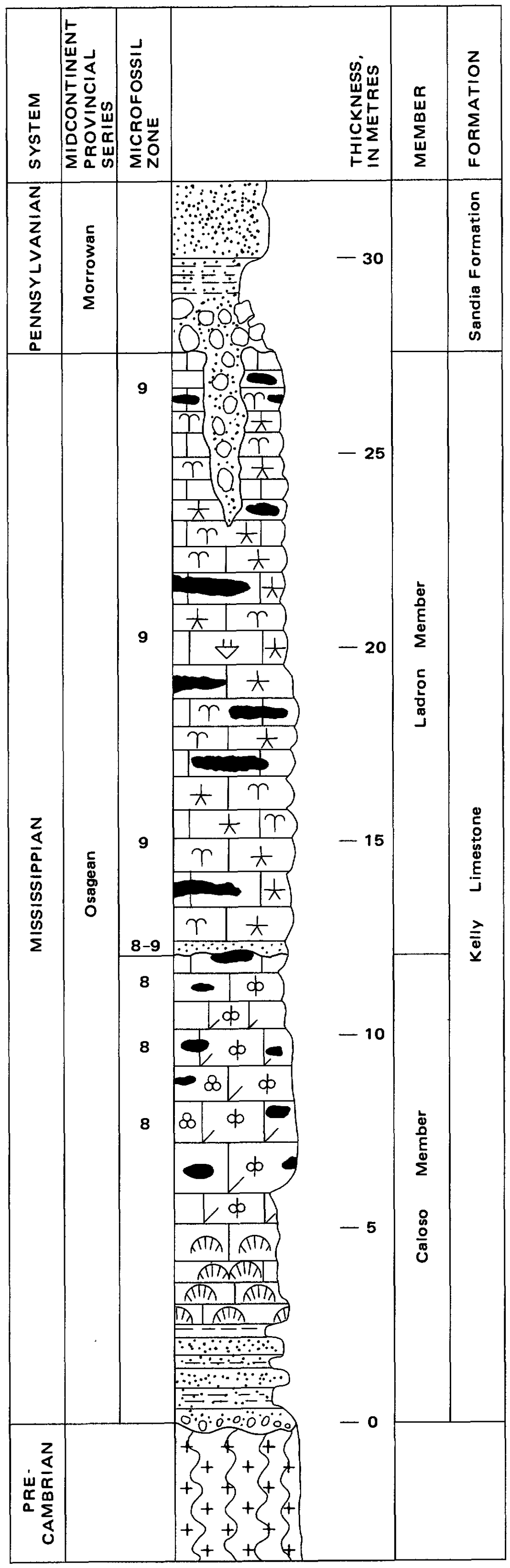


FIGURE 10.—Mississippian (Osagean) Caloso and Ladron Members of the Kelly Limestone, Ladron Mountains, west-central New Mexico.

brachiopods, considered the Ladron Member to be late Osagean (Keokuk).

Microfossils found in thin sections from the Ladron Member are of zone 9. In spite of the fact that not a single *Spinoendothyra* could be identified, a latest Tournaisian age was established on the first occurrence of *Priscella, Pseudotaxis,* and *Tetrataxis.* Brenckle, Lane, and Collinson (1974) have recently suggested that most of the Keokuk Limestone in its type region was younger than zone 9 because no *Spinoendothyra* could be detected. However, the Keokuk Limestone was deposited as an encrinite, and the *Spinoendothyra* fauna could not thrive in such a facies. In addition, spinose Endothyridae are scarce everywhere in the midcontinent, even in pellet grainstone. As the Keokuk Limestone exhibits the first occurrence of *Endothyra* sensu stricto, *Priscella, Tetrataxis, Pseudotaxis,* and *Eoforschia,* it may safely be considered to be late Tournaisian. Earliest Globoendothyridae are present in the upper part of the formation and indicate the Tournaisian-Viséan passage.

MICROFOSSILS

The following taxa of algae and foraminifera have been recognized in the Kelly Limestone section 70N-8, Rio Salado, Ladron Mountains; all material is from USGS loc. M1227.

Caloso Member:

Specimen numbers 70N–8 + 28–38 ft; 8.5 to 11.6 m above Precambrian contact.

Calcisphaera sp.
Calcisphaera laevis Williamson
Earlandia sp.
Kamaena sp.
Kamaena of the group *K. delicata* Antropov
Medioendothyra sp.
Latiendothyra sp.
Palaeoberesella sp.
Parathurammina sp.
Proninella sp.
Septabrunsiina sp.
Septabrunsiina parakrainica Skipp, Holcomb, and Gutschick
Septaglomospiranella sp.
Septaglomospiranella dainae Lipina
Septatournayella sp.
Tuberendothyra sp.
Tuberendothyra safanovae Skipp *in* McKee and Gutschick
Tuberendothyra tuberculata (Chernysheva)

Age: Zone 8, early late Tournaisian.

Lowest part of Ladron Member:

Specimen number 70N–8 + 40 ft; 12 m above Precambrian contact

Calcisphaera sp.
Calcisphaera laevis Williamson
Earlandia of the group *E. elegans* (Rauzer-Chernoussova)
Earlandia of the group *E. clavatula* (Howchin)
cf. *Earlandinella*? sp.
Kamaena sp.
Latiendothyra sp.
Latiendothyra of the group *L. latispiralis* (Lipina)
Latiendothyra parakosvensis (Lipina)
Palaeoberesella sp.
Parathurammina sp.
Proninella sp.
Pseudokamaena sp.
Septabrunsiina sp.
Septaglomospiranella dainae Lipina
Spinoendothyra sp.
Spinoendothyra spinosa (Chernysheva)
Tuberendothyra sp.
Tuberendothyra aff. *T. tuberculata* (Chernysheva)
Vicinesphaera sp.

Age: Zone 8–9 boundary, late Tournaisian.

Ladron Member:

Specimen number 70N–8 + 68–77 ft; 21 to 23.5 m above the Precambrian contact.

Calcisphaera sp.
Calcisphaera laevis Williamson
Earlandia sp.
Earlandia clavatula (Howchin)
Latiendothyra sp.
Priscella sp.
Priscella prisca (Rauzer-Chernoussova and Reitlinger)
Pseudotaxis sp.
Septaglomospiranella dainae Lipina
Tetrataxis sp.

Age: Zone 9, late Tournaisian.

LATE OSAGEAN MARINE TRANSGRESSION

The stratigraphic record clearly shows that a major regional marine transgression occurred in southwestern Colorado and New Mexico during zone 9, of late Osagean and late Tournaisian age (figs. 11, 12). It is represented in northern Arizona (McKee and Gutschick, 1969) by the Mooney Falls Member of the Redwall Limestone and in southwestern Colorado by the foraminifer-pellet-crinoid wackestone and packstone of the Leadville Limestone (pl. 3). In west-central New Mexico, disconformably overlying the subtidal-algal-foraminifer-pellet wackestone and packstone of the Caloso Member, of zone 8 age, is the high-energy shoaling-water crinoid packstone of the Ladron Member of zone 9 age (figs. 11, 12). In north-central New Mexico, the transgression is represented in the Arroyo Penasco Group by the Espiritu Santo Formation, of zone 9 age (fig. 12). Armstrong and

