Stratigraphy of Some Paleozoic Formations in the Independence Quadrangle Inyo County, California

GEOLOGICAL SURVEY PROFESSIONAL PAPER 396

Prepared in cooperation with the California Department of Conservation, Division of Mines and Geology

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By DONALD C. ROSS

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CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

STRATIGRAPHY OF SOME PALEOZOIC FORMATIONS IN THE INDEPENDENCE QUADRANGLE INYO COUNTY, CALIFORNIA

By Donald C. Ross

ABSTRACT

In the Mazourka Canyon area of the Independence quadrangle in the Inyo Mountains of California, a well-exposed conformable sequence of Upper Mississippian, Pennsylvanian, and Permian beds overlies an erosional surface cut on a conformable sequence of Cambrian, Ordovician, Silurian, and Devonian(?) rocks. The rocks from the Bonanza King Dolomite (Middle and Upper Cambrian) through the Rest Spring Shale (Upper Mississippian) are particularly well-exposed, easily accessible, and only moderately deformed and contact metamorphosed; and they reveal significant lithologic variations along strike.

The sequence of Cambrian, Ordovician, Silurian, and Devonian(?) rocks lying beneath the unconformity comprises about 10,000 feet of mostly thin-bedded fine- to medium-grained clastic rocks, dolomite, and limestone. Much of the carbonate material also is clastic. These rocks probably belong to a transitional assemblage between the siliceous eugeosynclinal assemblage and the carbonate miogeosynclinal assemblage of the Great Basin. Both geographically and lithologically, though, the rocks are nearer the carbonate assemblage.

The Upper Mississippian clastic beds that overlie the unconformity are probably part of the overlap assemblage of the Great Basin. These beds, about 3,000 feet thick, are dominantly shale and siltstone, although the lower several hundred feet is mostly sandstone and conglomerate containing abundant chert fragments.

Along the strike from the dominantly carbonate terrane southeast of the quadrangle to the northern part of the Independence quadrangle, major lithologic changes occur, particularly in the Ordovician and Silurian rocks. In the Mazourka Canyon area, for example, the interval occupied by the Eureka Quartzite over much of the western part of the Great Basin is made up of interbedded quartzite, dolomite, limestone, shale, and siltstone; and the Ely Springs Dolomite grades northwestward from cherty dolomite to dominantly massive black chert. The most striking change occurs in the Silurian rocks; dolomite, which is widespread southeast of the Mazourka Canyon area, grades northwestward in a few miles into coral-rich bioclastic and argillaceous limestone, which in turn grades northward into graptolite-bearing shale and limestone. The Mississippian and younger rocks of the overlap assemblage in the Independence quadrangle also have a higher percentage of clastic material than do equivalent rocks to the southeast.

INTRODUCTION

In the Inyo Mountains of the Independence quadrangle (fig. 1), near the west margin of the Great Basin, is a well-exposed structurally simple Paleozoic sedimentary section. The rocks are intruded and generally slightly metamorphosed by batholithic masses of Mesozoic granitic rock that are probably part of the Sierra Nevada composite batholith. A recent U.S. Geological Survey Bulletin (with an accompanying geologic map at a scale of 1: 62,500 (Ross, D. C., 1965)) briefly describes the map units in the Independence quadrangle.

The Paleozoic sedimentary section is about 16,000 feet thick and ranges in age from Early Cambrian to Permian (pl. 1). It appears to be conformable throughout except for an erosional unconformity that separates the Upper Mississippian rocks from the Silurian and Devonian(?) rocks.

The oldest sedimentary rocks in the section—the Poleta, Harkless, Saline Valley, and Mule Spring Formations (Early Cambrian), and the Monola Formation (Middle Cambrian)—are extensively exposed north of the quadrangle, where they were studied in detail by Nelson (1962). Inasmuch as these formations are exposed only over limited areas in the Independence quadrangle, are somewhat metamorphosed, and generally are not easily accessible, they will not be discussed in this paper. Brief descriptions of these units in the Independence quadrangle were published by D. C. Ross (1965).

The youngest Paleozoic sedimentary rocks—the Keeler Canyon Formation (Pennsylvania and Permian) and the Owens Valley Formation (Permian)—are extensively exposed southeast of the quadrangle (Merriam and Hall, 1957); there they are abundantly fossiliferous. Within the Independence quadrangle no complete sections are preserved, and the rocks are metamorphosed to such an extent that no fossils have been found. These formations, therefore, will not be discussed in this paper, but they are described briefly by D. C. Ross (1965). The diagrammatic columnar section (pl. 2) briefly summarizes the formations discussed in this report.

Formation descriptions in this report are mostly based on outcrops within the Independence quadrangle, but the distribution of some formations in other parts of the Inyo Mountains is also discussed. To avoid repetition in the discussions of stratigraphic relations, only the lower contact is described for each formation. The measured sections were made from tape and compass traverses by Fred K. Miller and me, except for the Rest Spring Shale section, where I was assisted by Craig D. Ross.

PREVIOUS STRATIGRAPHIC AND PALEONTOLOGIC STUDIES

The first stratigraphic study in the Independence area was made in 1912, when Edwin Kirk did a reconnaissance in the Inyo Mountains (in Knopf, 1918). Several references to the Paleozoic section in Mazourka Canyon were made in the report on this work.

Since the work of Kirk, which called attention to the fossiliferous Paleozoic section in Mazourka Canyon, numerous geologists have examined and reported on

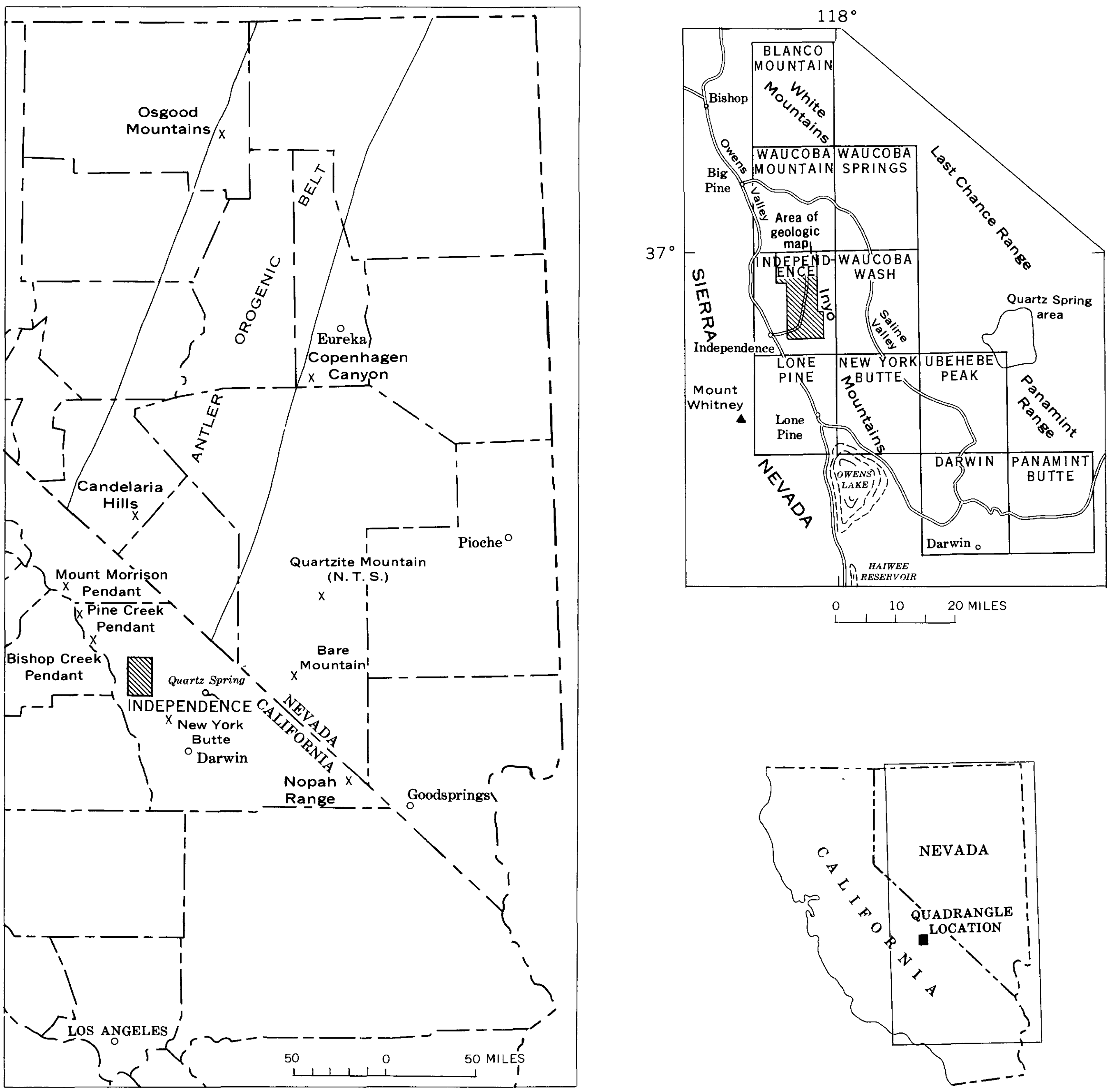


FIGURE 1.—Regional setting of the Independence quadrangle.

specific measured sections or small areas. Most of this work has been concerned with the paleontology of the units, and little systematic geologic mapping has been done.

Stauffer (1930) measured a section east of Kearsarge and collected fossils both there and near Barrel Springs from strata which at that time were referred to the Devonian.

Phleger (1933) named and briefly described two new Ordovician formations (Mazourka and Barrel Spring) in a report concerned chiefly with the systematic paleontology of the faunas in these formations.

Waite (1953), reporting on the fauna from the same beds that Stauffer studied, showed that these beds were Silurian rather than Devonian.

Langenheim and several of his students (1956) measured several sections in Mazourka Canyon and collected fossils from the Middle and Upper Ordovician rocks.

Pestanan (1960) described the fauna (mainly corals, including several new species) in the Johnson Spring Formation, which he named.

Greife and Langenheim (1963) described sponges and brachiopods from the Mazourka Formation.

CAMBRIAN SYSTEM

BONANZA KING DOLOMITE

NAME AND DISTRIBUTION

The Bonanza King Formation was named by Hazzard and Mason (1936, p. 234) for the Bonanza King mine in the Providence Mountains of southeastern California. It is a distinctive unit over much of the southwestern part of the Basin and Range province. In the Inyo Mountains the formation is almost exclusively dolomite, so the name Bonanza King Dolomite (Ross, D. C., 1965) is used in this report; the name Bonanza King Formation is used where rocks other than dolomite are abundant.

