Stratigraphy, Petrology, and Some Fossil Data of the Roberts Mountains Formation, North-Central Nevada

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1063

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By THOMAS E. MULLENS

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A description of the regional stratigraphic relations, composition, and age of a silty laminated carbonate rock that is the host rock for the large gold ore deposits at the Carlin and Cortez mines, Nevada

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1980

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, *Director*

Library of Congress Cataloging in Publication Data
Mullens, Thomas Ellison, 1924-
Stratigraphy, petrology, and some fossil data of the Roberts Mountains Formation, North-Central Nevada.
(Geological Survey Professional Paper 1063)
Bibliography: p.58
Supt. of Docs. no.: I 19.16:1063
1. Geology, Stratigraphic–Silurian. 2. Geology, Stratigraphic–Devonian. 3. Petrology–Nevada.
4. Paleontology–Nevada. 5. Geology–Nevada. I. Title. II. Series: United States Geological Survey Professional Paper 1063.
QE661.M9 551.7'3'0979332 77-608315

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock Number 024-001-03264-3

CONTENTS

ILLUSTRATIONS

TABLES

STRATIGRAPHY, PETROLOGY, AND SOME FOSSIL DATA OF THE ROBERTS MOUNTAINS FORMATION, NORTH-CENTRAL NEVADA

By THOMAS E. MULLENS[1]

ABSTRACT

Silty laminated very fine grained carbonate rock in the Roberts Mountains Formation is the host rock for the large gold-ore deposits at the Carlin and Cortez mines, north-central Nevada. Such rock forms the bulk of the Roberts Mountains Formation in north-central Nevada, although the type section of the formation was established in an area of facies change where silty laminated very fine grained carbonate rock is subordinate to thick-bedded coarse-grained carbonate rock. The facies change is related to deposition of rocks in the north-trending Cordilleran geosyncline or miogeocline, where there was a west-to-east gradation of volcanic and siliceous rocks through shale to carbonate rocks during early Paleozoic time. Thrust faulting during the Antler orogeny at the end of the Devonian and beginning of the Mississippian moved the volcanic, siliceous, and shaly rocks eastward over the carbonate rocks. The Roberts Mountains Formation is restricted to the autochthon and it is exposed mainly in windows of the allochthon. Several windows expose the eastward gradation of laminated carbonate rock to massive carbonate rock, but no known window exposes a westward gradation of laminated carbonate rock to shaly, siliceous, or volcanic rocks. In nearly all windows on the western side of the area of study, the Roberts Mountains Formation is the youngest formation exposed, and so the westward relations of the formation to younger rocks are unknown.

At the type section, the Roberts Mountains Formation is about 580 m (meters) thick and consists of four units. From bottom to top, these units are 2 m of cherty limestone, about 120 m of laminated limestone, about 175 m of interbedded laminated very fine grained carbonate rock and thin-bedded coarse-grained carbonate rock, and, at the top, about 275 m of thick-bedded to massive carbonate rock. The formation includes rocks of both Silurian and Devonian age in the type locality. Away from the type locality the Roberts Mountains Formation consists of a few to about 50 m of cherty limestone overlain by as much as 1,200 m of laminated silty carbonate rock. Only locally does the formation include an upper zone of interbedded laminated limestone and lenticular coarse-grained limestone. Part of the change in the dominant type of rock in the Roberts Mountains Formation away from the type section is related to facies changes, and part is related to nomenclature. Sequences of rock similar to the type locality occur in exposures to the southwest and northwest, but most thick-bedded coarse-grained carbonate rock in these sequences is assigned to other formations.

The basal cherty unit, locally as much as 50 m thick, is the only marker bed of regional extent. The basal unit is a relatively pure limestone that was partly silicified during diagenesis and is locally dolomitized. The overlying laminated rock, here called the laminated limestone unit, forms the bulk of the Roberts Mountains Formation. The laminated rock is a mixture of calcite, dolomite, quartz and feldspar silt, and clay minerals, and is black to very dark gray. The laminations form planes for platy weathering which are conspicuous and typical of weathered rock but not conspicuous in fresh rock.

The relative proportions of minerals in laminated limestone vary greatly from bed to bed, although the lower half of the laminated limestone unit generally contains more calcite than the upper half. The average mineralogic composition of about 120 samples of unaltered laminated limestone is about 45 percent calcite, 25 percent dolomite, 22 percent quartz and feldspar silt, and 8 percent clay minerals. The samples, however, do not cluster near this average. Instead they are uniformly distributed in a broad field that is roughly bounded by these parameters: 5–95 percent calcite, 0–50 percent dolomite, 5–45 percent quartz and feldspar, and 1–15 percent clay minerals. Minor but ubiquitous components that generally form less than 1 percent of laminated limestone are carbonaceous material and pyrite in fresh rock, and iron oxide in weathered rock. Very fine grained (<0.020 mm) calcite generally forms the matrix of laminated limestone. Irregular grains to euhedral rhombs of dolomite that average about 0.045 mm and angular grains of quartz and feldspar that average about 0.055 mm are set in the matrix of calcite. Mixtures of these minerals occur in laminations that range in thickness from less than 0.05 to about 4 mm, averaging about 0.2 mm. One set of a pair of laminations is generally marked in fresh rock by concentrations of carbonaceous material and pyrite and in weathered rock by iron oxide.

Locally, the upper part of the Roberts Mountains Formation contains as much as 185 m of laminated fine-grained limestone interbedded with coarse-grained limestone. The coarse-grained (0.2 to>2.0 mm) limestone is composed of angular fragments of clear calcite, pellets of dirty very fine grained (<0.005 mm) limestone, sparse dolomite rhombs, scattered silt-sized to fine grains of quartz, and veinlets of secondary quartz. At Bootstrap mine in western Elko County, some coarse-grained limestone beds assigned to the Roberts Mountains Formation have scour surfaces at the base and contain nonoriented fossils and angular fragments which decrease in size upward. These beds probably are debris flows from a reef. Similar beds occur in the type locality of the formation.

In most areas, strata similar to the massive carbonate rock in the upper part of the Roberts Mountains Formation at the type section are not included as part of the formation. The formation is restricted to include rocks from the base of the basal cherty unit upward to the base of a coarse-grained massive limestone.

The Roberts Mountains Formation contains fossils which indicate that it ranges in age from earliest Silurian into Early Devonian. Near Swales Mountain, the Roberts Mountains Formation seemingly is conformably overlain by Lower Mississippian rocks; this fact opens the possibility that locally the formation contains beds of Middle and Late Devonian age. The boundary between the Silurian

[1]Deceased.

and Devonian Systems is placed at the base of *Monograptus uniformis*-bearing beds which do not form a mappable horizon.

A reef (coarse-grained limestone) and forereef (laminated fine-grained limestone) environment of deposition is assumed for the Roberts Mountains Formation and equivalent rocks. The distribution of laminated fine-grained limestone and coarse-grained limestone indicates that by Late Silurian and Early Devonian time the reef line nearly enclosed a basin that was open to the northeast and probably had local openings to the west. The basinlike feature modified the general westward slope of the east side of the Cordilleran geosyncline or miogeocline. The source area for the silt in the laminated limestone is not known, but the silt is assumed to have been brought in from the north by longshore currents. The texture of the dolomite, and the presence of carbonaceous material and pyrite in the laminated limestone are interpreted as indicating that the basin was partly barred.

The Roberts Mountains Formation grades eastward into the Lone Mountain and Laketown Dolomites and south and southwestward into the Lone Mountain Dolomite. North and westward, equivalents of the Roberts Mountains Formation are present in both autochthon and allochthon of the Antler thrust system; those in the autochthon are assigned to other formations and no direct correlation can be made between the Roberts Mountains Formation and allochthonous units.

Laminated limestone in the upper part of the Roberts Mountains Formation is the host rock for large gold deposits at the Carlin and Cortez gold mines. In unoxidized ore the gold is associated mainly with small (<0.005 mm) grains of epigenetic arsenic-bearing pyrite. The small size of the gold-bearing pyrite is probably related to a stratigraphic control, which is the abundant microporosity along laminations that furnished permeability for the mineralizing solutions.

INTRODUCTION

PURPOSE

Silty laminated very fine grained carbonate rock in the Roberts Mountains Formation is the host rock for the large gold-ore deposits at the Carlin and Cortez mines, north-central Nevada. Such rock forms the bulk of the Roberts Mountains Formation, but the formation also includes a thin cherty unit at the base and locally it contains thick-bedded coarse-grained carbonate rock. Regional stratigraphic, geochemical, and petrographic studies of the Roberts Mountains and related formations were started in 1968 as part of the Heavy Metals Program of the U.S. Geological Survey. Regional study of the Roberts Mountains Formation was intended to furnish a framework for detailed studies of the gold deposits. During 1968–71 the Roberts Mountains and related formations were studied at more than 40 localities in north-central Nevada. This report presents the stratigraphic, petrographic, and paleontologic information obtained, gives data on trace elements in the samples collected, and presents a theory as to why the silty laminated carbonate rock is a favorable host for a specific type of gold ore. Details of the mineralogy and chemistry of individual samples are available in tabular form (Mullens, 1979); these details should be consulted by those interested in the composition of impure carbonate rock. This report is concerned mainly with the distribution and general composition of the laminated silty carbonate rock, which is hereafter called laminated limestone and which is locally as much as 1,200 m thick. The cherty unit and coarse-grained carbonate rock in the Roberts Mountains Formation received less attention than the laminated limestone, but these units are important in determining stratigraphic relations, age, and nomenclature problems associated with the Roberts Mountains Formation.

An outcrop map of the Roberts Mountains Formation is shown on plate 1. The general composition, correlation, and thickness of the Roberts Mountains and its relations to adjacent rocks are shown on plate 2. These plates reflect the isolated nature of the outcrops, the general lack of complete sections, and the unknown relations to overlying rocks in places where the laminated limestone is the upper unit exposed below thrust faults. The only conspicuous zone of regional extent is the basal cherty unit. Therefore, interpretations about stratigraphy and regional trends given in this report are based on sparse and inconclusive lithologic data. The lack of lithologic data is somewhat mitigated by paleontologic data which allow correlations and interpretations that could not be made on lithologic data alone.

ACKNOWLEDGMENTS

I gratefully acknowledge the assistance of W. H. Pierce, who dissolved rocks, prepared heavy mineral grain mounts, and made X-ray diffractograms for both whole rock and insoluble residue of samples collected in 1968 and 1969. Without his assistance, the work on the project would have been much delayed. The contributions and assistance of the following people are also greatly appreciated: M. A. Murphy of the University of California at Riverside graciously made available to me the results of several years' study of the Roberts Mountains Formation at and near the type section. W. B. N. Berry of the University of California promptly identified all graptolites collected during the study. G. L. Essington of Carlin Gold Mines and P. West of Newmont Mining Co. contributed much information about the Carlin gold mine and surrounding area. U.S. Geological Survey colleagues F. G. Poole, J. H. Stewart, C. W. Merriam, E. H. McKee, J. D. Wells, J. G. Evans, L. D. Cress, K. B. Ketner, J. F. Smith, Jr., H. W. Dodge, and C. L. Rogers guided me to exposures of the Roberts Mountains Formation and gave me the benefit of their years of experience in north-central Nevada. I would also like to express my appreciation for the assistance of three U.S. Geological Survey colleagues: J. Huddle, who identified conodonts from bulk samples collected during the study; I. C. Frost, who

determined the organic carbon and sulfur content of many samples; and L. Hedricks, who photographed all the hand specimens and thin sections shown in this report.

GEOLOGIC SETTING OF THE ROBERTS MOUNTAINS FORMATION

In gross pattern, Cambrian to Devonian rocks in north-central Nevada compose three contemporaneous sequences that are in thrust contact. The autochthonous sequence that contains the Roberts Mountains Formation is dominantly carbonate rock (about 90 percent of the total), although a little quartzite and shale are also present. The other two sequences are found mainly in the allochthon. One of the allochthonous sequences is mainly chert and siliceous clastic rocks, but it includes minor amounts of volcanic rocks and thin beds of limestone. The other allochthonous sequence comprises about equal amounts of chert, carbonate rock, and siliceous clastics; it is interpreted as transitional between the chert and siliceous clastic sequence and the carbonate sequence in the autochthon. These sequences, and their geologic implications, have been studied by many geologists (Merriam and Anderson, 1942; Nolan and others, 1956; Merriam, 1963; Roberts and others, 1958; Kay and Crawford, 1964; Roberts, 1964; Roberts, 1968; Gilluly and Gates, 1965; Smith and Ketner, 1968; Ketner, 1970; Smith and Ketner, 1975; Stewart and McKee, 1977; and Stewart and Poole, 1974). The rocks in the sequences have been interpreted by most of these geologists as representing deposition in the north-northeast-trending Cordilleran geosyncline, although Stewart and Poole (1974) interpreted the structure as a miogeocline where no major land mass or island is formed on the west side. Using terminology established by Kay (1951), the chert, siliceous clastic, and volcanic sequence is interpreted as having been deposited in a eugeosynclinal part of the geosyncline, which is west of the transitional rocks. The carbonate rock sequence is interpreted as having been deposited in a miogeosynclinal part of the geosyncline, which is east of the transitional sequence. Stewart and Poole (1974) recognized the same sequence of rocks, but they applied slightly different terminology in describing the areas of sedimentation. Exact locations of the boundaries between the sequences are not known because of oscillations of the sea and later structural complexities. At lat 40° N., most of the volcanic and siliceous sequence was deposited west of long 117° W. and most of the carbonate rock sequence was deposited east of long 117° W. (Roberts, 1968, fig. 6).

Roberts (1969) recognized six subfacies in the rocks. He divided the carbonate sequence into an easterly dolomite and limestone and a westerly limestone and limy shale facies. The transition rocks are divided into an easterly limestone-shale and a westerly shale-chert subfacies. The siliceous and volcanic rocks are divided into a chert-shale easterly facies and a volcanic-quartzite-chert-shale westerly facies. The Roberts Mountains Formation falls mainly in the westerly limestone and limy shale subfacies of the carbonate sequence of Roberts (1969), although true shale is nearly absent and the formation contains thick-bedded coarse-grained carbonate rock that is assigned to the easterly dolomite and limestone subfacies along its eastern and southern margins.

The present distribution of the lower Paleozoic rocks is attributed mainly to thrust faulting during the Antler orogeny (Roberts, 1951), which spanned time from the end of the Devonian to the beginning of the Mississippian (Smith and Ketner, 1968; Ketner, 1970). During this orogeny, volcanic, siliceous, and shaly rocks were thrust 80–160 km east and over the carbonate rocks. The Roberts Mountains Formation is in the autochthon and most of the outcrops of the Roberts Mountains Formation are in windows of allochthonous rocks related to the Antler orogeny (pl. 1). The only exposure east of the leading edge of Antler allochthon is in the Pequop Mountains, and this exposure is in a younger thrust plate (Thorman, 1970, pl. 2, p. 2426). The windows in the allochthon are caused mainly by post-Antler movements that include folding, thrust faulting, and normal faulting. These movements range in age from Mississippian to Tertiary, but Tertiary basin-and-range folding and faulting are the major causes of the present distribution of windows exposing the Roberts Mountains Formation.

Some of the windows where the Roberts Mountains Formation is exposed are places where laminated silty limestone grades into the coarse-grained carbonate rocks to the east. No known window, however, exposes the gradation between laminated silty limestone and the western siliceous rocks. The Roberts Mountains Formation is the youngest formation that is exposed in several of the windows on the west side of the area of study. Therefore, information on which to base original thicknesses, relations to overlying rocks, and lateral relations with equivalent rocks deposited westward is lacking in much of the area of study.

The lateral gradations—eastward gradation of laminated limestone to coarse-grained carbonate and southeastward gradation of laminated limestone to laminated dolomite and coarse-grained dolomite—cause nomenclature problems. Because of the gradations, the use of the name Roberts Mountains Formation will be limited to an area that extends as far as the edge of laminated limestone to the east and as far as a change to less silty laminated dolomite to the south. In addition to the gradational boundaries, the units involved are time transgressive. At the eastern edge, laminated rock assigned to the Roberts Mountains is probably entirely of Silurian age, whereas in western exposures of the Roberts Mountains, laminated rock is Silurian and Devonian in age.

METHODS OF STUDY

The Roberts Mountains Formation was examined at all outcrop areas shown on plate 1, except in the Pequop Mountains and the isolated outcrop in the northern part of the Sulphur Spring Range. No detailed description or collection of samples was made in the area of the Roberts Mountains which M. A. Murphy has mapped in detail, because his data were available. At other places the Roberts Mountains Formation and related formations were described, sampled, and, where possible, measured, and a search was made for fossils.

The laminated limestone is difficult to study in the field because it is poorly exposed, it lacks marker beds, and the relative amounts of quartz silt, clay, calcite, and dolomite cannot be determined with consistent accuracy with a hand lens and acid. These limitations make it difficult to make regional correlations or to determine the local structure, which is generally complicated by faults. No measured sections are included in this report, but the general character and thickness of rocks measured are shown on plate 2.

Because the laminated limestone lacks marker beds, intensive efforts were made to collect graptolites. Some 60 graptolite collections were made, although no graptolites were collected in the Roberts Mountains area and only a few were collected at Coal Canyon, where Murphy (1969) and Berry (1969) had already determined the graptolite sequence. The graptolites, all studied by W. B. N. Berry, allow correlation of several zones in the Roberts Mountains Formation. These zones are correlated with the Llandoverian, Wenlockian, Ludlovian, Pridolian, Gedinnian, and Siegenian Stages of Europe.

About 50 samples, including both laminated limestone and coarser-grained material, were collected and submitted to John Huddle for recovery and identification of conodonts. All but one of the laminated limestone samples and many of the coarse-grained samples collected from the Roberts Mountains Formation are barren or lack diagnostic conodonts. Several collections from coarse-grained beds above and below the Roberts Mountains contain diagnostic conodonts that allow age limits of the Roberts Mountains to be established locally.

Localities where fossils were collected are shown on plate 1. Fossils identified from these localities and some fossils collected by my colleagues are listed in the appendix.

A total of 246 samples of Roberts Mountains and related formations were collected to determine petrographic and chemical properties. Details of the mineralogy and chemistry of these samples are reported elsewhere (Mullens, 1979). The distribution of the samples collected is not uniform. A total of 89 samples were collected at the Coal Canyon and Rattlesnake Canyon localities (pl. 1) where complete sections are present and where the Roberts Mountains Formation consists mainly of unaltered laminated limestone. Nineteen samples, chiefly of altered rock, were collected at the Carlin mine. The remaining 138 samples were collected at 35 other localities.

The method of study used for the rock samples was as follows: All 246 samples were studied by spectrographic methods, and 228 were further studied by chemical, petrographic, and X-ray diffraction methods. Of the 228 samples studied in detail, rapid rock analyses (Shapiro and Brannock, 1962) were obtained for 82. In these analyses the major components were reported as oxides.

For the 228 samples studied in detail, part of each was retained as a hand sample from which a thin section was cut. The remainder was ground to minus-40 mesh (the largest particle was about 0.62 mm, about 10 times larger than the average grain size of the laminated limestone). Part of the ground sample was pulverized by mortar and pestle; this powder was used to make an acetate disk for X-ray diffraction. Fifty grams of the minus-40-mesh material was then dissolved in dilute hydrochloric acid (15 parts water and 1 part concentrated hydrochloric acid) at room temperature. After bubbling ceased, the acid solution was heated to about 35 °C to insure that all dolomite dissolved. The insoluble residue was filtered, dried, and weighed to determine the present insoluble residue in the sample. A split of the insoluble residue was pulverized by mortar and pestle to make an acetate disk for X-ray diffraction. The remainder of the insoluble residue was centrifuged in bromoform (specific gravity about 2.89) to separate heavy minerals. The heavy minerals were then mounted in Canada balsam on a slide.

X-ray diffractograms of both whole rock and insoluble residue were made, so that the methods of Gulbrandsen (1960), Schultz (1964), and Diebold, Lemish, and Hiltrop (1963) for determining quantitative mineralogical composition could be used. All diffractograms were made on the same machine with Ni-filtered CuKα_1 radiation with high gain at 2° 2θ per minute and a chart speed of 1 inch per minute. All samples were run from 4° to 60° 2θ. These settings were selected in an attempt to detect traces of minerals other than calcite, dolomite, quartz, feldspar, and clay.

For the most part this procedure was unrewarding inasmuch as other minerals seldom occurred in sufficient quantities to produce identifiable X-ray peaks. A faster speed would have produced equally good results in half the machine time.

Thin sections and heavy mineral mounts were studied to determine the variety and relative amounts of minerals, and the fabric of the rock. Grain counts were made at 100 × magnification; details of texture and replacement were generally studied at 500 ×. For the most part, thin-section study of the laminated limestone is difficult because of the small grain size and because most sections are smeared with carbonaceous material or iron oxides. The thin section data were integrated with the percent insoluble residue, X-ray diffractograms, spectrographic analysis, and oxide analyses to obtain the mineral composition.

For the 82 samples where rapid rock analyses are available, the actual amounts of calcite, dolomite, quartz, feldspar, and clay minerals are probably within 2 percentage points of the amounts shown in Mullens (1979). X-ray diffraction traces of the whole rock and insoluble residue of these 82 samples were used as standards for comparing X-ray information on mineral composition of the other samples. For the samples where oxide analyses were not obtained, the accuracy is less. I estimate that the values are ±5 percentage points of the correct value, where a mineral exceeds 50 percent. For values less than 50 percent, the probable error is greater and unbalanced. For minerals that form 15–50 percent of the rock, the probable error is within 5–10 percentage points of the correct value. For minerals that form less than 10 percent of the rock, the probable error is within 1–5 percentage points of the correct value.

The data for major components—calcite, dolomite, quartz, feldspar, and clay minerals—are calculated to 100 percent of the rock for most samples (Mullens, 1979). Only where pyrite, iron oxide, carbonaceous material, phosphatic material, or some alteration product exceeds 1 percent are the major components reduced below 100 percent. Water is ignored except to the extent that it is included in clay. The variety of clay recognized is based mainly on identification from X-ray diffraction studies. Kaolinite and montmorillonite were never positively identified in thin-section study.

STRATIGRAPHY AND PETROLOGY OF THE ROBERTS MOUNTAINS FORMATION

The Roberts Mountains Formation was defined by Merriam (1940, p. 11–12) for rocks exposed along the headwaters of Pete Hanson Creek in the north-central part of T. 23 N., R. 50 E. (unsurveyed), Roberts Mountains, Eureka County, Nev. At the type section, the Roberts Mountains Formation includes Silurian and Devonian rocks, and is about 580 m thick. From bottom to top, it consists of 2 m of cherty limestone, about 120 m of platy-weathering limestone, about 175 m of interbedded platy-weathering limestone and massive limestone, and 275 m of massive limestone and dolomite (M. A. Murphy, written commun., 1970). The Roberts Mountains Formation overlies dolomite and limestone of the Hanson Creek Formation, which Merriam believed to be entirely of Ordovician age, but which is now considered to be of Silurian age in the upper part (Mullens and Poole, 1972). The Roberts Mountains Formation, at the type section, is overlain by massive dolomite assigned to the restricted Lone Mountain Dolomite (Merriam, 1940, p. 13), which Merriam believed was of Late Silurian age, although he recognized the possibility that the Lone Mountain might contain beds of Early Devonian age.

The type section of the Roberts Mountains Formation, as established by Merriam, is in an area of abrupt facies changes. Winterer and Murphy (1960, p. 119–122, figs. 1–4) and Murphy (1969) mapped the changes in detail; they assigned a maximum of about 760 m of rock to the Roberts Mountains Formation and noted that as a mappable unit the formation ranges from a few meters to 760 m (Winterer and Murphy, 1960, p. 122). Merriam (1940, p. 11–12) assigned all rocks at the type section to the Silurian, but Murphy (1969), Klapper (1969), and Berry, Jaeger, and Murphy (1971) found that locally the upper part of the formation in the Roberts Mountains area is of Devonian age.

I did not study the type locality in detail; I have used the available literature, supplemented by written communications from M. A. Murphy (1968, 1969, and 1970), in relating my work to the type locality.

Sequences of rock similar in age and composition to those in the type area of the Roberts Mountains Formation occur in the Shoshone, Toiyabe, Toquima, Monitor, and Sulphur Spring Ranges and in the Cortez, Simpson Park, and Tuscarora Mountains. In those ranges, rocks above the silty laminated limestone have been excluded from the Roberts Mountains Formation (Gilluly and Masursky, 1965; Johnson, 1965; Kay and Crawford, 1964; Evans, 1972a, b; and Stewart and McKee, 1977). In this report, some limits are established for the Roberts Mountains Formation away from the type area, to avoid placing mappable thick-bedded and coarse-grained limestone of Devonian age in the upper part of the formation and to conform with previous work. The Roberts Mountains Formation away from the type area is subdivided in three parts: (1) a basal chert or cherty carbonate unit; (2) a laminated limestone unit; and (3) locally, an upper interbedded laminated limestone and thick-bedded coarse-grained carbonate unit. The cherty unit is the only marker bed of regional extent; regional correlations of rocks within the formation are based mainly on fossils. Berry and Boucot (1970, p. 206) recognized only two facies of the Roberts Mountains Formation: a platy limestone facies and a thick-bedded facies. Their platy limestone facies included the basal cherty unit. Some of the rocks in the Tuscarora Mountains that they and Merriam and McKee (1976) included in their thick-bedded facies are here excluded from the Roberts Mountains Formation.

The thickness and distribution of the units in the Roberts Mountains Formation and the relations of the units to underlying, laterally equivalent, and overlying rocks are shown on plate 2. The only conspicuous unit of regional extent in the Roberts Mountains Formation is the basal 0–50 m of interbedded chert, limestone, and dolomite. This cherty unit was called the upper member of the Gatecliff Formation in the Toquima Range by Kay and Crawford (1964), and was called the upper member of the Happy Camp Formation in the Independence Mountains by Kerr (1962).

A laminated rock that weathers platy and that consists mainly of calcite, dolomite, quartz and feldspar silt, and clay minerals forms the bulk of the Roberts Mountains Formation. Minor, but ubiquitous, constituents, which generally form less than 1 percent of laminated rock, are carbonaceous material and pyrite in unoxidized rock and iron oxides in oxidized rock. The term "laminated limestone" is used to describe this rock although much of it contains less than 50 percent calcite. The rock is very fine grained (the average detrital grain size is large silt), and it fizzes with dilute acid. Relative proportions of calcite, dolomite, quartz, and clay cannot be determined with hand lens and acid. The laminated rock was called Masket Shale in the Toquima Range by Kay and Crawford (1964), and was called the Taylor Canyon Formation in the Independence Mountains by Kerr (1962).

The Roberts Mountains Formation in most areas is restricted to strata extending upward from the base of the cherty unit to the base of the lowest coarse-grained massive limestone that can be mapped for about 3 km. In a few places, lenticular coarse-grained limestone beds of less than 3 km in extent are interbedded with laminated limestone. In these places, the upper contact of the Roberts Mountains is placed where coarse-grained massive beds become more abundant than fine-grained laminated beds. Using this restriction, coarse-grained nonlaminated limestone and dolomite form a major part of the Roberts Mountains Formation only in the type area, near Bootstrap mine in the Tuscarora Mountains, Goat Peak window in the Shoshone Range, and Petes Canyon in the Toquima Range, and at Miniature Grand Canyon in the Monitor Range.

The type locality of the Roberts Mountains Formation is near the west-to-east gradation of laminated limestone to massive dolomite and near a south and southeast gradation to laminated slightly silty dolomite. The massive dolomite has been assigned to the Lone Mountain Dolomite and was not studied. The laminated dolomite at Lone Mountain, Mahogany Hills, Hot Creek Canyon, and Rawhide Mountain, which I studied and sampled, is herein excluded from the Roberts Mountains Formation. Merriam (1973b, p. 12–17) has assigned the laminated dolomite at these places to his unit 1 of the Lone Mountain Dolomite.

The cherty carbonate rock at the base is present throughout the Roberts Mountains Formation. In most areas this unit overlies thick-bedded limestone or dolomite of Early Silurian or Late Ordovician age. Locally in the Shoshone, Toiyabe, and Toquima Ranges, the cherty unit overlies laminated or thin-bedded limestone that ranges in age from Early Ordovician to Late Ordovician. The upper contact of the Roberts Mountains Formation away from the type area is generally placed at the change from laminated limestone to laminated limestone interbedded with massive coarse-grained carbonate rock, or at the change from laminated limestone to massive carbonate rock only. In most places studied, this contact is above the *Monograptus uniformis* Zone, which is here used to indicate the base of Devonian rocks although no lithologic change occurs at this fossil zone. As a mappable unit, the Roberts Mountains Formation includes both Silurian and Devonian rocks.

Use of the *M. uniformis* Zone to indicate the base of the Devonian follows a recommendation of the committee established by the International Union of Geological Sciences and chaired by D. W. McLaren to select a boundary between the Silurian and Devonian Systems. This boundary has been accepted by some geologists (Berry, 1970; Berry and Boucot, 1970, p. 16; Berry and others, 1971, p. 1969; Klapper and others, 1970; and Berdan and others, 1969). Other geologists, notably C. W. Merriam (1973a, b; Merriam and McKee, 1976), disagree with this boundary and would place it somewhat higher on the basis of rugose corals.

There are exceptions to the above generalization about the upper contact of Roberts Mountains Formation. In parts of the Crescent Valley–Grass Valley area coarse-grained carbonate rock is absent above the laminated limestone. In those places the contact of the Roberts Mountains and the overlying Devonian Wenban Limestone locally can be defined by a subtle change based more on weathering characters than on composition. The upper contact of the Roberts Mountains Formation at the Carlin mine is placed at the base of a reddish-brown silty zone that is 6–10 m thick. The reddish-brown zone is overlain by very fine grained limestone that contains many features of turbidites but little silt or dolomite. Laminated limestone assigned to the Roberts Mountains Formation near the Swales Mountain is seemingly conformably overlain by Lower Mississippian very fine grained limestone that contains abundant borings (Ketner, 1970).

BASAL CHERTY UNIT

DISTRIBUTION AND COMPOSITION

The basal chert, limestone, and dolomite of the Roberts Mountains Formation constitute the only distinctive subdivision of regional extent in the formation (pl. 2, fig. 1). This unit is erratic in thickness and locally it is absent. Ranges in thickness in most of the outcrop bands are as follows:

	Meters
Shoshone Range	3.0–25
Toiyabe Range	0.0–30
Toquima Range (upper unit of Gatecliff Formation of Kay and Crawford, 1964)	0.0–50
Monitor Range	6.0–31
Cortez Mountains	0.0–23
Roberts Mountains	0.3–12
Sulphur Spring Range	0.6– 6
Tuscarora Mountains	3.0–25
Independence Mountains (upper unit of Happy Camp Formation of Kerr, 1962)	0.0–30

In both the Toquima Range (Kay and Crawford, 1964) and the Independence Mountains (Kerr, 1962), abrupt changes in thickness have been attributed to exposures being in different thrust plates.

Typically, the cherty unit contains about half chert and half carbonate rock in alternating beds 2.5–50 cm thick (fig. 2). The chert content, however, ranges from 25 to 100 percent and, generally, the thinner the zone, the greater the relative chert content. Most chert is black or brown and weathers black or brown, but medium-gray chert that weathers medium to light gray is found locally. Some beds that are seemingly pure chert at outcrop will be found to contain 20–40 percent carbonate several centimeters beneath the surface. In detail, the chert ranges from even beds through lenticular beds to nodules parallel to bedding, and in places veins of chert up to 5 cm thick cut across as much as 60 cm of beds. The contact with the interbedded carbonate rock ranges from sharp to gradational and most of the chert beds grade laterally into carbonate rock. Bedding in the chert zone ranges from gently lensed to wildly contorted. Where the bedding is only slightly lensed the chert beds are commonly laminated on a 0.5- to 4-mm scale. Locally the cherty beds are brecciated, and at many places distribution of the brecciated chert indicates that the breccia is diagenetic and not related to tectonic forces.

Carbonate rock interbedded with the chert is commonly dark to very dark gray, very fine grained (<0.02 mm), and laminated on a 0.25- to 2-mm scale; it contains little detrital silt or clay. The insoluble residue is generally less than 5 percent in places where the beds are not replaced by chert (Mullens, 1979, sample 8135, loc. 8; sample 9063, loc. 14; and sample 7001, loc. 25). This lack of insoluble residue is in contrast to the mix-

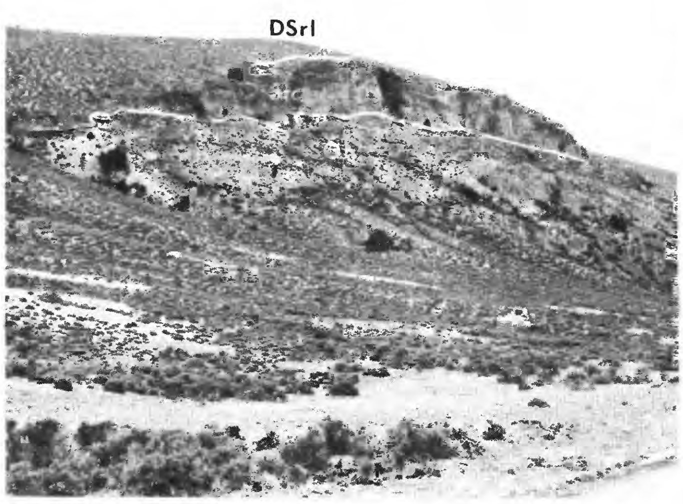


FIGURE 1.—Basal cherty unit of the Roberts Mountains Formation exposed on the west side of Copenhagen Canyon, Monitor Range, Eureka County, Nev. Basal beds of laminated limestone unit of Roberts Mountains Formation (DSrl) cap cliff. Basal cherty unit (Src) is 31 m thick and conformably overlies the Hanson Creek Formation (SOh).

FIGURE 2.—Basal cherty unit of the Roberts Mountains Formation exposed near the south end of South Ravenswood window, central Shoshone Range, Lander County, Nev. Thicker beds are completely silicified; thinner beds are partly silicified. White streaks and nodules are calcite.

ture of quartz silt, clay, calcite, and dolomite typical of the bulk of the Roberts Mountains Formation.

The following slightly condensed field description of the cherty unit at Copenhagen Canyon, Monitor Range, Eureka County, is typical of the entire cherty unit where it exceeds 6 m in thickness.

Limestone and chert are interbedded, 31 m thick. Limestone is dark gray to black, very fine to fine grained, and occurs in beds 5–20 cm thick. Limestone tends to be very fine grained, slightly dolomitic, and in beds 5–10 cm thick in lower 21 m; it is coarser (fine) grained, not dolomitic, and in beds 10–20 cm thick in upper 10 m. Chert is very dark gray to brown and occurs in beds 1–5 cm thick that are locally laminated, and in nodules which are up to 50 cm long and 10 cm thick and whose long dimension parallels bedding. Chert in lower 5 m is vitreous and smooth weathering, and contains no carbonate rock; chert above is definitely silicified carbonate rock as beds grade both laterally and vertically into carbonate rock that has sandy texture on the surface. Chert in upper 3 m is in small irregular lenses 1–5 cm thick and 0.6–3 m long and weathers grayish brown. All beds in unit are gently lensed, but the ends of some chert beds are contorted and have intruded as much as 50 cm of adjacent rock. No gradation of chert to carbonate rock is observed at the intruded ends of the chert. The contortions and the intrusive nature were seemingly caused by compaction during diagenesis as contortions disappear within 5–60 cm upward. Beds in upper third of unit are slightly more lenticular than in lower two-thirds. The lower 3 m contains more than 60 percent chert, the next 15 m above is about 50 percent chert, and the upper 13 m is about 40 percent chert. Unit forms banded zone, and upper 15 m weathers to conspicuous cliff.

At Pablo Canyon in the Toiyabe Range and at Black Cliff Canyon and Petes Canyon in the Toquima Range, the cherty unit contains scattered 0.4- to 5-cm-thick beds that seemingly are silicified claystone instead of carbonate rocks.

Where the cherty unit is less than 3 m thick it is dominantly irregularly bedded chert that retains few characters to indicate that the chert is silicified carbonate rock.