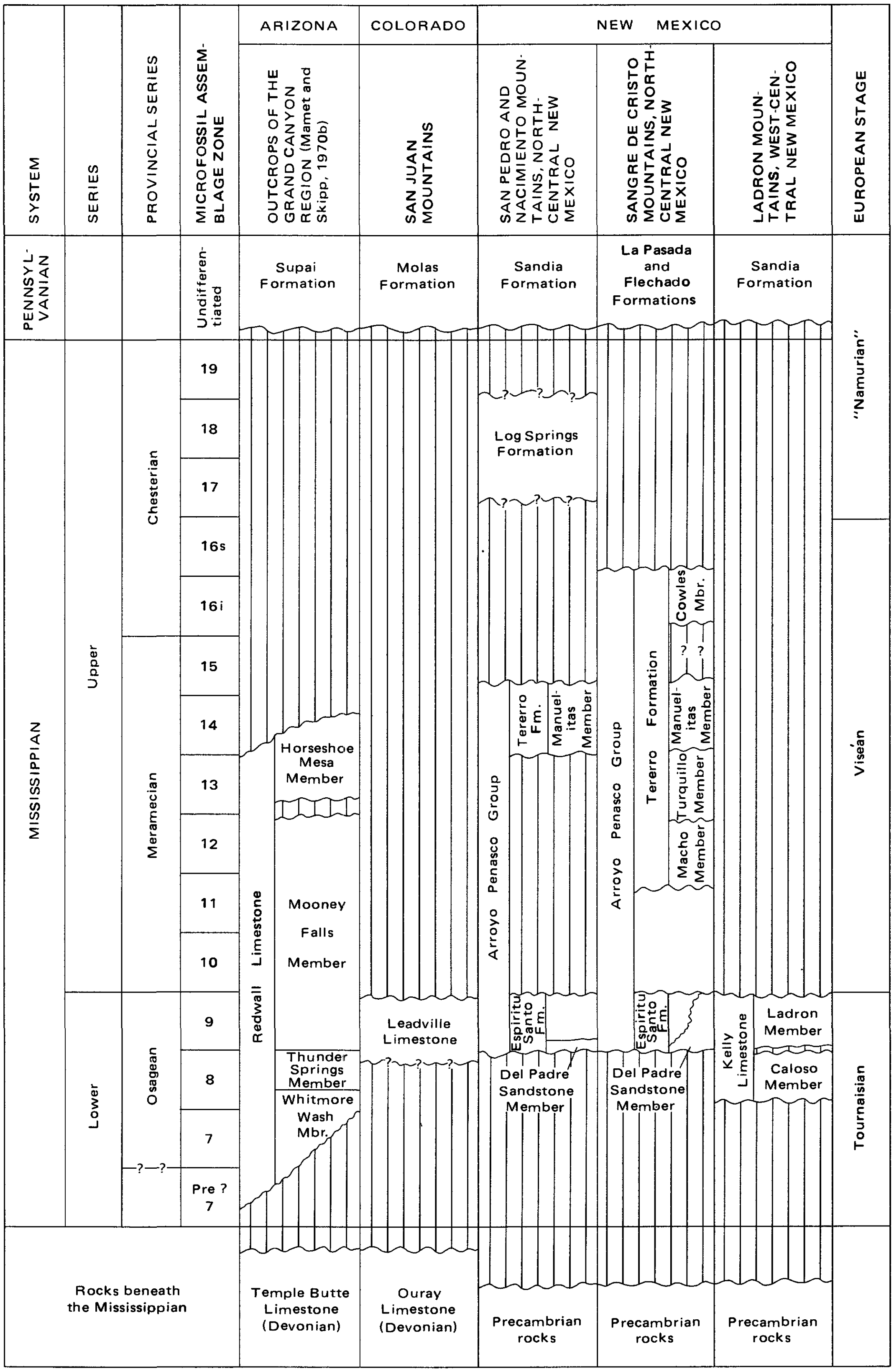


FIGURE 11.—Regional correlation diagram of the Leadville Limestone of the San Juan Mountains, Colo., and Mississippian rocks in adjacent areas.

Mamet (1974) reported that carbonate rocks of the Espiritu Santo Formation consist of dolomite, dedolomite, and coarse-grained poikilotopic calcite with corroded dolomite rhombs. Associated with these carbonate rocks are stromatolitic algal mats, *Spongiostromata* mats, echinoderm wackestone, kamaenid mudstone with birdseye structure, oncholitic-bothrolitic mats, and calcitic pseudomorphs after gypsum. These indicate very shallow water sedimentation in subtidal to supratidal environments.

The Espiritu Santo Formation represents, in part, subtidal to supratidal sabkha carbonate rocks deposited on part of the Paleozoic transcontinental arch in northern New Mexico. The relation of these sabkhalike deposits to the open-marine Leadville Limestone of the San Juan Mountains and Four Corners region and the crinoid-brachiopod of the Ladron Member of the Kelly Limestone of west-central New Mexico is shown in figures 11 and 12.

Calcite pseudomorphs of gypsum are common in the carbonate rocks of the Espiritu Santo Formation. Armstrong (1967) and Armstrong and Mamet (1974) suggested the possibility that the Macho Member, a breccia, may represent a collapse breccia formed by the solution, in Early Pennsylvanian time, of interbedded gypsum and limestone that represent the upper part of the Espiritu Santo Formation in the Sangre de Cristo Mountains of New Mexico.

These subtidal to supratidal beds began as the distal ends of the zone 9 transgression. They represent protected, shallow-water carbonate sedimentation. Within a short time they became carbonate offlap regressive facies to the open-marine, higher energy carbonate bioclastic sand of the Leadville Limestone of the San Juan Mountains and the Kelly Limestone of the Ladron and Magdalena Mountains of west-central New Mexico (Armstrong, 1967, fig. 6). Shallow-water subtidal carbonate regressive sediments may at one time have overlain the bioclastic carbonate rocks of the Leadville Limestone and the Kelly Limestone and were subsequently removed by pre-Pennsylvanian erosion.

An idealized Late Devonian paleogeologic map is shown in figure 13 and a paleogeographic map of southern Colorado and northern New Mexico at the end of Osagean (zone 9) time is shown in figure 14, which also presents an analysis and reconstruction of the carbonate environments. Armstrong and Mamet (1974) showed that the youngest known Mississippian marine deposits in the region are zone ⩾16i, lower Chesterian. In Chesterian and earliest Pennsylvanian time, the thin Mississippian carbonate sediments over the region were subjected to uplift, folding, and faulting. The consequent extensive erosion and weathering over much of Arizona, Utah, New Mexico, and Colorado (McKee and Gutschick, 1969; Merrill and Winar, 1958; Armstrong, 1958b) resulted in the removal of extensive areas of Mississippian carbonate rock. The present-day disjunct nature of Mississippian outcrops is in large part due to this erosion. An idealized pre-Pennsylvanian paleogeologic map is shown in figure 15.

LOCATION OF STRATIGRAPHIC SECTIONS AND FOSSIL LOCALITIES

U.S. Geological Survey fossil locality numbers: Those with an M prefix refer to locality numbers on file at the Pacific Coast Center of the Geological Survey at Menlo Park, Calif.; all others are Washington, D.C., numbers.

Rockwood Quarry sections 65A–12A, 66C–4; SW¼ sec. 12, T. 37 N., R. 9 W., La Plata County, Colo. USGS loc. 9206–SD and USGS loc. M1180–M1186; USGS loc. 9206 D; USGS loc. 25447–PC, 25448–PC.

Ouray section 66C–5; 1,207 m south of Box Canyon, on west side of Uncompahgre Gorge; sec. 6, T. 43 N., R. 7 W., Ouray County, Colo. USGS loc. M1193–M1197.