The formation crops out in a broad arcuate belt as much as 2½ miles wide along the crest of the Inyo Mountains from the north boundary of the quadrangle south to the latitude of Barrel Springs. South from Barrel Springs the outcrop becomes a much thinner, considerably faulted, and contact-metamorphosed belt that extends nearly to the mouth of Mazourka Canyon. North of the quadrangle this outcrop belt extends discontinuously for several miles along the east face of the Inyo Mountains in the Waucoba Mountain quadrangle (C. A. Nelson, written commun., 1961). South of Mazourka Canyon, faulting and granitic intrusions disrupt the belt of outcrop; but in the New York Butte quadrangle I have seen rocks that may correlate with the Bonanza King Dolomite on the east face of the Inyo Mountains (along the trail east of sec. 30, T. 15 S., R. 37 E.). The Bonanza King Dolomite also underlies rather extensive areas along the east side of the Inyo Mountains north of Paiute Canyon in the Waucoba Wash quadrangle.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Bonanza King Dolomite is about 2,800 feet thick at a measured section northeast of Badger Flat. The greatly expanded width of the Bonanza King outcrop southeast of the measured section is largely due to the topography and to exaggeration by a monoclinal bend in the formation, not to thickening of the formation.

At the type section in the Providence Mountains, Hazzard and Mason (1936, p. 234) included about 2,000 feet of strata in the Bonanza King. In the Nopah Range, Hazzard (1937, p. 318–319) measured 4,480 feet of beds in the combined Bonanza King and Cornfield Springs Formations. The Cornfield Springs in the Nopah Range is now considered to be equivalent to the upper part of the Bonanza King at the type section (Palmer and Hazzard, 1956, p. 2497–2499). At the Nevada Test Site, Barnes, Christiansen and Byers (1962, p. D30) assigned 4,600 feet of beds to the Bonanza King; and at Bare Mountain, Nev., Cornwall and Kleinhampl (1961) measured 3,800 feet of this formation. The Bonanza King Formation thus ranges in thickness from at least 2,000 feet to nearly 5,000 feet; the nearly 3,000 feet in the Inyo Mountains is somewhat less than an average thickness.

The Bonanza King Dolomite appears to rest conformably on limestone and fine-grained clastic beds of the Monola Formation (Nelson, 1965). The contact is marked by an abrupt change in lithology, but concordant attitudes near the contact in the vicinity of the measured section suggest continuous deposition. East of the crest of the Inyo mountains, some discordance was noted along the contact, but it is probably chiefly the result of faulting.

LITHOLOGY

The Bonanza King Dolomite is easily recognized in the field by its conspicuous color banding. The bands, in varied shades of gray, range from a fraction of an inch to a few tens of feet in thickness. This widespread banding was aptly described by Noble (1934, p. 177) as suggesting the stripes of a zebra.

Dolomite is the dominant rock type of the formation, almost to the exclusion of other rocks. Black chert, in nodules and in beds as much as 1 foot thick, is present locally. Limestone was noted at only two localities: (1) about 2,500 feet east of the Blue Bell mine, where two 1½-foot-thick layers of white to buff limestone are present in the light-gray dolomite sequence, and (2) 3.8 miles S. 36° W. of the northeast corner of the quadrangle (at the attitude symbol N. 10° E., 25° W.), where purplish-pink and black limestone as well as somewhat argillaceous dolomite make up a zone no more than 50 feet thick. This latter zone may equate to a regional marker described by Barnes and Palmer (1961, p. C102–C103) as a "persistent brown-weathering siliceous carbonate sequence about 40 feet thick" that separates the upper and lower members of the Bonanza King. The limestone zone was not recognized in the measured section.

Much of the dolomite in the Bonanza King is remarkably pure, but some layers are liberally flecked with tremolite, phlogopite, and, locally, forsterite, which attest to the reconstitution of impurities in the dolomite by contact metamorphism. Aside from these metamorphic minerals, insoluble residues contain minor quartz and argillaceous material but rarely contain any heavy minerals. North of Tamarack Canyon, near the northeast-trending fault (dashed on map) abundant pseudomorphs of iron oxide after pyrite were found in a thinly alluviated area. Some of the iron oxide masses were several inches across and massive. Others, as much as one-half inch in diameter, preserve in detail striated pyritohedrons. These iron impurities were not found in place, but they probably weathered out of the underlying dolomite. Small pseudomorphs of pyrite have been found in place in other outcrops of Bonanza King Dolomite.

No attempt was made to map members in the formation. Five units were distinguished along the measured section (see p. 43), chiefly on the basis of color changes due to differing proportions of light-to dark-gray bands. The uppermost unit (unit 5) could have been mapped separately over much of the area. It is massive and generally weathers to craggy yellowish-gray outcrops that strongly contrast with the striped gray lower units. South of the measured section a distinctive black dolomite unit at least 150 feet thick lies between unit 5 and the striped lower units. This black dolomite may correlate with a similar black dolomite band that is near the top of the Bonanza King Formation at Bare Mountain, Nev. (Cornwall and Kleinhampl, 1961). Unit 5 would then equate to the combination of the white and gray bands that overlie the black band at Bare Mountain. The three broad color bands at the top of the Bonanza King Formation are a regional characteristic of the unit, as similar thick bands also occur in the Nopah Range (Hazzard, 1937, p. 319) and at several other localities in the southwestern part of the Great Basin, including the Quartz Spring area (J. F. McAllister, oral commun., 1962). About 7 miles east of Mazourka Canyon, on the east side of the Inyo Mountains in the Waucoba Wash quandrangle, the three broad color bands at the top of the Bonanza King Dolomite are mappable. The black dolomite band, where mapped separately, is shown on the geologic map as a dotted line. It either pinches out to the north or is faulted out, for it was not recognized along the measured section.

Bedding in this formation is typically thin and irregular. Color-banded strata that are several tens of feet thick appear massive from a distance, but these, too, are generally thinly bedded. Commonly, coarse-grained white dolomite in anastomosing stringers produces a mottled or dappled surface (fig. 2*A*) in a variety of patterns (fig. 2*B*). Though a dark groundmass is most common, locally, darker dolomite mottles a lighter matrix. In places the dark-gray dolomite matrix is speckled with white dolomite and resembles what was called "Guinea-hen dolomite" by Calkins and Butler in an area in Utah (1943, pl. 11A, after p. 14). Mottled gray dolomite is common in other areas where the Bonanza King Formation is exposed; as far away as central Utah, rocks of a grossly similar age also exhibit this pronounced mottling (Morris and Lovering, 1961, fig. 21, p. 49).

Fucoid markings are also widespread (fig. 2*C*); some strikingly resemble features called "twiglike bodies" in a Cambrian carbonate unit in Utah (Calkins and Butler, 1943, pl. 10B). Very thinly laminated light-gray dolomite, which generally splits into slabby to flaggy fragments, is also locally abundant.

FOSSILS, AGE, AND CORRELATION

Spherical to ellipsoidal bodies 5–25 mm in diameter and having conspicuous concentric bands are abundant in unit 1 and present but much less abundant in unit 3. These features are probably algal structures; they resemble forms called *Girvanella* in other outcrop areas of this formation. Fucoid markings that resemble worm trails have also been found, but none of the fossils found in the quadrangle help establish the age of the formation. The Bonanza Kink Dolomite is underlain by rocks that are continuous with fossiliferous Middle Cambrian strata a few miles north of the quadrangle (Nelson, 1965) and is in turn overlain by a formation containing an Upper Cambrian fauna. On the basis of work at the Nevada Test Site and in nearby areas in southern Nevada, Barnes and Palmer (1961, p. C103) assigned most of the Bonanza King Formation to the Middle Cambrian, but the uppermost part is considered to be Late Cambrian. A similar age range is assumed for the formation in the Independence quadrangle.

The nearest correlative rocks that have been described in the literature belong to the Racetrack Dolomite in Racetrack Valley about 30 miles to the southeast (Mc-

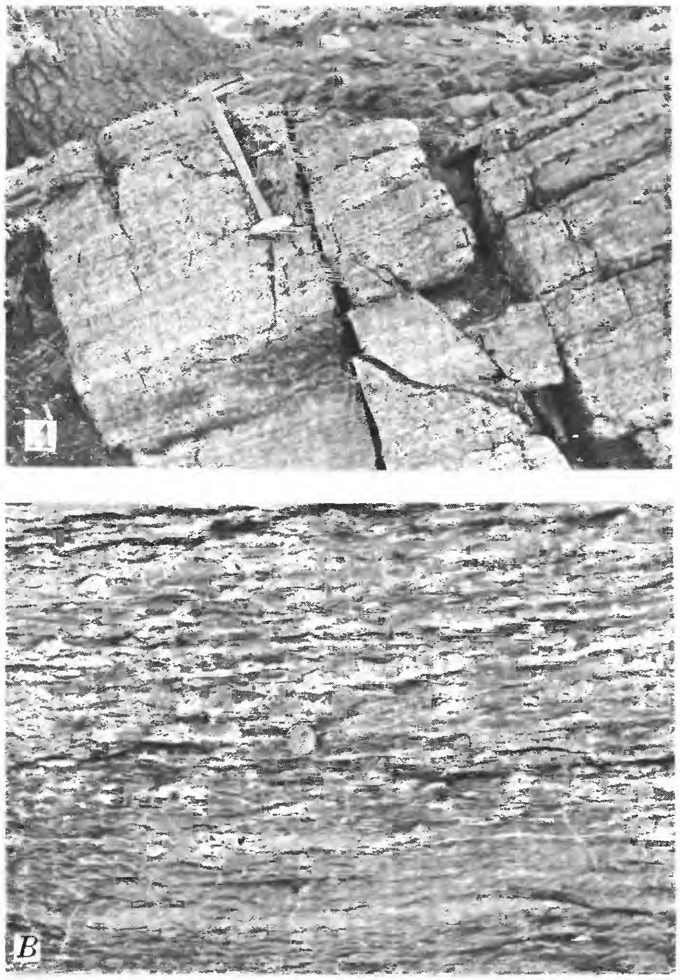


FIGURE 2.—Bonanza King Dolomite. *A*, Coarse-grained white dolomite and finer grained dark-gray dolomite in nodular beds. White dolomite in anastomosing irregular stringers produces a mottled surface. Outcrop along Inyo crest west of Badger Flat at elevation 10,960 feet. *B*, Irregular bedding shown by coarse white lenses of dolomite anastomosing through darker, gray dolomite. Along measured section northeast of the Blue Bell mine. *C*, Fucoid markings in the dolomite. Along measured section northeast of the Blue Bell mine.