STRATIGRAPHIC RELATIONS OF THE CHERTY UNIT

The cherty unit, as used here, includes the black chert unit that forms the upper part of the Gatecliff Formation of Kay and Crawford (1964) in the Toquima Range, and the upper member of the Happy Camp Formation of Kerr (1962, p. 446–447) in the Independence Mountains. In most of the east and northeast part of the area studied, the cherty unit conformably overlies thick- to medium-bedded dolomite and limestone assigned to the Hanson Creek Formation of Ordovician and, locally, Early Silurian age. In parts of the Shoshone, Toquima, and Toiyabe Ranges, the cherty unit locally conformably overlies rocks assigned to the Hanson Creek Formation or the basal unit of the Gatecliff Formation of Kay and Crawford (1964). At Black Cliff Canyon in the Toquima Range the cherty unit overlies, in probable conformable contact, very dark gray to black, laminated, very fine grained limestone of Late Ordovician age. In other places in these ranges the chert unconformably overlies beds assigned to the Copenhagen Formation of Middle Ordovician age or to part of the Pogonip Group of Early Ordovician age (Stewart and McKee, 1977).

The Upper Ordovician laminated limestone at Black Cliff Canyon is typical of rocks assigned to the transitional facies of Roberts (1969); thus the cherty unit conformably overlies both transitional shaly limestone and coarse-grained carbonate rock deposited eastward, and shelf rocks of the geosyncline. Also, west of the area of probable conformable contact with uppermost Ordovician rocks, the chert unconformably overlies Middle and Lower Ordovician rocks. The cherty unit seemingly conformably underlies laminated limestone typical of the bulk of the Roberts Mountains Formation.

LAMINATED LIMESTONE UNIT

GENERAL CHARACTER AND COMPOSITION

A laminated limestone unit that weathers platy forms the bulk of the Roberts Mountains Formation. Locally the unit contains medium- to coarse-grained limestone in lenticular beds a few centimeters to a few meters thick and thin beds of chert and small chert nodules. Nowhere do these coarser grained beds and chert make up more than 2 percent of the unit, and no observed coarse-grained limestone or cherty zone extended for more than 1 km. Because the coarser limestone and chert form such a small part of the laminated limestone unit and because the gold ore deposits are in laminated limestone, the emphasis in this report is on the laminated rock.

In fresh exposures, the laminated limestone is black to very dark gray and appears massive. Slight weathering produces conspicuous partings and a medium-gray color (fig. 3); more extensive weathering produces flags and small plates that are gray, tan, pale red, and reddish brown and that disintegrate to soil (fig. 4). Typically, the end result is a smooth slope uninterrupted by ledges (fig. 5). The tan, pale-red, and reddish-brown colors of plates in the Roberts Mountains Formation locally serve to distinguish the formation from Ordovician or younger Devonian laminated

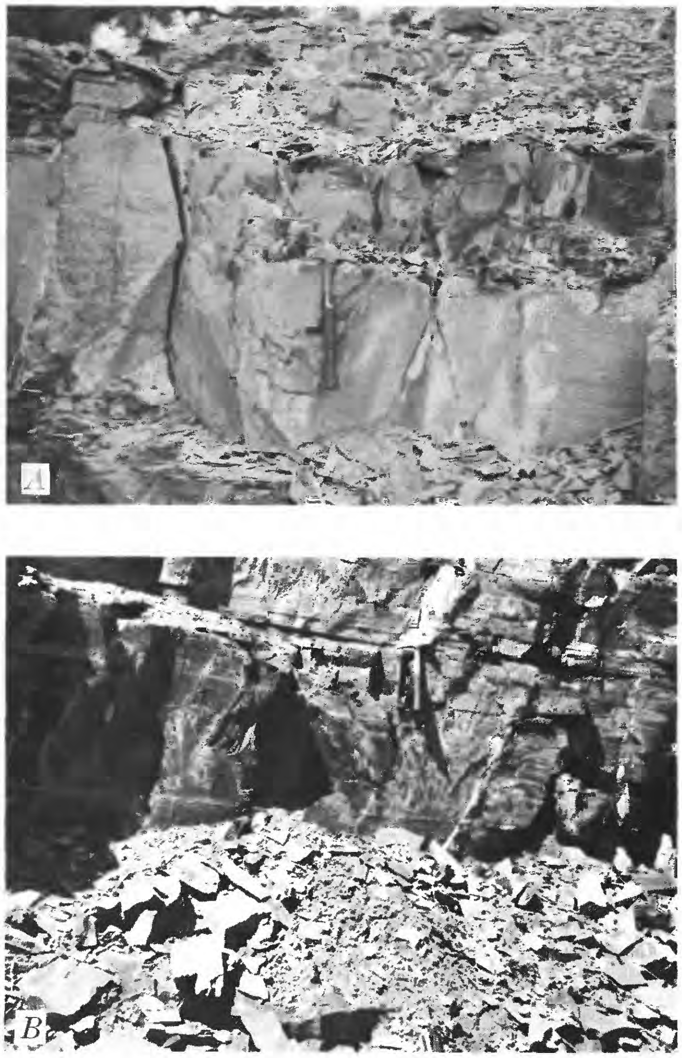


FIGURE 3.—Laminated limestone unit in the Roberts Mountains Formation, north-central Nevada. *A*, Outcrop in Petes Canyon area, Toquima Range. *B*, Man-made exposure in roadcut in Maggie Creek Canyon, Eureka County.

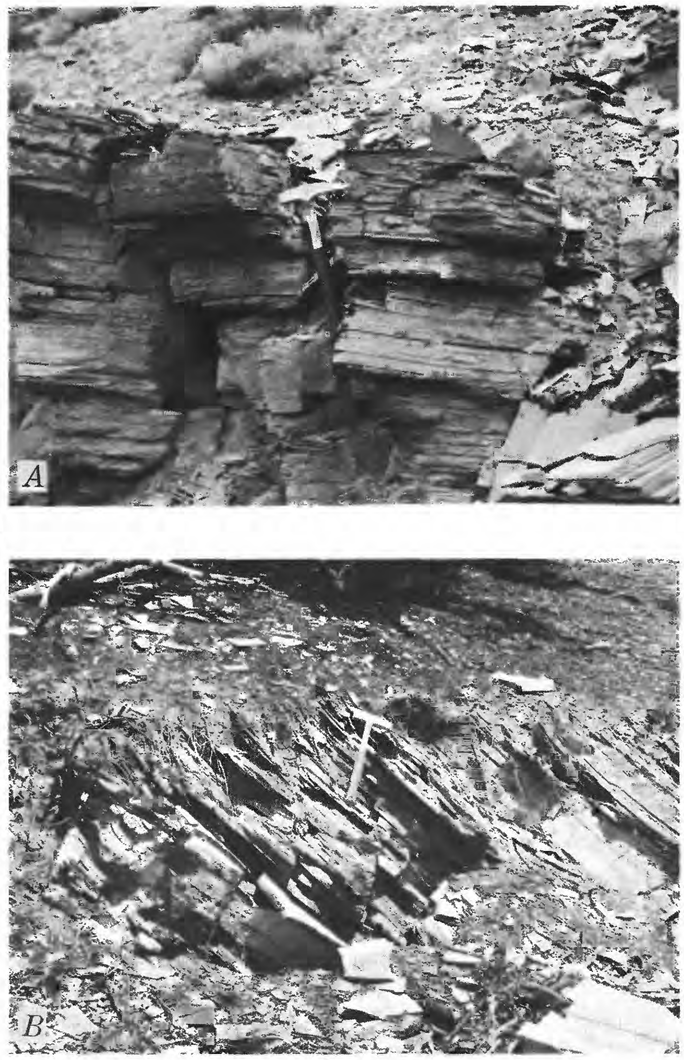


FIGURE 4.—Weathered laminated limestone unit in the Roberts Mountains Formation, Nev. *A*, Slightly weathered; Petes Canyon area, Toquima Range. Zone shown is weathered phase of zone shown in figure 3*A*. *B*, Weathered; exposed along bulldozer cut, Coal Canyon area, northern Simpson Park Mountains.

limestones of other formations that tend to weather black and dark gray.

The weathering is along laminations which are not conspicuous in fresh rock but which are conspicuous in weathered rock and in thin sections. Figures 6 and 7 show some details of these laminations. Most laminations are even and extend a few meters; some, however, are lenticular and contorted (fig. 7*B* and *D*) and extend a few millimeters to a few centimeters. The lenticular and contorted laminations seem more abundant in the upper part of the laminated limestone unit in the Tuscarora and Roberts Mountains than elsewhere.

The laminations range in thickness from less than 0.05 to about 4 mm, averaging about 0.2 mm. There seems to be no universal rhythmic composition control of the laminations. Concentrations of carbonaceous material and extremely fine grained pyrite generally form one set in a pair of laminations in unoxidized rock, and concentrations of iron oxide generally form one set in a pair of laminations in oxidized rock. These types of laminations separate other laminations that range in composition from relatively pure calcite to quartz silt. Locally, carbonaceous material and iron minerals are absent and laminations of relatively pure calcite separate laminations that contain abundant detrital material. Laminations relatively rich in detrital material do not show graded bedding.

Triangular diagrams showing amounts of calcite, dolomite, insoluble residue, quartz and feldspar, clay minerals, and total carbonate for all unaltered laminated limestone samples from the Roberts Moun-

FIGURE 5.—Slope formed in laminated limestone unit of Roberts Mountains Formation, northeast side of Maggie Creek Canyon, Eureka County, Nev. Ledges shown in upper right part of photograph are lenticular beds of coarse-grained limestone within the laminated limestone unit. Shows about 150 m vertical relief.

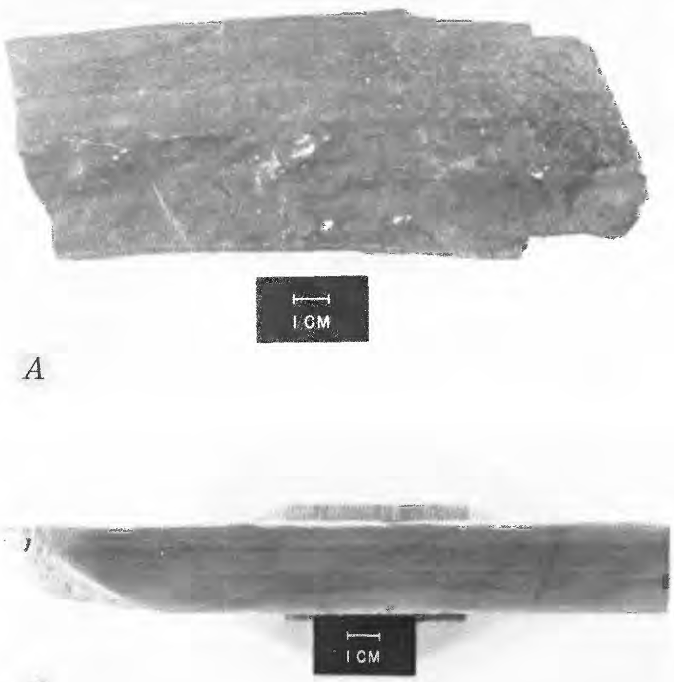


FIGURE 6.—Fresh and weathered laminated limestone from the Roberts Mountains Formation, Nev. *A,* Hand sample of fresh limestone, Rattlesnake Canyon, Eureka County. White spots are places where rock has been powdered. Conspicuous laminations near top and bottom of specimen are formed by epigenetic pyrite (Mullens, 1979, sample 8082, loc. 2, table 1). *B,* Sawed sample of weathered limestone from upper part of formation 1.5 km west of Carlin mine (Mullens, 1979, sample 7003, loc. 28, table 1).

tains Formation are shown on figure 8. Rock is considered altered if it contains more than 10 percent epigenetic minerals or more than 10 percent diagenetic silica. Triangular diagrams that show similar features for all rocks collected at each locality listed on plate 2 are shown on plate 3, which indicates that the wide spread in composition of laminated limestone shown in figure 8 is typical for most localities. The major exceptions to this general rule are in the southern Toiyabe and Toquima Ranges.

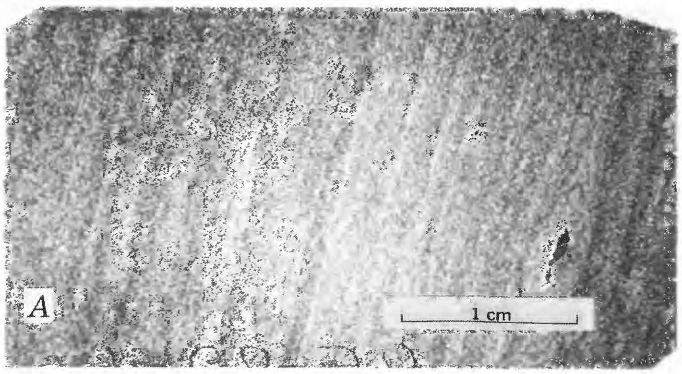
Laminated limestone in the southern Toiyabe and Toquima Ranges (pl. 3, nos. 32, 33, 34, and 36) is more dolomitic, tends to weather blocky instead of platy, and contains more silt and iron oxide than laminated limestone in other areas (pl. 3). The blocky weathering and high dolomite and silt content of rocks in the southern Toiyabe and Toquima Ranges reflect a facies change, but outcrops in those areas are so sparse, isolated, and complicated by faults that little detail of the change can be determined.

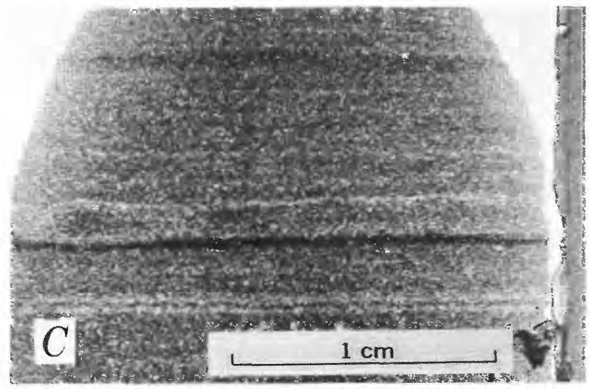
The average of all unaltered laminated limestone samples collected is about 70 percent total carbonate (45 percent calcite and 25 percent dolomite), and about 30 percent insoluble residue (22 percent quartz and feldspar silt and 8 percent clay minerals). The samples do not cluster near the average, but show a nearly uniform distribution in a relatively wide range of composition. Parameters for this wide range are 5–95 percent calcite, 0–50 percent dolomite, 5–60 percent insoluble residue (fig. 8*A*); and 1–15 percent clay minerals, 40–95 percent carbonate, and 5–45 percent quartz and feldspar (fig. 8*B*). Because the composition of the laminated limestone does not change greatly with geographic position, interpretations that relate composition to source and paleogeography are severely restricted.

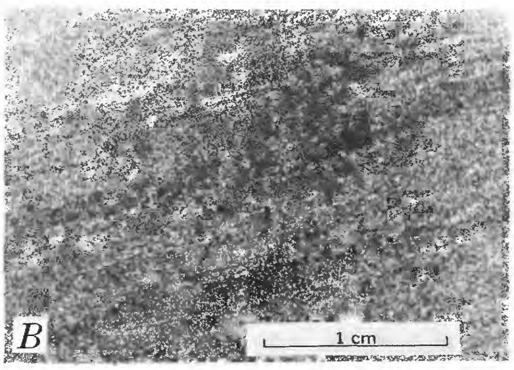
Along with the wide range in composition, figure 8 shows three features worthy of mention. First is the tendency for a vertical distribution in composition based on an arbitrary division of the laminated unit at each locality into two halves. Rocks in the lower half are more likely to contain 50 percent or more calcite (38 of 66 samples) than rocks in the upper half (11 of 42 samples). Second is the tendency for insoluble residue and dolomite to increase in about a 58:42 ratio as calcite decreases, and third is the tendency for quartz and feldspar, as compared to clay, to increase in a ratio of about 3:1 as total carbonate decreases.

DISTRIBUTION AND THICKNESS

The laminated limestone unit extends westward and northwestward from a probable wedge edge that is concealed in the valley between the Sulphur Spring Range and the Diamond Mountains. The unit is not present in the Pinon Range and its eastern extent is in







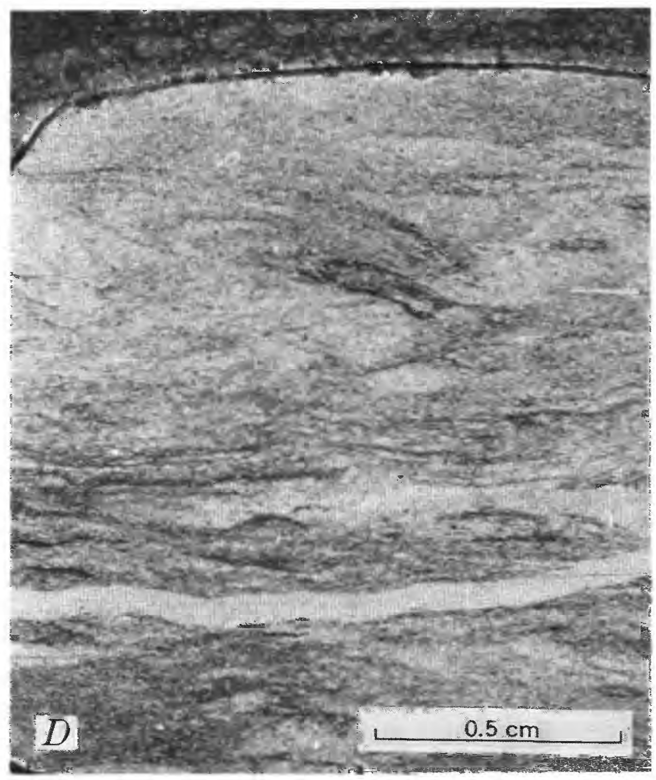


FIGURE 7.—Thin sections of laminated limestone from the Roberts Mountains Formation, Nev. *A*, Evenly laminated fresh limestone from Rattlesnake Canyon section. Laminations conspicuous because of carbonaceous material. Irregular black lens is pyrite enclosed by secondary quartz and clay (Mullens, 1979, sample 8058, loc. 2, table 1). *B*, Slightly unevenly laminated fresh limestone from Rattlesnake Canyon section. Laminations conspicuous because of carbonaceous material (Mullens, 1979, sample 8079, loc. 2, table 1). *C*, Weathered evenly laminated limestone. Lamination conspicuous because of iron oxide. Sample from 1.5 km west of Carlin mine (Mullens, 1979, sample 7003, loc. 28, table 1). *D*, Fresh irregularly laminated limestone. Gold ore from Carlin mine. Large white seam in lower part is where rock pulled apart (Mullens, 1979, sample 7006, loc. 3, table 1).

northern Pine Valley between the Pinon Range and Cortez Mountains. North of Pine Valley, the edge of the laminated limestone unit is inferred to trend east-northeasterly to the Pequop Mountains, but the edge is not exposed. The laminated limestone unit disappears eastward and southward by grading laterally into laminated dolomite and coarse-grained dolomite. The original west, northwest, and southwest extent of the laminated limestone unit is not known, because of structural complications and lack of outcrop. The exposures at Wall, Pablo, and Black Cliff Canyons contain laminated to medium-bedded dolomite and are interpreted to be near the edge of the laminated limestone unit.

The known thickness and distribution of the laminated limestone (pl. 2) suggest two depocenters. These depocenters are based on sections that contain more than 700 m of laminated limestone that apparently is not repeated by faults. If these sections contain unrecognized faults, the interpretations made herein must be modified. One depocenter extends from near Swales Mountain to near Antelope Peak north of Wells. Near Swales Mountain, a diamond-drill core hole penetrated 823 m of seemingly unfaulted laminated limestone that is assigned to the Roberts Mountains (Ketner and others, 1968) without reaching the cherty unit or recognizable Ordovician beds. No fossils were found in the core and the assignment was made on the basis of lithologic similarity. The laminated limestone near Swales Mountain is seeming-

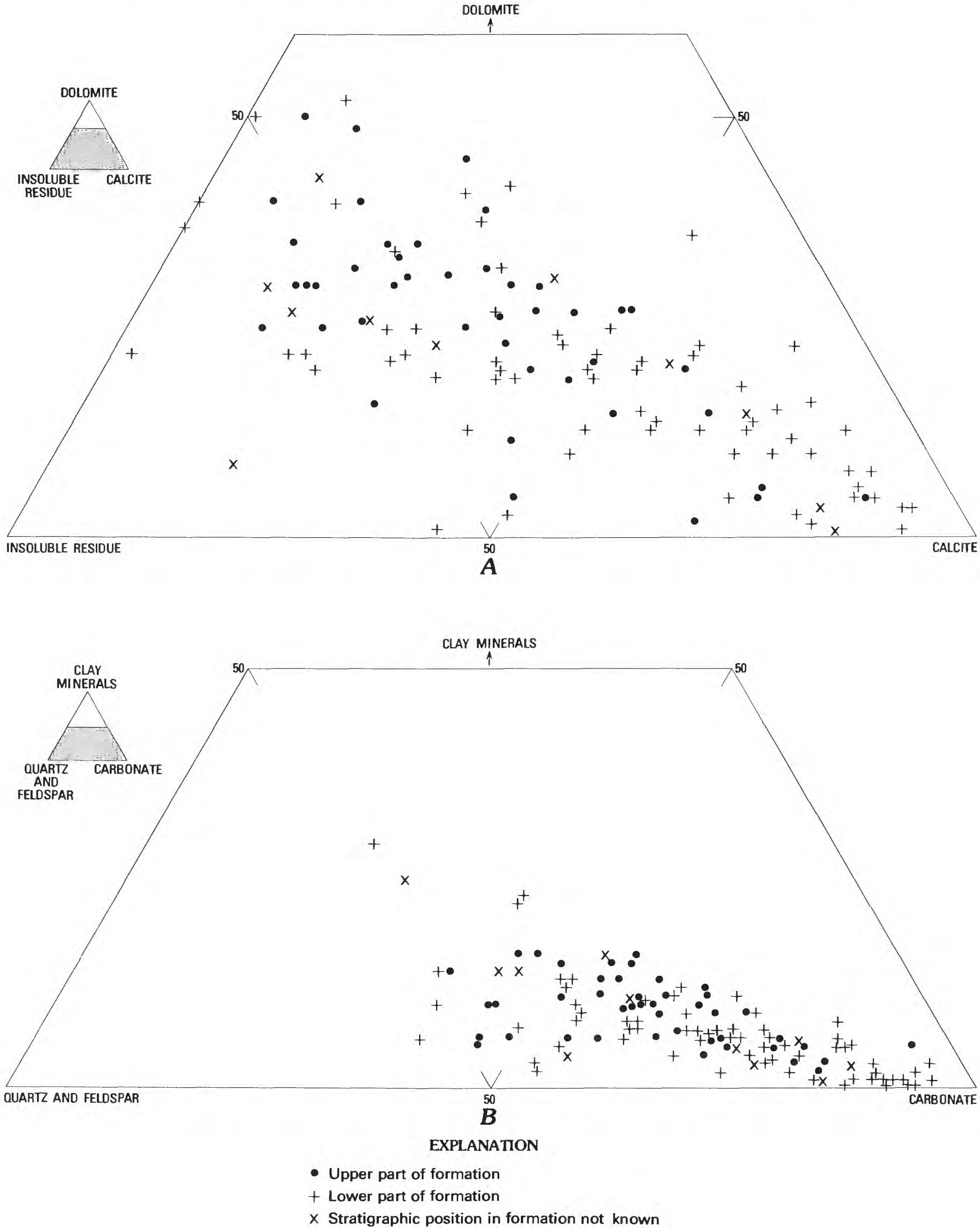


FIGURE 8.—Composition of unaltered laminated limestone samples from the Roberts Mountains Formation, Nev. *A,* Insoluble residue, calcite, and dolomite. *B,* Total carbonate, combined quartz and feldspar, and clay minerals.

ly overlain conformably by Lower Mississippian rocks (Ketner, 1970; Evans and Ketner, 1971). Ketner (1970) believed that laminated limestone was deposited during both Silurian and Devonian time. About 760 m of laminated limestone overlies the cherty unit and underlies coarse-grained limestone at Antelope Peak reported by Peterson (1968) to be of Middle Devonian age. Peterson indicated in his text that in the Antelope Peak area the laminated limestone assigned to the Roberts Mountains is about 460 m thick whereas in his cross section he showed it to be about 760 m thick. Faults and poor exposures prohibit exact measurements at Antelope Peak but my measurements indicate that 760 m is more reasonable than 460 m. The depocenter extending from Swales Mountain to near Antelope Peak nearly coincides with a depocenter for Ordovician quartzite reported by Ketner (1968, fig. 3).

The other depocenter for laminated limestone is in the Crescent Valley–Grass Valley area. Gilluly and Masursky (1965, p. 25–38) separated autochthonous Silurian and Devonian rocks in the Crescent Valley area into the Roberts Mountains Formation and the overlying Wenban Limestone of Devonian age. Locally this division is based on thick-bedded coarse-grained limestone of Devonian age that is assigned to the Wenban Limestone. In other places, coarse-grained limestone is absent and laminated limestone assigned to the Wenban Limestone directly overlies laminated limestone in the Roberts Mountains Formation. At outcrop, the Wenban locally can be separated from the Roberts Mountains Formation because of its different weathering characteristics and the occurrence of *Tentaculites* and *Styliolina* in the Wenban. This contact probably cannot be detected in unweathered rock. A diamond drill hole, 670 m deep, in Mill Canyon east of Crescent Valley crossed the projected subsurface contact of the Roberts Mountains and Wenban, but I could detect no change in the core that could be used as a contact.

Stewart and McKee (1968) mapped as Roberts Mountains Formation about 1,200 m of laminated limestone that is partly altered to hornfels in Grass Valley. This is the youngest rock exposed beneath a thrust and Quaternary basin fill. I could find no faults that repeated the section nor could I find a method of dividing the rocks into the Roberts Mountains Formation and Wenban Limestone. I suspect, however, that the upper 600 m is a lateral equivalent to the Wenban exposed in the Crescent Valley area.

The depocenters for the thick laminated limestone unit may connect southeast of Maggie Creek Canyon. This possibility would involve a southeastward thickening of the laminated limestone unit in the direction in which I assume the laminated limestone grades into thick-bedded carbonate rock. I doubt that the depocenters connect, but control points are not available to prove or refute this possibility. No control points are available to obtain the thickness of laminated limestone north and northwest of the Swales Mountain–Antelope Peak depocenter. The laminated limestone in the Grass Valley–Crescent Valley area seems to thin westward, northwestward, and southwestward. Several beds of coarse-grained carbonate of probable Late Silurian age occur about 460 m above the basal cherty unit, just beneath upper plate rocks at Goat Peak window in the west side of the northern Shoshone Range. Thick-bedded pelletal limestone of Late Silurian age is interbedded with laminated limestone at Bootstrap mine, and the base of the Roberts Mountains Formation is not exposed; so the thickness of the laminated limestone unit that is presumably beneath the exposed section could not be obtained. Southwestward of Grass Valley, a coarse-grained limestone about 9 m thick and of Early Devonian age overlies about 460 m of laminated limestone at Point of Rocks. The upper 22 m of the laminated limestone unit at Point of Rocks contains thin beds of bioclastic limestone. I place the upper contact of the Roberts Mountains at the base of the 9-m bed, although Stewart and McKee (1977) placed the upper contact of the Roberts Mountains at the lowest bioclastic limestone.

At the type section of the Roberts Mountains Formation, the laminated limestone unit is about 120 m thick and entirely of Silurian age. Sixteen kilometers northwestward at Coal Canyon the laminated limestone is about 460 m thick and includes beds of Devonian age in the upper 155 m. At Rattlesnake Canyon, the laminated limestone unit is about 310 m thick and includes Devonian beds in the upper 30 m. The Rattlesnake section lies slightly west and presumably closer to the middle of the Cordilleran geosyncline; thus, in theory, the laminated limestone should be thicker than at Coal Canyon. Rattlesnake Canyon, however, is near the crest of the Cortez–Uinta axis of Roberts (1968), which I interpret as being high enough to have caused deposition of coarse-grained limestone instead of laminated limestone in this area during Early Devonian time. I also attribute the absence of laminated limestone in the Pinon Range to this slight positive zone.

At Maggie Creek Canyon and the Carlin mine area the laminated limestone is faulted (Evans, 1972a, Evans and Cress, 1972), so that accurate measurements cannot be obtained. Evans (oral commun., 1970) believed that there was about 460 m of laminated limestone in these areas. Near the Carlin mine and at Maggie Creek Canyon the upper part of the laminated limestone contains a few lenses of coarse-grained limestone as much as 3.5 m thick.

ALTERATION

Locally the laminated limestone is visibly altered; the degree of alteration ranges from a minor replacement by quartz, slight increase in clay content, and minor decrease in calcite content to complete silicification or conversion to hornfels. The dividing point between altered and unaltered rocks used here and in the tabulated data of mineral and chemical composition of the rocks (Mullens, 1979) is based on 10 percent epigenetic minerals, or more than 10 percent diagenetic silica. The laminated limestone is probably easy to metamorphose as traces of epigenetic amphibole are found in about half the samples that megascopically seemed to be unaltered. In addition, sepiolite is found in three samples and talc in one sample that seemed to be unaltered.

The most conspicuous altered zones are silicified zones that are as much as several meters thick and that range in length from a few hundred to several thousand meters. These zones roughly parallel bedding, and form ledges. In these zones, the megatexture and laminations are faithfully preserved, the replacement by silica is complete, the color changes to dark brown and pale red, and the rock does not weather to plates. These zones are most common in the line of outcrop from Maggie Creek Canyon to Bootstrap mine and possibly are related to thrust faults of the Antler orogeny. A second and less conspicuous alteration is incomplete silicification that changes the texture of the laminated limestone to a rock resembling siltstone or very fine grained sandstone, generally alters the color to pale reddish orange, but does not alter the platy weathering character of the rock. These zones are a few meters to about 100 m thick and are fairly lenticular (most are only about 200 m long). These zones commonly cannot be related directly to faults or intrusive rock. Both the Carlin and Cortez mines are associated with silicified zones in the Roberts Mountains Formation that contain features common to both of these types of silicification.

In addition to some silicification, the gold ore at the Carlin and Cortez mines is in rocks that have added clay and reduced calcite content; the southwest pit of the Carlin mine contains many iron-oxide Liesegang rings that cross laminations. The southwest pit is the only place observed where features associated with silicification commonly cross laminations.

Near intrusives, the laminated limestone is locally altered to scapolite-bearing rock and hornfels. The largest scapolite-bearing zone observed is along the east side of the Tuscarora Mountains (Evans, 1972a, b). The Grass Valley outcrop is mainly altered to hornfels.

PETROGRAPHY OF THE LAMINATED LIMESTONE

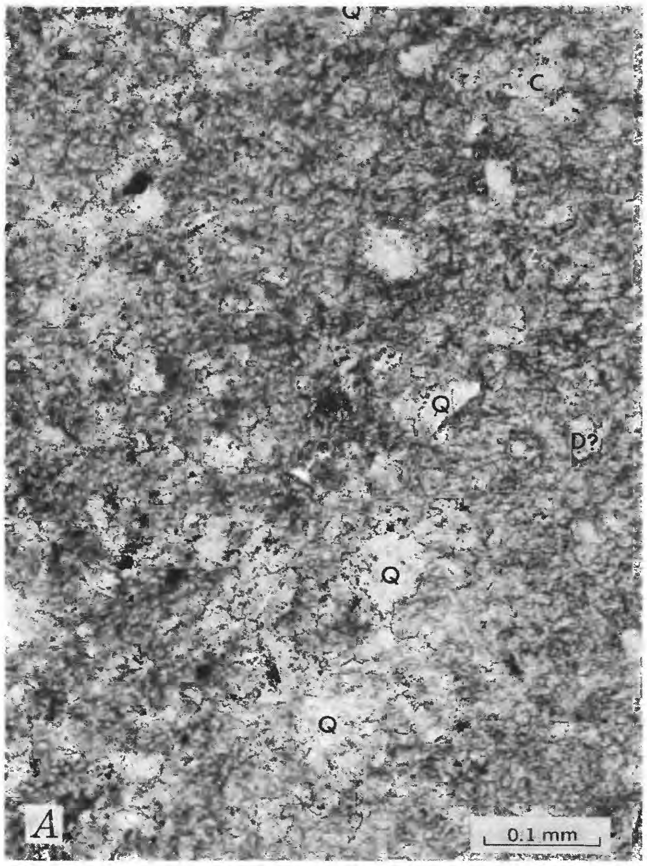
The laminated limestone consists of varying amounts of angular quartz and feldspar silt and very fine sand, silt-sized irregular grains to euhedral rhombs of dolomite and calcite, and clay minerals all set in an extremely fine grained calcite matrix. Fresh rock contains disseminated grains and tiny stringers of pyrite; specks, films, and coatings of carbonaceous material; and minute inclusions of carbonaceous material and pyrite in the calcite matrix. Weathered rock contains grains and stringers of iron oxide. In general, a slice the size of a thin section, cut across the laminations, is representative of the sample; but the sample is heterogeneous at a 1- to 2-mm scale (see figs. 10, 11). Graded bedding, though extremely scarce in rocks collected during this study, is present in the laminated limestone in the Roberts Mountains area, according to Winterer and Murphy (1960, p. 123–124).

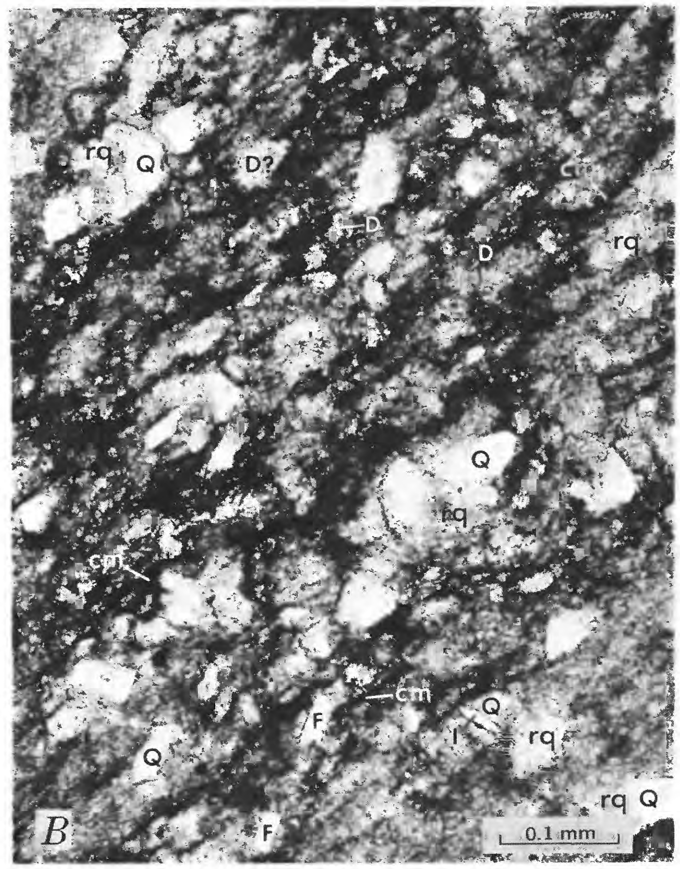
X-ray diffraction studies show that calcite and dolomite in the laminated limestone are nearly pure except in samples collected at Black Cliff Canyon in the southern Toquima Range. The calcite does not contain enough magnesium and the dolomite does not contain enough excess calcium to cause peak shifts in the $4°–60° \, 2\theta$ range. The amount of iron contained in the calcite and dolomite was not determined but is estimated from oxide analyses and X-ray diffraction studies to be less than 0.1 percent.

Information on chemical and mineralogical composition given in this report is a summary of integrated chemical, petrographic, and X-ray diffraction studies of individual samples collected. Amounts of the various minerals in individual samples collected are reported in detail elsewhere (Mullens, 1979). The amounts of two minor constituents, pyrite and iron oxide, are exceptions, based on point counts. Carbonaceous material, another minor constituent, was not determined although organic carbon, shown for most samples (Mullens, 1979), was determined by chemical methods. Chemical and X-ray diffraction studies are probably more accurate in determining the relative amounts of the major minerals than point counts on thin sections because of the fine-grained character and heterogeneous nature of the rock in the 2-mm range.

Many of the samples collected contain veins and veinlets of epigenetic calcite, and a few contain veinlets of epigenetic quartz. For the most part the vein calcite is not separated from deposited calcite in data shown by Mullens (1979). Secondary quartz shown in the data (Mullens, 1979) is mainly diagenetic chert or epigenetic replacement of minerals by quartz; epigenetic quartz veins are excluded from the data.