Molas Lake section 66C–2B; section is a roadcut on the north side of the road and begins at lake level; sec. 7, T. 40 N., R. 7 W., San Juan County, Colo. USGS loc. M1190–M1192.

Molas Creek section 66C–2; section is on the north side of Molas Creek, 550 m south of Molas Lake, below and beside where Molas Creek cascades over the Leadville Limestone; sec. 7, T. 40 N., R. 7 W., San Juan County, Colo. USGS loc. M1190–M1192.

Coalbank Hill section 66C–1; north side of U.S. Highway 550, 1,500 m north of Mill Creek Lodge; sec. 6, T. 39 N., R. 8 W., San Juan County, Colo. USGS loc. M1187–M1188.

Vallecito section 66C–3; 200 m north of the north end of Vallecito Campground; NW¼ sec. 16, T. 37 N., R. 6 W., La Plata County, Colo. USGS loc. M1198–M1199.

Piedra River section 65A–10; 200 m north of the junction of Davis Creek and the Piedra River; SE¼ sec. 22, T. 36 N., R. 3 W., Archuleta County, Colo. USGS loc. M1226–1226a.

Kerber Creek section 66C–6 and 66–6B; near crest of hill about 1,000 m south of the road and Kerber Creek; sec. 25, T. 46 N., R. 8 E., Saguache County, Colo. USGS loc. M1200, M1201.

Southern Ladron Mountain section 70N–8, in Caloso Arroyo, in E⅓ sec. 30, T. 2 N., R. 2 W., Ladron Mountains, Socorro County, N. Mex. (See Armstrong, 1958b, pl. 6, for photographs of outcrop.)

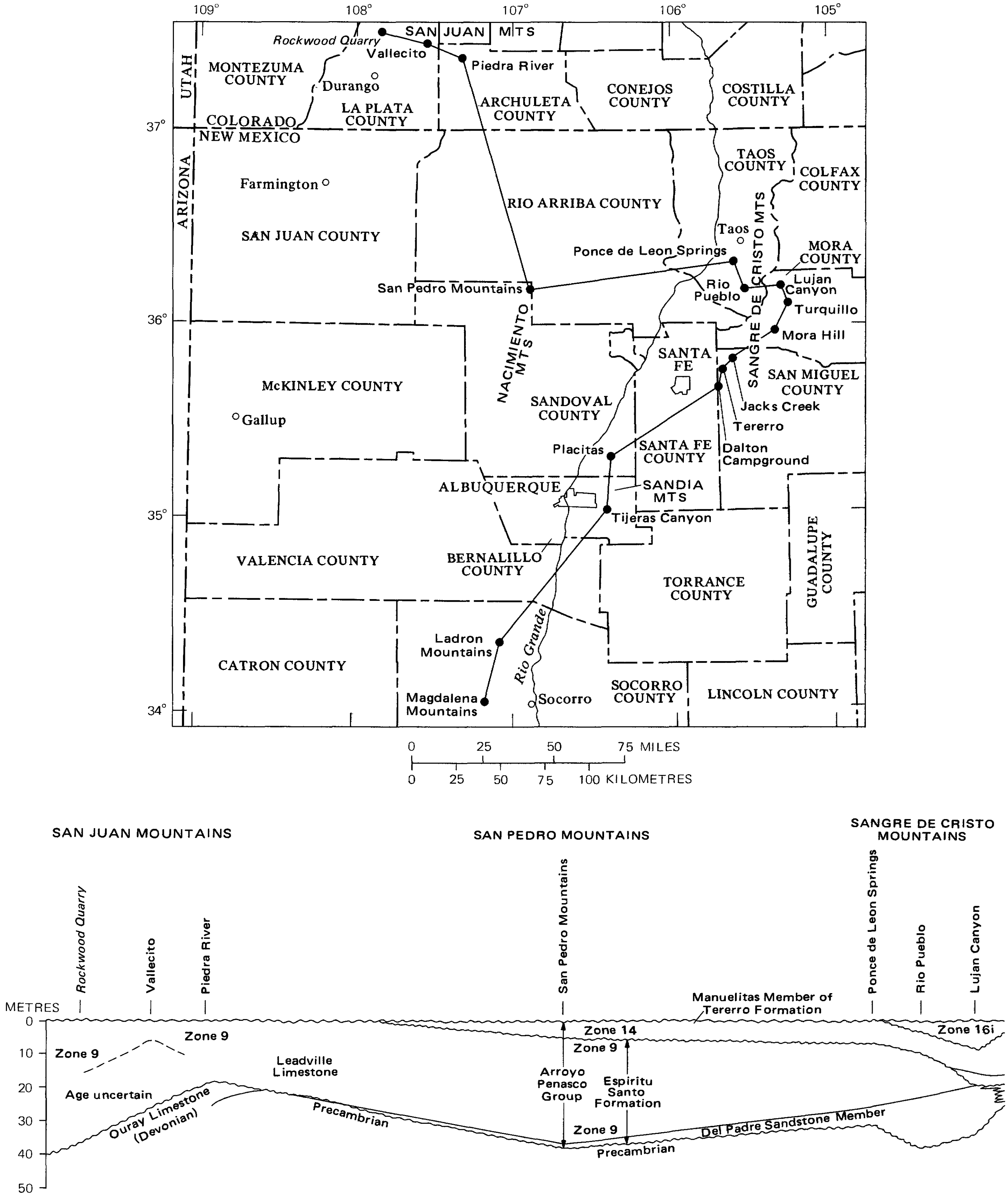


FIGURE 12.—Biostratigraphic correlation and facies relations of Mississippian rocks from the San Juan Mountains, southwestern Colorado, southeastward to the San Pedro and Sangre de Cristo Mountains of north-central New Mexico to the Ladron Mountains in west-central New Mexico. Detailed location maps of the stratigraphic sections shown in this diagram for New Mexico are given in Armstrong (1958b, 19767). Stratigraphic sections for the New Mexico outcrops are given by Armstrong and Mamet (1974).

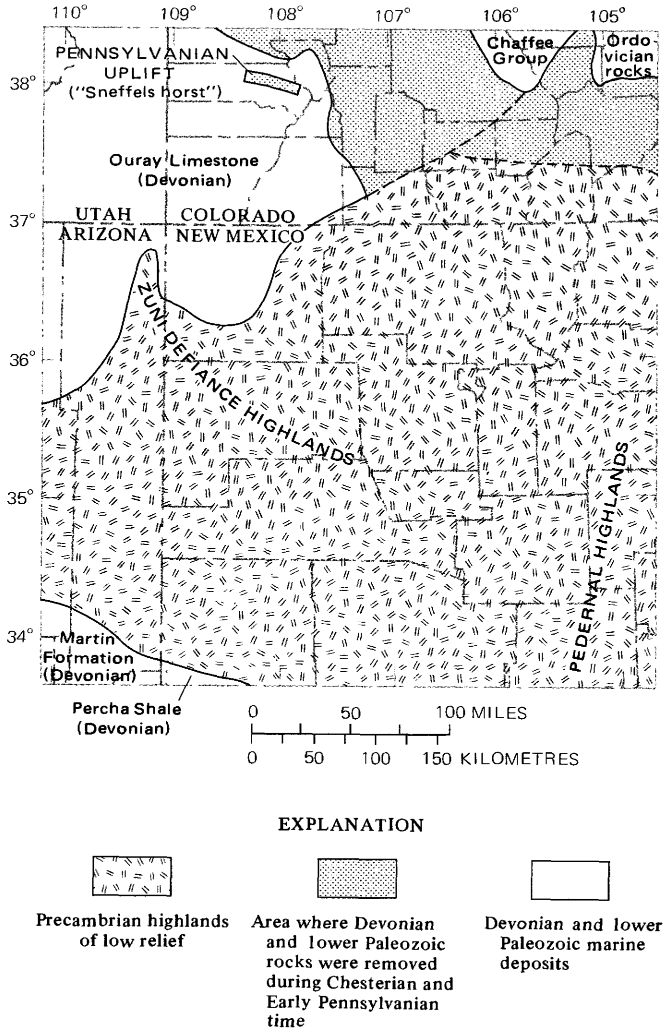


FIGURE 13.—Idealized Late Devonian paleogeologic map of southern Colorado and northern New Mexico.