Allister, 1952, p. 8–9). Correlative rocks are also present, but as yet unmapped, in the Saline and Last Chance Ranges between Racetrack Valley and the Independence quadrangle.

LEAD GULCH FORMATION

NAME AND DISTRIBUTION

The Lead Gulch Formation was named for exposures along Lead Gulch in the Independence quadrangle (Ross, D. C., 1963, p. B74). The formation is a thin relatively continuous faulted and folded belt which extends from the north edge of the quadrangle south to about the latitude of Independence. This belt of outcrop continues north into the adjoining Waucoba Mountain quadrangle for about 1 mile (C. A. Nelson, written commun., 1961). South of the Independence quadrangle, rocks having similar lithologies were seen at several points along the west face of the Inyo Mountains east of Lone Pine, in the New York Butte quadrangle. These rocks are well exposed along the trail east of sec. 30, T. 15 S., R. 37 E. The Lead Gulch Formation is also exposed along the east face of the Inyo Mountains north of Paiute Canyon, in the Waucoba Wash quadrangle.

THICKNESS AND STRATIGRAPHIC RELATIONS

At the type section of the Lead Gulch Formation (LG–1 on pl. 1), the measured thickness is 280 feet; however, the base of the formation is contorted and presumably is faulted. The maximum thickness probably is at least 300 feet, but it may well be more. At many localities the Lead Gulch Formation has been thinned considerably or squeezed out entirely between thick dolomite units that bound it.

The contact of the Lead Gulch Formation with the underlying Bonanza King Dolomite is almost everywhere structurally disturbed but is presumed to be conformable, as the attitude of the rocks on both sides of the contact is similar.

LITHOLOGY

The Lead Gulch Formation comprises limestone, siltstone, dolomite, chert, and shale interlayered in a reg-

FIGURE 3.—Lead Gulch Formation. Outcrop of dominantly orange-weathering metamorphosed calcareous siltstone (dark beds stand out in relief). Weathered back slits contain gray limestone. Exposure is about 600 feet east of the portal of the Whiteside mine (S½ sec. 5, T. 13 S., R. 36 E.).

ularly bedded sequence. Beds are most commonly ½–2 inches thick but locally are as much as 5 inches thick.

Blue- to medium-gray limestone and thinly laminated calcareous siltstone that weathers out in relief to shades of bright orange and red are the dominant and characterizing rock types of this formation. Most commonly these rock types are present in about equal amounts; at some places, however, the siltstone fraction dominates (fig. 3), and at other places thin-bedded limestone is far more abundant than the fine-grained clastic rocks. These lithologic types can most easily be seen in the exposures shown in figure 3 and along Lead Gulch, where a short trail leads from Mazourka Canyon, at the start of the Betty Jumbo mine road, to small mine workings in the Lead Gulch Formation. The siltstone beds are commonly folded and faulted, owing to their brittleness, but the regularity of the original beds still is readily apparent.

At the base of some sections is as much as 20 feet of fissile olive-brown to dark-green shale, or its metamorphosed equivalent. This unit, though not seen at the type section, probably was originally present but has been squeezed out. This shale, where present, is an excellent marker bed to indicate the base of the formation. It is particularly useful where the Lead Gulch Formation is contorted and overturned and the overlying and underlying dolomites are metamorphosed to coarse massive indistinguishable units, as north of Lead Gulch along the granitic contact. Where the shale is metamorphosed, it is altered variously to green chlorite schist containing minor quartz, or to a blocky, fractured green hornfels having a dense quartz groundmass (0.005 mm) in which is sprinkled abundant pale-green amphibole and some reddish-brown biotite.

Black chert in thin regular layers or nodular beds as much as 4 inches thick is also present in the formation, but much of what was thought in the field to be chert proved, on microscopic examination, to be siltstone or calcareous siltstone.

Thin-bedded dolomite in different shades of gray is locally common near the top of the formation. At the type section, dolomite is somewhat more abundant than at most exposures.

The alternation of gray limestone and brown-, orange-, and reddish-weathering siltstone is repeated several times in the stratigraphic column in the Independence area. The fairly regular interbedding of the two rock types, as shown in figure 3, distinguishes the Lead Gulch Formation from the formations in which these two rock types are irregularly interbedded. The Al Rose Formation (Lower Ordovician) is the unit most likely to be confused with the Lead Gulch. In most outcrops, however, the Al Rose has irregular bedding and a predominance of silty material. The limestone fraction commonly occurs in less resistant lenses that weather back to form distinctive "eyes," which are rare in Lead Gulch outcrops.

FOSSILS, AGE, AND CORRELATION

Trilobites establishing a Late Cambrian age for the Lead Gulch Formation have been identified and reported on as follows by A. R. Palmer (written commun., 1961, 1962):

USGS colln. 3749–CO. Collected 6,700 feet N. 70 E. from SE cor. sec. 36, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,271,900 E., 589,400 N.).

Homagnostus sp.
Pseudagnostus sp.
Indeterminate acrotretid brachiopods
Echinoderm parts

This collection contained two rock types: a fine-grained gray limestone without identifiable trilobites, and a white limestone with abundant trilobite hash. This latter sample was dissolved in formic acid and yielded a thoroughly deformed suite of small silicified (?) trilobites, indeterminate acrotretid brachiopods, and echinoderm parts. The dominant identifiable trilobites are agnostids representing the genera *Homagnostus* and *Pseudagnostus*. *Homagnostus* is a characteristic agnostid in the lower Nopah faunas, so this collection probably came from beds correlated with the lower Nopah. It is certainly from beds no older than the Late Cambrian *Aphelaspis* zone of Dresbach age. This is just about the westernmost dated Upper Cambrian locality in the United States (exclusive of Alaska).

USGS colln. 3750–CO. Collected about 7,000 feet east of Johnson Spring. (California coordinates, zone 4; 2,276,300 E., 574,750 N.).

Homagnostus?
Loganellus?

USGS colln. 3802–CO. Collected about 6,900 feet N. 80° E. of Johnson Spring (California coordinates, zone 4; 2,276,000 E., 576,200 N.).

Loganellus sp.

The specimens represent a species of what is currently being called *Loganellus*. This type of trilobite characterizes the beds just above the Dunderberg interval over much of Nevada. At most localities where I have seen these, they are at or near the base of an interval of interbedded thin limestones and black cherts.

The lithology of your sample is much like that in parts of the Emigrant Formation.

At several other localities in the formation, black chitinous shells of acrotretid brachiopods and trilobite fragments were found. No fossils were found in the basal green shale; all the identifiable fossils were from limestone beds. No fossils have been found in the beds presumed to be part of the Lead Gulch Formation elsewhere in the Inyo Mountains (in the Waucoba Mountain, Waucoba Wash, and New York Butte quadrangles).

The nearest occurrence of a similar section that has been dated by fossils is in the Quartz Spring area. Here, the lower 250 feet of unit 1 of the Nopah Formation (McAllister, 1952, p. 9) is "limestone, in places silty or cherty, weathering brown, interbedded with light-olive shale." Trilobites of the *Elvinia* zone of the Franconian Stage place this unit at the bottom of the middle division of the Upper Cambrian (McAllister, 1952, p. 10).

The Lead Gulch Formation is thus considered to be approximately equivalent to the basal unit (unit A) of the Nopah Formation in its type area (Hazzard, 1937, p. 320). The basal Nopah comprises limestone, shale, calcareous sandstone, and sandy shale; trilobites of the *Elvinia* zone are also found in these beds.

The Lead Gulch Formation also is probably approximately equivalent to the 100-foot-thick *Pseudagnostus*-bearing lower shale member plus the overlying 100- to 200-foot-thick limestone containing chert, siltstone, and dolomite lenses that make up the lower part of the Nopah Formation in the Bare Mountain area, Nevada (Cornwall and Kleinhampl, 1961). Sections of thin-bedded limestone, shale, siltstone, and some chert that are markedly similar to the Lead Gulch Formation occur at Striped Hills near Lathrop Wells, Nev., and in the Specter Range quadrangle, Nevada. These sections, which are at least in part referred to the Dunderberg Shale (H. R. Cornwall, oral commun., 1964; Burchfiel, 1964, p. 49), are exposed in reddish-brown-weathering slopes between the more resistant carbonate rocks of the Bonanza King and Nopah Formations.

The stratigraphic position of the Lead Gulch Formation is comparable to that of the Dunderberg Shale as described in the Nevada Test Site area (Barnes and others, 1962, p. D31). The thickness and general lithology of the Dunderberg are also comparable to those of the Lead Gulch; but the wavy, nodular bedding described both at the Test Site and in the type area of the Dunderberg in the Eureka region (Nolan and others, 1956, p. 18) differs somewhat from that of the typical Lead Gulch. At the Nevada Test Site, fossils in the Dunderberg Shale are in the *Dunderbergia* zone, which is of early Late Cambrian (Dresbach) age (Barnes and others, 1962, p. D31). Trilobites of the *Elvinia* zone of middle Late Cambrian (Franconian) age are present near the base of the overlying Windfall Formation (Barnes and others, 1962, p. D31).

On the basis of similar stratigraphic position, lithology, and fauna, the Lead Gulch Formation probably equates to the Dunderberg Shale plus at least some of the immediately overlying Catlin Member of the Windfall Formation (Barnes and Byers, 1961, p. C103). The same types of trilobites that are found in the Lead Gulch Formation (*Homagnostus*, *Pseudagnostus*, and *Loganellus*) are also found in the lower 350 feet of the Catlin Member of the Windfall Formation. The lower part of the Catlin Member also contains other trilobites of the *Elvinia* zone (Barnes and Byers, 1961, p. C105–C106).

The northward extent of the Lead Gulch Formation as a mappable unit is limited by a facies change in which the Middle and Late Cambrian are represented by the Emigrant Formation, a trilobite-bearing thin-bedded sequence of limestone, claystone, siltstone, and chert. This formation is widespread in Esmeralda County, Nev. (Albers and Stewart, 1962, p. D24; McKee and Moiola, 1962, p. 536–537), and has also been recognized in the Inyo Mountains in the Blanco Mountain quadrangle (Nelson, 1963) about 20 miles north of the Independence quadrangle.