Photomicrographs illustrating the range of textures





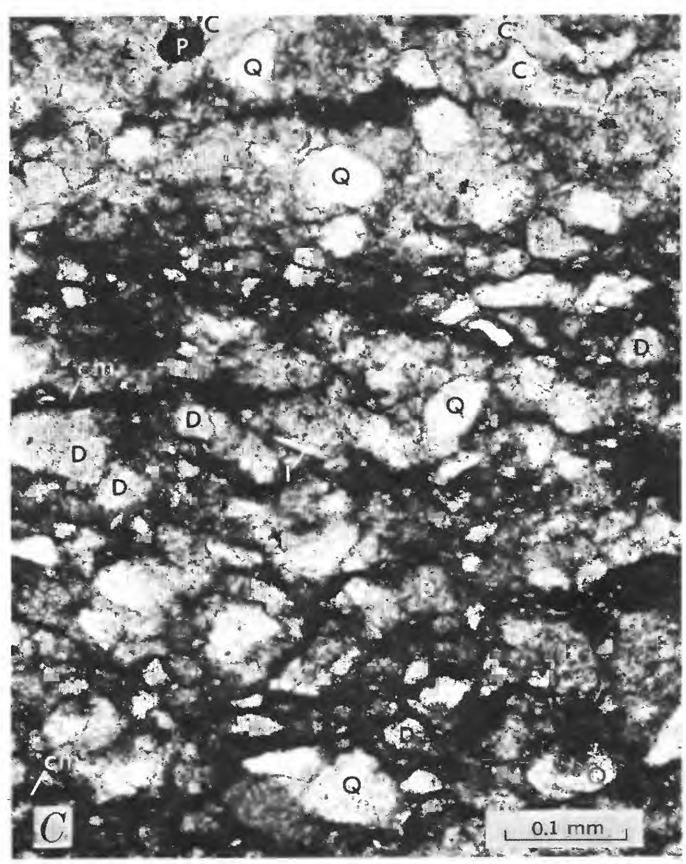
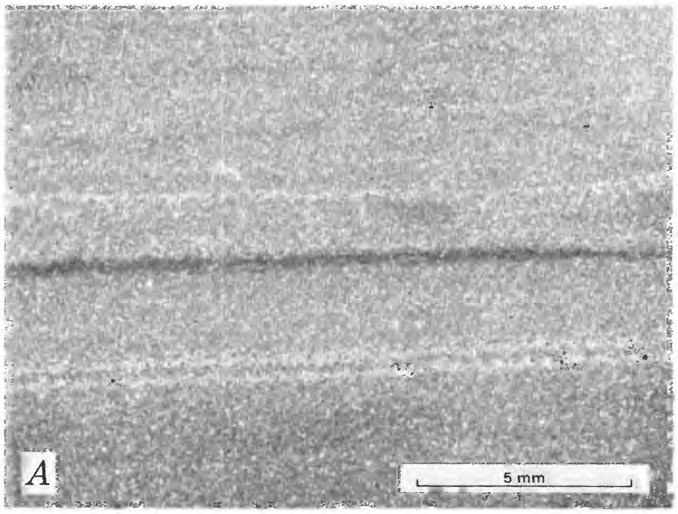


FIGURE 9.—Photomicrographs of laminated limestone from Rattlesnake Canyon. Larger grains are labelled: C, calcite; D, dolomite; Q, quartz; F, feldspar; I, illite; Z, zircon. P, large opaque grain is pyrite partly altered to red iron oxide; rq, areas where calcite has replaced quartz; cm, film of pure carbonaceous material. All plain light. *A*, Matrix is mainly calcite; opaque grains are red iron oxide (Mullens, 1979, sample 8055, loc. 2, table 1). *B*, Fine-grained light-gray matrix is calcite; dark areas are mainly carbonaceous calcite (Mullens, 1979, sample 8058, loc. 2, table 1). *C*, Dark matrix is carbonaceous calcite (Mullens, 1979, sample 8079, loc. 2, table 1).

and composition of unaltered laminated limestone are shown in figures 9 to 12. The composition given for the samples includes information from chemical and X-ray data as well as point counts, and the photomicrographs are not necessarily representative of the entire sample. Figure 9*A* is a photomicrograph of a high-calcite (87 percent), and low-dolomite (5 percent), quartz (7 percent), and clay-mineral (1 percent) sample from the lower part of the laminated limestone unit at Rattlesnake Canyon. Megascopically the rock seems unoxidized but microscopic study discloses specks of red iron oxide. Figure 9*B* shows fresh rock that approaches the "average" composition (see p. 10); this rock contains 50 percent calcite, 22 percent dolomite, 20 percent quartz, 2 percent potassium-feldspar, and 6 percent clay minerals. Figure 9*C* also shows a near-"average" rock; it contains 40 percent calcite, 23



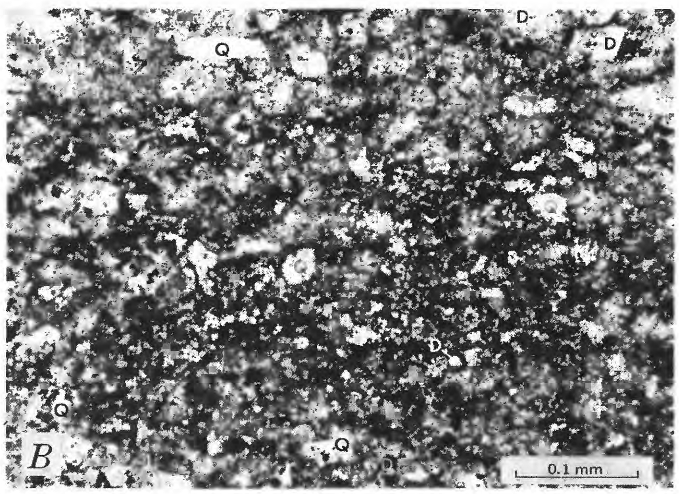
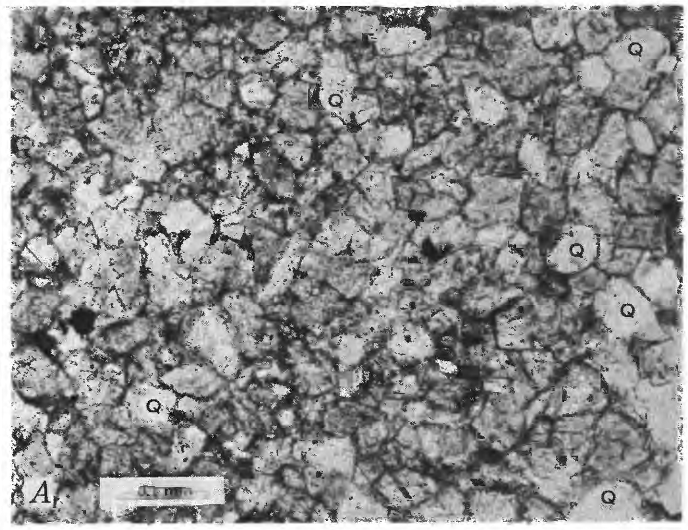


FIGURE 10.—Photomicrographs of laminated limestone from 1.5 km west of the Carlin mine. Plain light. *A*, Heterogeneity of rock at 1- to 2-mm scale. *B*, Many discrete particles of iron oxide in the 0.001- to 0.005-mm range. Matrix shown in *B* is mainly calcite and clay. Iron oxide grains not marked. Quartz (Q) and dolomite (D) form large grains (Mullens, 1979, sample 7003, loc. 28, table 1).



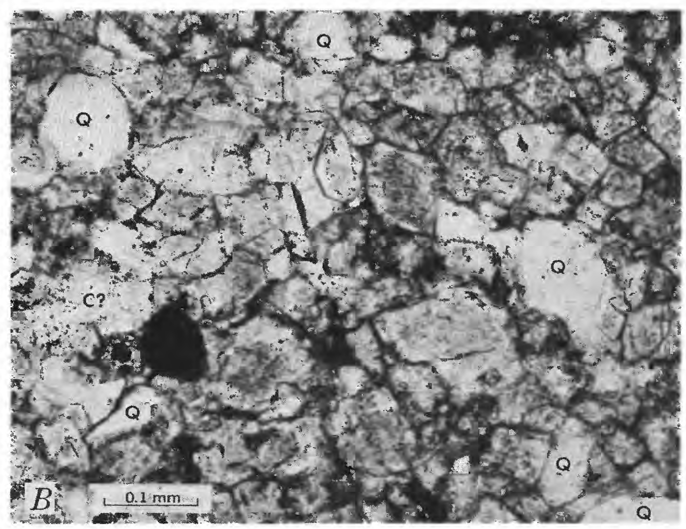


FIGURE 11.—Photomicrograph of laminated dolomite from Mill Canyon, Toquima Range. Laminations are in same thin section. Material between grains is mainly calcite, and opaque grains are red iron oxide. Note that dolomite approaches mosaic texture. D, dolomite; Q, quartz; C?, possible calcite. Plain light (Mullens 1979, sample 9066, loc. 31, table 1). *A*, Lamination composed mainly of grains less than 0.04 mm across. *B*, Lamination that contains grains more than 0.1 mm across.

percent dolomite, 26 percent quartz of which 2 percent is secondary, 2 percent potassium-feldspar, and 9 percent clay minerals. Figure 10 shows a weathered sample that contains 37 percent calcite, 27 percent dolomite, 18 percent quartz, 5 percent potassium-feldspar, and 12 percent clay minerals. Figure 11 shows parts of two different laminations in a sample with 9 percent calcite, 52 percent dolomite, 27 percent quartz, 4 percent potassium-feldspar, and 7 percent clay minerals. Figure 12 is a photomicrograph of a section of one of the thin coarse-grained limestone beds that are sparsely interbedded with the laminated limestone at Rattlesnake Canyon.

Calcite is the most abundant mineral in most of the laminated limestone, and most of this calcite forms the matrix in which other minerals are set. The matrix has all gradations from near opaque, in which no grains can be observed, to slightly cloudy and composed of grains 0.002 to 0.02 mm in size. Both end members can be found in most samples of laminated limestone, although the samples containing more than 70 percent calcite tend to be mainly mosaics of anhedral grains that are transparent or cloudy instead of nearly opaque. The near-opaque matrix can be determined as mainly a carbonate mineral under crossed nicols. Chemical and X-ray data indicate that the matrix is mainly calcite. The near-opaque calcite contains submicrometer specks of opaque material that is assumed to be mainly carbonaceous material and pyrite. The

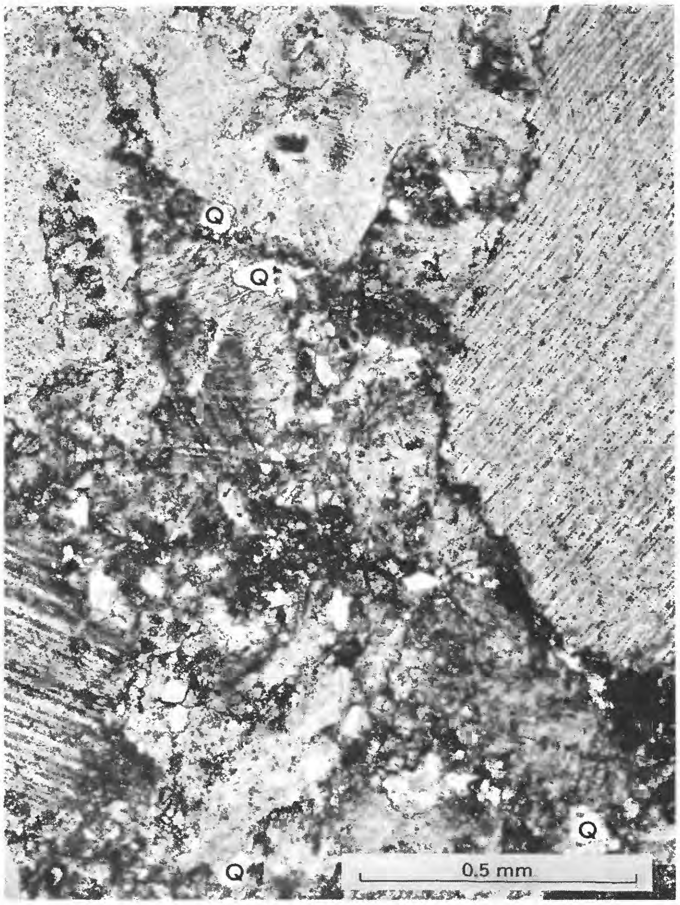


FIGURE 12.—Photomicrograph of coarse-grained limestone interbedded with laminated limestone at Rattlesnake Canyon section. Plain light. Rock is mainly calcite. Some quartz (Q) grains marked (Mullens, 1979, sample 8078, loc. 2, table 1).

cloudy matrix consists of tiny anhedral grains packed in a semimosaic pattern with submicrometer specks of opaque material along the grain boundaries. I interpret the semimosaic texture as slight recrystallizing of the calcite, although the texture may be due to original packing of tiny grains. Most laminated limestone samples also contain a minor amount of calcite in anhedral grains 0.03 to 0.15 mm in size. A few of the larger grains of calcite seem to be primary, others seem to be the result of "pinpoint" secondary crystallization, and some seem to be fragments of fossils. The larger grains are more abundant in areas where the laminated limestone grades into or is interbedded with coarse-grained limestone. In addition to the grains, calcite in quantitatively minor amounts but numerous occurrences replaces parts of quartz and feldspar grains. Generally this calcite is partly in continuity with matrix calcite; if the replacement is complete, the resulting grain of calcite cannot be identified definitely as replacement of a detrital grain. This partial replacement of quartz and feldspar by calcite is a fairly common phenomenon in laminated limestone, but in many of the sections examined, secondary quartz in tiny blebs and stringers has replaced calcite. Not uncommonly, both calcite replacement of detrital grains and quartz replacement of calcite are observed in the same section.

Dolomite is the second most abundant mineral in most samples of laminated limestone. Dolomite identified in thin sections occurred in irregular grains to euhedral rhombs that range in size from 0.02 to 0.12 mm, averaging about 0.045 mm. Generally, identifiable dolomite in thin sections amounts to 80–90 percent of the dolomite indicated by chemical and X-ray studies. Part of this discrepancy is interpreted as indicating that some of the grains of dolomite were so small that they could not be separated from the calcite matrix; the remainder includes larger carbonate grains that could not be positively identified as dolomite instead of calcite. Staining techniques to determine the relative amounts of calcite and dolomite are of little use because of the small grain size and the iron oxide or carbonaceous smear on cut sections. The dolomite grains are set in a calcite matrix; however, textures that I would interpret to indicate that the dolomite had replaced calcite are absent. In laminations composed mainly of dolomite, euhedral rhombs seem to replace irregular dolomite grains. None of the dolomite observed is "mixed grained"; a mixture might have indicated a true detrital origin from a preexisting dolomite. In general, irregular grains of dolomite are relatively more abundant as compared to euhedral rhombs in rocks that contain 2–20 percent dolomite, whereas subhedral to euhedral rhombs far outnumber irregular grains in rocks that contain more than 25 percent dolomite. Zoned crystals are common in rocks that contain more than 25 percent dolomite. The irregular shape of dolomite grains is interpreted as mainly the result of solution or imperfect crystallization of rhombs rather than the result of abrading.

In the range of $4°–60° 2\theta$, X-ray diffraction indicates that most dolomite in the laminated limestone is close to pure dolomite; peak distances are within 0.1° of pure dolomite in all but a few samples. The samples were not run past $60° 2\theta$, where Goldsmith and Graf (1958, fig. 1) showed that shift in peaks for impure carbonates was larger. In appearance and purity the dolomite is very similar to dolomite in Cretaceous marine sandstone which Sabins (1962) interpreted as primary dolomite. The texture of dolomite in the laminated limestone differs considerably from the mosaic texture of laterally equivalent laminated dolomite that contains little silt and is found at Lone Mountain, Mahogany Hills, and southern Monitor Range, and in the Hot Creek Range (fig. 13). Merriam (1973b, p. 12–17) assigned the laterally equivalent laminated dolomite to unit 1 of the Lone Mountain Dolomite. The rock shown on figure 13 is interpreted as secondary dolomite.

Detrital grains consisting mainly of quartz, but including minor amounts of potassium-feldspar and plagioclase feldspar, occur in all laminated limestone. The quartz and potassium-feldspar grains range in size from 0.02 to 0.15 mm, averaging about 0.055 mm. In most laminated rocks examined, the range is from 0.03 to 0.08 mm and the number of grains tends to be skewed only moderately below the 0.055-mm average, which indicates that the weight percent of detrital grains is highly skewed toward the larger grains. I interpret the skewness to indicate that many of the small grains were completely dissolved during deposition or completely replaced during diagenesis. Laminated limestone with detrital grains larger than 0.1 mm and with the wider range is mainly from the east and south

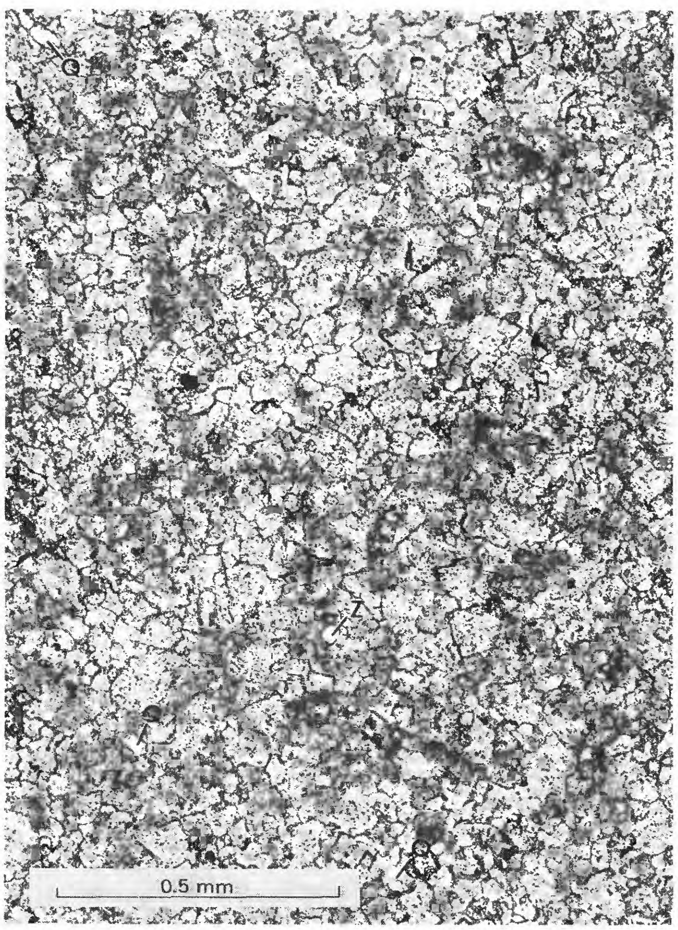


FIGURE 13.—Photomicrograph of secondary dolomite from Hot Creek Canyon, containing some detrital quartz (Q) and zircon (Z) grains. Plain light. Rock is typical of laminated dolomite in the less silty laminated dolomite at Lone Mountain (Eureka County), Mahogany Hills, Hot Creek Range, and southern Monitor Range. Note mosaic texture. Such laminated dolomite is the lateral equivalent of laminated limestone in the Roberts Mountains Formation (Mullens, 1979, sample 6901, loc. 17, table 1).

sides of the laminated limestone unit, where the unit grades into or is interbedded with coarse-grained carbonate rock. The detrital grains are mainly angular, although some of the grains that are larger than 0.08 mm are rounded or are fragments of rounded grains. In about half the samples, the quartz and potassium-feldspar grains are slightly corroded to deeply embayed and many of the grains are partly replaced by calcite. Generally, minute stringers and blebs of secondary quartz occur in samples where the quartz grains are embayed, a feature interpreted as indicating that the dissolved silica was not moved far before being redeposited. Few detrital quartz grains show undulatory extinction under crossed nicols, indicating that most quartz was derived mainly from preexisting sediments instead of from plutonic igneous rock or metamorphic rocks (Blatt and Christie, 1963, p. 574).

Plagioclase feldspar is relatively scarce in laminated limestone; its presence is more likely to be noted on X-ray diffraction traces than in thin sections. These diffractograms indicate that the plagioclase feldspar is albite. Plagioclase grains observed average about 0.03 mm and range from 0.01 to 0.08 mm. Most plagioclase feldspar grains are severely embayed. Their smaller average size, compared to the size of quartz and potassium-feldspar grains, is probably due to the relatively high solubility of plagioclase.

The quartz-feldspar (both potassium-feldspar and plagioclase) ratio ranges from about 3:1 to more than 100:1 in the samples studied. Wide ranges in this ratio are found in different samples collected at the same locality, but an average for all unaltered laminated limestones is about 7:1. Considering only quartz and feldspar, and ignoring clay minerals, the 7:1 ratio of quartz to feldspar indicates that the detrital material is subarkose in the classification of Pettijohn (1957, p. 291, table 48).

Clay minerals are present in most laminated limestone; all the clay recognized by optical methods was either illite or chlorite. Kaolinite and montmorillonite are present in some samples according to X-ray data, but they were never identified definitely in thin section. Montmorillonite is possibly more abundant than indicated (see Mullens, 1979), as the method of treating the samples would have lessened the chances of recognizing montmorillonite in the insoluble residue by X-ray diffraction. Some of the illite is interpreted as detrital; most, however, is probably related to diagenetic changes in detrital montmorillonite and to depth of burial (Müller, 1967, p. 155–156). A little illite occurs along epigenetic quartz seams and such illite is also epigenetic. The illite is commonly concentrated along laminations, although the long dimension of many flakes forms angles of 15°–90° with the laminations. The flakes are clear and colorless; they range in size from 0.01 × 0.03 mm to 0.03 × 0.15 mm, averaging about 0.02 × 0.08 mm. The flakes are not observed in "books" and most have 2*V*s in the 10°–20° range. For these reasons they are called illite instead of muscovite, although most flakes are larger than material generally considered as illite. When X-rayed, the flakes give diffraction patterns nearly identical to those of muscovite except that the peaks are not as sharp. Ketner (1969, p. B25) reported that illite separated from slightly metamorphosed Ordovician argillite in the Cordilleran geosyncline gave a diffraction pattern nearly identical to that of muscovite. Epigenetic amphibole, in widespread but trace amounts, in the laminated limestone indicates that the limestone is slightly metamorphosed, so the illite might have been changed slightly.

Chlorite occurs in about one-fourth of the samples studied. The chlorite flakes are pale green and have about the same size range as illite. Optically, they have small (0°–10°) 2*V*s. Some samples have flakes that are optically positive; others have flakes that are negative, but mixtures of positive and negative flakes are never found in the same sample. A detrital and diagenetic origin for most chlorite is assumed; Müller (1967, p. 142–146) indicated that much detrital montmorillonite entering seawater was changed to chlorite during diagenesis. Some chlorite, however, may be epigenetic and related to low-grade metamorphism.

X-ray diffraction indicates that kaolinite is most abundant in altered rocks at the Carlin mine, and is fairly abundant at Bootstrap mine and Maggie Creek Canyon where altered rocks are relatively common. Otherwise, kaolinite seems to occur mainly in samples that contain more than average iron oxide and in samples from the less calcitic upper part of the laminated limestone. The association of kaolinite with altered and weathered rocks probably indicates that much of the kaolinite is epigenetic.

The amount of organic carbon in many samples was determined in order to obtain information on the presence of carbonaceous material in laminated limestone. The mean organic carbon content of all laminated limestone samples analyzed is about 0.30 percent, but these samples include fresh as well as weathered and altered rocks. The average organic carbon content of samples that I consider mainly unoxidized and unaltered is about 0.35 percent and clustered in the 0.20- to 0.45-percent range. The range in organic carbon in seemingly unoxidized samples is from 0.18 to 1.34 percent. A general observation, not confirmed by extensive sampling, is that carbonaceous material is locally selectively concentrated in highly fractured zones and near intrusive rocks. Only three samples collected during this study contain more than 1.0 percent organic carbon. One of these (Mullens, 1979, sample 8001), from the base of the laminated limestone at Coal Canyon, a very clayey sample that contains abundant carbonaceous fragments of graptolites, has 1.34 percent organic carbon; another (Mullens, 1979, sample 7005), from a highly fractured zone where carbonaceous material is seemingly enriched epigenetically at the Carlin mine, contains 1.24 percent; the third (Mullens, 1979, sample 7105), from Grass Valley, is from an area where the laminated limestone is thermally metamorphosed. J. Fred Smith, Jr. (written commun., 1971) found 4.2 percent organic carbon in a sample of the Roberts Mountains Formation exposed in a fault slice in sec. 36, T. 29 N., R. 52 E., Elko County, Nev. Only eight of the samples collected contain between 0.50 and 1.0 percent organic carbon.

Using a factor of 1.22 (Gehman, 1962, p. 886) to convert the 0.35 percent organic carbon to carbonaceous material, the laminated limestone contains an average of about 0.42 percent carbonaceous material. This compares with 0.24 percent carbonaceous material in 346 limestone samples and 1.14 percent organic content for 1,066 shales analyzed by Gehman (1962, p. 885, fig. 1).

The type, or types, of carbonaceous material in the laminated limestone is not determined. In thin section, the carbonaceous material appears coaly and occurs in flakes, specks, and coatings that adhere to grains, as well as in tiny inclusions in the calcite matrix. The lack of permeability of fresh rock and the coaly nature of the carbonaceous material hinder recovery of carbonaceous material in cold organic solvents such as benzene, acetone, and sodium hydroxide on rock ground to minus-40 mesh. The fact that I never liberated enough carbonaceous material from this size material to discolor sodium hydroxide indicates that the carbonaceous material is not humate. Carbonaceous material in seven samples was separated by treating the rock with hydrochloric acid to remove carbonate minerals, hydrofluoric acid to remove silicate minerals, and then nitric acid to remove pyrite. After such treatment a fine black powder was obtained from each sample. When X-rayed, this powder gives a single broad curve approximately 10° 2θ wide that has a high point at 26.5° 2θ. The curve is so broad that the carbonaceous material is interpreted as nearly amorphous, although the high point of the curve corresponds closely with the major graphite peak.

Pyrite, in minor quantity, is ubiquitous in unoxidized laminated limestone. The amount of pyrite is highly variable, ranging from less than 0.1 to about 2.0 percent, averaging an estimated 0.5 percent. The pyrite includes both syngenetic and epigenetic varieties. Most recognizable pyrite is in disseminated anhedral to euhedral crystals, although in some samples irregular grains of pyrite are concentrated along laminations. Pyrite recognizable in thin section, using reflected light with a petrographic microscope, ranges from grains of about 0.005 mm to stringers about 3 mm in length. Pyrite locally lines minute vugs, occurs in minute irregular stringers as large as 0.15 × 3 mm that roughly parallel laminations, and occurs as subhedral to euhedral crystals associated with quartz veinlets. Some pyrite in grains of 0.005–0.01 mm forms spheres. Polished sections indicate that some unaltered rock contains pyrite in grains of less than 0.005 mm but that other unaltered rock does not contain such pyrite. In thin sections the very fine grained pyrite (less than 0.005 mm) cannot be identified separately from much of the fine-grained carbonaceous material.

The pyrite content of laminated limestone probably has a uniform distribution in the field of 0.2–1.0 percent and the content of individual samples does not cluster about an average. A guess on "average" content is made here because gold ore has epigenetic pyrite (Wells and Mullens, 1973; Radtke and others, 1972), and a background value of syngenetic pyrite is needed for comparison. I estimate the syngenetic pyrite content of laminated limestone to be about 0.25 percent and the epigenetic pyrite to be about 0.25 percent. A relatively high epigenetic pyrite content seems reasonable, as about half the places where rocks were collected locally contain silicified zones or intrusive igneous rocks and traces of epigenetic pyrite.

The pyrite cannot be determined consistently as syngenetic or epigenetic. Epigenetic pyrite can be identified if it occurs in fractures or associated with quartz veinlets. Otherwise, I know of no way of determining the origin of the pyrite. Pyrite along laminations cannot be considered as entirely syngenetic because rocks that contain epigenetic pyrite along fractures generally contain more epigenetic pyrite along laminations than other rocks.

Different methods of determining original pyrite in laminated limestone yield different results. Point counts of pyrite in seemingly unoxidized laminated limestone indicate a range of less than 0.1 to about 2.0 percent pyrite, averaging about 0.2 percent. Point counts of iron oxide in oxidized rock indicate an average of about 0.5 percent pyrite if all iron oxide is considered as being derived from pyrite. The laminated limestone generally contains no sulfur-bearing minerals besides pyrite and very minor and erratically distributed barite, although the carbonaceous material probably contains a little sulfur. Sulfur content of many samples that include unoxidized, oxidized, and altered rocks was determined (Mullens, 1979) with the thought that most of the sulfur would be in pyrite or would have been derived from pyrite. The average sulfur content of all the samples is less than 0.10 percent; and the average of relatively unoxidized and unaltered rock is about 0.15 percent. This would indicate about 0.3 percent pyrite in "average" unoxidized laminated limestone. This figure is about the same as pyrite content calculated from FeO content (Mullens, 1979). The 0.3 percent determined by sulfur and FeO content is slightly higher than pyrite content as determined by point count, but it is low by a factor of nearly 2 if most iron oxide observed was derived from pyrite. Thin- and polished-section study indicates that fresh pyrite is extremely scarce; most pyrite observed has iron oxide borders. Thus, the average content of pyrite based on sulfur and FeO content is probably low in comparison with pyrite originally in the rock.

Some of the very fine grained (less than 0.005 mm) pyrite forms black scum that accumulates at the top of dilute acid used to dissolve the laminated limestone. This pyrite cannot be distinguished optically from the fine-grained carbonaceous material that also accumulates in the black scum. Seven unoxidized laminated limestone samples were treated with hydrochloric and hydrofluoric acids. Visible pyrite was removed from the residue which consisted mainly of black powder. This powder was X-rayed and two of the seven X-ray diffractograms showed a strong pyrite pattern. The absence of pyrite in five residues does not indicate that those five rocks contain no ultra-fine-grained pyrite. Some fine-grained pyrite can be dissolved in extremely dilute acid or in distilled water contaminated only by air (H. W. Lakin, oral commun., 1970).

HEAVY MINERALS

Heavy minerals obtained by centrifuging the insoluble residue of 50 g of laminated limestone in bromoform (specific gravity about 2.89) include four types of minerals—detrital, syngenetic, diagenetic, and epigenetic. Weight of all heavy minerals obtained from 50 g of unaltered limestone ranged from 1.0 g (2 percent) to less than 0.005 g (0.01 percent), and the median was about 0.15 g (0.3 percent). In general, samples above the median simply contain more syngenetic, diagenetic, or epigenetic iron minerals; samples below the median also consist mainly of iron minerals as true detrital heavy minerals never exceeded 0.10 percent of unaltered rock.

The median of 0.3 percent heavy minerals obtained by mineral separating in bromoform is low when compared to the amount of iron minerals determined by point count in thin section. The discrepancy seemingly reflects the solubility of very fine grained pyrite and red, yellow, and brown iron oxide, inasmuch as some rocks rich in iron oxide produce little heavy mineral concentrate. The solubility of iron minerals is easily detected because the dilute HCl solution used to dissolve the rock turns green with iron chloride when heated to about 35 °C. Iron oxide also probably was not completely recovered because much of the iron oxide is extremely fine grained (see fig. 11), and some iron oxide that formed films on quartz was not recovered by centrifuging. Amounts of iron oxide and pyrite reported elsewhere (Mullens, 1979) are based on the study of thin sections instead of on iron minerals recovered in the heavy mineral concentrate.

Grain counts, based on area covered and converted to volume, indicate that pyrite and iron oxide derived from pyrite form 75–99+ percent of the total heavy mineral content in about 85 percent of the samples. The remaining 15 percent of the samples, where pyrite or iron oxide does not form the major part of the heavy minerals, are a diverse lot. In some samples a flood of epigenetic minerals reduced the iron minerals to less than 75 percent of the total. In some oxidized nearly pure carbonate rock only zircon and (or) tourmaline was recovered.

In addition to pyrite and iron oxide a few other syngenetic, diagenetic, and epigenetic minerals are common. Trace amounts of amphibole occur in about 50 percent of seemingly unaltered samples, and amphibole is a major component of altered rocks collected in Grass Valley (Mullens, 1979, loc. 32). Epigenetic diopside and garnet form the bulk of heavy minerals in samples collected at South Ravenswood window (Mullens, 1979, loc. 8). Epigenetic(?) barite is relatively common in trace amounts, and in a few samples it forms the bulk of the concentrate. Phosphatic material, sparsely distributed in laminated limestone, apparently always dissolved in the dilute hydrochloric acid used to dissolve samples. A lenticular coarse-grained limestone near the base of the laminated limestone at Copenhagen Canyon (Mullens, 1979, sample 8151, loc. 14) contains about 15 percent collophane, but none of the collophane was recovered in the insoluble residue. Opaque minerals, probably magnetite and ilmenite, as inclusions in tiny veins of quartz are found in about 5 percent of the samples. Epigenetic white mica, chlorite, epidote, fluorite, and sphalerite, and leucoxene in samples that contain opaque minerals in quartz veins, are found in a few samples. Periclase is found in a sample of laminated dolomite that is a lateral equivalent of the laminated limestone in the Hot Creek Range.

The relative abundance of all minerals in the heavy mineral concentrates and the absolute amount of iron minerals are greatly influenced by the degree of oxidation; first, because pyrite is present in unoxidized rocks and iron oxide is present in oxidized rocks; and second, because much of the iron oxide is soluble in dilute hydrochloric acid. For example, a concentrate of an unoxidized rock might contain 1 percent recoverable heavy minerals consisting of 90 percent pyrite, 5 percent zircon, and 5 percent tourmaline. An oxidized sample of the same rock might contain 0.5 percent recoverable heavy minerals consisting of 80 percent iron oxide and 10 percent each of zircon and tourmaline.

Detrital heavy minerals form 0.08–0.13 percent of the total detrital material in most laminated limestone but the percentage is generally higher in samples composed mainly of calcite. Zircon and tourmaline form about 99 percent of the detrital heavy minerals, but a few grains of detrital rutile and monazite are found in concentrates where the quartz and feldspar content exceeds 15 percent. Noteworthy is the fact that no detrital ilmenite, magnetite, or garnet is found. The dominance of zircon and tourmaline is expected for rocks as old as Silurian and Devonian (Pettijohn, 1957, p. 676, fig. 114) but the absence of garnet, magnetite, and ilmenite is probably due more to the pH and Eh of the environment of deposition than to removal by later intrastratal solution.

Zircon is slightly more abundant than tourmaline. When individual samples are compared, the zircon-tourmaline ratios have a range of two orders of magnitude—from 10:1 (10) to 1:10 (0.1) (Mullens, 1979). At most places, the ratio is between 2:1 and 1:2; it averages nearly 1:1 at Maggie Creek Canyon, Bootstrap mine, Carlin mine, and Mill Canyon. The ratio is higher, about 5:1, in rocks in the lower part of the laminated limestone at Rattlesnake Canyon, and about 10:1 for a couple of unaltered samples at South Ravenswood window and for rocks near, but not at, the Carlin mine. I am unable to relate the high ratios to other features of the laminated limestone.

Considering all samples, 85 percent of the zircon is colorless or pale yellow, about 10 percent is deep yellow, and 5 percent is pale to deep purple. A few medium-brown euhedral crystals and broken fragments of euhedral crystals that seem to be metamict zircon are observed. These grains are opaque in transmitted light, and any angular or rounded fragments of such material are probably counted as iron oxide. The zircon occurs in grains that range from 0.02 to 0.12 mm across, averaging about 0.045 mm. By number, about 5 percent of the zircon grains are well rounded and spherical and about 40 percent are euhedral crystals; the remainder range from subrounded to near-euhedral crystals that have slightly rounded edges. The relatively low proportion of rounded grains is probably a function of size inasmuch as grains above

0.06 mm tend to be rounded and euhedral crystals larger than 0.08 mm are scarce. Except for the brown opaque zircon, all concentrates contain zircon as described above, but relative proportions vary greatly. In a few of the high-calcite samples, zircon occurs mainly as medium silt-sized euhedral to slightly rounded euhedral crystals. Samples containing abundant detrital quartz and feldspar generally contain slightly larger and more rounded grains. The abundance of euhedral crystals <0.05 mm across would be favorable for solution of zircon in the postulated pH and Eh of the environment of deposition.