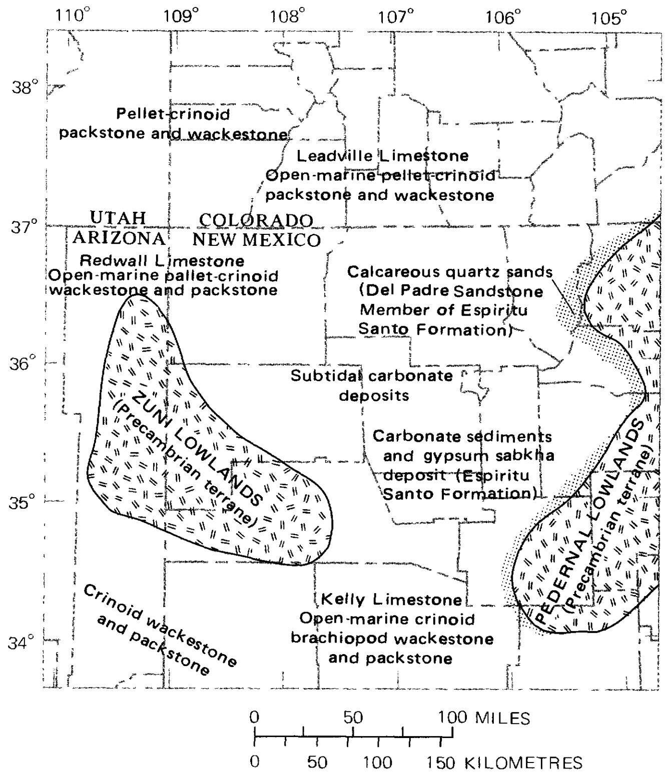


FIGURE 14.—Paleogeographic map of northern New Mexico, southern Colorado, and the Four Corners area at the end of Osagean, Mississippian time. The map is in part from Parker and Roberts (1963) and McKee (1972).

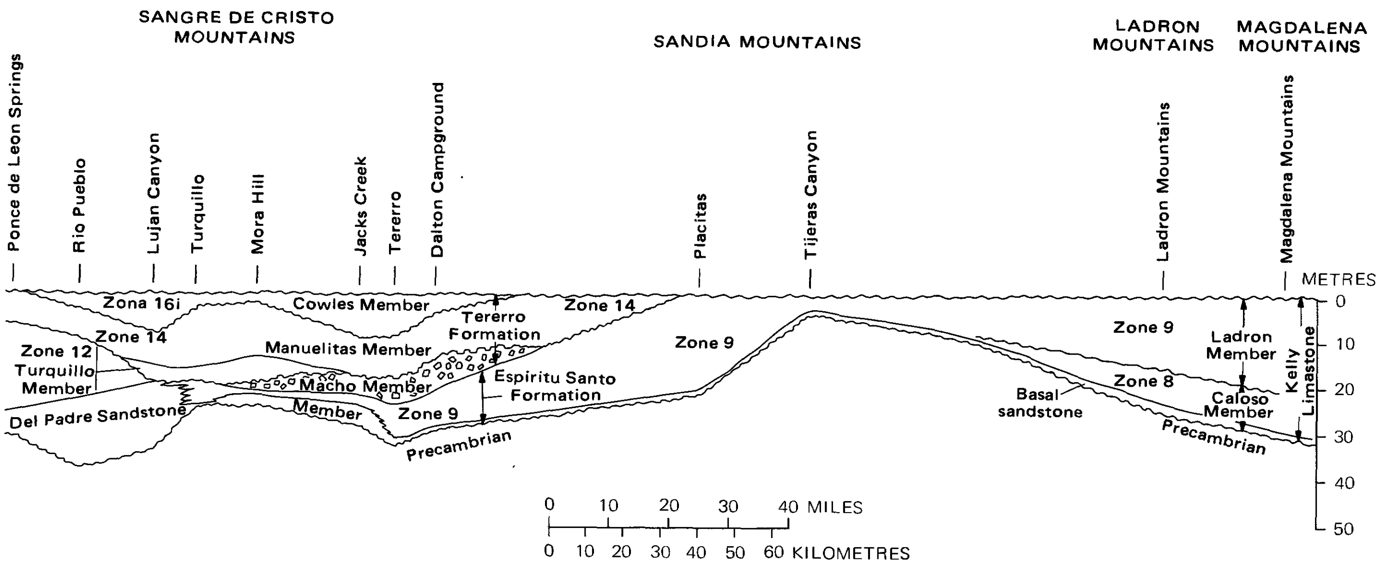


FIGURE 12.—Continued.

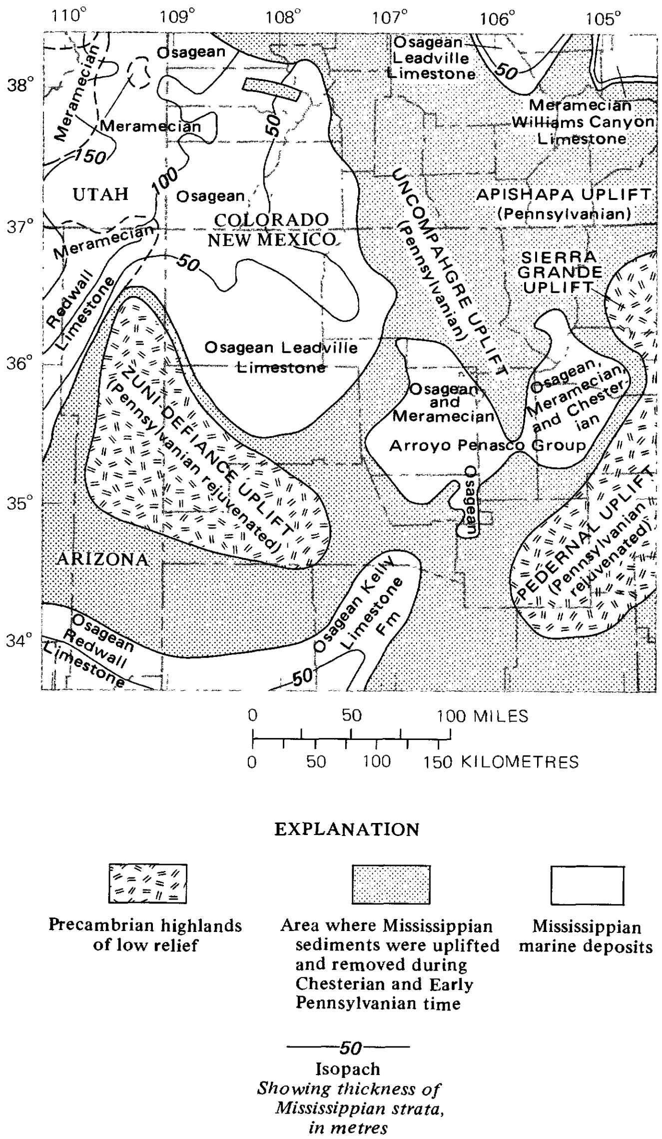


FIGURE 15.—Idealized pre-Pennsylvanian sedimentation paleogeologic map for southern Colorado and northern New Mexico. The map is in part from Parker and Roberts (1963), McKee and Gutschick (1969), McKee (1972), Mallory (1972), Baars (1966), and Armstrong (1967).