McKee and Moiola (1962, p. 537) described the upper member of the Emigrant Formation as approximately 2,000 feet of thin-bedded blue to gray limestone alternating with ½- to 2-inch-thick buff-to-black bands of chert or iron-stained limestone. Orange to reddish-gray calcareous shale, very thin bedded calcareous sandstone, and very thin bedded chert are abundant near the top. Trilobites found in this member include *Homagnostus* and *Pseudagnostus*. As described, this member is much like the Lead Gulch Formation but is thicker; this suggests that the Lead Gulch may be a tongue-like southward extension of the Emigrant Formation.

TAMARACK CANYON DOLOMITE

NAME AND DISTRIBUTION

The Tamarack Canyon Dolomite was named for exposures in the Independence quadrangle (Ross, D. C., 1963, p. B77). The strata now mapped as Tamarack

Canyon were considered to be part of a thick sequence of "limestones, probably of Beekmantown age" by Kirk (in Knopf, 1918, p. 34); more recently, Langenheim and others (1956, p. 2087) considered the Tamarack Canyon beds to be part of the Pogonip Group.

The formation is exposed in a fairly continuous arcuate belt from the north edge of the quadrangle to the latitude of Barrel Springs. From there south to the Betty Jumbo mine area, the Tamarack Canyon Dolomite is faulted and discontinuous, as well as strongly folded. The outcrop belt of the Tamarack Canyon continues northward for about 1 mile into the Waucoba Mountain quadrangle, and similar rocks are exposed a few miles farther north along the west front of the Inyo Mountains (C. A. Nelson, written commun., 1961). In the southern part of the Independence quadrangle, granitic rocks disrupt the outcrop belt of the Tamarack Canyon; but east of Lone Pine and north of Dolomite, in the New York Butte quadrangle, sequences with a similar lithology and in the correct stratigraphic position can be traced along the west face of the Inyo Mountains for about 2 miles. These beds are well exposed along the trail east of sec. 30, T. 15 S., R. 37 E. Other exposures of the Tamarack Canyon Dolomite have been noted in the northwest quarter of the Waucoba Wash quadrangle. The Tamarack Canyon Dolomite is thus a mappable unit throughout much of the Inyo Mountains.

THICKNESS AND STRATIGRAPHIC RELATIONS

At the measured section southeast of Badger Flat, the Tamarack Canyon Dolomite is 910 feet thick. In most other areas the formation is faulted, and a maximum thickness cannot be measured.

The basal contact of the Tamarack Canyon Dolomite with beds of the Lead Gulch Formation is undoubtedly conformable, as it is essentially gradational and somewhat arbitrary. It is marked by the highest occurrence of thin-bedded limestone in the underlying Lead Gulch Formation. In some places thin-bedded dolomite and limestone are interlayered near this contact.

LITHOLOGY

The predominant rock type is laminated to thick-bedded very light gray to medium-gray dolomite (fig. 4*A*) that normally weathers to a monotonous dull gray surface. The measured section described (see p. 44) is fairly typical. Outcrops that appear thick bedded to massive from a distance prove to be thin bedded on close observation; the bedding is shown chiefly by a fluted weathered surface that accentuates minor differences in the resistance of the thin dolomite layers.

Black chert, both as nodules and as nodular beds as much as a few inches thick, is scattered to abundant in the dolomite (fig. 4B); though widespread, it is absent in many outcrops. Chert nodules are particularly abundant in the rock near the mouth of Lead Gulch and directly across the Mazourka Canyon road to the west. The general form of many nodules suggests that they are secondary replacements of the carbonate.

Limestone was only noted at a few localities in the Tamarack Canyon Dolomite. Although generally very

A

B

FIGURE 4.—Thin-bedded gray Tamarack Canyon Dolomite. Penny for scale. *A*, Along measured section about 6,000 feet N. 60° E. from SE cor. sec. 36, T. 11 S., R. 35 E. *B*, Along measured section about 6,300 feet N. 64° E. from SE cor. sec. 36, T. 11 S., R. 35 E. Note irregular black chert nodules.

pure, the limestone and the dolomite may locally be somewhat argillaceous or contain scattered flakes of phlogopite that suggest metamorphism of impurities. Silty admixtures are rare in contrast to the overlying Ordovician carbonate rocks, which are characteristically silty.

In figure 4, the very thin beds and laminae in varied shades of gray give a distinct color banding to the outcrop. Though this thin banding is conspicuous locally, weathered surfaces much more commonly are a monotonous dull gray; nowhere is the color banding comparable to that which characterizes the Bonanza King Dolomite. The Bonanza King and Tamarack Canyon Dolomites, which are generally so distinctive, become indistinguishable near granitic contacts; there, both are coarse grained and dazzling white on fresh surfaces.

FOSSILS, AGE, AND CORRELATION

Fossils have not been found in the Tamarack Canyon Dolomite, but those found in the overlying and underlying formations indicate that it could be Late Cambrian or Early Ordovician or both. A Late Cambrian age is tentatively assigned to the Tamarack Canyon because the absence of clastic quartz and silty interlayers in this unit suggests more affinity with the Nopah Formation of Late Cambrian age than with the lower part of the Pogonip Group of Early and Middle Ordovician age, in which clastic material is widespread. The mappable lithologic break between the essentially clastic-free Tamarack Canyon Dolomite and the Al Rose Formation of Early Ordovician age, with its abundant clastic material, is thus tentatively correlated with the contact between the Nopah Formation and the Pogonip Group. This break also is considered to be the boundary between the Cambrian and the Ordovician.

Both the Nopah and Tamarack Canyon Formations are predominantly dolomite, but there appears to be a significant difference between them. The Nopah Formation has characteristic color banding in a wide range of shades of gray in its type area in the Nopah Range (Hazzard, 1937, p. 320), in the Quartz Spring area (McAllister, 1952, p. 9), and at many other localities, including the west flank of the Last Chance Range only 25 miles northeast of the Independence quadrangle. This banding, so aptly named "zebra-striping," which is diagnostic of both the Nopah Formation and the Bonanza King Formation, is conspicuously lacking in the Tamarack Canyon Dolomite throughout the Inyo Mountains. Speculation that the Tamarack Canyon is Nopah that has lost its banding owing to incipient metamorphism does not seem valid, for the diagnostic banding is well preserved in the underlying Bonanza King Dolomite, which had the same opportunity for metamorphism. The lack of color banding was the chief reason for proposing a local formational name in the Inyos for this presumed correlative of at least part of the Nopah Formation. Possibly the prevalence of extremely thin bedding in the Tamarack Canyon Dolomite is a precursor of the change from the thicker bedded dolomitic strata of the Nopah type to thin-bedded limestone and fine-grained clastic rocks of the Emigrant type.

All the Tamarack Canyon Dolomite except its lower member is tentatively correlated with the Nopah Formation of the Quartz Spring area (McAllister, 1952, p. 9); the lower member may be correlative with the Lead Gulch Formation. Similarly, the Nopah Formation at its type area (Hazzard, 1937, p. 321), but minus basal unit "A," is probably a Tamarack Canyon equivalent, as is at least the Smoky Member of the Windfall Formation in the Nevada Test Site area (Barnes and Byers, 1961, p. C105). Unit "a" of the Pogonip Group in the Darwin area (Hall and MacKevett, 1962, p. 8) also may be equivalent to the upper part of the Nopah, and hence to the Tamarack Canyon.

ORDOVICIAN SYSTEM

MAZOURKA GROUP

The term Mazourka Formation was first used by Phleger (1933, p. 2–3) to describe the rocks now referred to the Mazourka Group (Ross, D. C., 1963, p. B78). Detailed mapping in the Independence quadrangle showed that the two units that Phleger noted in his Mazourka Formation were mappable formational units almost the entire length of the Inyo Mountains, so they were named the Al Rose Formation and the Badger Flat Limestone by D. C. Ross (1963). Phleger's Mazourka Formation was raised to group status because it is correlative in part, and possibly in its entirety, with the Pogonip Group.

The term Pogonip Group is not used for rocks in the Independence quadrangle because of differing opinions as to what is its equivalent in the Inyo Mountains. Langenheim and others (1956, p. 2087, 2091) considered the Mazourka Formation of Phleger to be the uppermost formation of the Pogonip Group. They also considered the underlying dolomite to be part of the Pogonip, but I consider it to be part of the Upper Cambrian Tamarack Canyon Dolomite, a partial Nopah equivalent. In the New York Butte quadrangle, Merriam (1963b, p. 9) included units in his Pogonip Group that I believe are correlative with Upper Cambrian formations in the Independence quadrangle. As long as these differences of opinion exist as to what constitutes the Pogonip in the Inyo Mountains, it seems advisable to use the local term Mazourka Group in the Independence area.

To the south and east, lithologic and faunal correlations of the upper formation of the Mazourka Group (Badger Flat Limestone) can be made with the upper formation of the Pogonip Group (Antelope Valley Limestone) with some degree of confidence. Correlation of the remainder of the Mazourka Group (Al Rose Formation) with the remainder of the Pogonip Group (Goodwin and Ninemile Formations) is much more tenuous but is proposed in the following discussion. This doubt about correlation with the lower part of the Pogonip Group is a further reason for retaining the local name Mazourka in this area.

Exposures near the north boundary of the Independence quadrangle are the northwesternmost outcrops of the Mazourka Group and thus are the northwesternmost occurrence of rocks that can be lithologically correlated with the Pogonip. Farther northwest, the nearest fossiliferous Ordovician rocks are about 50 miles northwest of the Independence quadrangle. There, a thick section of pelitic hornfels, slate, marble, and calcareous quartz sandstone in the Mount Morrison pendant of the Sierra Nevada contains Early and Middle Ordovician graptolites (Rinehart and Ross, 1964, p. 18, 19, 21). Undoubtedly the time equivalent of the Mazourka Group is present in this thick section, but the change in facies from the Independence area to the Sierra Nevada precludes lithologic correlation. If the clastic-rich Al Rose Formation includes the equivalent of the Goodwin Limestone as well as the Ninemile Formation of the Pogonip Group, the Mazourka Group may reflect the beginning of the change from the dominantly carbonate strata of the Pogonip Group to the dominantly fine-grained clastic rocks of the same time interval in the Sierra Nevada. The Mazourka Group thus may be marginal between the eastern (carbonate) assemblage and the transitional assemblage of the Great Basin.