Study of the insoluble residue indicates that the average zircon content is about 0.06 percent, whereas counts on the thin sections indicate zircon forms less than 0.04 percent of the noncarbonate minerals. Zircon grains probably were selectively removed in preparing the thin sections, so estimates from the heavy mineral concentrates are assumed to be more accurate than zircon counts in thin sections. A method of approximating the amount of zircon by using spectrographic analyses of Zr (zirconium) gives results that are higher than my estimate of the amount of zircon in the laminated limestone. The "average" laminated limestone contains 22 percent quartz and feldspar silt and 100 ppm Zr to the nearest spectrographic step. If all Zr is placed in zircon, then the "average" rock contains about 0.02 percent zircon. For a rock composed entirely of detrital quartz, feldspar, clay, and zircon, the zircon content is calculated to be about 0.1 percent, considerably higher than my estimate of 0.06 percent for the insoluble residue. Ketner (1966, p. C56) also reported that spectrographic analyses indicated a higher zircon content in Ordovician quartzite from the Cordilleran geosyncline than he found in heavy mineral concentrates or thin sections of the quartzite. If excess Zr really exists, it may be in some form of hydrozircon, a Zr carbonate complex, or Zr hydroxide not recognized in the heavy mineral concentrate or thin section. Coleman and Erd (1961, p. C297–C300) reported hydrozircon in Wyoming, and Blumenthal (1958, p. 37–39, 210–213) indicated that zircon was soluble and formed a stable Zr carbonate complex in slightly alkaline solutions. Such alkaline solutions are postulated for deposition of calcite and dolomite which form the major part of laminated limestone.

Tourmaline tends to occur in slightly larger grains than zircon and the proportion of rounded and subrounded grains to euhedral or splintery fragments of euhedral crystals is about 1:1, regardless of size. About 60 percent of the tourmaline is brown to brownish black, about 35 percent is green, about 5 percent is pink and yellow, and a trace is blue. Clear, colorless authigenic extensions of the long axis of broken euhedral tourmaline crystals and authigenic tourmaline overgrowths on angular fragments of tourmaline are fairly common in samples from Rattlesnake Canyon and from a locality 1.5 km south of Bootstrap mine. Scattered samples from other localities also contain clear authigenic tourmaline on detrital tourmaline grains. The authigenic tourmaline is similar to that shown by Krynine (1946, fig. 3e). Only a few rounded tourmaline grains that have authigenic overgrowths are observed in concentrates from the Roberts Mountains Formation, whereas Krynine (1946) commonly found overgrowths on rounded grains in Paleozoic rocks in the Appalachian region.

Euhedral crystals as well as rounded grains of tourmaline are relatively common in the 0.06 to 0.12 mm range, implying a primary igneous or metamorphic source for some of the tourmaline and a reworked sedimentary source for some. Euhedral crystals of zircon are not common in this range, but many of the smaller euhedral crystals of zircon could have been derived from the same source that supplied the larger tourmaline crystals.

The 0.08- to 0.13-percent heavy mineral content of the total detrital material in the laminated limestone is a seemingly low figure when compared to some sandstones. Cadigan (1967, table 13) reported that 266 samples of the Salt Wash Member of the Jurassic Morrison Formation, collected throughout the Colorado Plateau, averaged 0.23 percent heavy minerals. Cadigan (1971, p. 34) further reported an average of 0.26 percent for sandstone in the Moenkopi Formation. The figures given for the Morrison and Moenkopi sandstones reflect a high percentage of iron oxide minerals and authigenic minerals not considered in this study. The approximate ratio of opaque to nonopaque to authigenic heavy minerals in sandstone in the Moenkopi Formation is 15:3:1 (Cadigan, 1971, p. 34). This ratio indicates an approximate content of 0.04 percent nonopaque heavy minerals in the Moenkopi sandstone. When considered in this manner, the nonopaque heavy mineral content of the laminated limestone is relatively high. And it is much higher than the <0.01 percent heavy mineral content that Ketner (1966, table 2) reported for Ordovician quartzites in the Cordilleran geosyncline. I suspect that the relatively high zircon and tourmaline contents are caused by zircon and tourmaline being more resistant to solution than quartz and feldspar in the environment where the laminated limestone was deposited.

INTERBEDDED LAMINATED LIMESTONE AND COARSE-GRAINED LIMESTONE UNIT

DEFINITION AND DISTRIBUTION

The type section of the Roberts Mountains Formation at Pete Hanson Creek contains a zone of interbedded laminated limestone and coarse-grained carbonate extending from about 125 m to about 295 m above the base (M. A. Murphy, written commun., 1970). This zone is overlain by about 275 m of mainly coarse-grained carbonate rock also assigned to the Roberts Mountains Formation. Somewhat similar rocks of the same or slightly younger age also occur in the Simpson Park, Cortez, and Tuscarora Mountains, and in the Monitor, Toiyabe, and Shoshone Ranges. Away from the Roberts Mountains area these rocks have not been treated consistently by geologists. Merriam (1963, p. 42–44) applied the name Rabbit Hill Limestone to thin-bedded limestone of Early Devonian age in the Monitor Range. Johnson (1965) established his Windmill Limestone, interbedded laminated limestone, and coarse-grained limestone in the Simpson Park Mountains, as Devonian age. Gilluly and Masursky (1965, p. 29–38) assigned the rocks in the Cortez area to the Devonian Wenban Limestone. Kay and Crawford (1964, p. 440) assigned Lower Devonian coarse-grained limestone and sparse beds of laminated limestone to the McMonnigal Limestone; these strata are underlain by laminated limestone which they assign to the Masket Shale in part of the Toquima Range. The Masket Shale is considered part of the Roberts Mountains Formation in this report. McKee, Merriam, and Berry (1972) found that the massive coarse-grained Tor Limestone also overlies laminated limestone of the Roberts Mountains Formation in the Toquima Range.

In this report, strata assigned to the Roberts Mountains Formation are restricted to rocks included in the zone extending from the base of the cherty unit to the base of the first coarse-grained limestone that is mappable for about 2 km. In several places the upper boundary is transitional and is placed where coarse-grained limestone dominates in an interbedded laminated limestone and coarse-grained limestone unit. Merriam and McKee (1977) assign overlying dominantly coarse-grained limestone to the Roberts Mountains Formation in a few places.

Places where I assign interbedded laminated limestone and coarse-grained limestone to the Roberts Mountains Formation include Miniature Grand Canyon, Petes Canyon, Goat Peak window, and Bootstrap mine. At Miniature Grand Canyon the section is faulted but about 80 m of interbedded laminated limestone and coarse-grained limestone is assigned to the Roberts Mountains Formation. Laminated limestone dominates in this zone, which is overlain by coarse-grained limestone that contains sparse beds of laminated limestone. The upper laminated limestone in rocks assigned to the Roberts Mountains Formation contains monograptids of probable Ludlovian age, and the overlying coarse-grained limestone contains conodonts of Early(?) Devonian age. In the Petes Canyon area, about 30 m of interbedded coarse-grained limestone and laminated limestone occurs just beneath a thrust fault. According to Stewart and McKee (1977) the underlying laminated limestone contains monograptids of Silurian age in the upper couple of meters, and the basal coarse-grained limestone contains corals of Early Devonian age. Stewart and McKee (1977) placed the top of the Roberts Mountains at the base of the lowest coarse-grained limestone. At Goat Peak window, a zone 60–120 m thick of coarse-grained limestone interbedded with laminated limestone exposed just beneath a thrust fault is assigned to the Roberts Mountains. Conodonts indicate a probable Late Silurian age for the coarse-grained limestone.

About 460 m of Silurian and Devonian rocks is exposed beneath a thrust fault at Bootstrap mine. The basal 180 m, which is assigned to the Roberts Mountains, consists of mainly laminated limestone but includes abundant coarse-grained limestone in lenticular beds 0.3–10 m thick (fig. 14). The upper 26 m of the Roberts Mountains Formation is laminated limestone. *Monograptus uniformis*(?) occurs about 6 m below the top of the 26-m laminated limestone that caps the Roberts Mountains. The upper 280 m of rock exposed beneath the thrust is excluded from the Roberts Mountains Formation although Merriam and McKee (1976) include the rock in the Roberts Mountains. The rocks consist mainly of coarse-grained limestone, but include sparse laminated limestone in beds 0.1–2 m thick.

COMPOSITION AND PETROGRAPHY

Laminated limestone interbedded with coarse-grained limestone was collected from Miniature Grand Canyon, Bootstrap mine, and Birch Creek in the Roberts Mountains. These samples do not differ materially from those of the laminated limestone unit

FIGURE 14.—Interbedded laminated limestone and coarse-grained limestone unit in the upper part of the Roberts Mountains Formation, Bootstrap mine, Elko County, Nev.

described on pages 8–10, except that some contain quartz grains of up to 0.15 mm. Figure 15*A*, shows a thin section of laminated limestone interbedded with coarse-grained limestone at Bootstrap mine. Note that the dolomite grains have the same habit as dolomite in the laminated limestone unit (figs. 11–13). Winterer and Murphy (1960, p. 123–124) reported that the calcite content of laminated limestone increased at the expense of silt and clay as the laminated units graded into coarse-grained units in the Roberts Mountains area. The single sample from Birch Creek (Mullens, 1979, sample 8152, loc. 15, table 1) supports their observation.

The coarse-grained limestone occurs in beds as much as 12 m thick, but averaging only about 3 m. The beds are relatively lenticular; none found could be traced more than 1 km along strike although faults instead of pinchouts terminated many beds that I examined. The coarse-grained limestone consists of fragments of clear calcite, sparse silt to fine sand-sized grains of quartz and feldspar, sparse silt-sized rhombs of dolomite, sparse crystals of pyrite or iron oxide pseudomorphs after pyrite, and pellets of very fine grained dirty calcite. Such rock is illustrated in figure 15*B*. Pellets form more than 50 percent of the coarse-grained limestone at Bootstrap mine but are less common at Miniature Grand Canyon, Goat Peak window, and Petes Canyon. The pellets range in diameter from about 0.1 to 1.5 mm, averaging about 0.3 mm; they are rounded to angular, and some are locally deformed by compaction to irregular shapes. A few of the pellets show concentric lines and are true oolites, but most pellets do not have the concentric bands. The pellets commonly contain secondary quartz in irregular blebs 0.02–0.10 mm long or in thin (0.02 mm) stringers of secondary quartz along the concentric rings. Secondary quartz in irregular blebs and stringers to 0.2 mm commonly form along fractures in both the clear calcite and the pellets. Euhedral crystals of authigenic quartz as much as 0.1 mm across are sparsely

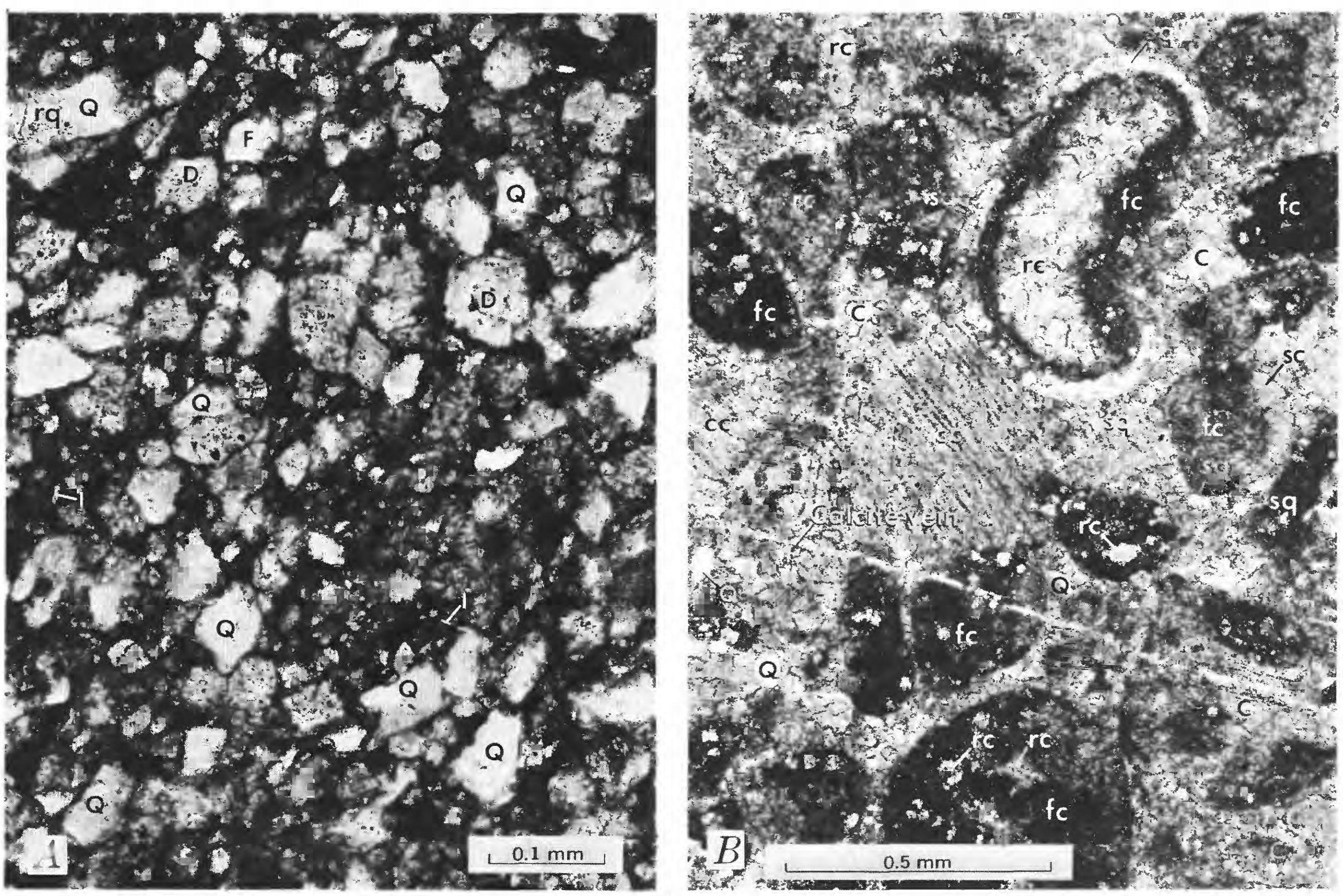


FIGURE 15.—Photomicrographs of laminated limestone interbedded with coarse-grained limestone at Bootstrap mine. D, dolomite; Q, detrital quartz; sq, secondary quartz; cc, coarse-grained calcite; fc, fine-grained calcite; rc, recrystallized calcite; F, potassium-feldspar; I, illite; rq, places where calcite has replaced quartz. Plain light. *A*, Matrix is mainly calcite (Mullens, 1979, sample 8129, loc. 6, table 1). *B*, Coarse-grained limestone is pelletal; most pinpoint-sized light spots in pellets are secondary quartz (Mullens, 1979, sample 8126, loc. 6, table 1).

distributed in the coarse-grained limestone. The detrital quartz and feldspar grains are angular to rounded, some are deeply embayed, and some are partly replaced by calcite. The coarse-grained limestone generally contains several times as much authigenic quartz as laminated limestone.

At Bootstrap mine much of the pelletal coarse-grained limestone assigned to the Roberts Mountains Formation contains angular fragments of coarse-grained pelletal limestone and nonoriented corals and stromatoporoids, and has scour surfaces at the base of the beds. The fossils and fragments in these beds show graded bedding. These features are interpreted as indicating that some of the coarse-grained material was emplaced as debris flows or as a debris apron from a reef. Winterer and Murphy (1960, p. 126–127) believed that many breccia beds in the Roberts Mountains Formation in the type area originated in a similar manner. Mountjoy and Playford (1972) indicated that many of the thinner coarse-grained limestone beds interbedded with shale in the Devonian reef complex in Canada were debris flows. The isolated beds at Bootstrap mine, however, cannot be traced into a reef complex as can the breccia beds in the Roberts Mountains area and in Canada. Coarse-grained limestone at Miniature Grand Canyon, Petes Canyon, and Goat Peak has little breccia.

The coarse-grained limestone interbedded with laminated limestone and assigned to the Roberts Mountains Formation is very similar to coarse-grained limestone in overlying Lower Devonian formations.

AGE OF THE ROBERTS MOUNTAINS FORMATION

Most of the information about the age of the Roberts Mountains given in this report is based on graptolites identified by W. B. N. Berry, supplemented by conodonts identified by J. W. Huddle. Information given here fits well with the age of the Roberts Mountains Formation at the type section as reported by Murphy (1969), Berry (1969), and Klapper (1969). Graptolites indicate that the Roberts Mountains Formation contains Silurian beds of Llandoverian, Wenlockian, Ludlovian, and Pridolian ages and Early Devonian beds of Gedinnian and Siegenian ages. Merriam (1973a, b) and Merriam and McKee (1976) include most of the rocks assigned here to the Early Devonian Epoch in the Silurian Period. The stages of the European Silurian are used instead of stages of the American Silurian or Lower, Middle, and Upper Series in accord with the suggestion of Berry and Boucot (1970, p. 14–15). The stages of the Silurian and early part of the Devonian as well as the graptolite zones of Great Britain and central Europe are shown in table 1.

TABLE 1.—*Silurian and Lower Devonian graptolite zones in Great Britain and central Europe*

[British zones from Elles and Wood (1901–18) and central European zones modified from Berry (1969; and 1970, table 2).]

SYSTEM	EUROPEAN STAGE OR SERIES		GRAPTOLITE ZONE		
DEVONIAN (part)	SIEGENIAN STAGE (part)			*Monograptus hercynicus*	CENTRAL EUROPE
	?				
	GEDINNIAN STAGE			*Monograptus praehercynicus*	
				Monograptus uniformis	
SILURIAN	PRIDOLI SERIES			*Monograptus transgrediens*	
				Monograptus dubius	
	LUDLOW SERIES		36	*Monograptus leintwardinensis*	GREAT BRITAIN
			35	*Monograptus tumescens*	
			34	*Monograptus scanicus*	
			33	*Monograptus nilssoni*	
			32	*Monograptus vulgaris*	
	WENLOCK SERIES		31	*Cyrtograptus lundgreni*	
			30	*Cyrtograptus ellesi* (= *C. rigidus* E & W)	
			29	*Cyrtograptus linnarssoni*	
			28	*Cyrtograptus rigidus* (= *C. symmetricus* E & W)	
			27	*Monograptus riccartonensis*	
			26	*Cyrtogreptus murchisoni*	
	LLANDOVERY SERIES	UPPER	25	*Monograptus crenulatus*	
			24	*Monograptus griestoniensis*	
			23	*Monograptus crispus*	
			22	*Monograptus turriculatus*	
			21	*Monograptus sedgwicki*	
		MIDDLE	20	*Monograptus convolutus*	
		LOWER	19	*Monograptus gregarius*	
			18	*Monograptus cyphus*	
			17	*Orthograptus vesiculosus*	
			16	*Akidograptus acuminatus*	
ORDOVICIAN (part)	ASHGILL SERIES				

The sequence of graptolites in the Llandoverian, Wenlockian, and Ludlovian parts of the formation fits the standard Silurian graptolite zones of Great Britain fairly well (Elles and Wood, 1901–18), and the graptolites in the upper part of the formation fit graptolite zones established for uppermost Silurian and lowermost Devonian rocks of central Europe (Berry, 1970, p. 513–520). Merriam (1973), and Merriam and McKee (1976) established zones based on rugose coral for the coarse-grained carbonate rock of Silurian and Devonian age. Johnson and Boucot (1969) and Johnson, Boucot, and Murphy (1973) established brachiopod zones for Silurian to Middle Devonian rocks in central Nevada. The laminated rocks that contain graptolites, correlated to central Europe, seem to grade into coarse-grained limestone which contains Merriam's Upper Silurian coral zone. Some of the information on graptolites collected in this study was included by Berry and Boucot (1970, p. 206–208).

Localities where fossils were collected are shown on plate 1; all fossils collected during this study and some fossils collected by other people are listed in the appendix to this report. Stratigraphic position and identification numbers for some of the fossils collected are indicated on the columnar sections shown on plate 2. The lists in the appendix are arranged in a geographic scheme based mainly on a west-to-east order of mountain ranges, and fossil localities within ranges are listed from south to north. Specific location and stratigraphic position, where known, are also included with the lists of fossils. Fossils are the chief means of correlating the isolated exposures in north-central Nevada and complete lists of fossils are needed so that the correlations can be evaluated. All fossil data are presented in a composite listing for the convenience of readers interested specifically in evaluating the correlations.

Graptolites are erratically distributed in the Roberts Mountains Formation; they are abundant in some areas and nearly absent in other areas. The manner of preservation is also erratic; some graptolites are well preserved as carbonaceous films, whereas others are only abraded impressions in the rock. Conodonts are found in some of the coarse-grained beds, but are nearly absent in the laminated limestone. Corals, brachiopods, algae, and ostracods locally are abundant in coarse-grained carbonate rock, but they were not collected extensively.

The only observed laminated limestone that contains relatively abundant brachiopods, all of a similar type, is in the upper part of the Roberts Mountains Formation, exposed in both the main and northeast pits at the Carlin mine. Boucot and Johnson (1972) identified the brachiopods in this bed as *Callicalyptella empelia*, n. gen., n. sp. This brachiopod is associated with *Monograptus microdon* and monograptids of the *M. hercynicus* group, which indicate an Early Devonian age for the bed. Except in the bed of Carlin mine, brachiopods are scarce in laminated limestone.

Poorly preserved corals were found in a laminated limestone in the upper half of the Roberts Mountains exposed along a bulldozer cut about 460 m south of the North Star mine in northern Eureka County. This limestone is slightly coarser grained and contains less silt and dolomite than most laminated limestone in the upper part of the formation.

Graptolites are used as time indicators in this section of the report although Berry and Boucot (1971) indicate that some of these graptolites may be related to water depth. In nearly all places where "a decrease in age" or "younger" are used, the phrases can also be interpreted as "a decrease in depth of water."

The basal cherty unit contains graptolites indicative of zones ranging from 16 to 24 (early, middle, and late Llandoverian) at Pablo Canyon in the Toiyabe Range, and Black Cliff, Wood, and Petes Canyons in the Toquima Range (USGS Coll. D304 SD, D305 SD, D306 SD, D313 SD, D314 SD, D329 SD, D320 SD, D327 SD, and D328 SD). Graptolites of these ages were first reported by Kay and Crawford (1964, p. 438) and were re-collected during this study. In addition conodonts from Wall Canyon in the Toiyabe Range (USGS Coll. 8822 SD) indicate a Llandoverian Age for the cherty unit in that area. Graptolites from the uppermost limestone of the cherty unit exposed at Copenhagen Canyon in the Monitor Range include *Glytograptus* sp. and *Dimorphograptus confertus* (USGS Coll. D256 SD), which, according to Berry, are indicative of zone 18 of Great Britain; but as this is the only known occurrence of these graptolites in the Great Basin, the zone 18 assignment is not firm in north-central Nevada.

No graptolites or other fossils were found in the basal cherty unit except in the aforementioned localities. Other information on the age of the cherty unit is based on fossils collected just below and just above the unit.

In Eureka County the Hanson Creek Formation contains a quartz sand-bearing zone in the upper part (Mullens and Poole, 1972). Conodonts from samples collected at Copenhagen Canyon in the Monitor Range (USGS Coll. 8488 and 8989 SD) and near the Carlin mine in the Tuscarora Mountains (USGS Coll. 8823 SD), identified by John Huddle, indicate that the part of the Hanson Creek above the quartz sand-bearing zone is early, but not earliest, Llandoverian in age. Thus, the cherty unit in Eureka County is probably not as old as the cherty unit in the Toquima and Toiyabe Ranges. Farther northeast, at Antelope Peak near Wells, Nev., the cherty unit overlies a couple of meters of sandstone that probably represents a greater accumulation of sand in the Hanson Creek; the cherty unit in that area probably is also younger than earliest Silurian. In the Knoll Mountain area northeast of Wells, a cherty unit near the base of the Noh Formation of Riva (1970) contains *Monograptus spiralis* according to Riva (1970, p. 2713). *M. spiralis* is indicative of zone 25 or uppermost Llandoverian, according to W. B. N. Berry (written commun., 1969). The cherty unit of the Noh Formation probably correlates with the basal cherty unit of the Roberts Mountains Formation.

The information given above indicates a decrease in age of the cherty unit from the southwest to northeast exposures. Such a decrease was first postulated by Berry and Roen (1963).

The cherty unit is overlain by the laminated limestone unit which generally contains *M. spiralis* in the basal meter. The only area where *M. spiralis* is known to occur more than a few meters above the cherty zone is at Pablo Canyon, Toiyabe Range, where F. G. Poole found *M. spiralis* about 25 m above the top of the basal cherty unit (USGS Coll. D323 SD). The only extensive area of outcrop where graptolites are fairly common and where *M. spiralis* or other graptolites indicative of zone 25 were not found just above the chert is the Independence Mountains. *M. spiralis* or other late Llandoverian fossils were not found at Antelope Peak nor in the Sulphur Spring Range, although at these places graptolites are scarce and poorly preserved in beds just above the chert. The absence of *M. spiralis* in the Independence Mountains and the probable absence at Antelope Peak and the Sulphur Spring Range, coupled with the occurrence of *M. spiralis* well above the base of the laminated limestone unit at Pablo Canyon, are interpreted as indicating that the base of the laminated limestone becomes younger northeastward. This inference is strengthened by the occurrence of possible late Wenlockian graptolites collected 9 m above the base of the Roberts Mountains Formation in the Sulphur Spring Range (USGS Coll. D326 SD).

Early Wenlockian graptolites generally occur within a few centimeters above *M. spiralis*, indicating no significant break between Llandoverian and Wenlockian beds. *Monograptus testis*, used to indicate uppermost Wenlockian, is scarce in the Roberts Mountains Formation. It was found about 38 m above the basal cherty unit at Coal Canyon in the Simpson Park Mountains (M. A. Murphy, oral commun., 1968), 65 m above basal cherty unit 3.3 km southwest of the Carlin mine in the Tuscarora Mountains (USGS Coll. D253 SD), and in float just above the basal cherty unit at Thomas Jose Canyon in the Independence Mountains (USGS Coll. D235 SD). Little, then, can be inferred about Wenlockian beds except for the possibility that the top of the Wenlockian approaches the basal chert in the Independence Mountains. This relation strengthens the inference that the base of the laminated limestone unit becomes younger northeastward.

Graptolites and other fossils indicate that most of the laminated limestone is of Ludlovian, Pridolian, Gedinnian, and Siegenian ages. The Ludlovian and younger graptolites occur in beds that, for the most part, grade eastward into and are overlain by coarse-grained limestone and dolomite in the area of study. This relation is interpreted as indicating westward regression of the sea and of deposition of laminated limestone during Late Silurian and Early Devonian time. Johnson (1971, p. 3265) noted that during late Early Devonian the extent of marine waters on the continent was at a minimum. The Llandoverian and Wenlockian beds seem to represent an eastward transgression during deposition of the basal cherty unit and of the lower part of the laminated limestone unit during Early Silurian time. If these interpretations are correct, then the general eastward migration of the Cordilleran geosyncline as postulated by Roberts (1968, fig. 6) was reversed in Late Silurian and Early Devonian time.

Zone markers in the Ludlovian and younger beds assigned to the Roberts Mountains Formation are fairly abundant, but few were found in complete sections where the distance above the base of the Roberts Mountains can be established. *Monograptus uniformis*, used here to mark the Silurian–Devonian boundary, occurs about 300 m above the base of the formation at Coal Canyon (W. B. N. Berry, oral commun., 1970) and 150 m below the first mappable coarse-grained limestone. *M. uniformis*(?) is about 300 m above the base, just north of Rattlesnake Canyon in the Cortez Mountains (USGS Coll. D293 SD), and is 30 m below a coarse-grained limestone assigned to the Wenban Limestone. At Bootstrap mine in the Tuscarora Mountains, *M. uniformis*(?) occurs in the interbedded laminated limestone and coarse-grained carbonate unit and about 175 m above the base of the exposed Roberts Mountains Formation (USGS Coll. D252 SD). It is about 6 m below a change to dominant coarse-grained limestone. *M. uniformis* has also been found at Willow Creek and Birch Creek (Berry and others, 1971, p. 1969–1971) in the interbedded limestone and coarse-grained carbonate unit on the north flank of the Roberts Mountains. None of the *M. uniformis* has been found at a contact that could be used to map lithologic units.

Monograptus praehercynicus group graptolites are 335–430 m above the base and *Monograptus hercynicus* group graptolites are about 460 m above the base at Coal Canyon (W. B. N. Berry and M. A. Murphy, oral commun., 1970). The *M. hercynicus* beds are overlain by coarse-grained limestone. *M. hercynicus* group graptolites were found at the Cortez and Carlin mines and about 1.5 km west of the Carlin mine (USGS Coll. D332 SD, D255 SD, and D254 SD); in the Toquima Range at Ikes Canyon beneath the McMonnigal

Limestone (USGS Coll. D310 SD) and beneath the Tor Limestone (McKee and others, 1972); in the Clear Creek area of the Toiyabe Range (Stewart and McKee, 1977); at Brock Canyon in the Monitor Range (USGS Coll. D310 SD); at Maggie Creek Canyon (USGS Coll. D278 SD); and at Birch and Willow Creeks, on the north flank of the Roberts Mountains (Berry and others, 1971, p. 1969).

As far as has been determined in this study, all laminated limestone beds containing *M. uniformis* or *M. hercynicus* group graptolites are near gradations of laminated limestone to coarse-grained carbonate beds. The beds bearing those graptolites at Coal and Rattlesnake Canyons and the ones at the Cortez mine apparently grade eastward into coarse-grained rocks assigned to the Roberts Mountains Formation in the Roberts Mountains area or to the Lone Mountain Dolomite in the Sulphur Spring Range. The *M. hercynicus* group graptolites in laminated limestone at and near the Carlin mine seem to grade northwestward into coarse-grained rock at Bootstrap mine. The graptolite-bearing laminated limestone beds at Maggie Creek Canyon presumably grade eastward into coarse-grained Lone Mountain Dolomite in the Ruby Mountains and Wood Hills. The beds with *hercynicus* group graptolites in the southern Toquima and Toiyabe Ranges are assumed to grade southeastward into coarse-grained Lone Mountain Dolomite in the southern Monitor Range. The western equivalents of the *hercynicus* group beds at Rattlesnake and Coal Canyons, Cortez mine, and Toquima and Toiyabe Ranges are not known because of structural complexity and lack of outcrop.

The only megafossils other than graptolites collected from the laminated limestone unit and submitted for identification are brachiopods collected at Carlin mine (see p. 26) and Coal and Cortez Canyons, and corals collected near the North Star mine. *Styliolina* and *Tentaculites* are present in laminated limestone assigned to the Roberts Mountains Formation at the North Star mine, but they were not collected. These criconarids are common in laminated limestone interbedded with coarse-grained limestone overlying the Roberts Mountains Formation.

Several samples of laminated limestone from the Roberts Mountains Formation were collected for conodonts. All except one from Antelope Peak are barren. Conodonts in a medium-grained laminated limestone about 490 m above the base and 275 m below the top of the Roberts Mountains Formation at Antelope Peak (USGS Coll. 8824 SD) suggest a Devonian age for at least the upper 275 m of laminated limestone.

The coarse-grained beds in the Roberts Mountains Formation were sampled for conodonts in a few places where graptolites could not be found and these conodonts furnish a little information about the age of the Roberts Mountains. No samples were collected in the type area of the Roberts Mountains Formation where Murphy (1969) and Klapper (1969) have studied the conodonts. These conodonts from the type area indicate that the upper part of the formation is of Early Devonian age. Away from the type area, however, coarse-grained limestone beds of equivalent age are generally assigned to formations other than the Roberts Mountains (p. 6). Coarse-grained beds of probable Silurian age assigned to the Roberts Mountains are conspicuous only at Miniature Grand Canyon in the Monitor Range (USGS Coll. 8435 SD), at Goat Peak window in the Shoshone Range (USGS Coll. 8809 SD), and at Bootstrap mine in the Tuscarora Mountains (USGS Coll. 8219 SD), although thin coarse-grained beds of limestone that contained Silurian conodonts were found in a few other localities. Conodonts from thin coarse-grained beds in the upper part of the laminated limestone unit in the Roberts Mountains at Maggie Creek Canyon and Coal Canyon seem to straddle the Silurian–Devonian boundary. Conodonts from other samples suggest that the first mappable coarse-grained rock above the Roberts Mountains Formation is of Devonian age.

Several of the coarse-grained samples collected for conodonts contain corals and brachiopods that were identified by J. T. Dutro and W. A. Oliver. Their reports on the fossils are included in the appendix.

The conodont samples were primarily taken to solve a specific age problem related to the Roberts Mountains Formation. Only collections from exposures about 1.5 km south of the North Star mine in the Tuscarora Mountains were used to establish a detailed chronology for rocks above the Roberts Mountains Formation. Seven collections were made through a mappable, but faulted, unit about 460 m thick; this unit overlies the Roberts Mountains Formation and consists of coarse-grained limestone with thick (to 150 m) interbeds of laminated limestone. Six of the seven collections contain conodonts and the beds range in age from Early to Late Devonian (USGS Coll. 8440 SD–8445 SD).

The information given in this section indicates a general range in age from Early Silurian (early Llandoverian) to Early Devonian (Siegenian) for the Roberts Mountains Formation in north-central Nevada. The lack of fossils in the upper part of thick sequences of laminated limestone at Grass Valley and near Swales Mountain, however, prohibits putting an upper age limit on rocks assigned to the Roberts

Mountains Formation. Quaternary basin fill caps the Grass Valley exposure so that a meaningful minimum age cannot be determined. Near Swales Mountain, the laminated limestone is seemingly conformably overlain by Lower Mississippian rocks (Ketner, 1970, p. D18–D19). If the contact is truly conformable, rocks assigned to the Roberts Mountains probably include Middle and Upper Devonian units.

CORRELATION OF THE ROBERTS MOUNTAINS FORMATION

Most of the Roberts Mountains Formation is of Early Silurian to Early Devonian age, although it probably contains Middle and Late Devonian age rocks at Swales Mountain and in Grass Valley. Considering the maximum probable age and facies changes, the Roberts Mountains Formation is equivalent to all other Silurian and Devonian rocks that surround it. A more restricted view is that the Roberts Mountains Formation grades eastward from the type area into the Lone Mountain Dolomite. Southeast of Antelope Peak it grades into the Laketown Dolomite. Southward and southwestward it grades into laminated dolomite that forms unit 1 of the Lone Mountain Dolomite (Merriam, 1973b, p. 12–15).

The basal cherty unit seemingly correlates with the basal chert of the Noh Formation of Riva (1970, p. 2693–2694) of the Knoll Mountain area in northeastern Nevada, northeast of the study area. The cherty unit is also the same as the basal chert of Silurian rocks exposed in the Nevada Test Site area in central Nye County (F. G. Poole, oral commun., 1968). The cherty unit may correlate with the chert and dolomite that Ross (1966, p. 27–29) included as the Late Ordovician upper member of the Ely Springs Dolomite in the Independence quadrangle, Inyo County, Calif., suggesting that the upper member may be Early Silurian in age. Eastward, into the shelf facies, a cherty zone near the base of the Laketown Dolomite probably correlates with the basal cherty unit of the Roberts Mountains Formation.

Chert and overlying laminated dolomite and limestone beneath the Lone Mountain Dolomite in the Bare Mountain quadrangle east of Beatty, in southern Nevada, were assigned to the Roberts Mountains by Cornwall and Kleinhampl (1961). Later work by F. G. Poole (oral commun., 1969) indicated that the chert and laminated rock near Bare Mountain did correlate with the Roberts Mountains Formation but that these rocks were more closely related lithologically with other Silurian rocks in southern Nevada than with the Roberts Mountains Formation. The Roberts Mountains Formation seems to correlate with the Vaughn Gulch Limestone and its equivalent Sunday Canyon Formation in the Independence quadrangle, Inyo County, Calif. (Ross, 1966, p. 29–35), both of Silurian and Devonian(?) age.