REFERENCES CITED

Armstrong, A. K., 1955, Preliminary observations on the Mississippian system of northern New Mexico: New Mexico Bur. Mines and Mineral Resources Circ. 39, 42 p.

———1958a, The Mississippian of west-central New Mexico: New Mexico Bur. Mines and Mineral Resources Mem. 5, 32 p.

———1958b, Meramecian (Mississippian) endothyrid fauna from the Arroyo Penasco Formation, northern and central New Mexico: Jour. Paleontology, v. 32, p. 970–976.

———1967, Biostratigraphy and carbonate facies of the Mississippian Arroyo Penasco Formation, north-central New Mexico: New Mexico Bur. Mines and Mineral Resources Mem. 20, 89 p., 10 pls., 45 figs.

Armstrong, A. K., and Mamet, B. L., 1974, Biostratigraphy of the Arroyo Penasco Group, lower Carboniferous (Mississippian), north-central New Mexico: New Mexico Geological Society Guidebook of north-central New Mexico, 25th Ann. Guidebook, p. 145–158, 17 figs.

Baars, D. L., 1965, Pre-Pennsylvanian paleotectonics of southwestern Colorado and east-central Utah: Colorado Univ., Ph.D. thesis, 179 p.

———1966, Pre-Pennsylvanian paleotectonics—key to basin evolution and petroleum occurrences in Paradox basin, Utah and Colorado: Am. Assoc. Petroleum Geologists Bull., v. 50, no. 10, p. 2082–2111.

Baars, D. L., and Knight, R. L., 1957, Pre-Pennsylvanian stratigraphy of the San Juan Mountains and Four Corners Area: New Mexico Geol. Soc., 8th Field Conf. Guidebook, p. 108–130.

Baars, D. L., and See, P. D., 1968, Pre-Pennsylvanian stratigraphy and paleotectonics of the San Juan Mountains, southwestern Colorado: Geol. Soc. America Bull., v. 79, p. 333–350.

Baltz, E. H., and Read, C. B., 1960, Rocks of Mississippian and probable Devonian age in Sangre de Cristo Mountains, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 44, no. 11, p. 1749–1774.

Bass, N. W., 1944, Correlation of basal Permian and older rocks in southwestern Colorado, northwestern New Mexico, northeastern Arizona, and southeastern Utah: U.S. Geol. Survey Prelim. Chart 7.

Brenckle, P. L., Lane, H. R., and Collinson, C. W., 1974, Progress toward reconciliation of Lower Mississippian conodont and foraminiferal zonations: Geology, Sept. 1974, p. 433–436.

Burbank, W. S., 1932, Geology and ore deposits of the Bonanza mining district, Colorado: U.S. Geol. Survey Prof. Paper 169, 166 p.

Dunham, R. J., 1962, Classification of carbonate rocks according to deposition texture, *in* Classification of carbonate rocks—A symposium: Am. Assoc. Petroleum Geologists Mem. 1, p. 108–121.

Emmons, S. F., and Eldridge, G. H., 1894, Anthracite-Crested Butte folio: U.S. Geol. Survey Geol. Atlas, Folio 9.

Girty, G. H., 1903, The Carboniferous formations and faunas of Colorado: U.S. Geol. Survey Prof. Paper 16, 546 p.

Gordon, C. H., 1907, Mississippian (Lower Carboniferous) formations in the Rio Grande valley, New Mexico: Am. Jour. Sci., ser. 4, v. 24, p. 58–64.

Grozdilova, L. P., and Lebedeva, N. S., 1954, Foraminifera of the Lower Carboniferous and Baschkirian Stage of the Middle Carboniferous of the Kolvo-Vishera Area [in Russian]: Vses. Neft. Nauchno-Issled. Geol.-Razved. Inst. Trudy 81 [VNIGRI 81], Mikrofauna SSSR, no. 7, p. 4–236, 15 pls.

Kelley, V. C., and Silver, Caswell, 1952, Geology of the Caballo Mountains: New Mexico Univ. Pub., Geol. Ser., no. 4, 286 p.

Kindle, E. M., 1909, The Devonian fauna of the Ouray Limestone: U.S. Geol. Survey Bull. 391, 50 p.

Kirk, Edwin, 1931, Devonian of Colorado: Am. Jour. Sci., v. 22, no. 5, p. 229–239.

Knight, R. L., and Baars, D. L., 1957, New development on age and extent of Ouray Limestone: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 10, p. 2275–2283.

Lipina, O. A., 1948, Foraminifera of the Chernyshinsk Suite, Tournaisian Series, Lower Carboniferous, Moscow Basin [in Russian]: Akad. Nauk SSSR Geol. Inst. Trudy 62, no. 19, p. 251–259, 2 pls.

———1963, *in* Results of the second colloquium on the systematics of the endothyroid foraminifers organized by the Commission of micropaleontological coordination [in Russian]: Akad. Nauk SSSR Voprosy Mikropaleontologii, v. 7, p. 223–227.

McKee, E. D., 1958, The Redwall Limestone: New Mexico Geol. Soc. 9th Ann. Field Conf., Guidebook, p. 74–77.

———1963, Nomenclature for lithologic subdivisions of the Mississippian Redwall Limestone, Arizona *in* Geological Survey research 1963: U.S. Geol. Survey Prof. Paper 475-C, p. C21–C22.

———1972, Mississippian System (part), *in* Geologic atlas of the Rocky Mountains region: Rocky Mountain Assoc. Geologists, Denver, Colo., figs. 1–7.

McKee, E. D., and Gutschick, R. C., 1969, History of the Redwall Limestone of northern Arizona: Geol. Soc. America Mem. 114, p. 1–132.

Mallory, W. W., 1972, Pennsylvanian arkose and the ancestral Rocky Mountains, *in* Geologic atlas of the Rocky Mountains region: Rocky Mountain Assoc. Geologists, Denver, Colo., p. 131–132.

Mamet, B. L., and Rudloff, B., 1972, Algues Carbonifères de la parties septentrionale de l'Amérique du Nord: Revue de Micropaléontologie, v. 15, no. 2, p. 75–114.

Mamet, B. L., and Skipp, Betty, 1970a, Preliminary foraminiferal zonation Lower Carboniferous Foraminifera; preliminary zonation and stratigraphic implication for the Mississippian of North America: Internat. Cong. Carboniferous Stratigraphy, 6th, v. 3, p. 1129–1146.

———1970b, Preliminary foraminiferal correlations of Early Carboniferous strata in the North American Cordillera: Liège Univ. Cong. et Colloques, v. 55, p. 327–348.

Merrill, W. M., and Winar, R. M., 1958, Molas and associated formations in San Juan Basin-Needle Mountains area, southwestern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 2107–2132.

Parker, J. M., 1961, The Cambrian, Devonian and Mississippian rocks and pre-Pennsylvanian structures of southwestern Colorado and adjoining portions of Utah, Arizona, and New Mexico: Rocky Mountain Assoc. Geologists Symposium on Lower and Middle Paleozoic rocks of Colorado, 12th Field Conf. Guidebook, p. 59–70.