AL ROSE FORMATION

NAME AND DISTRIBUTION

The Al Rose Formation was named (Ross, D. C., 1963, p. B79) for exposures in the Independence quadrangle. The formation crops out as a discontinuous belt from the north edge of the quadrangle south to the latitude of Independence. The lower contact is commonly a fault; along some segments of the outcrop belt the Al Rose is entirely faulted out. The belt extends northward beyond the quadrangle boundary for only about half a mile; there it is cut out by granitic rocks in the Waucoba Mountain quadrangle. The southern extension of the belt is also terminated by a granitic intrusive southwest of the Betty Jumbo mine. About 14 miles southeast of the Independence quadrangle, in the New York Butte quadrangle, however, similar rocks extend along the west face of the Inyo Mountains for about 3 miles, from the latitude of Alico north to the prominent granitic hill that juts out from the front of the range. These rocks are the brown-weathering unit referred to by Merriam (1963b, p. 9) as Pogonip B. Hornfelsed equivalent rocks are exposed about 3 miles north of the Willow Creek Camp, in the Waucoba Wash quadrangle.

THICKNESS AND STRATIGRAPHIC RELATIONS

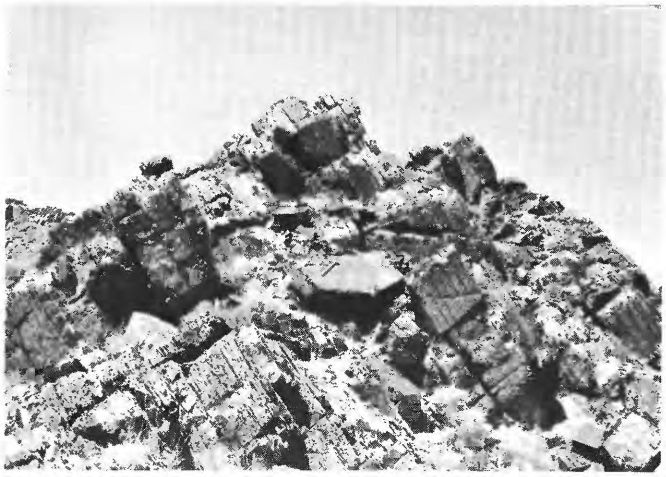
No accurate determination of the thickness of the Al Rose Formation has been made because faulting and folding have almost everywhere disturbed this relatively incompetent unit. At the type section (see p. 44), the formation is about 400 feet thick.

The Al Rose Formation probably lies conformably on beds of the Tamarack Canyon Dolomite. Although the contact is commonly disturbed, similar attitudes near the contact suggest conformity.

LITHOLOGY

The Al Rose Formation is a distinctive unit in the field. It weathers to shades of orange and red brown and is readily distinguished from the overlying and underlying gray-weathering units. The colorful outcrops are made up mostly of siltstone, mudstone, and shale but contain some chert. Very thin irregular bedding is typical. Generally silty medium-gray to bluish-gray, limestone is subordinate to the red-brown-weathering clastic rocks but in some places is the dominant rock type. The limestone occurs in elongate lenses that weather back as holes, or "eyes," in the outcrop. This feature, named "crepe structure" by McAllister (1952, p. 10), is particularly noticeable in somewhat hornfelsed exposures (fig. 5*A*). Clastic quartz grains are common in the limestone layers. In some specimens the carbonate also is obviously clastic. Much of the limestone probably is calcarenite, but recrystallization has altered the original form of the calcite grains. A thin bed of edgewise conglomerate was noted near the base of the measured section (fig. 5*B*).

The uppermost member of the formation (unit 3 of the measured section) is much darker than the rest of the formation at many localities. It is also more regularly bedded in 1- to 2-inch-thick beds composed mainly of mudstone and siltstone (fig. 6). Gray limestone forms elongate lenses or thin interbeds. This unit, 52 feet thick at the measured section, is the same unit that Langenheim and others (1956, p. 2087) referred to as unit 4 in their measured section.



A

B

FIGURE 5.—Al Rose Formation. *A*, Outcrop of predominantly contact metamorphosed siltstone in which nodular beds and lenses of limestone weather back to "eyes" (darker in photograph). Outcrop is about 4,000 feet N. 10° W. of Bee Springs. *B*, Thin layer of edgewise conglomerate near base of measured section.

FOSSILS, AGE, AND CORRELATION

Graptolites and trilobites have been collected from several localities, mostly near the top of the formation in unit 3. These forms, which establish an Early Ordovician age for the formation, were identified by R. J. Ross, Jr. (written commun., 1962), as follows:

USGS colln. D915–CO. Collected 5,000 feet east-southeast of Johnson Spring (California coordinates, zone 4; 2,274,200 E., 574,200 N.).

Phyllograptus cf. *P. ilicifolius* Hall
Didymograptus protobifidus Elles

USGS colln. D916–CO. Collected near top of Al Rose Formation in Water Canyon (California coordinates, zone 4; 2,274,600 E., 570,500 N.).

Didymograptus protobifidus Elles

USGS colln. D917–CO. Collected about 5,000 feet N. 80 E. of SE cor. sec. 36, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,270,800 E., 587,900 N.).

Phyllograptus anna Hall

USGS colln. D918–CO. Collected 5,000 feet N. 75 E. of Johnson Spring (California coordinates, zone 4; 2,274,100 E., 576,400 N.).

USGS colln. D811–CO. Collected about 5,000 feet N. 80 E. of Johnson Spring (California coordinates, zone 4; 2,274,300 E., 575,900 N.).

Didymograptus protobifidus Elles

USGS colln. D1054–CO. Collected about 1,800 feet N. 55 E. of SE cor. sec. 25, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,267,000 E., 593,300 N.).

Didymograptus artus Elles and Wood (1 specimen)
Didymograptus protobifidus Elles (abundant specimens)
Tetragraptus bigsbyi Hall
Phyllograptus anna Hall
Ampyxinid trilobite
Olenid aff. *Parabollinella*
Asaphid?, indeterminate

The following collection was made in 1964 and was kindly loaned to the U.S. Geological Survey for identification and study by Wilfrid D. Davis, San Jose State College. R. J. Ross, Jr., made the identification.

Davis 157. Collected about 700 feet southeast of I–524, about a mile north along strike from D918–CO. (California coordinates, zone 4; 2,273,300 E., 581,300 N.).

Didymograptus protobifidus Elles
Indeterminate agnostid trilobite
Indeterminate trilobite thorax and pygidium

According to R. J. Ross, Jr., the above-listed fossils, all from near the top of the Al Rose Formation, are of late Arenig age of zones 4 and 5 of Elles (1925), and probably correlate with trilobite zone "J" of the Garden City Formation in northeastern Utah (Ross, R. J., 1951), and with the Ninemile Formation.

The following three collections are from rocks stratigraphically beneath the graptolite localities previously discussed.

FIGURE 6.—Al Rose Formation. Graptolite-bearing uppermost member of the formation. Thinly and relatively regularly bedded siltstone and shale. Note thin nodular beds and eyelike lenses of limestone below knife. Exposed about 1 mile east of Johnson Spring in canyon that trends northeast from Blue Stone talc mine.

USGS colln. D919–CO. Collected 2,500 feet N. 40 E. of SE cor. sec. 25, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,267,200 E., 594,200 N.).
Shumardia sp.
Trilobite pygidium, Kainellid or apatokephelid, poorly preserved.

USGS Colln. D920–CO. Collected from same area as D919 but stratigraphically somewhat higher (California coordinates, zone 4; 2,267,000 E., 594,000 N.).
Trigonocerca? sp. (a large pygidium)

USGS colln. D1024–CO. Collected from measured section near base (California coordinates, zone 4; 2,272,800 E., 586,000 N.).
Indeterminate asaphid trilobite thorax and pygidium

Collection D919 is from near the base of the Al Rose Formation and is tentatively correlated by R. J. Ross, Jr., with some part of the Goodwin Limestone of the Eureka, Nev., area. D920 is from about the middle of the formation and contains the same trilobite (*Trigonocerca*?) that is characteristic in R. J. Ross, Jr.'s, zone H (1951, p. 28) of the Garden City Formation of northeastern Utah. The *Trigonocerca* zone is also present in the lower beds of the Ninemile Formation at its type section (R. J. Ross, Jr., written commun., 1964).

As was already noted, Pogonip B of Merriam (1963b, p. 9) in the New York Butte quadrangle is probably correlative with the Al Rose Formation. Examination of the section studied by McAllister (1952, p. 11) in the Quartz Spring area, only 30 miles to the east, suggests that units 4–7 of the Pogonip all are correlative with the Al Rose Formation. Similar comparison suggests correlation with units "b" and "c" of the Pogonip Group in the Darwin area, 30 miles to the southeast (Hall and MacKevett, 1962, p. 8). At Bare Mountain, Nev., both east of Secret Pass and north of the Diamond Queen mine, the Pogonip Group could be separated into two units, the lower of which is similar to the Al Rose Formation. The lower unit would be the lower third of the Pogonip, which was described by Cornwall and Kleinhampl (1961) as commonly containing silty and cherty layers that give outcrops a yellowish-gray to brownish-gray color. At Bare Mountain the ratio of carbonate to clastic material is higher than in the Al Rose Formation, but the overall brownish color caused by the local abundance of silty layers gives a definite Al Rose appearance to the lower Pogonip.

Based on its stratigraphic position and its relation to the fossiliferous Lead Gulch Formation of Late Cambrian age, the Al Rose Formation may include the equivalent of both the Goodwin and the Ninemile Formations of the Pogonip Group. This would mean a westward thickening of the brown-weathering clastic-rich Ninemile equivalent at the expense of the dominantly carbonate Goodwin. The section at Darwin tends to confirm this possibility if, as suggested by Hall and MacKevett (1962, p. 8), the lowest member of their Pogonip is actually equivalent to part of the Nopah Formation.