R. J. Ross, Jr., and James Dover (written commun., 1973) have assigned laminated limestone of Wenlockian age and an underlying cherty carbonate unit exposed along the east side of Wildhorse Creek in the Standhope Peak quadrangle, southern Custer County, central Idaho, to the Roberts Mountains Formation. These rocks are underlain by cherty dolomite that Ross assigns to the Hanson Creek Formation. According to R. J. Ross, the name Trail Creek Formation applied by C. P. Ross (1937, pl. 1) to strata along Malm Gulch in the Bayhorse area, central Custer County, central Idaho, also should be assigned to the Roberts Mountains Formation. The beds R. J. Ross assigns to the Roberts Mountains are considerably different from the impure quartzite at the type locality of the Trail Creek Formation in the Wood River region, Custer and Blaine Counties, central Idaho (Umpleby and others, 1930, p. 23–24). Graptolites collected by R. J. Ross, James Dover, and S. W. Hobbs, and identified by W. B. N. Berry, indicate that the type locality of Trail Creek was deposited, in part, at the same time as the Roberts Mountains Formation. Seemingly, the Trail Creek and Roberts Mountains Formations in Idaho represent similar deposition in relation to the Cordilleran geosyncline, as do the allochthonous Silurian siliceous beds and autochthonous laminated limestone of the Roberts Mountains Formation in central Nevada.

Decker (1962, p. 18–21) described the Chellis and Storff Formations of probable Silurian age and the Van Duzer Limestone of probable Devonian age in autochthonous rocks exposed in the Bull Run quadrangle, northern Elko County, Nev. R. R. Coats (oral commun., 1973) found brachiopods in the upper part of the Van Duzer Limestone that Mackenzie Gordon, Jr., identified as indicating a probable Mississippian age for part of the Van Duzer. I examined the lower part of the Van Duzer Limestone and the Storff and Chellis Formations exposed on the south side of Pennsylvania Hill in the Bull Run quadrangle, but the following descriptions are paraphrased more from Decker (1962) than from my notes. The Chellis Formation is about 580 m thick and consists of laminated-to-massive finely crystalline limestone, and minor argillaceous dolomitic very fine grained limestone and thin beds of chert. The overlying Storff Formation is about 1,190 m thick and consists mainly of thin-bedded phyllites, low-rank slates, and argillaceous limestone. The Van Duzer Limestone is locally more than 2,200 m thick and consists of laminated-to-massive limestone. All three formations are slightly metamorphosed, are conformable, do not contain reeflike coarse-grained carbonate rocks, and are locally difficult to map separately. I could not determine a direct correlation of these rocks with the Roberts Mountains Formation. The Chellis and Storff Formations cannot be classified as volcanic and siliceous rocks, although they may be a transitional shale and carbonate rock assemblage between volcanic and siliceous rocks and carbonate rocks. These formations seem to represent deposition in a more central part of the Cordilleran geosyncline or miogeocline than the Roberts Mountains Formation. The thickness of 1,770 m for the Chellis and Storff Formations of Decker greatly exceeds the thickness of known Silurian and Devonian carbonate rock exposed southward and eastward (Berry and Boucot, 1970; Poole and others, 1967). If, however, the more than 825 m of laminated limestone near Swales Mountain is considered as indicating a northward thickening of Silurian and Devonian rocks toward a thick sequence of siliceous rocks, then the thickness of 1,770 m for the Storff and Chellis Formations plus an unknown thickness of part of the Van Duzer Limestone might represent a normal thickness for Silurian and Devonian rocks deposited in that part of the geosyncline or miogeocline.

Silurian and Lower Devonian rocks are common in the allochthon associated with the Antler orogeny. Because of structural complications and lack of faunal data in the allochthonous rocks, no coherent picture of the rocks has been obtained. General descriptions and location of rocks in the upper plate, rocks which are in part lateral equivalents of the Roberts Mountains Formation, are given in the following paragraphs. These rocks are believed to have been deposited west and northwest of the Roberts Mountains and moved by faults to the present location. The age of the rocks discussed is not firmly established; sequences more than 1,000 m thick have yielded fossils in only one or two places.

The Noh Formation of Riva (1970) crops out in the Knoll Mountain area of northeastern Nevada and is of Silurian age. According to Riva (1970, p. 2693–2694, 2699) the Noh Formation consists of siltstone, shale, thin beds of limestone, and a cherty zone at the base. About 300 m of the Noh Formation is preserved, but the original thickness is not known. The Noh Formation is exposed in the upper plate that moved south-southeastward along a thrust fault which is younger than the Antler orogeny (Riva, 1970, p. 2708–2709). The Noh Formation might have been part of the allochthon of the Antler thrust system before the later faulting. Gardner and Peterson (1969) described Silurian age siltstone, sandstone, chert, and sparse limestone in the upper plate of an Antler thrust fault in the Antelope Peak area north of Wells. The Seetoya sequence of Kerr (1962, p. 449–450) is part of the Antler allochthon in the Independence Mountains. The Seetoya sequence consists of medium-bedded chert, poorly bedded quartzite, minor siltstone, dark volcanic rocks, and at least one bed of black shale (Kerr, 1962, p. 449). The thickness is not known but it probably exceeds 1,000 m. The bed of black shale, in the lower part of the sequence, contains graptolites along Water Pipe Canyon which indicate a middle to late Llandoverian age for the shale (Kerr, 1962, p. 448; Coll. D236 SD of this report). Upper and lower limits of age of the Seetoya sequence are not known. Lovejoy (1959, p. 551, pl. 1) found monograptid-bearing siltstone in a thick sequence of shale and chert that also contains Ordovician graptolites near Lone Mountain in Elko County. Lovejoy did not give a thickness for this unit, but I estimate at least 300 m of Silurian and possibly Devonian rock to be present. The sequence of shale and chert is in the upper plate of an Antler system thrust (Lovejoy, 1959, p. 542). Evans (1972a, b) and Evans and Cress (1972) recognized shale, chert, quartzite, laminated limestone, and coarse-grained carbonate of Silurian and Devonian age in the upper plate rocks extending from Maggie Creek Canyon to Bootstrap mine. Probably a minimum of 1,000 m of Silurian and Devonian rocks is present, but complicated structure prohibits exact measurements. Smith and Ketner (1975) recognized black shale, sandstone, and sparse coarse-grained carbonate rocks in the Devonian Woodruff Formation, which is in the upper plate in the Carlin–Pinon Range area. The Woodruff is locally more than 1,000 m thick and it contains *Monograptus hercynicus nevadensis* (Berry, 1967).

Gilluly and Masursky (1965, p. 54–61) and Gilluly and Gates (1965, p. 35–42) mapped the Fourmile Canyon Formation and Elder Sandstone of Silurian age in allochthonous rocks exposed in the Cortez quadrangle and northern Shoshone Range. The Fourmile Canyon Formation is more than 2,000 m and consists of chert, siltstone, argillite, and scattered beds of sandstone, but contains no beds of carbonate (Gilluly and Masursky, 1965, p. 54–57). Monograptids indicative of an age somewhere between zones 16 and 21 of the British zones were found in the Fourmile Canyon Formation at one locality in Fourmile Canyon (Gilluly and Masursky, 1965, p. 57; Coll. D92 SD of this report). The Elder Sandstone is 600–1,200 m thick in the Shoshone Range and consists mainly of silty fine-grained feldspathic sandstone, but includes minor amounts of chert and shale, and possibly devitrified volcanic glass shards in the sandstone (Gilluly and Gates, 1965, p. 35).

Monograptids indicative of zones 19–22 of the British section were found at two localities in the Elder Sandstone in the Shoshone Range (Gilluly and Gates, 1965, p. 36).

Shale, chert, and coarse-grained carbonate beds of Silurian and Devonian age are known in allochthonous rocks in the region south and southeast of the northern Shoshone Range (J. H. Stewart and M. A. Murphy, oral commun., 1970). Since these rocks have not been studied in detail, the thicknesses and relative amounts of shale, chert, and carbonate rock are not known.

Except for the Noh Formation of Riva (1970) the rock types and stratigraphic sequence of the Silurian allochthonous units described above have little in common with the Roberts Mountains Formation and adjacent rocks. The Noh Formation contains a basal chert, and the overlying thin-bedded rocks slightly resemble rocks in the Roberts Mountains Formation. Possibly the Roberts Mountains grades directly into the Noh Formation. The other upper plate units probably were deposited several kilometers west and northwest of the westernmost rocks here assigned to the Roberts Mountains. These units may have been deposited within a few kilometers of rocks assigned to the Roberts Mountains, but there is no known evidence for such an abrupt facies change in rocks in either autochthon or allochthon.

Some rocks in a structural complex area at Goat Peak window in the northern Shoshone Range were mapped as Roberts Mountains by Gilluly and Gates (1965, pl. 1). I believe the only Roberts Mountains Formation present is in the first outcrop of lower plate rocks west of Goat Peak. Other rocks mapped as Roberts Mountains in the Goat Peak window are in different thrust plates according to Gilluly and Gates and, in my opinion, are more similar to Ordovician laminated limestone than to the laminated limestone in the Roberts Mountains Formation.

ENVIRONMENT OF DEPOSITION OF THE ROBERTS MOUNTAINS FORMATION

Lack of knowledge of lateral relations of equivalent rocks on the western and northwestern edges of the formation prohibits definite conclusions about the environment of deposition or the source of detrital material in the Roberts Mountains Formation. This lack of knowledge about the formation is further compounded by the apparent absence of current analogs to the environment of deposition assumed for the Roberts Mountains. The interpretations of environment of deposition given here are slanted to include shallow water to the east and, generally, somewhat deeper water to the west. Locally and occasionally reefs formed in the deeper water to the west. These interpretations conflict slightly with the Silurian and Early Devonian parts of the Cordilleran geosyncline model as represented by Roberts (1968, p. 106–108, fig. 6) and Roberts and others (1958, fig. 4), or (and) with the model of the miogeocline postulated by Stewart and Poole (1974). Basically, I believe that the water in which the sediments were deposited was not as deep as indicated by their models and that reefs existed west of their westernmost reefs. Roberts (1968, fig. 6) indicated more than a kilometer of water in the area where the Roberts Mountains Formation was deposited during Middle Devonian time; and Stewart and Poole (1974, p. 45) postulated that the laminated limestone "* * * represents moderately deep water deposition on the outer shelf." This implies water about 200 m deep.

Lateral relations of rock types in the Roberts Mountains and underlying and overlying formations are shown on plate 2. The reef environment for coarse-grained rock and the fore-reef environment for the laminated limestone in the type area of the Roberts Mountains Formation postulated by Winterer and Murphy (1960) are accepted and extended north and northeast of the type area to near Wells, Nev. Only in the area northwest of Wells, however, does the laminated limestone seem to grade consistently into a more basinward zone. The evidence for this gradation is scanty as the Roberts Mountains cannot be directly related to the Storff and Chellis Formations which are assumed to represent deposition closer to the middle of the geosyncline (p. 29 of this report). South of the type area the laminated limestone grades to only slightly silty laminated carbonate rock that has been dolomitized. Westward and southwestward of the type area, the upper part of the laminated limestone seems to grade locally into coarse-grained reeflike carbonate rocks. The distribution and lateral relations of the rocks require some modification of a simple fore-reef grading to deeper water. In addition, these relations seemingly require an eastward curve in the reef line in the Carlin-Elko area where the trend of the edge of the Roberts Mountains Formation deviates from the northward trend of the Cordilleran geosyncline as postulated by Roberts (1968, fig. 5). Stewart and Poole (1974) attributed the eastward curve to much later oroflexural bending.

The basal cherty unit of the Roberts Mountains Formation is inorganically precipitated calcite that was partly to completely silicified before it was lithified. The source of the silica that replaced the calcite is not known. Study of thin sections revealed no evidence for either volcanic glass or tests of siliceous organisms that could have furnished the silica. Possibly the silica was derived from ash falls related to the volcanic rocks in the Seetoya sequence of Kerr (1962, p. 449) and to the shards in the Elder Sandstone (Gilluly and Gates, 1965, p. 35). The Seetoya sequence and Elder Sandstone contains beds of about the same age as the cherty unit (p. 30 and 31), but no bentonite beds have been identified in the cherty unit. I believe the calcite formed in shallow water (a few meters deep) during a time when little detrital material was being supplied. The chert replacement of beds at the same stratigraphic position continues into coarse-grained carbonate rock in southern Nevada (F. G. Poole, oral commun., 1968), where the replaced beds contain pentamerid brachiopods that lived in relatively shallow water.

Where completely silicified, the cherty unit of the Roberts Mountains Formation resembles cherty units of the volcanic and siliceous assemblage of Roberts (1969) and Stewart and Poole (1974). These authors indicated that the volcanic and siliceous assemblage of the Cordilleran miogeosyncline formed in deep water (more than 200 m). They also considered the laminated limestone unit of the Roberts Mountains Formation to represent a transitional unit between rocks deposited in deep water and in fairly shallow water. No undoubted evidence exists that the siliceous assemblage was deposited in deep water. Goldstein and Hendricks (1953) postulated that some sediments of the Ouachita geosyncline in Arkansas and Oklahoma that are similar to the siliceous rocks in the Cordilleran geosyncline were deposited in shallow water to tidal flat environments. Folk (1973) gave evidence that the Devonian and Mississippian Caballos Novaculite of west Texas, also deposited in the Ouachita geosyncline, was deposited in a peritidal environment.

Wise (1972) reported that silica in the form of spherical aggregates 0.0025–0.003 mm in diameter occur in Cenozoic deep sea chalks deposited in the South Atlantic Ocean and Caribbean Sea. The silica in the chalk is presumed to be derived from volcanic glass or from tests of siliceous organisms. During lithification the movement of interstitial fluids could redistribute the silica so as to replace calcite and form deep sea chert. Similar processes might have been responsible for forming the cherty unit if it is really a deep sea deposit.

The laminated limestone probably was deposited in water not more than 100 m deep. That water was west of a major reef throughout the time of deposition, but east of a minor reef line formed in the Late Silurian and Early Devonian time in parts of the south and west sides of the area of deposition. These relations modify the general concept of a uniform westward-sloping sea floor, by locally reversing the westward slope of the sea floor of the Cordilleran geosyncline or miogeosyncline to form a nearly closed basin in which laminated limestone was deposited in latest Silurian and earliest Devonian time.

The type and distribution of rocks being deposited in north-central Nevada at five times ranging from Early Silurian to Early Devonian are shown by figures 16–20. The maps incorporate fossil data along with distribution of rocks; they are my interpretation of stratigraphic relations and relative depth of water during Silurian and Early Devonian. The change in rock type is interpreted as mainly representing changes in depth of water from a few meters to about 100 m. Coarse-grained fossiliferous carbonate rock is assumed to have been deposited in water a few meters deep and the laminated limestone in water a few tens of meters deep. The reasons for the changes in depth of water, which also changed the depositional pattern near the end of Silurian time, are not known. The relatively more abundant detrital material in the upper half of the laminated limestone unit suggests an elevated, or new, source of material near the end of Silurian time. Possibly the forces that altered the source of the detrital material also changed the configuration of the sea floor.

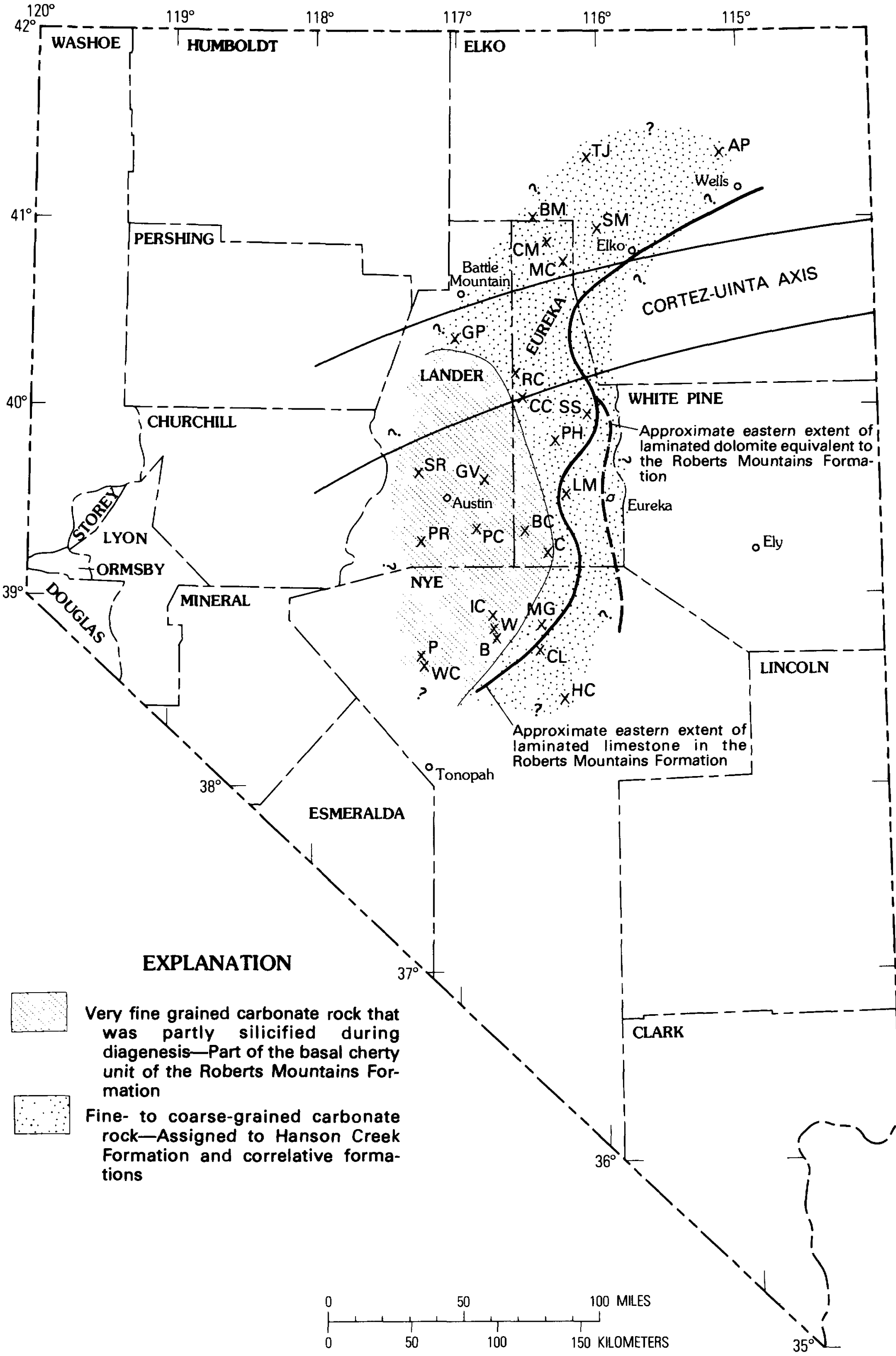
My interpretations about water depth are of the same order of magnitude as Ziegler (1965) postulated for some Silurian rocks in Great Britain. Ziegler defined five faunal zones, based on brachiopods. The areal distribution of these zones is roughly parallel and the zones are believed to represent changes in depth of water associated with the edge of the sea. The ranges between the zones are in tens instead of hundreds of feet according to Ziegler (1965), which I interpret to be several meters instead of possibly a hundred meters. Berry and Boucot (1971) believed monograptids in the Roberts Mountains Formation could be related directly to the lower four zones of Ziegler. To some extent, this association would invalidate the use of monograptids as time lines. The depth control of monograptids would, however, add strength to part of the interpretation given below because, according to Berry and Boucot (1971), *Monograptus spiralis* is associated with deeper water than the *M. hercynicus* group graptolites.

The presence of pyrite and organic material indicates that a reducing environment existed at the time of deposition of the laminated limestone. This reducing environment was probably toxic to boring organisms, as the laminations are preserved. The toxic conditions

CORRECTED PAGES

U.S. Geological Survey Professional Paper 1063, Stratigraphy, Petrology, and Some Fossil Data of the Roberts Mountains Formation, North-Central Nevada, by Thomas E. Mullens: U.S. Government Printing Office, Washington, D.C. 20402, 1980, Stock Number 024-001-03264-3.

The patterned areas in figures 16 through 20 (pages 33 to 37) were positioned incorrectly when the report was printed. Reprinted pages with corrected illustrations are attached. Page 38 is also included in the reprinting for convenience; this page is not incorrect in the original printing.



LOCALITIES

AP	Antelope Peak
B	Black Cliff Canyon
BC	Brock Canyon
BM	Bootstrap mine
C	Copenhagen Canyon
CC	Coal Canyon
CL	Clear Creek Mountain
CM	Carlin mine
GP	Goat Peak window
GV	Grass Valley
HC	Hot Creek Canyon
IC	Ikes Canyon
LM	Lone Mountain
MC	Maggie Creek Canyon
MG	Miniature Grand Canyon
P	Pablo Canyon
PC	Petes Canyon
PH	Pete Hanson Creek (type section of Roberts Mountains Formation)
PR	Point of Rocks
RC	Rattlesnake Canyon
SM	Swales Mountain
SR	South Ravenswood window
SS	Sulphur Spring Range
TJ	Thomas Jose Canyon
W	Wood Canyon
WC	Wall Canyon

FIGURE 16.—Type of rock deposited in north-central Nevada during mid-Llandoverian time. Approximately graptolite zone 20.

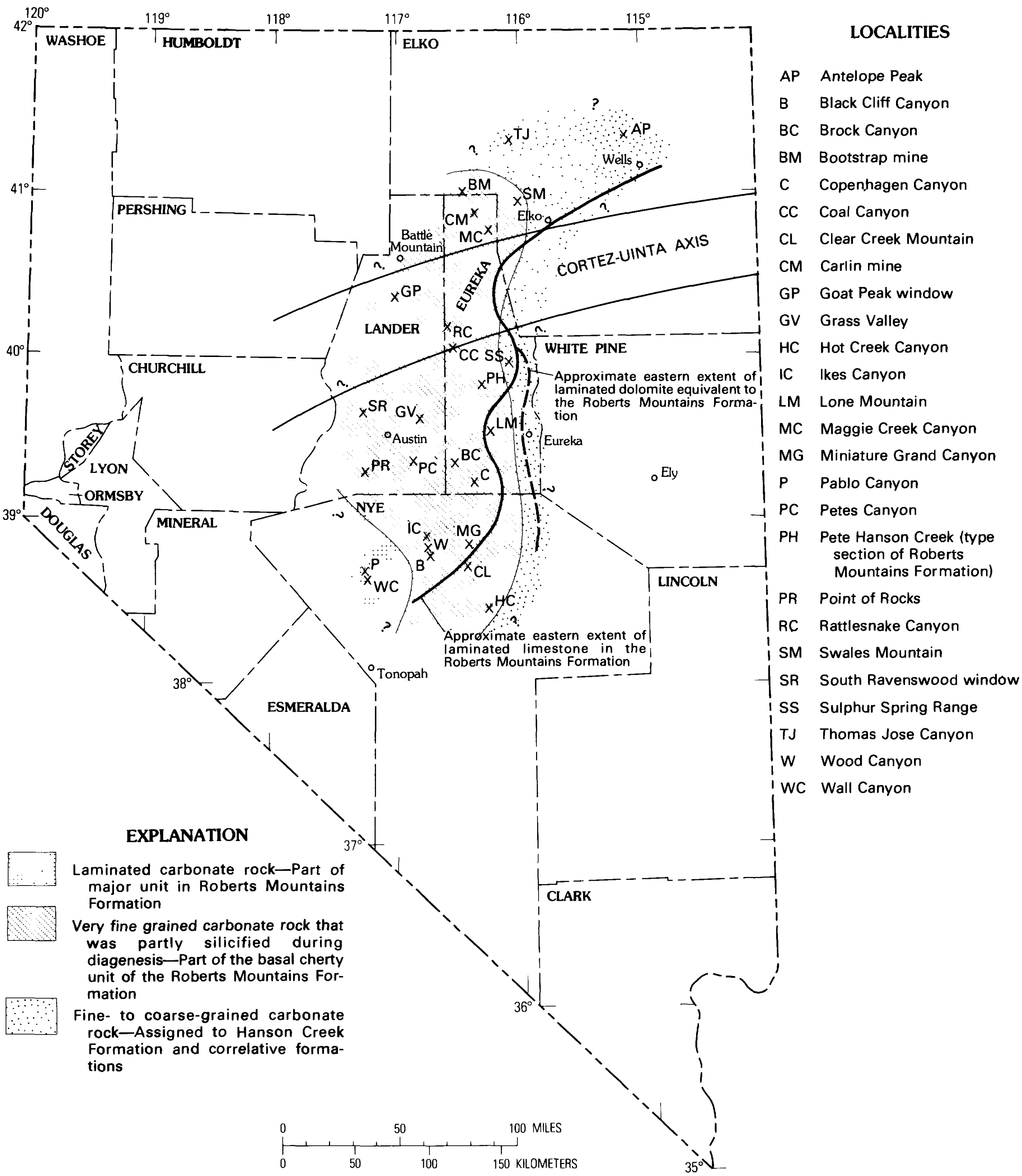
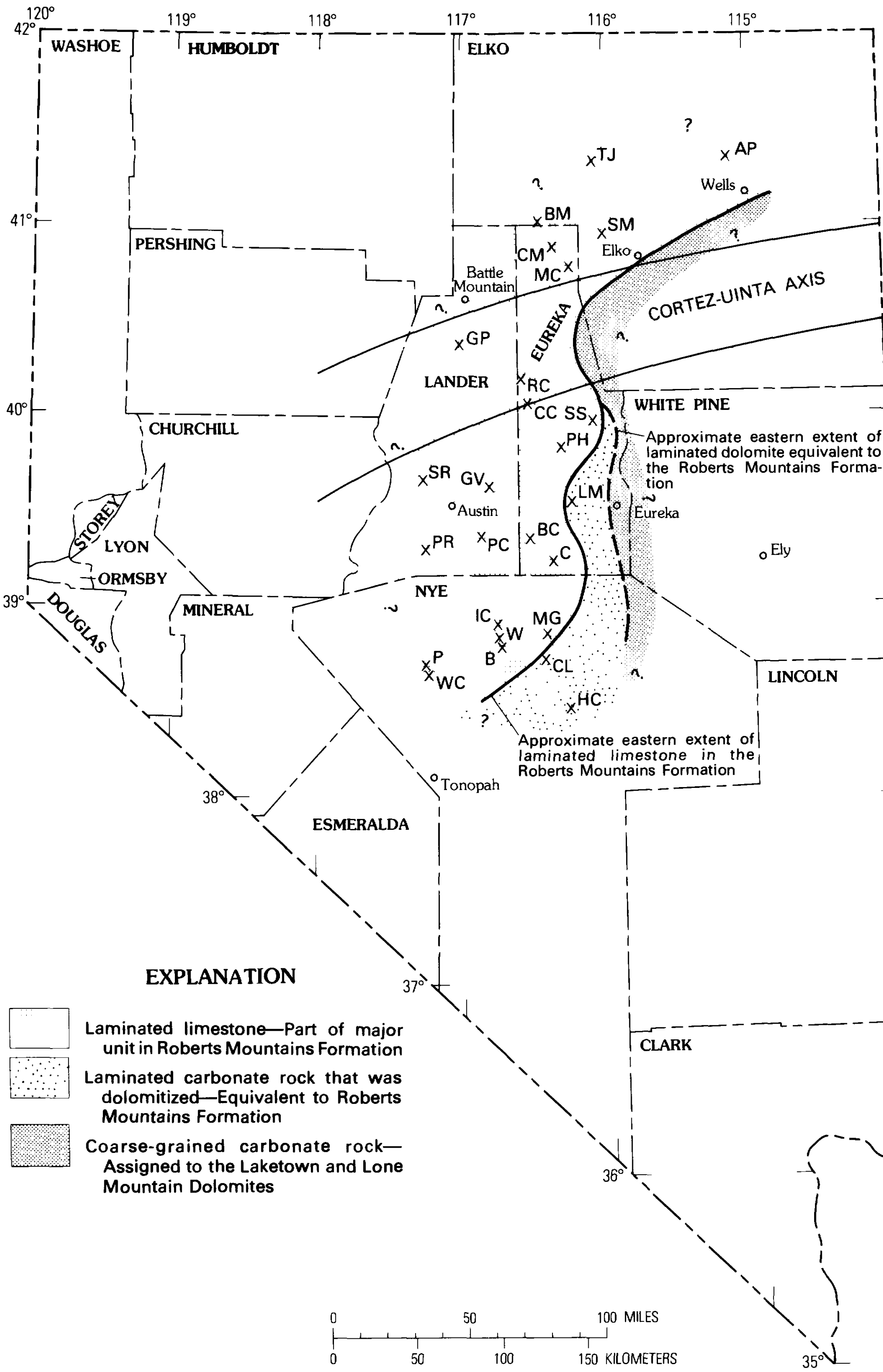


FIGURE 17.—Type of rock deposited in north-central Nevada during late Llandoverian time. Approximately graptolite zone 24.



LOCALITIES

- AP Antelope Peak
- B Black Cliff Canyon
- BC Brock Canyon
- BM Bootstrap mine
- C Copenhagen Canyon
- CC Coal Canyon
- CL Clear Creek Mountain
- CM Carlin mine
- GP Goat Peak window
- GV Grass Valley
- HC Hot Creek Canyon
- IC Ikes Canyon
- LM Lone Mountain
- MC Maggie Creek Canyon
- MG Miniature Grand Canyon
- P Pablo Canyon
- PC Petes Canyon
- PH Pete Hanson Creek (type section of Roberts Mountains Formation)
- PR Point of Rocks
- RC Rattlesnake Canyon
- SM Swales Mountain
- SR South Ravenswood window
- SS Sulphur Spring Range
- TJ Thomas Jose Canyon
- W Wood Canyon
- WC Wall Canyon

FIGURE 18.—Type of rock deposited in north-central Nevada during late Wenlockian time. Approximately graptolite zone 31.

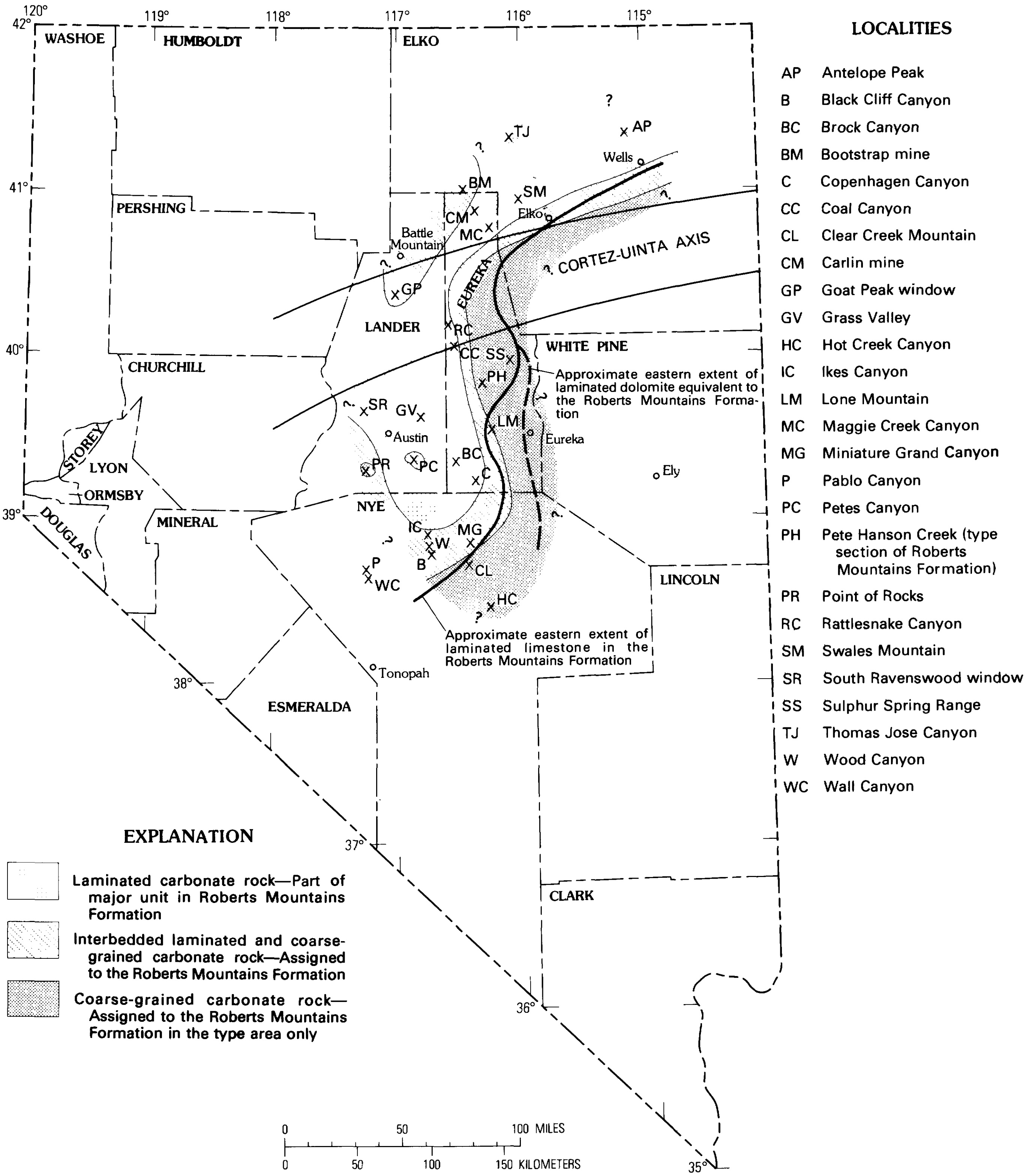


FIGURE 19.—Type of rock deposited in north-central Nevada during latest Silurian and earliest Devonian time. Approximately *Monograptus uniformis* Zone.

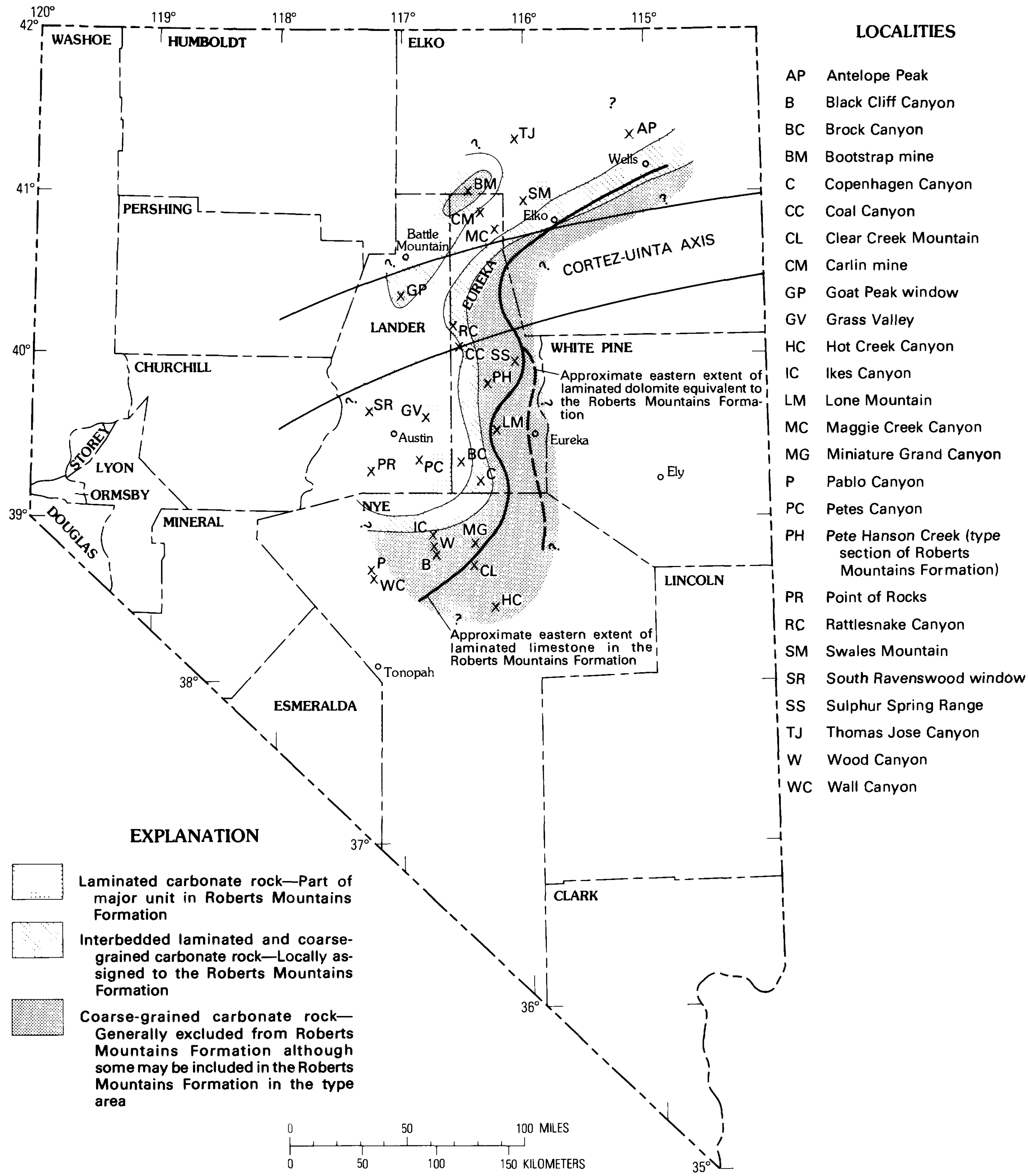


FIGURE 20.—Type of rock deposited in north-central Nevada during mid-Early Devonian time. Approximately *Monograptus hercynicus* Zone.

and the reducing environment are interpreted to be in the mud bottom, but not necessarily in the water a few meters above. The composition, pH, and Eh of the water at and above the sea floor were favorable for precipitation of both very fine grained calcite and silt-sized grains that became dolomite. At the sea floor, the pH was probably in the 7.9–8.2 range and the Eh was probably near −0.3 (Krumbein and Garrels, 1952, fig. 8), but the Eh might have been higher a few meters above. The degree of toxicity of the water above the sea floor is not known, but probably the water supported algae that secreted no calcareous parts, graptolites, and a few corals and brachiopods. Anaerobic bacteria probably lived on and near the sea floor.