Parker, J. W., and Roberts, J. W., 1963, Devonian and Mississippian stratigraphy of the central part of Colorado Plateau: Four Corners Geol. Soc. Guidebook, Symposium—Shelf carbonates of the Paradox Basin, p. 31–60.

Sando, W. J., Mamet, B. L., and Dutro, J. T., Jr., 1969, Carboniferous megafaunal and microfaunal zonation in the northern Cordillera of the United States: U.S. Geol. Survey Prof. Paper 613-E, p. 1–29.

Skipp, Betty, 1969, Foraminifera, Chap. 5, *in* McKee, E. D., and Gutschick, R. C., History of the Redwall Limestone of northern Arizona: Geol. Soc. America Mem. 114, p. 173–255, pls. 16–28.

Skipp, Betty, Holcomb, L. D., and Gutschick, R. C., 1966, Tournayellinae, calcareous Foraminifera, in Mississippian rocks of North America: Cushman Found. Foram. Research Spec. Pub. 9, 38 p., 7 pls.

Spencer, A. C., 1900, Devonian strata in Colorado: Am. Jour. Sci. ser. 4, v. 9, p. 125–133.

Stainbrook, M. A., 1947, Brachiopoda of the Percha Shale of New Mexico and Arizona: Jour. Paleontology, v. 21, p. 297–328.

Steven, T. A., Schmitt, L. J., Jr., Sheridan, M. J., and Williams, F. E., 1969, Mineral resources of the San Juan Primitive Area, Colorado: U.S. Geol. Survey Bull. 1261-F, 186 p.

Sutherland, P. K., 1963, Paleozoic rocks, *in* Miller, J. P., Montgomery, Arthur, and Sutherland, P. K., Geology of part of the southern Sangre de Cristo Mountains, New Mexico: New Mexico Bur. Mines and Mineral Resources Mem. 11, p. 22–46.

Wengerd, S. A., 1962, Pennsylvanian sedimentation in Paradox Basin, Four Corners Region, *in* Branson, C. C., ed., Symposium, Pennsylvanian system in the United States: Am. Assoc. Petroleum Geologists, p. 264–330.

Wood, G. H., Jr., Kelley, V. C., and MacAlpin, A. J., 1948, Geology of southern part of Archuleta County, Colorado: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 81.

PLATES 1–2

Contact photographs of the plates in this report are available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225.

PLATE 1

[Bar scale = 0.5 mm]

FIGURE 1. University of Montreal 291/2, section 66C–2+140; 10.7 m above base. Leadville Limestone, undertermined zone. Chertified pseudomorphs after gypsum crystals, in fine-grained dolomite.

2. University of Montreal 291/4, section 66C–2B+0, at the base of the section. Leadville Limestone, zone 9, late Tournaisian. Euhedral quartz crystal "envelopes" in medium-grained, well-sorted lump grainstone. Quartz crystals are restricted to the ooids and do not transect the cement.

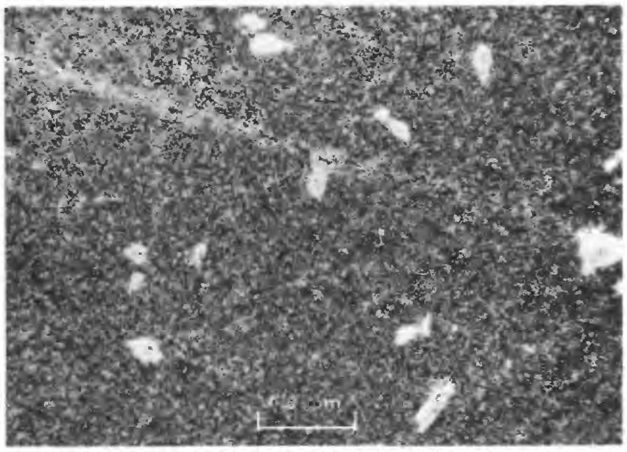
3, 4. University of Montreal 291/6 and 291/7, section 66C–2B+0, at the base of section. Some facies as fig. 2, but most of the lumps are mud-filled *Spinoendothyra spinosa* (Chernysheva).

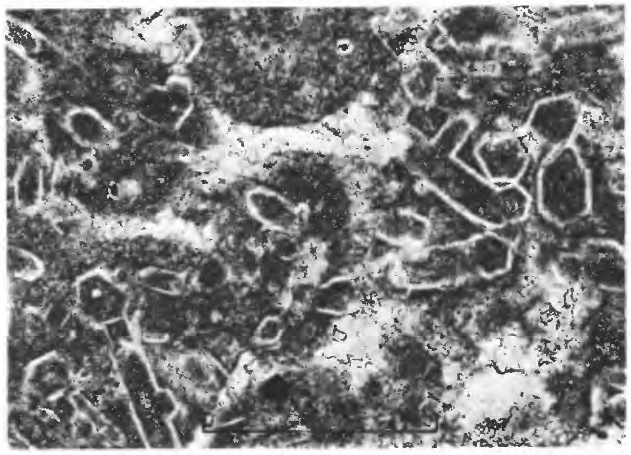
5. University of Montreal 291/10, section 66C–4+130; 3 m above base. Leadville Limestone, undetermined zone. Well-sorted fine-grained pellet grainstone suggestive of early cementation. A few calcispheres (*Calcisphaera laevis* Williamson, *Parathurammina* sp.) are present.

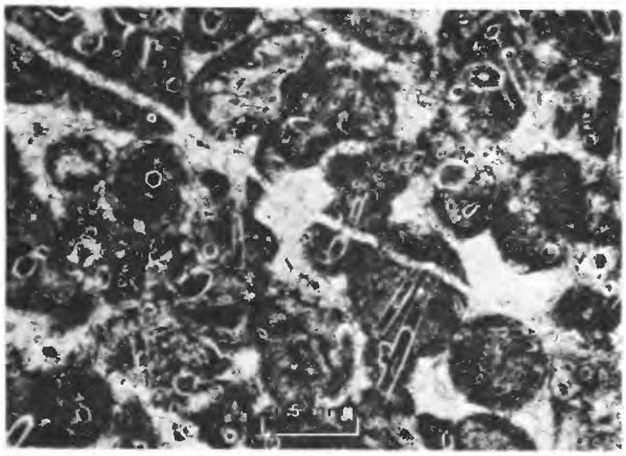
6. University of Montreal 291/11, section 66C–5+185; 30.2 m above base. Leadville Limestone, undetermined zone. Quartz crystal "envelopes" in a slightly recrystallized pellet wackestone.

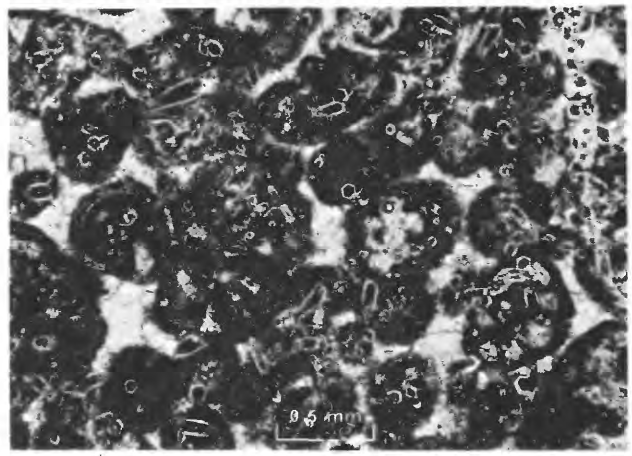
7. University of Montreal 291/13, section 66C–5+225; 42.4 m above base. Leadville Limestone, undetermined zone. Abundant intertwined thalli of *Palaeoberesella* sp. mixed with scarce debris of pelmatozoans, bryozoans, and brachiopods.