BADGER FLAT LIMESTONE

NAME AND DISTRIBUTION

The Badger Flat Limestone was named (Ross, D. C., 1963, p. B80) for exposures in the Independence quadrangle. A belt of nearly continuous outcrop extends from the Squares Tunnel area in Mazourka Canyon nearly to the north boundary of the quadrangle. A small area of outcrop near the south edge of the Waucoba Mountain quadrangle (C. A. Nelson, written commun., 1961) is the northern limit of this formation. South of Squares Tunnel, discontinuous outcrops extend as far south as the Betty Jumbo mine, where a granitic body cuts out the Badger Flat. Lithologically similar rocks in the correct stratigraphic position reappear about 14 miles to the southeast, in the New York Butte quadrangle, along a strike length of about 3 miles on the east face of the Inyo Mountains. These beds were referred to by Merriam (1963b, p. 9) as Pogonip C. Small exposures having the same lithologic features are also present on the east side of the Inyo Mountains in a rubbly, poorly exposed area north of the Cerro Gordo mine, in Bonham Canyon (Merriam, 1963b, p. 9), and near the White Eagle talc mine, in the Waucoba Wash quadrangle.

THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness of four relatively undisturbed measured sections of the Badger Flat Limestone ranges from 511 to 586 feet. (See p. 44–45.) This range compares favorably with Phleger's (1933, p. 2) measurement of 550 feet for the upper unit of his Mazourka Formation. The thickness of the Badger Flat also suggests that the rocks described by Kirk (in Knopf, 1918, p. 35) as about 500 feet of fossiliferous argillaceous limestone were actually the Badger Flat Limestone. Langenheim and others (1956, p. 2087) reported a thickness of 428 feet for that part of Phleger's Mazourka Formation which equates to the Badger Flat Limestone. Structural thinning near the base of that section probably accounts for this lower figure. At several other localities in the quadrangle, suspiciously thin measurements of the Badger Flat Limestone were also the result of faulting.

The thickness of the Badger Flat Limestone (500–600 ft) is comparable to that of its presumed equivalents in the southern Inyo Mountains (600 ft, Pogonip C; Merriam, written commun., 1961), at Darwin (540 ft, Pogonip "d"; Hall and MacKevett, 1962, p. 8), and at Quartz Spring (485 ft, unit 8 of the Pogonip; McAllister, 1952, p. 11). In the Nevada Test site area, however, the Antelope Valley Limestone (presumably equivalent to the Badger Flat) is 1,355 feet thick (Byers and others, 1961, p. C108).

Beds of the Badger Flat Limestone rest conformably on strata of the Al Rose Formation. The contact is easily recognized because of the sharp color contrast between the blue-gray Badger Flat and the brown Al Rose, but sedimentation appears to have been continuous across the contact.

LITHOLOGY

Blue-gray-weathering outcrops and nodular, irregular bedding characterize the Badger Flat Limestone, which stands out in bold contrast to the brown-weathering strata both above and below it. Though a considerable variety of textures and structures are present in this unit, most subdivisions shown in the measured sections (see p. 44–45) are somewhat artificial; the Badger Flat, though not homogeneous, is difficult to subdivide into members.

Blue-gray limestone is the dominant rock type in the formation, but the association of this limestone with irregular lenses and beds of light-gray-, orange-, and red-brown-weathering silty and marly beds (fig. 7) is the most diagnostic feature of this formation. Though the term "limestone" is used in describing the measured sections, almost all specimens studied in thin section contained abundant scattered quartz grains, commonly in an obviously clastic calcite matrix (fig. 8). The clastic nature of this unit is also shown by the fragmental nature of the abundant fossils. Much, if not most, of the limestone could more precisely be called calcarenite or calcilutite.

FIGURE 7.—Badger Flat Limestone. Darker areas are blue-gray silty limestone; lighter areas are yellowish- to brown-weathering silty and argillaceous layers. This extreme irregularity in bedding is common in the formation and produces picturesque mottled outcrops. Exposed near top of unit 5 of the measured section.

212-460 O—66——2

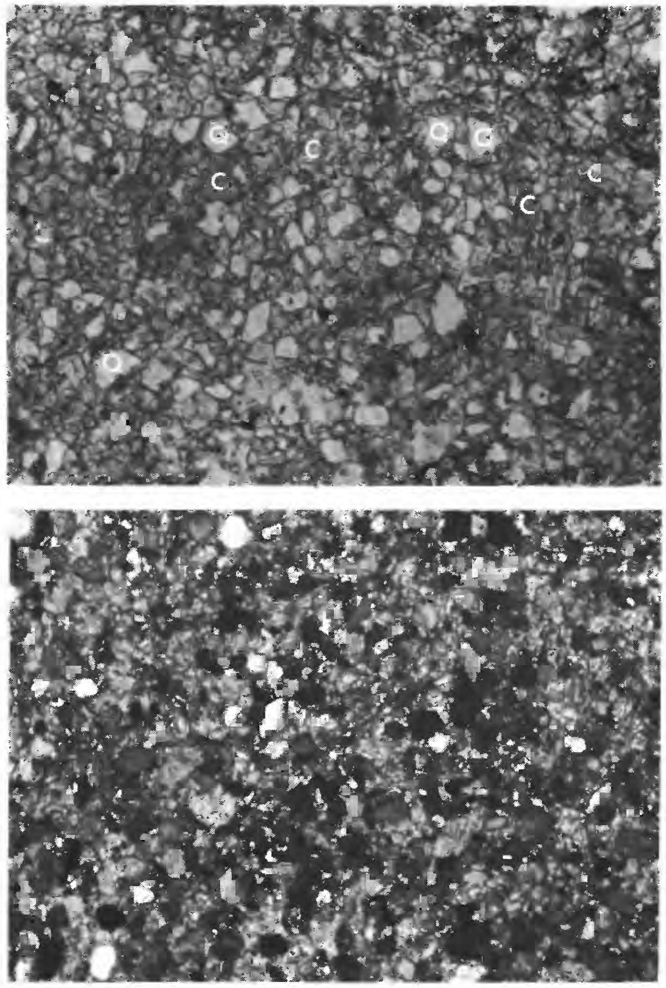


FIGURE 8.—Badger Flat Limestone. Photomicrograph of calcarenite from prominent east-trending ridge south of Barrel Springs; quartz (Q), calcite (C). Largest quartz grains are about 0.1 mm in diameter. Upper: plane-polarized light. Lower: crossed nicols.

The presence of irregular lenses composed of different proportions of quartz and calcite is accentuated on weathered surfaces, where the more silty layers weather out in relief as spines, ridges, and rather exotic irregular patterns. Black chert, both as nodules and as nodular beds, is locally abundant, particularly in the lower part of some sections.

In the northern part of the outcrop area (see p. 45), thin beds of fairly pure but somewhat calcareous quartzite are present near the top of the formation. These beds seem to be the forerunners of more abundant quartzite in the overlying formation.

FOSSILS, AGE, AND CORRELATION

The Badger Flat Limestone is assigned a Middle Ordovician age on the basis of fossils. In an interval from 100 to 200 feet below the top of the formation, gastropods as much as 3 inches across are locally abundant enough to be a mappable feature of the formation. Elsewhere (generally lower in the formation) brachiopods, trilobites, and cephalopods have been collected. Pelmatozoan fragments are abundant throughout the formation; small concentric structures as much as half an inch across, thought to be the algal form *Girvanella*, are also present.

Large gastropods from one locality, and probably representative of the widespread gastropod zone, were identified by E. L. Yochelson (written commun. 1960) as follows:

USGS colln. D751–CO. Collected about 1,000 feet N. 30° W. of NE cor. sec. 8, T. 13 S., R. 36 E. (California coordinates, zone 4; 2,270,300 E., 546,000 N.).
 Palliseria robusta Wilson

Yochelson reported that this is a guide fossil to the Whiterock Stage of Cooper (1956), which is of earliest Middle Ordovician age, and that this species is found in the Antelope Valley Limestone of the Pogonip Group in Nevada.

All the following fossils, except as noted, were identified and reported by R. J. Ross., Jr. (written commun., 1960, 1961, 1962):

USGS colln. D750–CO. Collected on east side of Mazourka Canyon about 2.4 miles north of Johnson Spring (California coordinates, zone 4; 2,270,300 E., 587,300 N.).
 Orthambonites? *mazourkaensis* (Phleger)
 Orthambonites? *patulus* (Phleger)

USGS colln. D752–CO. Collected on east side of Mazourka Canyon about 1.5 miles southeast of Badger Flat (California coordinates, zone 4; 2,269,700 E., 589,100 N.).
 Orthambonites? *patulus* (Phleger)
 Two trilobite pygidia—neither identifiable generically, but one obviously a bathyurid.

USGS colln. D753–CO. Collected on east side of Al Rose Canyon, south of Badger Flat (California coordinates, zone 4; 2,266,300 E., 592,800 N.).
 Orthmbonites? *cf. O. mazourkaensis* Phleger
 Unidentifiable gastropods
 Isotelus-like trilobite
 Unidentifiable brachiopod, possibly an *Orthidiella*

USGS colln. D921–CO. Collected 4,000 feet N. 45° E. of SE cor. sec. 36, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,269,000 E., 589,400 N.). Age: probably Middle Ordovician.
 Asaphid with minimum of six thoracic segments
 Pygidium but no cephalic parts
 Pterygometopid (aff. *Achatella*) (cranidium)
 Pygidium, digitate, possibly pliomerid, possibly dalmanitid

USGS colln. D922–CO. Collected from measured section BF–4 about 420 feet below top (California coordinates, zone 4; 2,271,800 E. 585,400 N.).
 Pseudomera? sp. (pygidium only)
 Cystid plate, showing hydrospires
 Fragment of cephalopod, unidentifiable

USGS colln. D1002–CO. Collected about 20 feet below top of measured section BF–4 (California coordinates, zone 4; 2,271,300 E., 585,100 N.).
 Sponge?
 Cystid plates
 Bryozoans, two genera but indeterminate

USGS colln. D1003–CO. Collected about 190 feet below top of measured section BF–4 (California coordinates, zone 4; 2,271,500 E., 585,200 N.).
 Sponges
 Rhysostrophia nevadensis Ulrich and Cooper
 Gastropods

USGS colln. D1004–CO. Collected from about 230 feet below top of measured section BF–4 (California coordinates, zone 4; 2,271,500 E., 585,200 N.).
 Calycocoelia sp.
 Orthambonites patulus (Phleger)
 Orthambonites? cf. *O. mazourkaensis* (Phleger)
 Rhysostrophia occidentalis Ulrich and Cooper
 Rhysostrophia n. sp.