The mineral assemblage in laminated limestone is interpreted as containing two major components—detrital grains from preexisting rocks and chemical precipitates that formed in seawater above or at the sea floor. Detrital grains that were derived from preexisting rock include quartz, feldspar, some of the clay, and heavy minerals such as zircon, tourmaline, monazite, and rutile. Most carbonate in the laminated limestone is here interpreted as either having precipitated in the sea or having crystallized by nucleation at or slightly below the sea floor before the sediment was compacted. Minor components in the laminated limestone are of varied origin. Some angular grains of calcite as much as 0.2 mm across are probably fragments of fossils. The carbonaceous material is likely of two origins: most films and specks are interpreted as parts of graptolites or other organisms; the carbonaceous coatings adhering to quartz and dolomite grains, and carbonaceous inclusions in calcite are interpreted as derived from algae that secreted no hard parts or from anaerobic bacteria. The pyrite is interpreted as formed from iron derived from dissolving iron-bearing minerals and then combined with H_2S at or slightly below the sea floor. Presumably, anaerobic bacteria and decaying organic matter had some role in producing the H_2S needed to precipitate pyrite.

The coarse-grained limestone in the upper part of the Roberts Mountains Formation, as well as laterally equivalent coarse-grained carbonate rock assigned to other formations, are interpreted as deposited in water not more than several meters deep and as part of a reef complex. The reefs varied from long-lived major features where the Lone Mountain Dolomite was deposited (Winterer and Murphy, 1960) to short-lived patch reefs where only a few meters of limestone were deposited. At Bootstrap mine and near the type section, much of the coarse-grained limestone in the Roberts Mountains Formation might have been emplaced as debris flows from major reefs. At other places, the coarse-grained limestone in the Roberts Mountains seemingly accumulated in patch reefs that existed only for short periods before being covered by laminated limestone.

The reef limestone is interpreted as mainly bioclastic. It probably formed in well-aerated water where currents were strong enough to remove silt, to transport fine to medium quartz grains, and to move limestone pellets as large as 2 mm in diameter.

Tenuous evidence indicates that laminated limestone in the upper part of the Roberts Mountains Formation was deposited in a nearly closed basin (figs. 19 and 20). The interbedded coarse-grained limestone and laminated limestone at Bootstrap Hill, at Goat Peak, and at Miniature Grand Canyon, coupled with the Tor Limestone of Devonian age (Johnson and Boucot, 1970) and the McMonnigal Limestone, which is in part Early Devonian in age, in the Toquima Range, and the 10-m bed of coarse-grained Lower Devonian Limestone at Point of Rocks in the Toiyabe Range suggest that local to extensive reefs existed west and south of the main area of deposition of the laminated limestone during latest Silurian and earliest Devonian time. The lack of outcrops of equivalent rocks west of the Shoshone Range allows several interpretations of the distribution of these reefs. I believe that a reef probably extended from Bootstrap mine to Goat Peak window but that it probably did not extend far southward. Another reef, extending from Point of Rocks eastward through the Toquima Range to the Monitor Range, is also indicated. Probably this reef connected in Late Silurian and Early Devonian time with the Roberts Mountains area via Mahogany Hills. The laminated limestone that overlies the single bed of coarse-grained limestone at Point of Rocks indicates that the reef there did not persist long. Stewart and McKee (1977) found no extensive coarse-grained limestone of Devonian age in the area south of Austin.

The lack of interbeds of coarse-grained reeflike limestone in the laminated limestone at Swales Mountain and in Silurian and Lower Devonian rocks at Antelope Peak indicates that no reef line formed in rocks assigned to the Roberts Mountains Formation northwest of Wells, Nev. This interpretation is strengthened by the absence of reeflike carbonate rocks in presumed correlative autochthonous beds of the Chellis and Storff Formations, and of part of the Van Duzer Limestone of Decker (1962) in the Bull Run quadrangle (see p. 29).

The nearly enclosed basin outlined in figure 20 is about 200 km long and 30–80 km across. The size and open end of the basin approximate the Delaware basin in Texas and New Mexico (King, 1934, p. 704). The depth of water within the nearly closed basin where most of the rocks assigned to the Roberts Mountains Formation were deposited is not known. The maximum depth is assumed to have been about 100 m, but it could have been as much as 4,500 m; this latter figure is the calcite compensation depth according to Berner (1965), although the compensation depth of calcite is not uniform (Heath and Culberson, 1970). The depth was less—probably less than 30 m—near the margin where laminated limestone, assumed to have been deposited in reducing and toxic water, graded into coarse-grained carbonate. Newell and others (1953, p. 96) noted that toxic and reducing conditions also prevailed near the foot of a growing reef in the Permian basin of Texas and New Mexico. The general evenness of the laminations cannot be used as indicating depth below wave base. Laminations are preserved in modern tidal and supratidal deposits (Reineck, 1972, p. 148, fig. 4; Lucia, 1972, table 1), in pools marginal to the sea (Friedman and others, 1972), in lagoonal deposits (Behrens and Land, 1972, p. 155, fig. 2), as well as in rocks presumably deposited below wave base (Rubey, 1931, p. 40–43). If the interpreted depth is correct, then the sea floor had an extremely gentle slope that approached the slope that Irwin (1965, fig. 2) postulated for epeiric seas. As a corollary, the accumulation of laminated limestone probably is related to crustal subsidence rather than to filling of the sea.

In texture and composition the laminated limestone is similar to parts of the Paradox Member of the Hermosa Formation of eastern Utah (Peterson and Hite, 1969, p. 892) and to the limy clastic basin deposits associated with the Permian reef complex in west Texas (King, 1948, pl. 10A; Newell and others, 1953; Albritton and Smith, 1965, fig. 5). These units are believed to have been deposited in barred basins (King, 1934; Peterson and Hite, 1969, p. 893–894). The laminated limestone of the Roberts Mountains Formation is here interpreted to have been deposited in a partly barred basin although the location of the bar, or bars, is not known.

High salinity probably existed in the partly barred basin and extraction of Ca^{++} to form limestone in the reef areas caused the water to become relatively enriched in Mg^{++} and Cl^-. Currents, probably of the longshore type, strong enough to transport clay, silt, and a little sand, and to mix waters of different composition, were also present. Near the reef line longshore currents are postulated, as the laminated limestone in these areas contains very fine to fine sand grains that are not found in the bulk of the laminated limestone.

The precipitation of fine-grained calcite in seawater upsets no established geologic dogma, but the precipitation of large amounts of nearly primary dolomite from subtidal water is controversial. A high-magnesian calcite can be precipitated in large amounts in a slightly restricted basin and the high-magnesian calcite can be changed to dolomite early in diagenesis. Friedman and others (1972) reported high-magnesian calcite in highly carbonaceous modern sediments near the Red Sea. Müller and others (1972, p. 162–163) reported that high-magnesian calcite formed in lacustrine water with a 7-15:1 molecular ratio of Mg to Ca converts to dolomite. Dolomite is found in sediments of such lakes. Removal of Ca^{++} by precipitating calcite either by organic or inorganic methods would bring the magnesium-to-calcium ratio of seawater into this range. The high-magnesian-calcite converts to dolomite as the calcite acts as a matrix for dolomite nucleation; then further growth involves dissolution of the calcite with reprecipitation as dolomite. The dissolution probably takes place in the sediments of the lake floor (Müller and others, 1972, p. 163).

Possibly, however, much of the dolomite in the laminated limestone is a primary precipitate, since the texture and composition of the dolomite give no evidence that the dolomite evolved from a high-magnesian calcite. The texture of dolomite in the laminated limestone is very similar to that of the primary dolomite shown by Sabins (1962, fig. 5). X-ray diffraction studies indicate that the dolomite is pure, a feature Sabins (1962, table 1) found in dolomite he believed to be primary. I saw no undoubted evidence that dolomite grains had replaced any other mineral. The irregular shape of many of the grains is interpreted as solution of dolomite or incomplete crystallization instead of as abrasion by rolling on the sea floor. Gypsum precipitated by mixing brines shows the same range of irregular grains to perfect crystals (R. J. Hite, oral commun., 1972) as the dolomite in the laminated limestone. Even if the dolomite was precipitated as a high-magnesian calcite, the calcite was converted to dolomite before compaction, as the dolomite rhombs grew in an unconfined environment.

I do not believe that the laminated limestone was deposited on a supertidal flat where most undoubted primary dolomite has been reported. Behrens and Land (1972, p. 155–161) reported a bed of primary dolomite in anhedral to euhedral 0.005 mm rhombs in laminated subtidal lagoonal sediments in Baffin Bay, Tex. Raup (1970) has shown that halite can be precipitated by mixing brines of different composition and specific gravity without further loss of water by evaporation. R. J. Hite (oral commun., 1972) believed that the model used by Raup can be extrapolated to allow dolomite to precipitate in seawater if variable compositions are included. Such a condition might prevail in water depleted in Ca^{++} by inorganic deposition of calcite or organic deposition of calcite in a reef, slightly enriched in carbonaceous material and H_2S, and then mixed with normal seawater.

The dolomite grains seem to be in hydrologic equilibrium with the quartz grains. The amount of dolomite in the laminated limestone also shows a good correlation with the increase in quartz, feldspar, and clay content (see fig. 8). These features seem to indicate that the dolomite, or its high-magnesian calcite precursor, acted like clastic grains, but the grains are so small that they would not be abraded by current action.

I interpret the eastward trend of the reef line from Carlin to Wells, shown on figures 19 and 20, to represent the original pattern of deposition caused by a curve in the basin of deposition. Stewart and Poole (1974, p. 45, fig. 12), however, related the eastward trend of the reef line from Carlin to Wells to later oroclinal folding. Although exact reasons for the curve are not known, I believe the basin of deposition had curves resembling modern ocean shores instead of being a linear trough. Part of the curve is interpreted as related to the Cortez-Uinta axis (Roberts, 1968, fig. 5) which, I believe, influenced the depositional pattern in northeastern Nevada during the Silurian and Early Devonian. Also, I interpret the work of Gilluly and Gates (1965), Gilluly and Masursky (1965), Webb (1958), and Ketner (1968) to indicate that the arch was high in part of Ordovician time, and the work of Yochelson and Fraser (1973) to indicate that the arch was active in Pennsylvanian and Permian time. Seemingly the arch was asymmetrical, the north side dipping steeper, during Silurian and Early Devonian time. Evidence that I interpreted to indicate that the arch influenced deposition during Silurian and Early Devonian time is found in the Pinon and Sulphur Spring Ranges and Cortez Mountains. The coarse-grained limestone extends farther west along the crest of the arch in these ranges than does the coarse-grained carbonate rock to the south. This relation is interpreted to indicate that the crest of the Cortez-Uinta axis influenced the depth of water and allowed the higher energy coarser grained material to be deposited.

The coarse-grained limestone interbedded with laminated limestone is not shown as connected from Rattlesnake Canyon to Goat Peak window on figure 19, although these localities are along the axis. The reason for not connecting the localities and sealing off a basin is that a 670-m-deep drill hole in Mill Canyon east of Crescent Valley and only a few kilometers north of Rattlesnake Canyon did not penetrate coarse-grained carbonate rock.

SOURCE OF DETRITAL MATERIAL IN THE ROBERTS MOUNTAINS FORMATION

Berry and Boucot (1970, p. 63-65) examined the problem of source areas for detrital material in Silurian rocks in North America and found that, except in the Appalachian region, no known areas are adequate to furnish detrital material for Silurian quartz-rich sediments. Study of the Roberts Mountains Formation does not modify their conclusions, as the source area of the detrital minerals in the formation and the method of transport are not known to me. The quantities of silt and feldspathic sandstone (p. 31-32) in equivalent rocks in the allochthon of the Antler orogeny suggest that a landmass existed west and northwest of the area of deposition of the Roberts Mountains Formation. The detrital material in the Roberts Mountains, which is mainly silt sized, could represent an eastern extent and dilution of the more clastic rocks deposited to the west. If so, the transport was probably by water currents. The size of the detrital material in the Roberts Mountains Formation indicates that air-current transport was also possible.

Any landmass that furnished sediments from the west or northwest seems now to be concealed by younger rocks or metamorphosed beyond recognition. Or, in view of plate tectonics, such a landmass could have been subducted or moved a great distance by transcurrent faults. As an alternative to coming from a westward landmass, the detrital material could have been transported by longshore currents from a source far removed to the north. The more abundant larger grains in laminated limestone closer to coarse-grained limestone lend support to transport by longshore currents. Ketner (1968, p. B174-B175) postulated that much of the quartz in Ordovician quartzite in the Cordilleran miogeosyncline was derived from the north. Possibly such a source existed into Silurian and Devonian time.

An eastern or southern source, in my opinion, is not plausible, as it would have required the transporting of the detrital material in the Roberts Mountains Formation across many kilometers of water in which coarse-grained carbonate rock of equivalent age was deposited.

The type of material in the source area is nearly as unknown as the location of the source area. The detrital minerals suggest a mixture of plutonic rocks and sedimentary rocks in the source area, but this mixture must be considered in view of the unknown type of weathering in the source area, the unknown method of transport from the source area, and the probable environment of deposition of the laminated limestone. The probable 7.9-8.2 range of pH and the probable Eh of about −0.3 of water needed for the deposition of carbonaceous and pyritic limestone (Krumbein and Garrels, 1952, fig. 8) possibly destroyed diagnostic minerals. Magnetite and ilmenite, if present in the source, were dissolved. Only the most resistant heavy minerals—zircon, tourmaline, rutile, and monazite—are preserved; much of the quartz and feldspar was partly to completely dissolved. The remaining quartz is dominantly nonundulatory quartz, which is more resistant than undulatory quartz (Blatt and Christie, 1963, p. 570–572). Seemingly, the only definite conclusion about the source rocks is that they did not include major amounts of Ordovician quartzite. Ketner (1966) found no feldspar in these quartzites and the heavy mineral content of the quartzites is an order of magnitude lower than that of the detrital material in the Roberts Mountains Formation.

TRACE ELEMENTS IN THE ROBERTS MOUNTAINS FORMATION

Spectrographic analyses were made on 246 samples of the Roberts Mountains Formation and related formations collected during this study. The object of the spectrographic analyses was to obtain information on the trace element content of the Roberts Mountains and related formations. Details of the spectrographic analyses are given elsewhere (Mullens, 1979). Representative spectrographic analyses of laminated limestone in the Roberts Mountains Formation and coarse-grained limestone from the Roberts Mountains and overlying Devonian formations are shown in table 2. The laminated limestone seems to have the average elemental composition of a rock composed of about 80 percent limestone and 20 percent shale when compared to the composition of carbonates and shale reported by Turekian and Wedepohl (1961, table 2). The elemental content of the coarse-grained limestone is close to that of carbonates reported by Turekian and Wedepohl. The major exception to the composition reported by Turekian and Wedepohl is that the manganese content is low in both the laminated limestone and coarse-grained limestone. The laminated limestone averages about 200 ppm manganese and the coarse-grained limestone averages about 100 ppm manganese. These numbers are low when compared to the 1,100 ppm manganese in carbonates and 850 ppm manganese in shale that Turekian and Wedepohl reported. The reason, or reasons, for the low manganese content in the Roberts Mountains and related formations was not determined. Possibly it is low because the rocks were deposited mainly in a reducing environment where manganese hydroxide remained in solution (Rankama and Sahama, 1950, p. 648).

A few trace elements in the laminated limestone show positive correlations with some major components of the rock. Boron generally correlates with the amount of clay; vanadium correlates mainly with organic carbon content, although it is abundant in some clay-rich samples and in rocks that contain traces of collophane; and lanthanum and zirconium generally are related to the silt content. Yttrium is probably mainly related to the carbonate content of the rock (Rankama and Sahama, 1950, p. 528), although some may be in the zircon. Cobalt, chromium, nickel, and titanium are generally more abundant in rocks that have a relatively high iron content. The distribution of copper and zinc is erratic and some samples high in these elements contain epigenetic sulfide minerals.

TABLE 2.—*Representative spectrographic analyses of limestone in the Roberts Mountains Formation and overlying Devonian formations*

Element	Roberts Mountains Formation laminated limestone	Roberts Mountains Formation and overlying Devonian coarse-grained limestone
	In percent	
Fe	1.5	0.2
Mg	5	0.2
Ca	>10	>10
Ti	0.1	0.02
	In parts per million, except that N = not detected, and L = present, but below limit of detection	
Mn	200	100
Ag	N	N
As	N	N
Au	N	N
B	30	L
Ba	200	200
Be	N	N
Bi	N	N
Ca	N	N
Co	L	N
Cr	30	15
Cu	15	10
La	20	N
Mo	5	N
Nb	L	L
Ni	15	L
Pb	15	L
Sb	N	N
Sc	L	N
Sn	N	N
Sr	200–500	500
V	200	50
W	N	N
Y	15	15
Zn	L to N	N
Zr	100	30

The mercury and gold contents of many of the samples collected were determined by atomic absorption methods (Mullens, 1979). Mercury values are high, more than 0.2 ppm, in several areas, but mercury anomalies are common in Nevada and I cannot relate the high values to original sedimentary or stratigraphic features. The gold values are low, about 0.01 ppm, except near known gold deposits which are only indirectly related to the sedimentary and stratigraphic features. The near absence of gold in the Roberts Mountains and related formations is interpreted as indicating that the gold deposits at Carlin and Cortez do not represent reconcentration of gold originally in the rocks.

GOLD DEPOSITS IN THE ROBERTS MOUNTAINS FORMATION

Laminated limestone in the Roberts Mountains Formation is the host rock for most ore at the Carlin and Cortez gold mines and for a small part of the ore at Gold Acres mine. These ore deposits do not contain visible gold in unoxidized ore nor are they known to contribute gold to placer deposits. For these reasons, they are commonly known as invisible gold deposits. The deposits are surrounded by a distinctive geochemical halo, but the halo and unoxidized gold-bearing rock can be determined only by chemical analyses. Probably the "invisible" character of the gold and associated elements is due to a stratigraphic control, namely, the character of the permeability and porosity of laminated limestone. The source of gold and associated elements and the fractures that furnished the plumbing are assumed to have little effect on the character of the ore.

The occurrence of gold and geochemical halo at the Carlin deposit is described by Hausen (1967), Hausen and Kerr (1968), Akright, Radtke, and Grimes (1969), Radtke and Scheiner (1970), and Wells and Mullens (1973). These features have been studied at the Cortez deposit by Wells, Stoiser, and Elliott (1969), Wells and Elliott (1971), Wells and Mullens (1973), and Erickson and others (1966). The Gold Acres deposit was briefly described by Ketner (in Gilluly and Gates, 1965, p. 134) and in more detail by Wrucke and Armbrustmacher (1975). The Gold Acres mine is structurally so complicated that few details about the Roberts Mountains Formation can be determined. The Getchell gold deposit in Humboldt County, Nev. (described in Joralemon, 1951), is in Cambrian rocks, but otherwise the deposit seems similar to the deposits in the Roberts Mountains Formation. A summary description of all these deposits is given by Roberts, Radtke, and Coats (1971).

Each of the gold deposits named has a characteristic suite of elements associated with the ore. Besides gold, these elements include arsenic, mercury, tungsten, antimony, nickel, copper, zinc, and lead (Akright and others, 1969, fig. 5; Wells and others, 1969, figs. 13–14). Altered and non-ore samples collected from the Carlin mine and the only sample of gold ore collected during this study, sample 7006 from the Carlin mine, suggest that iron and sulfur should also be considered as part of the suite of elements associated with gold ore. Pyrite commonly is the only sulfide mineral that can be identified in unoxidized ore without recourse to polished section although orpiment and realgar are locally abundant at the Carlin mine. The only other sulfides identified in polished section are minor amounts of pyrrhotite, arsenopyrite, and sphalerite. At the Carlin and Cortez mines, the ore is associated with rocks that have had most of the calcite removed and clay and quartz added (Wells and others, 1969; Wells and Mullens, 1973). The major part of the ore at both mines occurs in the upper and more silty part of the laminated limestone.

Radtke and Scheiner (1970) postulated that the gold at the Carlin mine occurred as a carbon complex. Microprobe study of unoxidized gold ore from both the Carlin and Cortez deposits, however, indicates that most of the gold and arsenic occures in tiny (<0.005 mm) grains of pyrite and in the rims of larger grains of pyrite disseminated in the ore (Wells and Mullens, 1973). The tiny grains are abundant in ore but are relatively sparse in barren rock. The amount of pyrite in the ore, about 1–1.5 percent, exceeds by a factor of about 5 my estimate of syngenetic pyrite in unaltered laminated limestone (p. 19–20). The relative abundance of pyrite in the ore indicates that some pyrite has been added, but it is not possible, without isotope studies, to prove that most of the pyrite is epigenetic. Probably most of the syngenetic pyrite is in larger grains where only the edges contain gold. Although some of the pyrite may be syngenetic, all gold associated with the pyrite is interpreted as epigenetic. If pyrite in unaltered laminated limestone contained amounts of gold equivalent to the pyrite in the gold ore, then the unaltered rock would contain about 1–3 ppm gold, an amount easily detected by atomic absorption methods. No such gold was found in samples away from ore deposits.

I interpret the fine size of the gold- and arsenic-bearing pyrite as due to the type of permeability in the laminated limestone. The typical weathering to platy material indicates that surface waters attack the limestone along laminations, although fresh rock is seemingly impervious (figs. 3–4). Mineralizing solutions, controlled basically by wide-spaced fractures, could also attack along laminations. If so, the surface area of rock exposed to mineralizing solutions is enormous, although movement of solutions is along a zone that approaches a plane. Thus, while the effective permeability is probably great, it is actually due to an enormous number of microscopic pores along laminations. The quartz and feldspar silt and the dolomite content of the laminated limestone are apparently great enough to prevent collapse of the rock as calcite along laminations is dissolved, and thereby to allow continued permeability in the altered limestone. The microscopic pores would control the size of mineral grains that filled open space, but not the site of minerals that replaced parts of the rock. The dissolving and precipitation of minerals could be related to some specific component of the rock or it could be related solely to the gross chemistry, pressure, and temperature of the hydrologic system.

The theory that the character of the ore is related to certain types of permeability and porosity suggests that all silty laminated limestone is a potential host for ore similar to that in the Carlin and Cortez mines. Such silty laminated limestone occurs in many formations other than the Roberts Mountains Formation in north-central Nevada. Probably such formations will contain gold ore where they occur over a suitable fracture system and source of gold. Finding the gold, however, will be done only with chemical analyses, as the gold is too fine grained to form placer deposits.

APPENDIX

FOSSIL DATA

Many graptolites and samples to be examined for conodonts were collected while studying the Roberts Mountains and related formations. All graptolites were studied by W. B. N. Berry and all conodonts were studied by John W. Huddle. Sparse collections of brachiopods and corals were made and these collections were studied by J. T. Dutro, Jr., A. J. Boucot, J. G. Johnson, and W. A. Oliver. Jean M. Berdan identified ostracodes from several samples originally submitted for conodonts. Fossils collected during this study and a few collected by colleagues are listed in the following pages. The lists of fossils were reviewed in late 1973 by R. J. Ross, Jr., J. W. Huddle, J. T. Dutro, Jr., W. A. Oliver, and J. M. Berdan.

The fossils are listed by localities arranged generally by a west-to-east grouping of mountain ranges and a south-to-north grouping within the mountain ranges. The localities are shown on plate 1. Identification numbers, such as 8220 SD, indicate that the fossils are part of the permanent collection of the U.S. Geological Survey. Field numbers such as TM-F-4-70 show the year the collection was made. Most of the graptolites and some of the conodonts and brachiopods are tied to the Great Britain and Central Europe stages shown in table 1.

SHOSHONE RANGE

South Ravenswood window, Shoshone Range, Lander County, Nev. About sec. 9, T. 20 N., R. 42 E. (unsurveyed), Mount Airy Mesa quadrangle.

USGS Coll. D231 SD (TM-F-24-68). Graptolites collected from laminated limestone unit within 1.3 m of the top of the basal cherty unit of the Roberts Mountains Formation.

Monograptus priodon (Bronn)
Monograptus spiralis (Geinitz)
Monograptus variabilis (Perner)?
Monograptus sp. (of the *M. vomerinus* type)
Monograptus sp. (possibly *M. pandus* (Lapworth))
Retiolites geinitzianus Barrande

Age: late Llandoverian—this is an association typical of zone 1 of the Silurian-Devonian faunizones outlined by Berry in abstract for Tucson meetings of GSA. It is the approximate correlative of the late Llandoverian zones of *Monograptus griestoniensis* and *M. crenulatus* of Elles and Wood.

William B. N. Berry
November 8, 1968

USGS Coll. D261 SD (TM-F-60-69) Graptolites 0.3-0.6 m above basal cherty unit of Roberts Mountains Formation. Same location and zone as TM-F-24-68. Re-collected to include better specimens.

Cyrtograptus lapworthi (Tullberg)
Monograptus spiralis (Geinitz)
Monograptus priodon (Bronn)
Monograptus vomerinus cf. var. *gracilis* Elles and Wood
Monograptus sp. (d streptograptid)

Age: late Llandoverian *M. spiralis* Zone

William B. N. Berry
January 5, 1970

Horse Mountain window, northern Shoshone Range, Lander County, Nev. NW¼ sec. 24, T. 28 N., R. 44 E. (unsurveyed) Mt. Lewis quadrangle

USGS Coll. D259 SD (TM-F-58-69) Graptolites from laminated limestone float, poorly preserved, meager collection, about 46 m above base of Roberts Mountains Formation.

Cyrtograptus sp.
Monograptus flemingii (Salter)

Age: Wenlockian

William B. N. Berry
January 5, 1970

Mill Creek window, northern Shoshone Range, SE¼SW¼ sec. 4, T. 28 N., R. 45 E., Lander County, Nev. Mt. Lewis quadrangle

USGS Coll. D260 SD (TM-F-59-69) Graptolites from Roberts Mountains Formation, stratigraphic position not known, basal and upper parts of exposure bounded by faults.

Gothograptus nassa (Holm)
Monograptus sp. (of the *M. dubius* group)
Monograptus sp.

Age: in span of late Wenlockian-early Ludlovian; could be "*dubius/nassa interregnum* of Jaeger" which is at Wenlockian-Ludlovian border

William B. N. Berry
January 5, 1970

Goat Peak window, northern Shoshone Range, sec. 28, T. 29 N., R. 45 E., Lander County, Nev., Mt. Lewis quadrangle

USGS Coll. D303 SD (TM-F-15-70) Extremely poorly preserved graptolites. Mainly about 15 m above base of Roberts Mountains Formation W½ sec. 28, T. 29 N., R. 45 E.

Monograptus flemingi (Salter)

Age: Wenlockian

William B. N. Berry
August 12, 1970

USGS Coll. 8809 SD (TM-F-16-70) Coarse-grained limestone, upper part of Roberts Mountains Formation, S½SE¼SW¼ sec. 28, T. 29 N., R. 45 E., at the 7200-ft contour, 605 m east and 60 m north of the SW corner of sec. 28, Mt. Lewis quadrangle. About 60 m below rocks in upper plate of thrust.

Hindeodella sp.	6
Icriodus sp.	1

Neoprioniodus excavatus (Branson and Mehl)	1
Panderodus sp.	3
Plectospathodus sp.	2
Spathognathodus inclinatus Rhodes	22
Spathognathodus sp.	1

Age: I am not sure of the age of this sample. There is nothing diagnostic and the conodonts are altered. The *S. inclinatus* looks like the subspecies *S. inclinatus posthamatus* Walliser. This has been reported only from rocks of Ludlovian Age and on this basis I suggest that this may be Silurian in age rather than Devonian.

John W. Huddle
January 18, 1971

TOIYABE RANGE

Wall Canyon, southern Toiyabe Range, Nye County, Nev. About sec. 35, T. 10 N., R. 42 E. (unsurveyed), Pablo Canyon Ranch quadrangle

USGS Coll. D2144 Co-supplement (69-FP-102-AF) Basal Roberts Mountains Formation chert exposed on south side of Wall Canyon. Collected by F. G. Poole.

Climacograptus cf. *C. scalaris* Hisinger
Climacograptus sp.

Age: probably early Llandoverian (Early Silurian)

William B. N. Berry
January 11, 1971

USGS Coll. 8822 SD (TM-70-20-F) Laminated limestone in basal cherty unit and 2.4 m above the base of the Roberts Mountains Formation. Same location as 69-FP-102-AF.

Distacodus cf. *D. obliquicostatus* Branson and Mehl	11
D. sp.	4
Distimodus sp.	4
Ligonodina sp.	1
Trichonodella sp.	1

Age: These specimens are altered and fragile and therefore difficult to identify. Probably this is an Early Silurian collection because it contains forms common in the Early Silurian of the Cincinnati arch area.

John W. Huddle
February 25, 1971

Pablo Canyon, southern Toiyabe Range, Nye County, Nev. About sec. 22, T. 10 N., R. 42 E. (unsurveyed), Pablo Canyon Ranch quadrangle

USGS Coll. D323 SD (70 FP-517F) SW¼ sec. 22, T. 10 N., R. 42 E. (unsurveyed). Large coiled graptolites from measured section A on south side of Pablo Canyon about 3.2 km WNW of Pablo Canyon Ranch. Collected from float in a 6-m interval between 45 and 52 m above base of Roberts Mountains Formation and 18 to 25 m above basal cherty unit. Collected by F. G. Poole.

Monograptus spiralis (Geinitz)
Monograptus sp. (cf. *M. vomerinus* var. *gracilis)*

Age: Silurian–late Llandoverian, *Monograptus spiralis* Zone

USGS Coll. D324 SD (70 FP-518F) SW¼ sec. 22, T. 10 N., R. 42 E. (unsurveyed). Graptolites from measured section A on south side of Pablo Canyon about 3.2 km WNW of Pablo Canyon Ranch. Collected from float in a 12-m interval between 40 and 52 m above base of Roberts Mountains Formation, and 15 to 28 m above basal cherty unit. Collected by F. G. Poole.

Cyrtograptus sp.
Monograptus priodon (Bronn)
Monograptus spiralis (Geinitz)
Monograptus cf. *M. vomerinus* var. *gracilis* Elles and Wood
Retiolites geinitzianus Barrande

Age: Silurian–late Llandoverian, *Monograptus spiralis* Zone

William B. N. Berry
October 23, 1970

USGS Coll. D304 SD (TM-F-22-70) In-place collection 10 m above base of 25-m-thick basal cherty unit of Roberts Mountains Formation on south side of and 3.2 km above mouth of Pablo Canyon. (Cherty unit is about 25 m thick.)

Climacograptus sp. (of the *C. Medius-C. rectangularis* type)
diplograptid
Monograptus convolutus Hisinger
Monograptus sp. (of the *M. triangulatus* type)

Age: Silurian–early–early middle Llandoverian, probably about zone 20.

In-place graptolites from about 11 m above base of basal cherty unit of Roberts Mountains Formation and 0.4 km east of collection.

Climacograptus sp.
Monograptus sp. (of the *M. triangulatus* type)

Age: Silurian–early–early middle Llandoverian, possibly about zone 19–21

USGS Coll. D305 SD Float collection just above cherty unit of Roberts Mountains Formation on south side and 3.2 km above mouth of Pablo Canyon.

Climacograptus sp. (similar to *C. medius*?)
Monograptus convolutus Hisinger
Monograptus jaculum Lapworth
Monograptus sp. (of the *M. triangulatus* type)
Monograptus sp. (hooked thecae—somewhat similar to *M. sedgwicki)*
Retiolites geinitzianus Barrande

Age: Silurian–Llandoverian, overall association indicates age in span of zone 20–22 or 23

USGS Coll. D306 SD (TM-F-24-70) Float collection from base to top of basal cherty unit of Roberts Mountains Formation on south side and about 3.2 km above mouth of Pablo Canyon. Collected at exposures where D304 SD was collected and at another exposure 0.4 km east.

Eastern collection:

Climacograptus sp.
Monograptus convolutus Hisinger
Monograptus sp. (hooked thecae and similar to *M. sedgwicki)*

Age: Silurian–Llandoverian, in span of zones 20–22

Western collection:

Climacograptus sp.
Monograptus convolutus Hisinger
Monograptus clingani?
Monograptus regularis?
Monograptus revolutus Kurck

Age: Silurian–Llandoverian, in span of zones 19–20

William B. N. Berry
January 11, 1971

Clear Creek, Toiyabe Range, Lander County, Nev. Sec. 11 (unsurveyed), T. 15 N., R. 43 E., Millet Ranch quadrangle

USGS Coll. D249 SD (12349-18J). Roberts Mountains Formation, or equivalent, 0.8 km north of Clear Creek, east side of Toiyabe Range, east central part of sec. 11 (unsurveyed). Collected by J. H. Stewart.

Monograptus sp. (This fragment appears to be a good mono-

graptid and the thecal form appears to be most similar to that in *M. scanicus*)
Age: Silurian—possibly early Ludlovian (latest Middle Silurian)

USGS Coll. D250 SD (12349-25J). Roberts Mountains Formation, 1.2 km north of Clear Creek, NE part of sec. 11 (unsurveyed) (about 460 m north of 12345-18J). Collected by J. H. Stewart.
Monograptus sp. (appears to have uncinate thecae—could be a member of the *M. hercynicus* group)
Age: Late Silurian or Early Devonian, probably in the span of Ludlovian-Gedinnian

William B. N. Berry

Point of Rocks, SE¼ sec. 36 (unsurveyed), T. 17 N., R. 42, E., Lander County, Austin quadrangle
USGS Coll. D246 SD (14052-6J). Roberts Mountains Formation, probably near middle. Collected by J. H. Stewart.
Monograptus sp. (hooked thecae)
monograptid or cyrtograptid fragments
Age: Silurian(?) (could be Devonian)

USGS Coll. D247 SD (14052-6JA). Roberts Mountains Formation, about 15 m below top as mapped. Collected by J. H. Stewart.
Monograptus sp. (a monograptid of the *M. hercynicus* group very similar to *M. yukonensis*—it may be that form or something closely related to it)
linograptid fragments
Age: Early Devonian, probably in the span of late Siegenian-Emsian

USGS Coll. D248 SD (14052-6JB). Roberts Mountains Formation, about 15 m below top but 90 m west of 6JA. Collected by J. H. Stewart.
Monograptus aff. *M. kodymi* Boucek
Monograptus sp. (has simple tubular thecae)
Age: Silurian, in span of late Llandoverian-Wenlockian and probably latest Llandoverian

William B. N. Berry
October 15, 1969

Silver Creek, west side of Toiyabe Range, Lander County, Nev. About sec. 21, T. 21 N., R. 44 E. Vigus Butte NE quadrangle.
USGS Coll. D258 SD (TM-F-57-69) Graptolites from Roberts Mountains Formation, float, stratigraphic position not known—thrust faults at base and top of exposure. Unit in thrust contact—both above and below—with rocks mapped as Ordovician Antelope Valley Limestone by Stewart and McKee (1970).
Monograptus nilssoni (Barrande)
Monograptus sp. (of the *M. scanicus* type)
Age: early Ludlovian

William B. N. Berry
January 5, 1970

USGS Coll. 6918 CO (TM-F-6-69) Fine-grained blue-gray limestone near crest of ridge. About 120 m above thrust fault and from unit mapped as Antelope Valley Limestone.