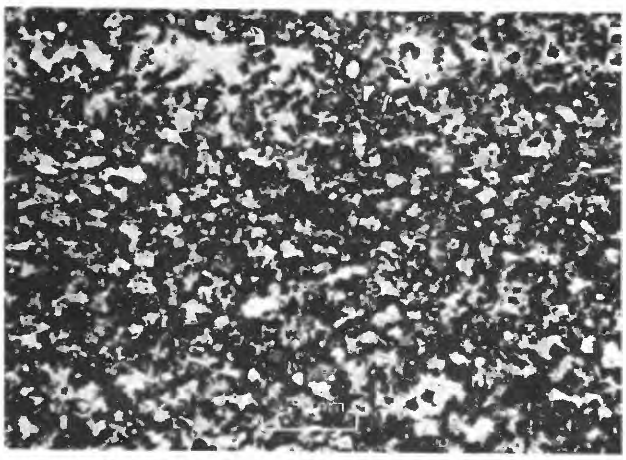
8. University of Montreal 291/34, section 66C–5+185; 30.2 m above base. Leadville Limestone, zone 9, late Tournaisian. Medium- to coarse-grained foraminifer-lump-intraclast-crinoid grainstone. Pressure solution of a crinoid fragment into the foraminifer *Septabrunsiina parakrainica* Skipp, Holcomb, and Gutschick.

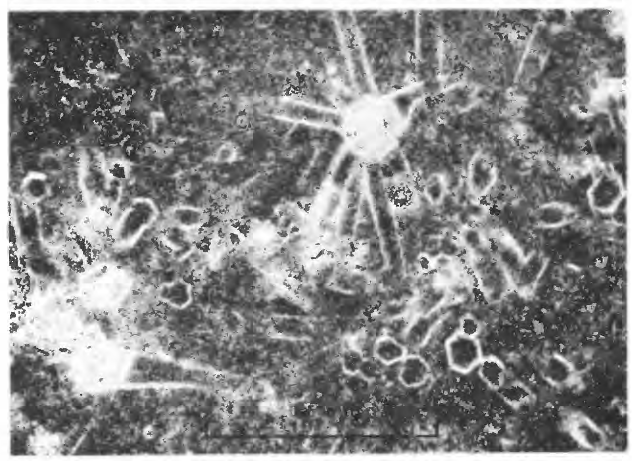

1

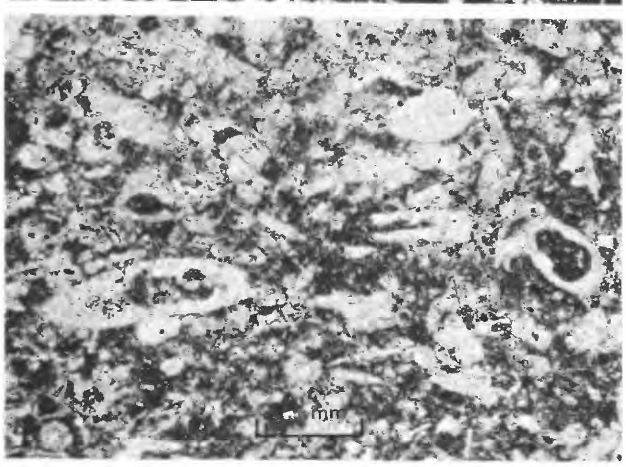

2

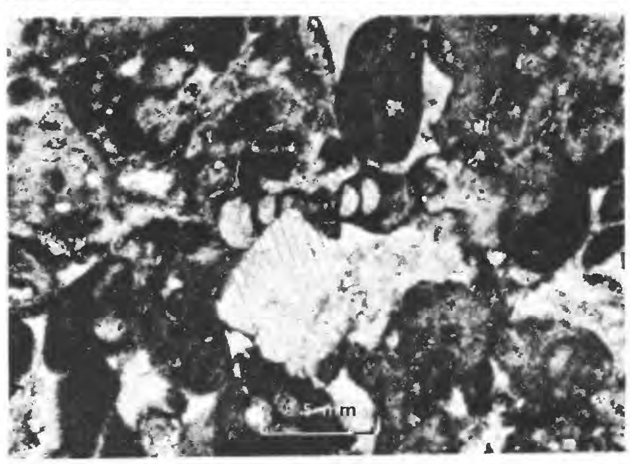

3


4


5


6


7


8

PHOTOMICROGRAPHS OF LEADVILLE LIMESTONE AND MICROFOSSILS

PLATE 2

[Bar scale = 0.5 mm]

FIGURE 1. University of Montreal 291/34, section 66C−5+185; 30.2 m above base. Leadville Limestone, zone 9, late Tournaisian. Medium- to coarse-grained foraminifer-lump-intraclast-crinoid grainstone. Slight pressure solution. Algae are mostly kamaenids (*Kamaena maclareni* Mamet and Rudolff, *Palaeoberesella* sp.). Foraminifers are *Spinoendothyra spinosa* (Chernysheva) and a mud-filled *Latiendothyra* sp.

2. University of Montreal 291/33, as fig. 1. Same facies, with mud-coated fragments and *Spinoendothyra tenuiseptata* (Lipina).

3. University of Montreat 291/33, as fig. 1. Same facies, with *Spinoendothyra spinosa* (Chernysheva) and *Septabrunsiina parakrainica* Skipp, Holcomb, and Gutschick.

4. University of Montreal 291/20, section 66C−6B+321; 58.2 m above base. Leadville Limestone, undetermined zone. Fine-grained well-sorted pellet grainstone. *Calcisphaera laevis* Williamson, *Palaeocancellus* sp., *Vicinesphaera* sp., and radiospheres are present.

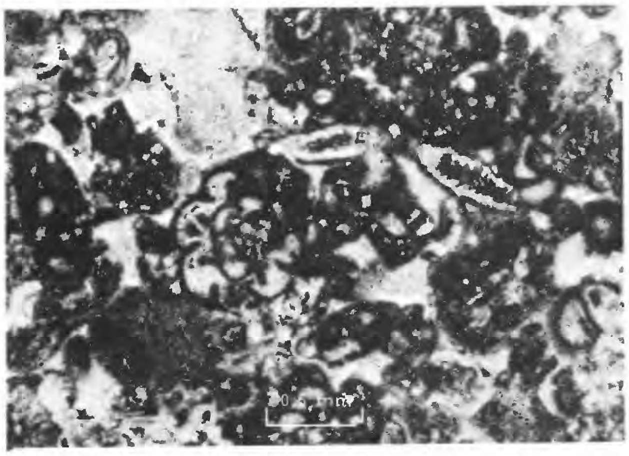
5. University of Montreal 291/36, section 66C−6B+338; 63.4 m above base. Leadville Limestone, undetermined zone. An oolite-lump packstone.

6. University of Montreal 291/22, section 65C−12A+18. Late Devonian Ouray Limestone, 2.4 m below the contact with the Leadville Limestone. *Kamaena itkillikensis* Mamet and Rudloff in a strongly recrystallized pellet-brachiopod packstone.