USGS colln. D1006–CO. Collected about 300 feet below top of formation about 4,500 feet east of Johnson Spring (California coordinates, zone 4; 2,273,800 E., 575,000 N.).
 Orthambonites? cf. *O. mazourkaensis* (Phleger)
 Conodonts, undetermined

USGS colln. D1007–CO. Collected about 350 feet below the top of formation about 4,500 feet east of Johnson Spring (California coordinates, zone 4; 2,273,800 E., 575,000 N.). The following cephalopods were identified by R. H. Flower.
 Reudemannoceras sp.
 Rossoceras sp.

I–550. Collected about 4,000 feet N. 60° E. of SE cor. sec. 36, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,269,300 E., 588,700 N.). Identified by W. A. Oliver.
 Massive favositoid coral

On the basis of these fossils, R. J. Ross, Jr. (1964, p. 86, fig. 9), assigned the Badger Flat Limestone to the Whiterock Stage and part of the overlying Marmor Stage of Cooper (1956). Ross considered the Badger Flat Limestone to be essentially equivalent to the Antelope Valley Limestone of the Pogonip Group as described in the Eureka district of Nevada (Nolan and others, 1956, p. 28).

Greife and Langenheim (1963, p. 564), on the basis of studies of brachiopods and sponges from that part of Phleger's Mazourka Formation that I refer to the Badger Flat Limestone, suggested that "Faunal elements described in this study indicate deposition starting in the *Anomalorthis* zone and possibly extending into the *Rhysostrophia* zone of Cooper's Whiterock stage."

The Badger Flat Limestone is probably correlative both with unit 8 of the Pogonip in the Quartz Spring area (McAllister, 1952, p. 11) and with unit "d" of the Pogonip in the Darwin area (Hall and MacKevett, 1962, p. 8). In both areas, the upper part of the Pogonip Group like the Badger Flat Limestone, is blue-gray, irregularly bedded, contains abundant silty material, and bears a distinctive gastropod zone. At both Darwin and Quartz Spring, however, the carbonate is almost entirely dolomite, whereas that in the Badger Flat is virtually all calcite.

BARREL SPRING FORMATION

NAME AND DISTRIBUTION

The name Barrel Spring Formation was proposed by Phleger (1933, p. 5) for "a succession of quartzites, impure limestones, and argillaceous shales of Middle Ordovician age, in the Inyo Mountains." Phleger designated the type section "in the south fork of Mexican Canyon, which is the second canyon north of Barrel Spring Canyon." On the present topographic map, Barrel Spring Canyon is called Water Canyon, and Mexican Canyon (not named on the map) is the first canyon north of Bonanza Gulch. Langenheim and others (1956, p. 2091) referred to Mexican Gulch, which is the same as Phleger's Mexican Canyon.

The Barrel Spring Formation crops out as a thin but widespread and easily recognizable unit from the Squares Tunnel area north to Badger Flat. About a mile northwest of Badger Flat, the formation is cut out by faulting, but it reappears for a short distance along the south margin of the Waucoba Mountain quadrangle, which is its northernmost occurrence. South of the Squares Tunnel area the formation is discontinuously exposed in fault blocks as far south as the Betty Jumbo mine area, where granitic rocks interrupt the belt of outcrop. In the New York Butte quadrangle, Merriam (1963b, p. 10) described similar beds along the west side of the Inyos and in San Lucas Canyon; these rocks are the basal beds of the Eureka Quartzite. Beds of the Barrel Spring Formation are also exposed in a structurally complex area near the White Eagle talc mine, in the Waucoba Wash quadrangle.

On Badger Flat and to the northwest, as well as near the Snowcaps mine near the mouth of Mazourka Canyon, the Barrel Spring Formation is too thin to be mapped separately and is therefore mapped with the overlying Johnson Spring Formation.

THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness of the Barrel Spring Formation in 10 sections along its outcrop belt ranges from 70 feet in Willow Springs Canyon to 206 feet about half a mile south of Barrel Springs (pl. 3). At the type section the measured thickness is 157 feet, but Phleger (1933, p. 5) reported 130 feet and Langenheim (1956, p. 2091) measured only 100.5 feet, presumably for the same section. The differences lie chiefly in the reported thickness of the upper shale unit.

The Barrel Spring Formation thins northward and is only 100 feet thick at the northernmost measured section south of Badger Flat. Farther north it is only a few feet thick in some outcrops, possibly because faulting has disturbed the section. The formation also thins southward, as it is about 70 feet thick at the southernmost measured section. The section of similar lithology in the New York Butte quadrangle is only 40–75 feet thick according to Merriam (1963b, p. 10). Near the White Eagle mine, in the Waucoba Wash quadrangle, the formation is, at most, 100 feet thick. It thus appears to be a lens in the Inyo Mountains that is thickest near Barrel Springs and thins to the north, east, and south.

The Barrel Spring Formation comformably overlies the Badger Flat Limestone. At the base of the Barrel Spring is commonly an impure quartzite, in places contact metamorphosed to calc-hornfels, so that the contact between these rocks and the blue-gray carbonate beds of the underlying Badger Flat Limestone is readily mappable. North of the type section, however, the distinction between the two formations is not everywhere obvious.

LITHOLOGY

At the type section of the Barrel Spring Formation, Phleger (1933, p. 5) recognized three units: a quartzite at the base, an overlying impure limestone, and a capping argillaceous shale. (See section BS–6, p. 46.) Langeheim and others (1956, p. 2091) noted the same three members a mile north of the type section and in two intervening canyons. North and south of this belt the three-fold division cannot readily be made. However, the lower two units described by Phleger together make up a light-colored lower member at most Barrel Spring sections and can be distinguished from a darker colored upper unit (fig. 9). The lower member is absent at the north edge of the area and in the Waucoba Mountain quadrangle, to the north; it must also thin and disappear to the south, for it was not reported in the Barrel Spring equivalent by Merriam (1963b) and does not appear to be present in the Waucoba Wash quadrangle to the east.

Phleger's upper unit, the argillaceous shale, which I informally call the upper member, has been locally differentiated from the lower two units combined (pl. 1), but generally the thinness of the Barrel Spring precludes showing this subdivision on the geologic map.

LOWER MEMBER

The lower member, a light-colored limestone, impure quartzite, and siltstone unit, comprises the lower two units of Phleger's type section. The lower member is not present in section BS–8, but limestone beds within the upper member are probably tongues of the lower member, which is notably variable and lenticular.

The member is mostly carbonate (fig. 10), but it contains much silt and many sand-size quartz grains. The composition ranges from almost pure carbonate to relatively pure quartzite, which is uncommon. The lower

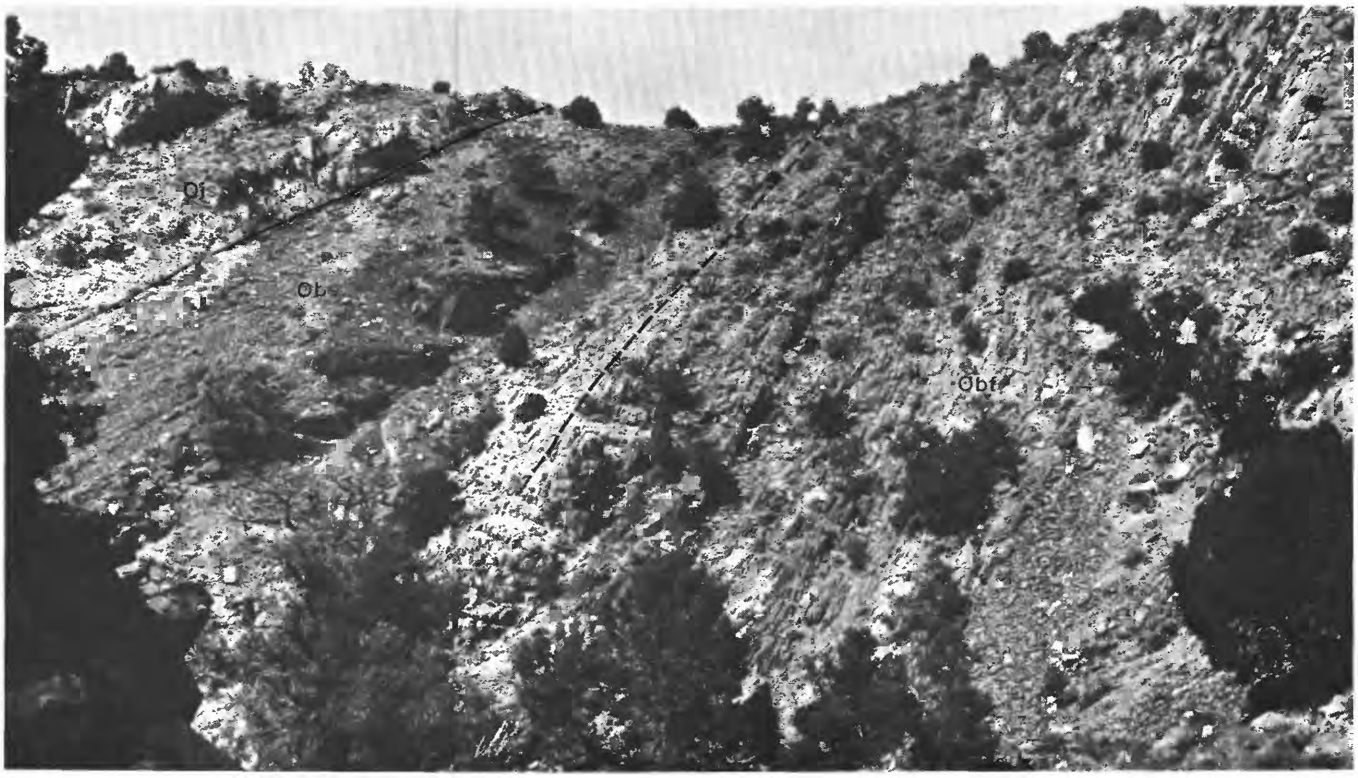


FIGURE 9.—Barrel Spring Formation (Obs) in south side of ridge north of the Blue Stone talc mine. Also shown are the Johnson Spring Formation (Ojs) and the Badger Flat Limestone (Obf). Section BS–7 was measured along this ridge.

member appears to be particularly susceptible to contact metamorphism, for diopside, scapolite, antigorite, tremolite, and phlogopite(?) are mixed with the carbonate and the quartz. Calcite is the dominant carbonate mineral, although dolomite is locally abundant, as in sections BS–5 and BS–2. The magnesium-bearing calc-hornfels minerals show that the dolomite was widespread and common.