Oepikodus sp.	2
Belodella? sp.	1

Age: This is probably Ordovician in age, but these species are new to me.

John W. Huddle
February 19, 1970

Grass Valley between Toiyabe Range and Simpson Park Mountains, Lander County, Nev. Sec. 13, T. 21 N., R. 46 E., Mt. Callaghan quadrangle.
USGS Coll. D330 SD (TM-F-71-6) Scrap graptolites, all float from basal 23 m of Roberts Mountains Formation, NW¼SW¼ sec. 13, T. 21 N., R. 46 E.
Monograptus sp. (appear to be monograptids of the *M. vomerinus* and *priodon* groups)
Age: Silurian, probably in span of late Llandoverian-Wenlockian

USGS Coll. D331 SD (TM-F-71-7) Three poorly preserved fragments of monograptids and a couple of plates with odd possibly organic markings. Collected just east of prospect in south part of sec. 13, T. 21 N., R. 46 E. Rocks have more of a Wenban Limestone look (gray nonplaty weathering) than most of the Roberts Mountains Formation. If no faults are present, the collection is about 610 m above base of Roberts Mountains and about 610 m below top of exposed laminated limestone.
linograptid?
Monograptus sp. (could be *M. dubius* type)
Age: probably in span of Late Silurian-Early Devonian

William B. N. Berry
June 16, 1971

TOQUIMA RANGE

Black Cliff Canyon (informal name), central Toquima Range, Nye County, Nev. About sec. 8, T. 12 N., R. 46 E. (unsurveyed), lat 38°53′ N., long 116°50′ W., Northumberland Pass quadrangle
USGS Coll. D2214 CO (TM-F-31-70) Graptolites in place in laminated limestone about 1 m below top Perkins Canyon Formation (Ordovician) of Kay and Crawford (1964) about 1.6 km above mouth of canyon just south of East Northumberland Canyon.
Dicellograptus complanatus ornatus Elles and Wood
Dicellograptus complanatus arkansasensis Ruedemann
Climacograptus supernus Elles and Wood
Diplograptus cf. *D. crassitestus*
Orthograptus truncatus abbreviatus Elles and Wood
Age: latest Ordovician, zone 15 (*D. complanatus ornatus* Zone)
One piece in the collection does not bear any of the above listed species but instead bears the following:
Leptograptus sp.
Pleurograptus? sp.
Climacograptus sp. (similar to *C. styloideus)*
Age: This association of forms suggests a zone 14 age. (See USGS Coll. D2277 CO).

USGS Coll. D313 SD (TM-F-32-70) Graptolites from greenish-gray silicified claystone in place 35 m above base of basal cherty unit of Roberts Mountains Formation (cherty unit is 50 m thick) exposed 1.6 km above mouth of canyon just south of East Northumberland Canyon.
Monograptus convolutus Hisinger
Monograptus jaculum?
Monograptus lobiferus?
Monograptus sp. (of the *M. priodon* type)
Retiolites geinitzianus Barrande
Age: Silurian-Llandoverian, about zone 22-23

USGS Coll. D314 SD (TM-F-33-70) Float collection from upper 15 m of the basal cherty unit in the Roberts Mountains Formation, Black Cliff Canyon, same location as D313 SD.
Monograptus sp. (of the *M. spiralis* type)
Monograptus sp. (of the *M. priodon* type)
Monograptus cf. *M. crispus* Lapworth
Retiolites geinitzianus Barrande
plegmatograptid

Age: Silurian-Llandoverian, probably about zones 23-24

William B. N. Berry
January 11, 1971

USGS Coll. D2277 CO (TM-F-71-4) Graptolites. Perkins Canyon Formation of Kay and Crawford (1964). Collected in laminated black limestone 4.5 m below top and 3.2 m below D2214 CO.

Climacograptus hvalross Ross and Berry
Dicellograptus complanatus var. *ornatus* Elles and Wood
Orthograptus truncatus var. *abbreviatus* Elles and Wood

Age: Ordovician, zone 15 without question (all but one piece in D2214 CO had the same zone graptolites and the graptolites on that one piece were so highly smeared that precise identification to species was not possible, hence the suggested zone 14 age for it was highly questionable—and a suggestion that perhaps zone 14 material was present in the section)

USGS Coll. D329 SD (TM-F-71-5) Scraps of graptolites from float of silicified claystone below *M. convolutus* Zone in basal chert of the Roberts Mountains Formation, Black Cliff Canyon.

Climacograptus sp.
Diplograptus?
Glyptograptus???

Age: in span of Late Ordovician-Early Silurian. The climacograptid seems similar to species known from the Early Silurian such as *C. rectangularis* and *C. medius.*

William B. N. Berry
June 16, 1971

Wood Canyon, east side of Toquima Range, Nye County, Nev. About sec. 4, T. 12 N., R. 46 E. (unsurveyed), Northumberland Pass quadrangle.

USGS Coll. D320 SD (TM-F-43-70) Graptolites from about 8 m above base of Roberts Mountains Formation, basal cherty unit north side of Wood Canyon, and about 2.4 km above mouth. Cherty unit is about 35 m thick. Collected by E. H. McKee.

Climacograptus cf. *C. scalaris* Hisinger
Climacograptus sp. (similar to *C. medius)*

Age: Silurian-Early Llandoverian, about zones 16-19

William B. N. Berry
January 11, 1971

USGS Coll. D327 SD (TM-F-71-2) Sparse collection of graptolites from about 15 m above base of Roberts Mountains Formation, north side of Wood Canyon and about 2.4 km above mouth. Same locality as D320 SD.

Climacograptus sp. *(C. medius-C. rectangularis* type)
Pseudoclimacograptus hughesi (Nicholson)
Monograptus sp. (cf. *M. revolutus* Kurck)

Age: Silurian-Llandoverian, approximately zone 18 or 19

William B. N. Berry
June 16, 1971

USGS Coll. D242 SD (E8FP-170F). Graptolites from south side of Wood Canyon and about 2.4 km above mouth. From basal cherty unit of Roberts Mountains Formation. Collected by F. G. Poole.

Climacograptus of *C. scalaris* (Hisinger) (Linne?)
Climacograptus sp.
Diplograptus sp.
Monograptus sp. (fragments have the aspect of *M. revolutus)*
Rhaphidograptus? sp.

Age: Silurian-Llandoverian, probably in the span of zone 18 *(Monograptus cyphus)* and 19 *(Monograptus gregarius)*

William B. N. Berry
April 16, 1969

West Northumberland Canyon, Toquima Range. Land not surveyed. About lat 39°00′ N., long 116°53′ W., near border of Jet Spring and Wildcat Peak quadrangle

USGS Coll. D237 SD (TM-F-30-68). North side of West Northumberland Canyon. About 0.4 km upstream from Badwater Canyon. Single graptolite from float just above basal cherty unit of Roberts Mountains Formation. Graptolite is not well preserved.

cyrtograptid cladial fragment? (Only a fragment is present)

Age: inasmuch as this fragment has plain thecae and may be a part of a cyrtograptid—or perhaps it may be a piece of a long, slender rhabdosome with plain thecae—it is Silurian in age and probably falls within a late Llandoverian-Wenlockian span

William B. N. Berry
November 8, 1968

USGS Coll. D307 SD (TM-F-25-70) Float collection of graptolites from just above basal cherty unit of Roberts Mountains Formation on west side of mouth of Badwater Canyon at West Northumberland Canyon.

Monograptus vomerinus cf. var. *gracilis* Elles and Wood
cyrtograptid scrap?

Age: in span of late Llandoverian-Wenlockian

William B. N. Berry
January 11, 1971

Mill Canyon, Toquima Range, Nye County, Nev. About lat 39°01′ N., long 116°47′ W., Wildcat Peak quadrangle

USGS Coll. D308 SD (TM-F-26-70) Float collection from just above base of Roberts Mountains Formation (no basal chert) from east side and about 1.2 km up first major fork at Mill Canyon.

Monograptus colonus Barrande
Monograptus dubius Suess
Monograptus nilssoni Barrande

Age: Silurian-early Ludlovian, *Monograptus nilssoni* Zone

USGS Coll. D309 SD (TM-F-27-70) Float collection about 23 m above base of Roberts Mountains Formation. Same location as D308 SD

Monograptus bohemicus Barrande
Monograptus colonus Barrande
Monograptus nilssoni Barrande
Monograptus uncinatus?

Age: Silurian-early Ludlovian, *Monograptus nilssoni* Zone

William B. N. Berry
January 11, 1971

Ikes Canyon, Toquima Range, Nye County, Nev. About sec. 13, T. 14 N., R. 46 E. (unsurveyed), Dianas Punch Bowl quadrangle

USGS Coll. D310 SD (TM-F-28-70) Graptolites in place but distance above base of Roberts Mountains Formation not known—probably about 115 m above base and 3 m below top. Just below basal bed of McMonnigal Limestone. About 0.4 km south of Ikes Cabin and on south side of and 1.8 km above the mouth of Ikes Canyon.

Monograptus sp. (*M. hercynicus* group—could be *M. angustidens)*
Monograptus sp. (uncinate thecae—could be *M. bouceki)*
Monograptus sp. (appears similar to *M. transgrediens)*

Age: in span of latest Silurian-earliest Devonian, possibly latest Silurian

USGS Coll. D311 SD (TM-F-29-70) Float collection of graptolites. All about 8 m above base of Roberts Mountains Formation (no basal chert) exposed along ridge that extends southwest from mouth of Ikes Canyon. Possibly Roberts Mountains Formation is in fault contact with underlying rocks and an unknown thickness of basal Roberts Mountains is missing.

Monograptus bohemicus Barrande
Monograptus colonus Barrande
Monograptus dubius Suess
Monograptus scanicus?
Age: Silurian–early Ludlovian, *Monograptus nilssoni* Zone (?)

USGS Coll. D312 SD (TM-F-30-70) Float collection of graptolites. Three fragments about 85 m above base of Roberts Mountains Formation, and two fragments about 105 m above base which is probably a fault instead of a sedimentary contact. About 100 m southwest of D311 SD on ridge that extends southwest from mouth of Ikes Canyon.
85 m:
Monograptus sp. (of the *M. dubius* type)
Monograptus nilssoni? Barrande
105 m:
Monograptus nilssoni?
Age: Silurian, probably Ludlovian
William B. N. Berry
January 11, 1971

Petes Canyon area, Toquima Range, Lander County, Nev. Sec. 10, T. 16 N., R. 46 E., Wildcat Peak quadrangle and sec. 5, T. 16 N., R. 46 E., Spencer Hot Springs quadrangle.
USGS Coll. D232 SD (TM-F-25-68) Sec. 10, T. 16 N., R. 46 E., Graptolites collected from the lower part of the Roberts Mountains Formation at Petes Canyon window.
Bag 1—Graptolites in chert float near base of basal cherty unit of Roberts Mountains Formation.
Monograptus sp. (of the *M. priodon* group)
Monograptus sp. (plain tubular thecae)
Age: in the span of late Llandoverian–Wenlockian
Bag 2—Sparse collection of graptolites that are either from within the upper part of the lower cherty unit of the Roberts Mountains Formation or within the lower 0.3 m of rock that overlies the chert.
Cyrtograptus cf. *C. solaris* Boucek
Monograptus spiralis (Geinitz)
Retiolites geinitzianus Barrande
Age: late Llandoverian, this association is typical of zone 1 of the Silurian-Devonian faunizones outlined by Berry (1969). It is the approximate correlative of the late Llandoverian zones of *Monograptus griestoniensis* and *M. crenulatus* of Elles and Wood.
Bag 3—Float of straight graptolites that could have been in the upper meter of the chert or in the lower 3 m of rock that overlie the chert.
Cyrtograptus sp. (of the *C. lapworthi* type)
Monograptus priodon (Bronn)
Monograptus sp. (of the *M. vomerinus* group)
Age: probably late Llandoverian (could be early Wenlockian). The presence of a cyrtograptid close to *C. lapworthi* is suggestive that this collection is more likely of late Llandoverian age.
Bag 4—Graptolites that occur 23–35 m above the base of the Roberts Mountains Formation.
Monograptus sp. (of the *M. dubius* group)
Monograptus sp. (fragment appears to be a monograptid of the *M. vomerinus* type)
Age: in the span of late Llandoverian–Wenlockian
Bag 5—Graptolites collected from float at the top of the basal cherty unit of the Roberts Mountains Formation in sec. 5, T. 16 N., R. 46 E.
Cyrtograptus sp. (of the *C. lapworthi* type)
Monograptus priodon (Bronn)
Stomatograptus grandis Suess
Age: late Llandoverian, the presence of *S. grandis* is indicative of a latest Llandoverian age
William B. N. Berry
November 8, 1968

USGS Coll. D299 SD (TM-F-11-70) Single fragment of graptolite collected about 150 m above basal cherty unit of Roberts Mountains Formation at Petes Canyon area, sec. 10. Probably float from older Roberts Mountains exposed across fault to south.
Monograptus sp.—*M. dubius* group?
Age: in the span of late Llandoverian–Pridoli
William B. N. Berry
August 12, 1970

USGS Coll. D328 SD (TM-F-71-3) Very sparse float collection of graptolites in lower 23 m of basal cherty unit of the Roberts Mountains Formation, north-central sec. 10, T. 16 N., R. 46 E. Chert is about 43 m thick if not faulted. Chert is across normal fault from D232 SD.
In place collection: about 23 m above base of chert
Climacograptus sp.
Retiolites geinitzianus angustidens Elles and Wood
Monograptus convolutus (Hisinger)
Age: Silurian–Llandoverian, about zone 22 or 23
Float collection: float below in place collection
Climacograptus sp.
Diplograptus sp.?
Monograptus?
Orthograptus?
Age: Silurian–early part of the Llandoverian, in span of zones 18–23 or 24
William B. N. Berry
June 16, 1971

MONITOR RANGE

Clear Creek Mountain (informal name), Monitor Range, Nye County, Nev. About sec. 31, T. 12 N., R. 49 E. (unsurveyed), Danville quadrangle
USGS Coll. D262 SD (TM-F-61-69) Sparse collection of monograptids from laminated dolomite float in lower 15 m of beds equivalent to the Roberts Mountains Formation.
Cyrtograptus? sp.
Monograptus sp. (of the *M. vomerinus* type?)
Age: in span of late Llandoverian–Wenlockian
William B. N. Berry
January 5, 1970

USGS Coll. 8222 SD (TM-F-14-68) Grab sample of medium-grained light-gray massive dolomite. About 30 m above laminated dolomite that is equivalent to the Roberts Mountains Formation at Miniature Grand Canyon a few miles north T. 12 N., R. 49 E.

Acodus sp.	2
Belodella sp.	1
Prioniodina sp.	1
Icriodus?	fragment
Icriodus woschmidti? Ziegler	1
Hindeodella sp.	1

Age: probably Early Devonian based on the *I. woschmidti*? I would need a larger collection to be sure of this identification.
John W. Huddle
April 4, 1969

USGS Coll. 8485 SD (69FP-237F) Brown medium-grained 4.5-m-thick dolomite cliff-former estimated to be about 60 m above top of Ely Springs Dolomite or Hanson Creek Formation interbedded with laminated dolomite beds equivalent to the Roberts Mountains Formation. Collected by F. G. Poole.

Ligonodona sp.	1
Prioniodina sp.	1
Spathognathodus exiguus Phillip	1

Age: *S. exiguus* has been reported from Lower Devonian rocks in Nevada, Canada, and Australia.

USGS Coll. 8486 SD (69FP-238F) Coarse-grained dolomite about 15 m above 8485 SD. Collected by F. G. Poole.

Belodella sp.	1
Ozarkodina sp.	1
O. cf. *O. media* Walliser	1
Panderodus sp.	3
Plectospathodus sp.	1
Spathognathodus sp.	2

Age: This collection could be Silurian or Early Devonian in age. Nothing diagnostic but there is nothing inconsistent with a Devonian age indicated by the samples above and below.

USGS Coll. 8487 SD (69 FP-239F) Coarse-grained dolomite probably equivalent to the Lone Mountain Dolomite and 15 m above 8486 SD. Collected by F. G. Poole.

Diplododella sp.	1
Hindeodella sp.	10
Ozarkodina denkmanni Ziegler	9
Panderodus sp.	6
Plectospathodus sp.	1
Spathognathodus remscheidensis Ziegler	20

Age: The conodonts in this collection are fractured and most specimens are broken. The identification of *S. remscheidensis* is doubtful but this seems to be an Early Devonian fauna.

John W. Huddle
September 18, 1970

Miniature Grand Canyon, Monitor Range. About sec. 32, T. 13 N., R. 49 E. and sec. 5, T. 12 N., R. 49 E. Stargo Creek quadrangle, Nye County, Nev.

USGS Coll. D257 SD (TM-F-56-69) About sec. 32, T. 12 N., R. 49 E. Graptolites probably about 60 m above base of exposed Roberts Mountains Formation, but base of exposure of Roberts Mountains is at a fault. Collected above second coarse-grained fossiliferous limestone exposed just east of fault. Between 8435 SD and 8436 SD.

Monograptus chimaera (Barrande)?
Monograptus colonus (Barrande)
Monograptus dubius (Suess)
Monograptus nilssoni (Barrande)
Monograptus of *M. praedubius* (Boucek)

Age: early Ludlovian

William B. N. Berry
January 5, 1970

USGS Coll. 8435 SD (TM-F-3-69) Basal coarse-grained limestone in zone of interbedded laminated limestone and coarse-grained limestone unit of the Roberts Mountains Formation. Below D257 SD.

Belodella cf. *B. resimus* Philip	1
Hindeodella sp.	6
Neoprioniodus excavatus (Branson and Mehl)	3
Ozarkodina sp.	1
Panderodus sp.	31
Plectospathodus sp.	1
Ozarkodina sp.	1
Prioniodina sp.	1
Spathognathodus inclinatus inclinatus Rhodes	16
S. sp.	3
Trichonodella sp.	1
"Oneotodus" beckmanni Bischoff and Sanneman	1

Age: There is nothing in this fauna restricted to the Silurian or Lower Devonian. It could be as old as early Ludlovian or as young as Emsian.

John W. Huddle
February 19, 1970

pentameroid brachiopod, probably *Rhipidium*
Coelospira sp.
atrypid fragment, indet.

Age: The presence of a probable *Rhipidium* suggests a Late Silurian (Ludlovian) rather than a Devonian age.

J. T. Dutro, Jr.
September 27, 1971

Alveolites sp.
Cladopora sp.
Coenites sp.
Favosites?
Undetermined rugose corals, 8+ species

Age: Silurian or Devonian

William A. Oliver, Jr.
September 14, 1971

USGS Coll. 8436 SD (TM-F-4-69) Unnamed Devonian beds. Coarse-grained limestone 15 m above the base of the interbedded coarse-grained limestone and silty limestone that overlies the laminated silty limestone in the Roberts Mountains Formation where D257 SD was collected.

Belodella cf. *B. resimus* Philip	1
Bryantodus sp.	1
Hindeodella sp.	10
Neoprioniodus excavatus (Branson and Mehl)	5
Ozarkodina denckmanni (Ziegler)	1
O. media Walliser	18
O. robustus (Bischoff and Sannemann)	3
Panderodus sp.	1
Plectospathodus extensus (Rhodes)	11
Scolopodus devonicus Bischoff and Sannemann	2
Spathognathodus remscheidensis (Ziegler)	23
S. wurmi Bischoff and Sannemann	38

Age: This collection appears to be Early Devonian in age. The presence of *O. denckmanni*, *S. remscheidensis*, *B.* cf. *resimus*, and *S. devonicus* all suggest an Early Devonian age but a Late Silurian age is not impossible.

John W. Huddle
February 19, 1970

Machaeraria? sp.
Atrypina cf. *A. simpsoni* Johnson
brachiopod fragments, indet.

Age: This most likely represents the Early Devonian *Quadrithyris* Zone.

J. T. Dutro, Jr.
September 27, 1971

Cladopora sp.
Coenites sp.
Favosites sp.

Age: Silurian or Devonian

William A. Oliver, Jr.
September 14, 1971

Stargo Spring area, Monitor Range, Nye County, Nev. About sec. 20, T. 13 N., R. 49 E. (unsurveyed), Stargo Creek quadrangle.

USGS Coll. D300 SD (TM-F-12-70) Graptolites from laminated limestone about 15 m above basal chert of Roberts Mountains Formation, but there is a fault of unknown displacement between graptolite-bearing rocks and top of basal cherty unit. Sparse float collection from isolated outcrop a few hundred meters east of main collection.

Monograptus dubius Suess
Monograptus "praedeubeli"
Age: latest Wenlockian, *M. dubius/G. nassa* Zone
Float—*M. dubius* and *M. scanicus.*

William B. N. Berry
August 12, 1970

Copenhagen Canyon, Monitor Range, Eureka County, Nev. SW¼ sec. 36 T. 16 N., R. 49 E., Horse Heaven Mountain quadrangle.

USGS Coll. D234 SD (TM-F-27-68) Collection includes one bag of graptolites from laminated limestone float collected just above the basal cherty unit and 35 m above base of Roberts Mountains Formation, one bag from float extending 35 to 85 m above base; and one bag from 100 m above base.

Graptolites from laminated limestone float near top of the basal cherty unit and 35 m above base of the Roberts Mountains Formation.

Cyrtograptus sp.
Monograptus priodon (Bronn)
Age: in the span of late Llandoverian-early Wenlockian

Graptolites in float 35 to 85 m above base of the Roberts Mountains Formation.

Cyrtograptus sp.
Monograptus flemingii (Salter)
Age: probably Wenlockian

Graptolites from 100 m above base of the Roberts Mountains Formation.

Monograptus dubius (Suess)
Monograptus uncinatus Tullberg
Gothograptus spinosus Wood
Age: early Ludlovian, *Monograptus nilssoni-M. Scanicus* Zone

William B. N. Berry
November 8, 1968

USGS Coll. D256 SD (TM-F-55-69)

Bag A—Graptolites from upper 0.3 m of basal limestone and chert unit (31 m thick) of Roberts Mountains Formation.

Climacograptus of *C. rectangularis* (McCoy)
Dimorphograptus confertus of var. *Swanstoni* (Lapworth)
Glyptograptus sp.
Age: early Llandoverian, zone 18 of Elles and Wood

Bag B—Graptolites, mainly float, at 120 m above base of Roberts Mountains Formation.

Monograptus bohemicus (Barrande)
Monograptus colonus (Barrande)
Monograptus of *M. crinitus* (Wood)
Monograptus micropoma (Jaekel)
Age: early Ludlovian

Bag C—Graptolites, mainly float, at 150 m above base of the Roberts Mountains Formation.

Monograptus bohemicus (Barrande)
Monograptus colonus (Barrande)
Monograptus of *M. crinitus* (Wood)
Monograptus dubius (Suess)
Monograptus micropoma (Jaekel)
Monograptus nilssoni (Barrande)
Monograptus of *M. praedubius* (Boucek)
Monograptus scanicus (Tullberg)
Age: early Ludlovian

Bag D—Graptolites in float 150-185 m above base of Roberts Mountains Formation.

185 m—*Monograptus* sp. (of the *M. dubius* type)
175 m—*Monograptus bohemicus* (Barrande)
Age: Ludlovian

William B. N. Berry
January 5, 1970

USGS Coll. D297 SD (TM-F-9-70) Two meager float collections of graptolites from Roberts Mountains Formation.

Bag A—From about 230 m above base and bag B from about 245 to 305 m above base if no faults crossed.

Age: *Monograptus* of the *M. dubius group*—age is in span of late Llandoverian-Pridoli; *Monograptus* sp. with uncinate thecae—possibly Pridoli or Early Devonian

William B. N. Berry
August 12, 1970

USGS Coll. 8214 SD (TM-F-15-68) Thin beds of bioclastic limestone 120 m above base of Roberts Mountains Formation.

"Neoprioniodus" excavatus (Branson and Mehl)	1
Ozarkodina media Walliser	1
Panderodus sp.	12
Plectospathodus extensus Rhodes	4
Plectospathodus sp.	1
Spathognathodus inclinatus Rhodes	2
S. remscheidensis? Ziegler	1
"Synprioniodina" silurica? Walliser	1
Trichonodella sp.	1

S. remscheidensis and *S. inclinatus* occur in Upper Silurian and lower Devonian rocks.
Age: Late Silurian or Early Devonian

John W. Huddle
March 4, 1969

Collection contains a number of silicified fragments of brachiopods, including *Resserella*?, *Salopina, Atrypa* and pentameroids (at least one specimen of *Conchidium* or *Kirkidium*).
Age: most likely Late Silurian (Ludlovian)

J. T. Dutro, Jr.
March 9, 1972

USGS Coll. 8304 SD (TM-F-15-68) Thin beds of medium-grained limestone 190 m above base of Roberts Mountains Formation.

Hindeodella sp.	1
Panderodus sp.	4
Ozarkodina aff. *O. ziegleri* Walliser	1
Spathognathodus inclinatus Rhodes	5
S. sp.	1

Age: Late Silurian or Early Devonian

John W. Huddle
March 4, 1969

USGS Coll. 8304 SD (TM-F-15-68) Same location as 8214 SD, 190 m above base of Roberts Mountains Formation.

Collection contains scraps of orthoids (perhaps *Salopina), Atrypa* and costate pentameroids (perhaps *Kirkidium).*
Age: most likely Late Silurian (Ludlovian)

J. T. Dutro, Jr.
March 9, 1972

USGS Coll. 8449 SD (TM-F-16-69) Platy weathering fine-grained limestone about 180 m above the base of the Roberts Mountains Formation. 1.6 m above 8304 SD.

Ancyrognathus? sp.	2
Hindeodella sp.	2
Drepanodus sp.	1
Ozarkodina sp.	1
Panderodus sp.	1
Plectospathodus extensus Rhodes	2
Polygnathoides emarginatus (Branson and Mehl)	1
Prioniodina sp.	1
Spathognathodus inclinatus Rhodes	2

Age: If I am correct in my identification of *P. emarginatus*, from a single specimen, this collection is Late Silurian.

John W. Huddle
March 13, 1970

USGS Coll. 8488 SD (69FP-246F) About 5 m below top of Hanson Creek Formation. Collected by F. G. Poole.

Icriodina cf. *I. stenolopata* Rexroad	1

Age: If this identification is correct the age is Early Silurian. The species was described from the Brassfield Formation. More specimens needed to be sure.

USGS Coll. 8489 SD (69FP-247F) About 1 m below top of Hanson Creek Formation. Collected by F. G. Poole.

Acodus unicostatus Branson	1
Drepanodus sp.	2
Panderodus sp.	2
Paltodus cf. *P. dyscritus* Rexroad	2

Except for the *Drepanodus*, these species occur in the Brassfield Formation of Kentucky.
Age: probably Early Silurian

John W. Huddle
September 18, 1970

Brock Canyon, Monitor Range, Eureka County, Nev. About SW¼ sec. 25, T. 17 N., R. 48 E. (unsurveyed), Hickison Summit quadrangle.

USGS Coll. D315 SD (TM-F-34-70) Float collection of graptolites from base of cherty unit (about 9 m thick) to 45 m above base of Roberts Mountains Formation at Brock Canyon.
Monograptus bohemicus (Barrande)
Monograptus colonus (Barrande)
Monograptus nilssoni (Barrande)
Monograptus uncinatus?
Age: Silurian-early Ludlovian, *Monograptus nilssoni* Zone

USGS Coll. D316 SD (TM-F-35-70) Float collection of graptolites from about 60 to 140 m above base of Roberts Mountains Formation, Brock Canyon.
Monograptus colonus (Barrande)
Monograptus dubius Suess
Monograptus scanicus Tullberg
Age: Silurian-early Ludlovian, *Monograptus scanicus* Zone

USGS D317 SD (TM-F-36-70) In place collection of graptolites from about 185 m above base of Roberts Mountains Formation, Brock Canyon, and a float collection 100 m southeast of in-place collection.
Monograptus sp. (*M. hercynicus* group)
Age: Early Devonian(?)

William B. N. Berry
January 11, 1971

SIMPSON PARK MOUNTAINS

Coal Canyon, northern Simpson Park Mountains, Eureka County, Nev. SE¼ sec. 17 and N½ sec. 20, T. 25 N., R. 49 E. Horse Creek Valley quadrangle.

USGS Coll. 8218 SD (TM-F1-68) Laminated limestone just above chert at base of Roberts Mountains Formation in SW¼ sec. 17.
Monograptus griestoniensis (Nicol)
Monograptus sp.
Stomatograptus grandis (Suess)
Age: latest Llandoverian

USGS Coll. 8218A SD Roberts Mountains Formation—float from 60 m above base. SW¼ sec. 17
Fragments of graptoloids, slender, two pieces with plain thecae and one with slightly hooked thecae. These could be parts of cyrtograptids.
Age: Silurian, possibly Wenlockian.

USGS Coll. 8218B SD 105 m above base of Roberts Mountains Formation at SW¼ sec. 17.
Monograptus bohemicus cf. var. *tenuis* Boucek
Monograptus uncinatus Tullberg
Age: Ludlovian, probably early Ludlovian

William B. N. Berry
March 17, 1969

USGS Coll. D228 SD (TM-F-21-68) Central part N½ sec. 20, T. 25 N., R. 49 E. Poorly preserved graptolites from about 380 m above the base of the Roberts Mountains Formation of the Coal Canyon section.
Monograptus praehercynicus Jaeger
Monograptus cf. *M. praehercynicus* Jaeger (This is a thin form commonly found to occur in the *M. uniformis* Zone and to range upwards to occur with *M. praehercynicus* in the *M. praehercynicus* Zone.)
Age: Devonian, *Monograptus praehercynicus* Zone—this is a probable correlative of the late Gedinnian

William B. N. Berry
November 8, 1968

USGS Coll. 8216 SD (TM-F-2-68) Roberts Mountains Formation across fault and about 67 m above creek on east side of Coal Canyon, SE¼ sec. 17, T. 25 N., R. 49 E.

Belodella devonicus (Stauffer)	3
B. n. sp.	7
Hindeodella sp.	11
Icriodina? sp.	1
Kockelella variabilis Walliser	1
Lonchodina walliseri Ziegler	1
Neoprioniodus excavatus (Branson and Mehl)	2
Ozarkodina denkmanni Ziegler	2
O. gaertneri? Walliser	1
O. media Walliser	14
O. typica Branson and Mehl	2
Neoprioniodus multiformis? Walliser	5
Paltodus n. sp.	1
Panderodus sp.	1
Plectospathodus extensus Rhodes	12
P. aff. *P. alternatus* Walliser	10
Scolopodus devonicus Bischoff and Sannemann	2
Spathognathodus dubius (Ethington and Furnish)	26
S. eosteinhornensis (Walliser)	14
Synprioniodina sp.	1

Age: The fauna is probably Late Silurian, Ludlovian in age. The

Late Silurian age is based primarily on the presence of *S. eosteinhornensis*. *O. gaertneri*, *Icriodina* and *Kockelella* should not occur with *O. denkmanni*, *S. eosteinhornensis* and *O. typica*. Perhaps this is a mixed or contaminated sample.

John W. Huddle
April 4, 1969

Collection contains:
echinoderm debris, indet.
favositid and horn corals, indet.
ramose bryozoans, indet.
orthoid brachiopods, indet.
Leptaena? sp.
Gypidula aff. *G. pelagica* (Barrande)
Cyrtina sp.
Atrypa sp.
Age: probably earliest Devonian (Gedinnian)

J. T. Dutro, Jr.
March 9, 1972

CORTEZ MOUNTAINS

Rattlesnake Canyon (informal name), Cortez Mountains, Eureka County, Nev. Includes secs. 4 and 9, T. 26 N., R. 48 E., Cortez quadrangle.

USGS Coll. D229 SD (TM-F-22-68) NW¼ sec. 9, T. 26 N., R. 48 E. Only graptolites found in place in section measured at Rattlesnake Canyon. They are 8 m above base of Roberts Mountains Formation. One specimen of a *Monograptus spiralis* found at base of Roberts Mountains Formation 0.8 km south of section.
Monograptus cf. *M. praedubius* Boucek
Monograptus priodon (Bronn)
Monograptus riccartonensis Lapworth
Possible cyrtograptid cladia
fragments of monograptids that may be of the *M. vomerinus* group
Age: early Wenlockian, probably *Monograptus riccartonensis* Zone. The presence of a *Monograptus spiralis* at the base of the formation is indicative of a slightly older age—a latest Llandoverian age—for the beds bearing it.

William B. N. Berry
November 8, 1968

USGS Coll. D293 SD (TM-F-5-70) Meager collection of graptolites from laminated limestone about 300 m above base of Roberts Mountains Formation and 30 m below lowest coarse-grained limestone assigned to the Wenban Limestone. SE¼SW¼ sec. 4. About 0.8 km north of section measured in Rattlesnake Canyon.
Monograptus uniformis?—a hercynicus group form anyway.
Age: Early Devonian

William B. N. Berry

Cortez mine, Lander County, Nev., Cortez quadrangle. Land not surveyed. Approximately lat 40°11′30″ N., long 116°37′00″ W.

USGS Coll. D289 SD (TM-F-1-70) Poorly preserved iron-stained graptolites(?), Roberts Mountains Formation; stratigraphic position not known. From gold ore float, 1550-m level, high wall on south side of west pit.
?*Monograptus flemingii*

USGS Coll. D290 SD (TM-F-2-70) Poorly preserved graptolites and a leaf-shaped marking on bedding surface. Roberts Mountains Formation; stratigraphic position not known. From gold ore, 5200-ft level, west end of east pit.
Monograptids, but not identifiable as to genus

USGS Coll. D291 SD (TM-F-3-70) Extremely poorly preserved graptolites(?), Roberts Mountains Formation; stratigraphic position not known. From 1550-m level, west end of east pit.
Monograptus sp. of the *M. dubis* group
Age: These three collections indicate an age in the span of late Llandoverian to Pridoli

William B. N. Berry
August 12, 1970

USGS Coll. D332 SD (TM-F-8-71) Two collections from float of Roberts Mountains Formation. 1550-m bench, north side of southeast pit.
Bag 1 contains graptolites and possible *Styliolina* or *Tentaculites;* bag 2 contains different graptolites from other float. Stratigraphic position in Roberts Mountains Formation not known.
Bag 1: *Monograptus* cf. *M. praehercynicus* Jaeger
Age: Early Devonian—probably late Gedinnian.
Bag 2: *Monograptus* aff. *M. praehercynicus* (a new species)
Age: Early Devonian—this is the *M. hercynicus* group monograptid cited by Berry (1970) as being indicative of the *M. uniformis* Zone in central Nevada; thus an Early Devonian-early Gedinnian age is suggested for the blocks bearing it.
It appears that these rocks from the Cortez mine area are Early Devonian in age and that two graptolite zones—*M. uniformis* and *M. praehercynicus*—are represented.

William B. N. Berry
June 16, 1971

Cortez Canyon, Lander County, Nev. Land not surveyed. Approximately lat 40°11′ N., long 116°38′ W., Cortez quadrangle. Collections made across contact of Roberts Mountains Formation and Wenban Limestone as mapped by Gilluly and Masursky (1965, pl. 1) about 0.5 km above mouth of Cortez Canyon.

USGS Coll. 8220 SD (TM-F-13-68) Float from the upper 15 m of the Roberts Mountains Formation.
Age: A number of specimens of *Strophochonetes* and poor scraps of a possible *Leptocoelia*. If latter is actually that genus, age is Early Devonian. It could be a similar-looking genus, however, and age range would be Late Silurian-Early Devonian.