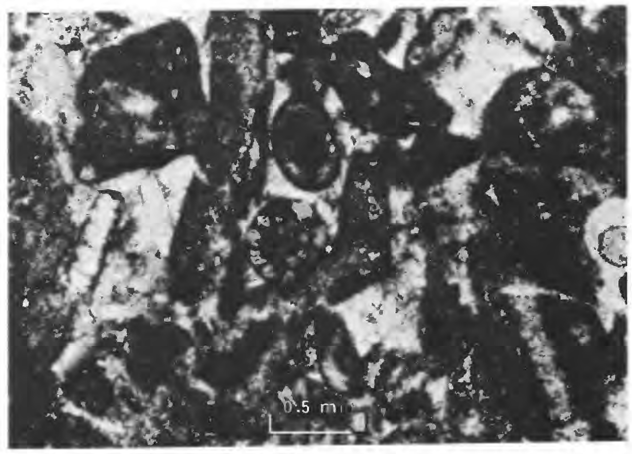
7. University of Montreal 291/23, section 65C−12A+55; 9 m above base. Leadville Limestone, undetermined zone. Rhombs of dolomite in lime mudstone. Calcite zones are developed parallel to the original dolomite rhomb survace (dedolomitization).

8. University of Montreal 291/25, section 65C−12A+60; 10.5 m above base. Leadville Limestone, undetermined zone. Calcite pseudomorphs of dolomite (dedolomite) in a well-sorted coarse-grained bahamite grainstone.

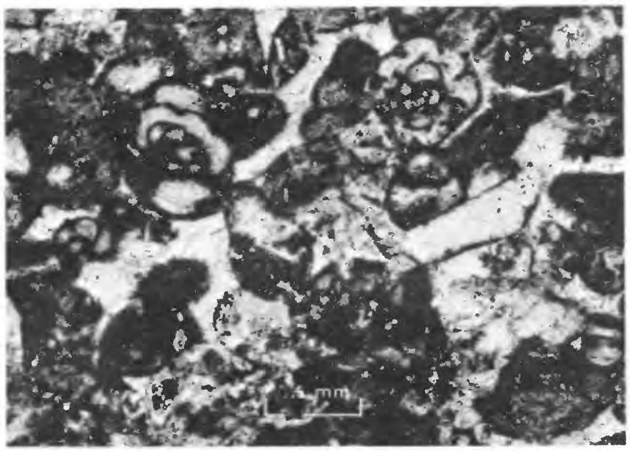
☆GPO 789-787—1977



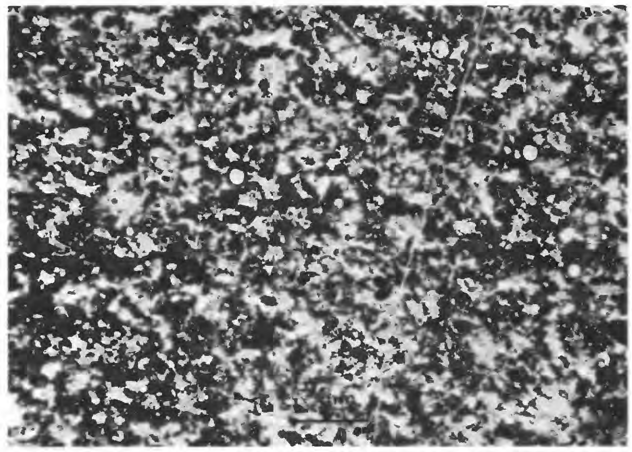
1



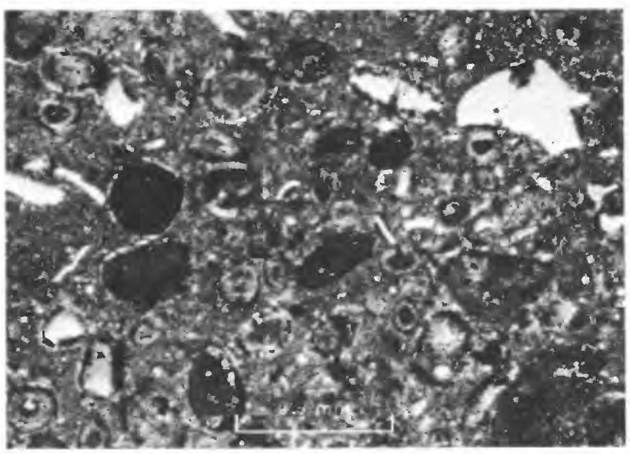
2



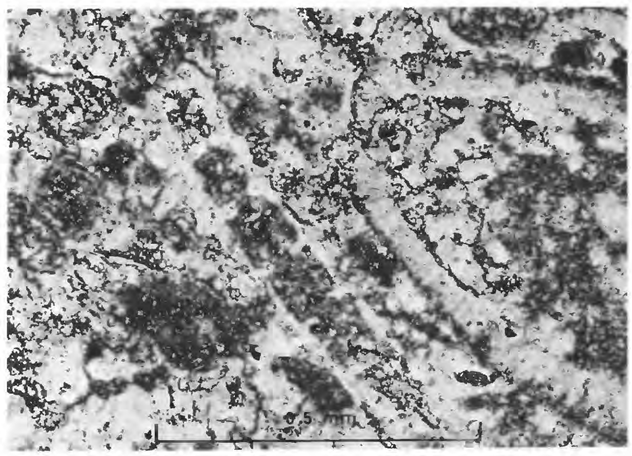
3



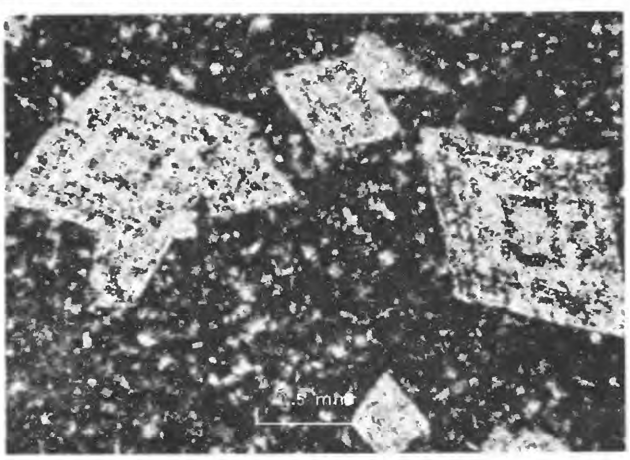
4



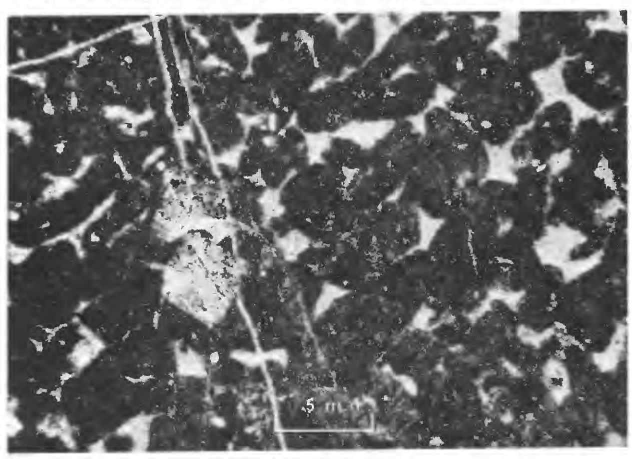
5



6



7



8

PHOTOMICROGRAPHS OF LEADVILLE LIMESTONE AND MICROFOSSILS