USGS Coll. 8220A SD (TM-F-13-68) Same locality as 8220 SD. Float from the lower 30 m of the Wenban Limestone.
Collection contains indeterminate brachiopod fragments, a possible *Leptocoelia*, and several partial trilobites, probably phacopids.
Age: probably Early Devonian

J. T. Dutro, Jr.
March 9, 1972

Icriodus? sp.
Age: probably Devonian

John W. Huddle
April 4, 1969

Fourmile Canyon, Cortez quadrangle. About lat 40°13′N., long 116°32′30″ W.

USGS Coll. D92 SD Supplemental collection by TEM—Fourmile Canyon Formation, about 2.5 km above mouth and on north side of Fourmile Canyon, Cortez Mountains, Eureka County, Nev. Supplement to collection F 20A made by Gilluly and Masursky (1965, pl. 2 and table 2).
Climacograptus sp. of the *C. scalaris* type
Monograptus sp.

Age: early Llandoverian

William B. N. Berry
August 12, 1970

SULPHUR SPRING RANGE

Sulphur Spring Range, Eureka County, Nev. Unnamed canyon about NE¼NE¼ sec. 27, T. 25 N., R. 52 E. (unsurveyed), Mineral Hill quadrangle.

USGS Coll. D326 SD (TM-F-1-71) Sparse collection of monograptids in laminated limestone from 9 m above base of Roberts Mountains Formation.

Cyrtograptus?
Monograptus retroflexus Tullberg
Monograptus sp. (*M. dubius* group)
Monoclimacis flumendosae Gortani
Monoclimacis sp.

Age: Silurian-Wenlockian, possibly later part of Wenlockian

William B. N. Berry
June 16, 1971

MAGGIE CREEK CANYON

Maggie Creek Canyon, Eureka County, Nev. Secs. 24, 26, and 27, T. 34 N., R. 51 E., Schroeder Mountain quadrangle.

USGS Coll. D230 SD (TM-F-23-68). Stratigraphic position in Roberts Mountains Formation not known.

Graptolite from float from Roberts Mountains Formation high on south side of Maggie Creek Canyon, NW¼ sec. 26.

Monograptus bohemicus (Barrande)

Age: Ludlovian

In-place collection from Roberts Mountains Formation exposed in roadcut, south side of Maggie Creek Canyon, NE¼ sec. 26.

Monograptus bohemicus (Barrande) (thin form)
Monograptus dubius (Suess)
Monograptus micropoma (Jaekel)
Monograptus sp. (of the *M. colonus* type?)

Age: early Ludlovian, probably *Monograptus nilssoni-M. scanicus* Zone

William B. N. Berry
November 8, 1968

USGS Coll. 8227 SD (TM-F-7-68) Basal coarse-grained limestone in Roberts Mountains Formation northeast side of Maggie Creek Canyon (unit 2 of measured section), NW¼NE¼ sec. 26.

Hindeodella equidentata Rhodes	16
"*Neoprioniodus*" *excavatus* (Branson and Mehl)	7
Ozarkodina media Walliser	14
Plectospathodus extensus Rhodes	26
Spathognathodus inclinatus Rhodes	33
Trichonodella excavatus (Branson and Mehl)	10

The conodont elements listed above are thought to belong in a single conodont-bearing animal, Apparat H of Walliser (1964).

Panderodus sp.	26
Ligonodina sp.	2
Icriodella? sp.	1
Spathognathodus sp.	1
Prioniodina sp.	1

Age: Walliser (1964) says that Apparat H ranges from Late Silurian to Early Devonian (Emsian) and this whole fauna falls in that range. If it were Devonian, I would expect to see other genera present and I think that this collection is probably Late Silurian. To be sure of the age we would need a suite of samples through the whole section.

John W. Huddle
January 29, 1969

USGS Coll. 8217 SD (TM-F-8-68) Bioclastic limestone lens, Roberts Mountains Formation, NW¼NE¼ sec. 26, about 40 m above 8227 SD.

Hindeodella equidentata Rhodes	1
Ozarkodina media Walliser	1
Panderodus sp.	4
Paltodus sp.	2
Spathognathodus inclinata Rhodes	2

Apparently the same fauna as 8214 SD [Copenhagen Canyon, Monitor Range] and 8227 SD [Maggie Creek Canyon].

John W. Huddle
January 29, 1969

USGS Coll. D277 SD (69CM-179A) Basal platy limestone in Roberts Mountains Formation, SE¼ sec. 27. Collected by L. D. Cress.

Cyrtograptus sp.
Monograptus spiralis (Geinitz)
Monograptus sp. (of the *M. priodon* group)
Stomatograptus grandis (Suess)

Age: Silurian-late Llandoverian, beds are approximately correlative with Elles and Wood zones 24-25

USGS Coll. D278 SD (69CM-192). Upper part of Roberts Mountains Formation, SW¼ sec. 24. Collected by L. D. Cress.

Monograptus sp. (of the *M. hercynicus* group—cf. *M. praehercynicus* (Jaeger))

Age: Devonian-Gedinnian, possibly *M. praehercynicus* Zone.

USGS Coll. D279 SD (69CM-193). Roberts Mountains Formation, SW¼ sec. 24. Collected by L. D. Cress.

Monograptus sp. (of the *M. colonus* type)
Monograptus sp. (with simple, tubular thecae—possibly a fragment of *M. bohemicus*)

Age: Silurian-early Ludlovian

William B. N. Berry
December 30, 1969

TUSCARORA MOUNTAINS

Carlin mine area, including secs. 14, 15, 23, and 27, T. 35 N., R. 50 E., and sec. 30, T. 35 N., R. 51 E., Rodeo Creek NE quadrangle, Eureka County, Nev.

USGS Coll. 8221 SD (TM-F-5-68) Lowest massive coarse-grained limestone at Carlin gold mine, 160 m above base of Popovich Formation of Hardie (1966) and about 30 m below thrust fault near top of Popovich Hill. NE¼ sec. 14, T. 35 N., R. 50 E., Eureka County, Nev.

Belodella triangularis Stauffer	1
Hibbardella sp.	1
Hindeodella sp.	1
Nothognathella sp.	5
Polygnathus asymmetricus asymmetricus B & Z	20
P. a. ovalis Ziegler and Klapper	4
P. cristatus Hinde	5
P. decorosus Stauffer	14
P. normalis? Miller and Youngquist	1
Spathognathodus sp.	2

Age: this fauna is early Late Devonian (Frasnian, lower *P. asymmetricus* Zone)

John W. Huddle
January 29, 1969

USGS Coll. D255 SD (TM-F-54-69) About sec. 14, T. 35 N., R. 50 E. Graptolites from altered, laminated limestone (gold ore) in upper part of Roberts Mountains Formation at survey marker TT-451,

main pit, Carlin gold mine. Graptolites just below bed that contains *Tentaculites*.
Dendrograptus sp.
Monograptus hercynicus Perner
Monograptus praehercynicus Jaeger?
Age: Early Devonian, probably Siegenian

William B. N. Berry
January 5, 1970

USGS Coll. D294 SD (TM-F-6-70) Graptolites, poorly preserved. From ore zone at base of main pit, Carlin mine, NW¼SE¼ sec. 14, T. 35 N., R. 50 E. This collection is from the same zone as 69-FP-269-F which contained a new kind of brachiopod (Boucot and Johnson, 1972). The beds containing the graptolites strike so as to be just under the *M. hercynicus* beds (D254 SD), but a dike-filled fault separates the localities. Displacement along fault not known, but interpreted as minor.
Monograptus microdon?
Monograptus of the *M. hercynicus* group
Age: Early Devonian

USGS Coll. D296 SD (TM-F-8-70) Two bags. Poorly preserved graptolites. From gold ore, 6440 bench, east pit of Carlin mine. NE¼SE¼ sec. 14, T. 35 N., R. 50 E. Graptolites probably are from the same beds as D294 SD, but several faults and a lot of cover make it impossible to be exact. They should be Late Silurian or Devonian unless there is a thrust fault.
Monograptus of the *M. hercynicus* group—probably *M. praehercynicus*.
Age: Early Devonian

USGS Coll. D301 SD (TM-F-13-70) Poorly preserved graptolite from Roberts Mountains Formation exposed above measured section but probably across a fault, SE¼NW¼ sec. 27.
Monograptus sp.—*M. priodon* type??
Age: might be Wenlockian but could be younger.

USGS Coll. D302 SD (TM-F-14-70) Graptolites—fairly well preserved. Collected by G. L. (Mel) Essington, geologist at Carlin mine. From 1950-m level, east pit of the Carlin mine. Essington believes this collection was made a little lower (6-10 m) stratigraphically than D296 SD.
Monograptus microdon?
Monograptus of the *M. hercynicus* group—possibly *M. uniformis*
Age: Early Devonian

William B. N. Berry
August 12, 1970

USGS Coll. 8724 SD (TM-F-17-70) is from the NW¼ sec. 30, T. 35 N., R. 51 E. The fossils, a well-preserved coral and ostracodes, were collected by G. L. (Mel) Essington. The fossils are from interbedded fine- and coarse-grained limestone that Evans (1972a) has assigned to the upper part of the Roberts Mountains Formation, but these rocks correlate with the Popovich Formation of Hardie (1966). The fossils are from beds just below a thrust that contains western assemblage rocks in the upper plate.
Age: The single coral in this collection is referred to *Lyrielasma*. In eastern North America the genus ranges from the uppermost Silurian (Pridoli) through the Lower Devonian although its known range elsewhere is Lower to lower Middle Devonian. Similarly, the presumably related forms are common in the Middle Devonian. The earlier *Lyrielasma* are characterized by morphologic features not present in the specimen at hand and this new specimen is almost certainly from the Lower Devonian.

William A. Oliver, Jr.
September 14, 1971

This collection contains the following ostracodes:
Aechmina sp. aff. *A. longispina* Coryell and Cuskley, 1934
Aechmina sp.
Aechminaria? sp.
Ulrichia sp.
Hanaites sp.
Abditoloculina sp.
Parabolbina sp.
Tetrasacculus sp.
Psilokirkbyella? sp.
Neothlipsura bispinosa (McClean, 1973)
Geisinid ostracodes
Berounella sp.
Bairdia sp. cf. *B. leguminoides* Ulrich, 1891
Birdsallella sp.
smooth ostracodes, indet.
This ostracode assemblage has definite Appalachian affinities and resembles that of the Port Ewen Limestone of New York. According to Johnson (1970, p. 50–51) the first influx of Appalachian elements is in his *Spinoplasia* Zone, which he also correlates with the Port Ewen. These ostracodes probably belong in the *Spinoplasia* Zone and the rocks containing them may be equivalent to at least a part of the Rabbit Hill Limestone.

Jean M. Berdan
February 16, 1972

TM-F-18-70 A sparse collection of brachiopods from an altered zone in the east wall of the west pit of the Carlin mine. NE¼SW¼ sec. 14, T. 35 N., R. 50 E. On lithologic correlation, these brachiopods seem to be above the *M. hercynicus* Zone in the main pit and in rocks assigned to the Popovich Formation of Hardie (1966), but cover, faults, and altered rocks make lithologic correlations between pits risky.
Leptocoelina squamosa Johnson
Spinoplasia roeni Johnson
Age: *Spinoplasia* Zone, Siegenian

TM-F-19-70 A sparse collection of poorly preserved brachiopods from the 1950-m level, west pit of the Carlin mine, NW¼SW¼ sec. 14, T. 35 N., R. 50 E. These brachiopods seem to be from less altered rocks in the same zone as TM-F-18-70.
Leptocoelia? sp.
Age: probable Siegenian or Emsian

J. G. Johnson
A. J. Boucot
July 16, 1970

USGS Coll. D253 SD (TM-F-52-69) Sec. 27, T. 35 N., R. 50 E. About 3.2 km southwest of Carlin gold mine.
Bag A—Graptolites from in place and from float in zone extending from top bed of basal chert to 1.5 m above basal chert of Roberts Mountains Formation.
Cyrtograptus lapworthi Tullberg
Monograptus spiralis (Geinitz)
Monograptus sp. (*M. priodon* group)
Retiolites geinitzianus var. *angustidens* (Elles and Wood)
Age: late Llandoverian, *M. spiralis* Zone
Bag B—Graptolites from float 12 to 16 m above basal cherty unit.
Cyrtograptus sp.
Monograptus cf. *M. praedubius* (Boucek)
Monograptus vomerinus cf. var. *gracilis* (Elles and Wood)

Age: Wenlockian

Bag C—Graptolites from in place and float 65 m above basal cherty unit.

Cyrtograptus sp.
Monograptus testis (Barrande)
Monograptus sp. (of the *M. dubius* group)

Age: late Wenlockian, *M. testis* Zone

William B. N. Berry
January 5, 1970

USGS Coll. 8823 SD (TM-F-21-70) Upper 1.5 m of the Hanson Creek Formation, SE¼NE¼ sec. 23, T. 35 N., R. 50 E.

Drepanodus cf. *D. aduncus* Nicoll and Rexroad	2
Hindeodella sp.	1
Icriodina irregularis Branson and Branson	1
Ligonodina cf. *L. kentuckyensis* Branson and Branson	9
Neoprioniodus sp.	3
Ozarkodina sp.	2
Paltodus dyscritus Rexroad	17
Panderodus sp.	60
Synprioniodina sp.	1
Trichonodella aff. *T. papilo* Nicoll and Rexroad	2

Age: early Silurian

John W. Huddle
February 25, 1971

USGS Coll. D254 SD (TM-F-53-69) About sec. 15, T. 35 N., R. 50 E., about 1.5 km west of Carlin gold mine. Highest graptolites found in Roberts Mountains Formation and about 30 m below change to interbedded laminated limestone and coarse-grained limestone unit.

Linograptus sp.
Monograptus sp. (of the *M. hercynicus* group)
Tentaculitid

Age: early Devonian

William B. N. Berry
January 5, 1970

USGS Coll. 8446 SD (TM-F-15a-69) About sec. 15, T. 35 N., R. 50 E. Gray medium- to coarse-grained partly pelletal limestone bed 0.3 m thick in upper part of Roberts Mountains Formation. About 12 m above the highest graptolites found (D254 SD).

Acodina sp.	1
Belodella triangularis (Stauffer)	1
Hindeodella	3
Icriodus pesavis Bischoff and Sannemann	1
Panderodus sp.	3

Age: The presence of *I. pesavis* suggests that this collection is Early Devonian, Siegenian in age (*Quadrithyris* Zone).

John W. Huddle
March 13, 1970

USGS Coll. 8447 SD (TM-F-15b-69) Same location as 8446 SD. Gray coarse-grained partly pelletal limestone about 6 m above base of zone with dominant coarse-grained limestone and about 60 m above 8446 SD. Unnamed Devonian limestone that overlies Roberts Mountains Formation.

Acodus? sp.	1
Hindeodella sp.	10
Icriodus sp.	2
Ligonodina sp.	2
Lonchodina cristagalli Ziegler	4
L. greilingi? Walliser	3
L. walliseri? Ziegler	1
Neoprioniodus excavatus (Branson and Mehl)	2
"*Oneotodus*" *beckmanni* Bischoff and Sannemann	1
Ozarkodina denckmanni Ziegler	3
O. cf. *O. fundementata* Walliser	1
O. media Walliser	8
O. cf. *O. ortus* Walliser	8
Panderodus sp.	34
Plectospathodus extensus Rhodes	1
P. sp.	2
Spathognathodus boucoti Klapper	9
S. remscheidensis Ziegler	7
Trichonodella symmetrica (Branson and Mehl)	3

Age: *S. boucoti* is confined to the *Icrodus pesavis-S. boucoti* Zone in the Early Devonian Seigenian rocks in western North America. This collection is probably Early Devonain in age, although some of the species have not been reported from rocks of this age previously.

John W. Huddle
March 13, 1970

USGS Coll. 8448 SD (TM-F-15c-69) Dark-gray coarse-grained partly pelletal limestone 125–150 m above 8847 SD. Unnamed Devonian limestone.

Belodella sp.	2
Hindeodella species	2
Ozarkodina denckmanni Ziegler	2
O. sp.	1
Plectospathodus sp.	1
Spathognathodus remscheidensis Ziegler	10

Age: Early Devonian, but there is nothing in the conodont fauna to date it more precisely.

John W. Huddle
March 13, 1970

North Star mine area includes W½ sec. 4 and N½ sec. 9, T. 35 N., R. 50 E., Eureka County, Nevada, Rodeo Creek NE quadrangle

69 FP-265F, Limestone float from basal coarse-grained limestone that overlies laminated limestone assigned to the Roberts Mountains Formation on east flank of hill 0.8 km south-southwest of North Star mine SW¼ sec. 4, T. 35 N., R. 50 E. Collected by F. G. Poole. Bed possible equivalent of bed where 8440 SD collected 1.5 km south.

Gypidula? sp.
Cyrtina? sp.
indet. brachiopods

Age: probably Devonian, based on the presence of *Cyrtina*? sp.

J. G. Johnson
A. J. Boucot
January 21, 1971

USGS Coll. 8433 SD (TM-F-1-69). Unnamed Devonian bioclastic limestone, medium- to coarse-grained, about 15 m above the sandstone bed that overlies the Roberts Mountains Formation.

Belodella sp.	1
Hindeodella sp.	1
Icriodus sp.	2
Silicified bryozoa	

Age: probably Early Devonian based on the presence of *Icriodus*

John W. Huddle
February 19, 1970

USGS Coll. 8434 SD (TM-F-2-69) Fine-grained limestone and interbedded silty laminated limestone in Roberts Mountains Formation. About 460 m south of the North Star mine, W½ sec. 4.

About 120 m below the sandstone that overlies the Roberts Mountains Formation.

Belodella cf. *B. resimus* Philip	1
Hindeodella sp.	6
Neoprioniodus excavatus (Branson and Mehl)	5
Ozarkodina media Walliser	7
O. sp. B of Philip	2
O. sp.	2
Plectospathodus extensus (Rhodes)	11
Prioniodina sp.	1
Spathognathodus remscheidensis? Ziegler	5
S. cf. *S. transitans* n. subsp.	4
S. wurmi Bischoff and Sannemann	22
S. sp.	2
Trichonodella inconstans Walliser	3
T. symmetrica (Branson and Mehl)	2

Age: This fauna includes elements that are found in the Lower Devonian of Alaska and Australia. Most of the species range from the Upper Silurian through the Lower Devonian. *S. remscheidenses* and *S. wurmi* suggest an Early Devonian age, but it could be Silurian in age.

John W. Huddle
February 19, 1970

Emmonsia sp. Upper Silurian to Middle Devonian.

William A. Oliver, Jr.
September 14, 1971

The following six collections were made on a line extending southwest from the east flank of a minor hill in NE¼ sec. 9 to hill 6052 in NW¼ sec. 9. They were collected to obtain an age for a few hundred meters of coarse-grained limestone and laminated limestone that overlies the Roberts Mountains Formation. The upper two collections are across a fault that seems to repeat lower part of unit.

USGS Coll. 8440 SD (TM-F-14a-69) Sec. 9, T. 35 N., R. 50 E., about 1.5 km south of North Star mine. Coarse-grained limestone at base of 120-m unit of coarse-grained limestone interbedded with and underlain and overlain by laminated limestone. Base of unit forms mapping contact of Roberts Mountains Formation and overlying unnamed Devonian beds.

Acodina sp.	2
Spathognathodus remscheidensis (Ziegler)	8
"*Oneotodus*" *beckmanni* Bischoff and Sannemann	10

Age: probably Early Devonian. This is indicated by the presence of *S. remscheidensis* and "*O.*" *beckmanni*. "*O.*" *beckmanni* may not be a conodont but it has been found in the United States, Australia, and Germany in Lower Devonian rocks and is not known from the Silurian.

John W. Huddle
March 13, 1970

Strepula? sp.
Aparchitellina? sp.
Saccarchites sp.
Alaskabolbina? sp.
Hypotetragona sp.
Marginia sp. aff. *M. sculpta multicostata* Polenova, 1952
Aechmina sp.
Tubulibairdia? sp.
Newsomites? sp.
Bairdiocypris sp.
Praepilatina sp. aff. *praepilata sibiriea* Polenova, 1972
Bairdia sp. cf. *B. leguminoides* Ulrich, 1891
Camdenidea sp.
Bashkirina sp.
Silus sp. cf. *S. acclivis* Polenova, 1968
Miraculum sp. aff. *M. simplex* Polenova, 1960
Tricornina sp.
alate podocope, new genusaff. "*Beecherella*" *angularis* Ulrich, 1891

Age: This association of ostracodes is new, but is almost certainly Early Devonian. Possibly it is Gedinnian, as *Miraculum* sp. aff. *M. simplex*, *Bairdia* sp. cf. *B. leguminoides* and *Saccarchites* sp. also occur in collection USNM 12323 made by A. J. Boucot, which he described as float from beds of Gedinnian Age in the Roberts Mountains Formation. It is interesting that six of the ostracodes listed above are related to species described from the Devonian of Siberia.

Jean M. Berdan
September 4, 1969

USGS Coll. 8441 SD (TM-F-14b-69) Coarse-grained limestone. Same locality as 8440 SD, but 60 m stratigraphically above 8440 SD. Unnamed Devonian limestone.

Belodella sp.	1
Hindeodella sp.	7
Neoprioniodus excavatus (Branson and Mehl)	4
Ozarkodina media Walliser	3
Plectospathodus extensus Rhodes	8
Spathognathodus inclinatus wurmi? Bischoff and Sanneman	7
S. johnsoni (Klapper)	1
S. sp.	2
Trichonodella symmetrica (Branson and Mehl)	1

Age: The two species of *Spathognathodus* indicate an Early Devonian age. *S. johnsoni* has been reported from the *Quadrithyris* Zone at Coal Canyon, Nevada, and from the Royal Creek section, Yukon Territory, Canada, by Klapper (1969) and is regarded as early Seigenian.

John W. Huddle
March 13, 1970

USGS Coll. 8442 SD (TM-F-14c-69) Same locality as 8440 SD, base of a sandy, coarse-grained limestone overlying a 150-m laminated limestone with *Styliolina* in the upper part. Somewhere between 180 and 250 m above 8441 SD, if no faults are present. Devonian limestone probably above Popovich Formation of Hardie (1966) at Carlin mine.

Belodella triangularis (Stauffer)	8
Hindeodella sp.	6
Icriodus sp.	2
Panderodus sp.	1
Plectospathodus sp.	1
Polygnathus linguiformis linguiformis Hinde	8
Po. sp.	2
Synprioniodina sp.	2

Age: probably Middle Devonian. *Polygnathus linguiformis linguiformis* ranges from late Emsian to early Late Devonian. All the other species have longer ranges. The collection is probably older than 8221 SD (TM-F-12-68) from 167 m above the base of the Popovich Formation at Carlin mine.

John W. Huddle
March 13, 1970

USGS Coll. 8443 SD (TM-F-14e-69) About 50 m above 8442 SD, same locality, dark-gray medium-grained partly pelletal limestone. Unnamed Devonian limestone.

Ancyrodella rotundiloba rotundiloba (Bryant)	1
Hindeodella sp.	4
Ozarkodina sp.	1
Polygnathus decorosus Stauffer	2
Synprioniodina sp.	1

Age: early Late Devonian, lower or middle *asymmetrica* Zone

John W. Huddle
March 13, 1970

USGS Coll. 8444 SD (TM-F-14f-69) Dark-gray, partly pelletal medium-grained limestone. Same general locality as 8443-SD, but there is a fault between 8443 SD and 8444 SD. Fault is in swale just east of hill 6052 in NW¼ sec. 9. Unnamed Devonian limestone.

Belodella triangularis (Stauffer)	1
Icriodus cf. *I. pesavis* Bischoff and Sannemann	4
Ligonodina sp.	3
Neoprioniodus bicurvatus (Branson and Mehl)	1
Ozarkodina denckmanni Ziegler	12
O. aff. *O. fundementala* Walliser	3
Spathognathodus cf. *S. sagitta* (Walliser)	29

Age: *S. sagitta* and *O. fundementala* suggest a Silurian age while the *I. pesavis* and *O. denckmanni* suggest an Early Devonian age. *I. pesavis* is confined to beds of early Siegenian age in Coal Canyon, Nevada, and Royal Creek, Yukon Territory, Canada. I think the collection is Early Devonian.

John W. Huddle
March 13, 1970

USGS Coll. 8445 SD (TM-F-14g-69) Dark-gray, coarse-grained pelletal limestone. Same locality about 6 m stratigraphically above 8444 SD. Unnamed Devonian limestone.

Icriodus sp.	1
Neoprioniodus bicurvatus (Branson and Mehl)	1
Spathognathodus cf. *S. remscheidensis* (Ziegler)	1
"*Oneotodus*" *beckmanni* Bischoff and Sannemann	22

Age: probably Early Devonian. "*Oneotodus*" has been found in rocks of Early Devonian age in Europe, Australia, and the United States and is not known from rocks of other ages.

John W. Huddle
March 13, 1970

Strepula? sp.
Camdenidea sp.
Silus sp.

These ostracodes are few and broken, but appear to represent about the same horizon as 8440 SD.

Jean M. Berdan
September 4, 1969

Bootstrap mine, western Tuscarora Mountains approx. secs. 10 and 15, T. 36 N., R. 49 E. (unsurveyed). Rodeo Creek NW quadrangle, Elko and Eureka Counties, Nevada, and McDermitt 1°×2° quadrangle (mine not shown on 1°×2° quadrangle). About 460 m of rock is exposed beneath a thrust fault at Bootstrap mine. The lower 180 m is assigned to the Roberts Mountains Formation and the base of the Roberts Mountains is not exposed. The upper 280 m are in an unnamed Devonian formation.

USGS Coll. D233 SD (TM-F-26-68) Sec. 10. Sparse collection of graptolites in float 45 m above base of exposure and three fragments of graptolites from float 85 m above base of exposure.

Graptolites from 45 m above base of exposure:
Monograptus sp. (plain thecae)
Monograptus sp. (fragment could be *M. uncinatus* Tullberg)
Monograptus sp. (specimen appears to have thecae with spines similar to those in *M. chimaera*)

Age: Ludlovian(?)— the presence of a fragment with uncinate thecae is suggestive of the Ludlovian as is the presence of a specimen with what appear to be spines similar to those in *M. chimaera*.

Monograptids from float 85 m above base of exposed rock:
Monograptus sp. (of the *M. dubius* type?)
Monograptus sp. (thecae appear to be similar to those in *M. uncinatus*)

Age: possibly Late Silurian-Ludlovian or Pridoli—the presence of a specimen with thecae similar to those in *M. uncinatus* is suggestive of a Late Silurian age

William B. N. Berry
November 8, 1968

USGS Coll. D252 SD Sec. 10.

Bag A—Graptolites from 175 m above base of exposure of Roberts Mountains Formation and 6 m below change from dominantly laminated limestones to dominantly coarse grained limestone above. Coarse-grained limestone is probably Rabbit Hill Limestone equivalent.
Monograptus angustidens Pribyl
Monograptus uniformis Pribyl

Age: earliest Devonian-Gedinnian

Bag B—Graptolites from 20 m above base of exposure of Roberts Mountains Formation
Monograptus sp. (of the *M. dubius* group)
Monograptus sp. (*M. uncinatus* Tullberg?)
Monograptus sp. (an *M. vomerinus*? or possibly *M. micropoma mannopoma* Jaeger)

Age: in span of late Llandoverian-early Ludlovian

William B. N. Berry
January 5, 1970

USGS Coll. D319 SD (TM-F-42-70) One specimen from float about 9 m above *M. uniformis* Zone of D252 SD.
Monograptus uniformis Pribyl

Age: Early Devonian-Gedinnian, *Monograptus uniformis* Zone

William B. N. Berry
January 11, 1971

USGS Coll. 8228 SD (TM-F-9-68) From coarse-grained limestone in Roberts Mountains Formation in lowest 15 m of rock exposed at Bootstrap mine, sec. 10. The following conodonts were found in the residue of 5000 grams of rock:

Hindeodella sp.	1
"*Neoprioniodus*" *excavatus* (Branson and Mehl)	1
Ozarkodina media Walliser	5
Plectospathodus extensus Rhodes	3

Age: Silurian or Early Devonian, probably Late Silurian

USGS Coll. 8219 SD (TM-F-10-68) 37 m above base of exposed section, west side of Bootstrap mine, sec. 10.

Belodella devonicus (Stauffer)	1
Hindeodella sp.	8
"*Neoprioniodus*" *excavatus* Walliser	2
Ozarkodina aff. *O. media* Walliser	5
O. ziegleri Walliser	1
Paltodus aff. *P. migratus* Rexroad	2
Paltodus sp.	1
Panderodus sp.	19
Plectospathodus extensus Rhodes	2
Spathognathodus eosteinhornensis (Walliser)	2

S. inclinatus (Rhodes) 5
S. primus (Branson and Mehl) 1
Age: Most of these species occur in Upper Silurian and Lower Devonian rocks. I think that this collection is Late Silurian but it is little more than a guess, based on the absence of *Icriodus woschmidti* (a rare form in this area) and the species of *Spathognathodus* present.

John W. Huddle
April 4, 1969

Collection contains echinoderm debris, indeterminate fragments of strophomenoid and orthoid brachiopods and one fair pentameroid, probably *Kirkidium* or *Conchidium*.
Age: Late Silurian

J. T. Dutro, Jr.
March 9, 1972

USGS Coll. 8219A SD (TM-F-10A-68) Same locality as 8219 SD coarse-grained limestone in Roberts Mountains Formation. 120 m above base of outcrop.

Belodella devonicus (Stauffer) 2
"Neoprioniodus" excavatus (Branson and Mehl) 1
Ozarkodina gaertneri Walliser 1
Paltodus aff. *P. migratus* Rexroad 1
Panderodus sp. 17
Spathognathodus ranuliformis (Walliser) 7
S. sp. 1
Age: *O. gaertneri* and *S. ranuliformis* are reported only from the *amorphognathoides* Zone (Valentian and Wenlockian in Europe); probably Middle Silurian

John W. Huddle
April 4, 1969

USGS 8215 SD (TM-F-11-68) Coarse-grained limestone 245 to 267 m above base of outcrop at Bootstrap mine. Unnamed Devonian limestone above Roberts Mountains Formation.

Icriodus? sp. 4
Prioniodina sp. 1
Ozarkodina sp. 1
Trichonodella inconstans Walliser 1
Spathognathodus primus (Branson and Mehl) 1
Age: these species range from Middle Silurian to Early Devonian

John W. Huddle
April 4, 1969

Collection contains:
orthoid, indet.
strophomenoid, indet.
Leptaena sp.
Gypidula cf. *G. pelagica* (Barrande)
Age: probably earliest Devonian (Gedinnian)

J. T. Dutro, Jr.
March 9, 1972

USGS Coll. D292 SD (TM-F-4-70) Graptolites from Roberts Mountains Formation. NW¼SE¼ sec. 15, T. 36 N., R. 49 E. About 1.6 km south of measured section at Bootstrap mine. In complexly faulted area and stratigraphic position in the Roberts Mountains Formation not known.

Monograptus colonus (Barrande)
Monograptus dubius?
Monograptus nilssoni (Barrande)
Monograptus uncinatus?
Age: early Ludlovian, *Monograptus nilssoni* Zone

William B. N. Berry
August 12, 1970

INDEPENDENCE MOUNTAINS

Water Pipe Canyon, Elko County, Nev. NE¼ sec. 19, T. 39 N., R. 53 E., Tuscarora quadrangle

USGS Coll. D236 SD. Graptolites from black shale from adit on north side of Water Pipe Canyon. Graptolites from Silurian upper plate (western facies) first reported by Kerr (1962).

Climacograptus hughesi Nicholson
Climacograptus sp. (of the *C. medius*–*C. rectangularis* type)
Glyptograptus sp. (of the *G. tamariscus* Nicholson group)
Monograptus sp. (fragment of distal part of rhabdosome—a monograptid similar to *M. argutus* Lapworth and *M. atavus* Jones)
Monograptus cf. *M. lobiferus* (M'Coy)
Monograptus triangulatus (Harness)
Age: middle Llandoverian, falls in the span of Elles and Wood British zones 19 (*Monograptus gregarius* Zone) and 20 (*Monograptus convolutus* Zone)

William B. N. Berry
November 8, 1968

Thomas Jose Canyon, Elko County, Nev. Secs. 6 and 7, T. 39 N., R. 53 E., Tuscarora quadrangle

USGS Coll. D235 SD (TM-F-28-68) All graptolites from float just above basal cherty unit of Roberts Mountains Formation. Float is from the base of the Taylor Canyon Formation of J. W. Kerr (1962) which is equivalent to the Roberts Mountains Formation above the basal cherty unit.

Cyrtograptus hamatus (Baily)
Cyrtograptus sp.
Monograptus flemingii (Salter)
Monograptus testis Barrande
Monograptus sp. (of the *M. vomerinus* group)
Age: late Wenlockian. This association is indicative of zone 4 of the Silurian-Devonian graptolite faunizones outlined by Berry (1969). It is the approximate correlative of the *Cyrtograptus lundgreni* Zone of Elles and Wood.

William B. N. Berry
November 8, 1968

USGS Coll. D263 SD (TM-F-62-69) In place collection probably 15–30 m above basal cherty unit of Roberts Mountains Formation, but low-angle faults separate the graptolite-bearing rocks from the cherty unit. NW¼ sec. 7.

Monograptus bohemicus (Barrande)
Monograptus chimaera (Barrande)?
Monograptus dubius (Suess)
Monograptus fritschi (Perner)
Monograptus scanicus (Tullberg)
Monograptus uncinatus (Tullberg)
Age: early Ludlovian

William B. N. Berry

USGS Coll. D295 SD. Graptolites, poorly preserved. Isolated exposures in a faulted area, but collected above the *M. bohemicus*–*M. dubius* Zone of D263 SD.

Monograptus bohemicus (Barrande)
Monograptus colonus (Barrande)
Monograptus dubius Suess
Age: early Ludlovian, *Monograptus nilssoni* Zone

William B. N. Berry
August 12, 1970

ANTELOPE PEAK, ELKO COUNTY NEVADA

About NE¼ sec. 32, T. 40 N., R. 62 E., Summer Camp quadrangle.

USGS Coll. 8824 SD (TM-F-41-70) Medium-grained laminated dark-gray limestone about 490 m above base of Roberts Mountains Formation. The limestone is slightly coarser grained and contains less silt than laminated limestone beds above and below.

Hindeodella sp.	1
Neoprioniodus excavatus (Branson and Mehl)	1
Panderodus sp.	5
Pelekysgnathus furnishi? Klapper	1
Prioniodina sp.	1
Spathognathodus inclinatus Rhodes	3

P. furnishi has previously been reported from the Emsian of Royal Creek, Yukon Territory, but its range is not known.

John W. Huddle
February 25, 1971

HOT CREEK CANYON

Sec. 19, T. 8 N., R. 50 E., Nye County, Nev., Little Fish Lake quadrangle. From rocks equivalent to Roberts Mountains Formation but probably should be assigned to unit 1 of the Lone Mountain Dolomite (Merriam, 1973b, p. 9-17)

USGS Coll. 8437 SD. Fine-grained, dark-gray dolomite 10 m above the basal cherty unit.

Acontiodus sp.	1
A.? sp.	3
Acodus sp.	1
Hindeodella sp.	6
Ligonodina sp.	1
Lonchodina cf. *L. greylingi* Walliser	2
Neoprioniodus bicurvatus (Branson and Mehl)	1
Ozarkodina media Walliser	4
Panderodus sp.	6
Plectospathodus extensus Rhodes	4
Spathognathodus inclinatus inclinatus Rhodes	12
Trichonodella symmetrica (Branson and Mehl)	3

Age: Most of these forms range from Silurian (Ludlovian) to Devonian (Emsian). On the basis of the lack of other species of *Spathognathodus* and *Icriodus* it seems probable that this is Silurian but nothing here demonstrates a Silurian age.

USGS Coll. 8438 SD (TM-F-10-69) Fine-grained, dark-gray dolomite with silicified fossil fragments. 33 m above basal cherty unit.

Ozarkodina sp.	1
Panderodus sp.	4
Spathognathodus inclinatus Rhodes	1
Trichonodella symmetrica (Branson and Mehl)	1

Age: Late Silurian or Early Devonian

John W. Huddle
February 19, 1970

Cladopora sp.
Favosites? sp.
Age: Silurian or Devonian

William A. Oliver, Jr.
September 14, 1971

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INDEX

[Italic pages numbers indicate major references]

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