FIGURE 10.—Barrel Spring Formation. Exposure of the middle limestone member at the type section in Mexican Gulch.

In the silty limestones the quartz grains range from subangular to well rounded and from 0.01 to 0.1 mm in diameter. Sand-size particles are also locally abundant, but much of the rock that superficially looks like quartzite is actually calc-hornfels or calcareous siltstone. A typical sample of Phleger's "impure quartzite" from the type section, for example, comprises about 10 percent tremolite and about 90 percent rock composed of virtually equal amounts of 0.03 to 0.06 mm quartz and calcite clasts; the rock, therefore, is actually a calcareous siltstone.

Clastic calcite probably was very abundant originally, but recrystallization and formation of calc-hornfels minerals have destroyed the original clastic grains in most places. In some places the calcarenite contains well preserved rounded calcite grains as large as 1–2 mm. One calcarenite specimen from unit 2 of section BS–7 is what might be termed a "microconglomerate"; rounded calcite grains as much as 1.5 mm in diameter are scattered through a dense groundmass mostly composed of 0.01–0.1 mm calcite fragments and quartz grains.

UPPER MEMBER

The upper member is the same as the "argillaceous shale" of Phleger (1933, p. 5) and units 9, 10, and 11 of Langenheim and others (1956, p. 2086). It is a dis-

FIGURE 11.—Barrel Spring Formation. Blocky red-brown-weathering shale and mudstone in upper part of the formation. Looking north in canyon south of ridge shown in figure 9.

tinctive red-brown-weathering shale, mudstone, and siltstone unit that forms an easily recognizable dark outcrop belt (fig. 9). Being somewhat less resistant than the bounding units, it is poorly exposed, but the red-brown rubbly slopes are obvious. Although the member is generally "soft," some outcrops are blocky and bold (figs. 9, 11), particularly where the rocks have been baked and metamorphosed.

Outcrops of this unit are variously shale, mudstone, or siltstone (see p. 45–47), which are locally phyllitic. Thin quartzite layers are less common. Carbonate layers are rare, and the clastic rocks are not calcareous. Individual specimens show some difference in color and texture, but the unit in outcrop appears homogeneous. Two specimens of dark shale from the upper member were collected east of the Bluestone talc mine and submitted for semiquantitative spectographic analysis. The following results were reported (J. D. Vine, written commun., 1963) (only one number is shown where both analyses gave the same trace element amount): Ti, 0.7; Mn, 0.005; B, 0.02, 0.03; Ba, 0.3, 0.1; Cr, 0.01, 0.015; Cu, 0.002, 0.003; Ga, 0.0015, 0.003; La, 0.005, 0; Nb, 0.003; Ni, 0.0015, 0.00015; Pb, 0.002, 0.0015; Sc, 0.0015; Sr, 0.01; V, 0.015, 0.02; Y, 0.002, 0.0015; Yb, 0.0002; Zn, 0.05, 0; and Zr, 0.1, 0.07.

Metamorphism is reflected locally by the presence of mica and, possibly also, chlorite. Blocky, somewhat harder outcrops are also evidence of metamorphism. In some places sericitic hornfels is present that is considerably lighter colored than the original rock. Occurrences of mica and chlorite are scattered, however, so that superficially the rocks look unaffected.

The rocks of the upper member are composed chiefly of rounded to angular quartz fragments from 0.01 to 0.1 mm in diameter or larger. Iron oxide is a common constituent and is the cause of the distinctive red-brown-weathering color. Dark carbonaceous material is also abundant locally. The original presence of argillaceous material is reflected in the mica and chlorite.

FOSSILS, AGE, AND CORRELATION

Brachiopods, trilobites, bryozoans, and graptolites are present, but not common, in the lower part of the upper member. Fossils are also present near the base of the lower member, but these are generally highly silicified and too poorly preserved to be identified. On the basis of the identified fossils, the Barrel Spring Formation is regarded as of Middle Ordovician age. The following fossils were identified by R. J. Ross, Jr. (written commun., 1959, 1961, 1962):

USGS colln. D924–CO. Collected about 70 feet below the top of the type section in Mexican Gulch (California coordinates, zone 4; 2,273,900 E., 571,200 N.).
- *Isotelus* (?) *spurius* Phleger

This species has been reported only from the Barrel Spring Formation.

USGS colln. D1005–CO. Collected about 75 feet below the top of the type section in Mexican Gulch (California coordinates, zone 4; 2,273,900 E., 571,200 N.).
- *Orthambonites* cf. *O. decipiens* (Phleger)
- *Remopleurides* sp.
- *Dicellograptus sextans*

USGS colln. D1017–CO. Collected about 60 feet below top of the type section in Mexican Gulch (California coordinates, zone 4; 2,274,000 E., 571,200 N.).
- *Orthambonites decipiens* (Phleger)
- *Orthambonites* sp.
- *Valcourea* cf. *V. plana* Cooper
- *Valcourea* sp.
- Bryozoans, indeterminate
- *Lonchodomas* sp.
- *Ampyx* (?) sp.
- *Isotelus* (?) *spurius* Phleger

I–1579. Collected from rubbly float, but almost in place, in the SE¼ sec. 25, T. 11 S., R. 35 E., just south of Badger Flat (California coordinates, zone 4; 2,264,800 E., 594,400 N. No fossils have been collected from the Barrel Spring Formation north of this locality.
- *Remopleurides*

I–7. Collected 3,300 feet northeast of Barrel Springs.
- Orthid brachiopod, possibly *Hesperorthis*

I–1. Collected about 10,000 feet N. 10° E. of Johnson Spring.
- Trilobite pygidium

I–232. Collected 750 feet northeast of SE cor. sec. 25, T. 11 S., R. 35 E. This is the only collection from the lower member and is from near the base of the member.
- Brachiopods
- Bryozoans
- Trilobites
- Pelmatozoan columnals

This material is so highly silicified that the specimens are poorly preserved and cannot be properly prepared.

The following collections, made in the summer of 1964 by Wilfrid D. Davis, San Jose State College, were kindly loaned to the U.S. Geological Survey for identification and study. The identifications were made by R. J. Ross, Jr.

Davis 169. Collected about 1,500 feet east-southeast of SE cor. sec. 25, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,267,100 E., 591,750 N.).
Hesperorthis cf. *H. dubia* Cooper

Davis 170. Collected about 2,000 feet southeast of SE cor. sec. 25, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,267,500 E., 591,200 N.).
Hesperorthis cf. *H. dubia* Cooper
Rafinesquina-like species

Davis 173. Collected about 3,000 feet southeast of SE cor. sec. 25, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,267,900 E., 590,600 N.).
Hesperorthis cf. *H. dubia* Cooper
Plaesiomys? sp.

Davis 176. Collected about 4,000 feet northeast of SE cor. sec. 36, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,268,900 E., 589,300 N.).
Isotelus sp. (A much larger specimen than is common for *I. spurius*)

Davis 158. Collected about 9,300 feet southeast of SE cor. sec. 36, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,273,000 E., 580,900 N.).
Isotelus spurius Phleger
Valcourea sp.
Dicellograptus? sp.

Davis 180. Collected from bottom of canyon just east of Blue Stone talc mine (California coordinates, zone 4; 2,273,500 E., 575,000 N.).
Orthambonites decipiens (Phleger)
Isotelus spurius Phleger

Davis 180A. Collected half way up ridge southeast of Davis 180 (California coordinates, zone 4; 2,273,600 E., 574,600 N.).
Isotelus sp. (large)

Phleger (1933, p. 6) tentatively referred the Barrel Spring to the Trenton. On the Ordovician correlation chart (Twenhofel, 1954, following p. 298) the formation was questionably assigned to the Trentonian Stage, but Twenhofel thought that it might be of Richmond age, and Cooper (in Twenhofel, 1954, p. 263) thought that it might extend down to include beds of Black River age. Langenheim and others (1956, p. 2092) believed the Barrel Spring to be Mohawkian (Black River and Trenton) on the basis of their faunal collection, which contained about the same forms as Phleger's original collection.

The *Dicellograptus sextans* in collection D1005–CO establishes the Barrel Spring Formation as the equivalent of zone 9 or 10 of Elles (1925), or lower Caradoc. This is probably equivalent to the Porterfield or Wilderness Stage (Ross, R. J., and Berry, 1963, table 1) and to part of the Black River.

Langenheim, and others (1956, p. 2094) used the term Eureka Group to include the Barrel Spring Formation and the overlying unit that was later named the Johnson Spring Formation by Pestana (1960, p. 862). As is explained later (p. 24), I have chosen not to use the name Eureka in this area, but I feel that Langenheim and his associates were correct in correlating the Barrel Spring Formation with the lower part of the Eureka Quartzite. Exact lithologic equivalents of the Barrel Spring, and in particular of the upper member, do not seem to be present in nearby sections of the Eureka south and east of the Inyo Mountains, but probable correlatives are found.

On a spur east of the Viking mine, in the Darwin quadrangle (California coordinates, zone 4; 2,381,000 E., 372, 750 N.), for example, about 165 feet of sandy and silty dolomite and limestone is present above undoubted Antelope Valley beds of the Pogonip Group that look similar to the Badger Flat Limestone, and below massive quartzite that is undoubtedly Eureka Quartzite. Very likely this interval contains (or is) the Barrel Spring equivalent.

In the Panamint Butte quadrangle about 2¼ miles south-southeast of Panamint Butte (California coordinates, zone 4; 2,489,000 E., 393,800 N.), about 130 feet of dolomite, siltstone, and quartzite is present above limestone beds assigned to the Antelope Valley Limestone and below the Eureka Quartzite. These beds are in part red and orange weathering and also may represent the Barrel Spring interval.

In the Dry Mountain quadrangle about 1½ miles north of Teakettle Junction (California coordinates, zone 4; 2,429,000 E., 533,000 N.), about 175 feet of silty and sandy dolomite forms a transition zone between the Pogonip Group and the Eureka Quartzite. This thin-bedded, yellow- to orange-weathering zone is currently assigned to the Pogonip (J. F. McAllister, written commun., 1962), but its thickness and stratigraphic position suggest that it may be a Barrel Spring correlative, although it does have a much higher percentage of carbonate. McAllister (written commun., 1962) also noted a similar 170-foot-thick section of transitional beds north of Pyramid Peak in the Funeral Mountains east of Death Valley. There reddish-brown-weathering silty and shaly beds and some dolomite are present in the lower part of the Eureka Quartzite.

The lower part of the Eureka Quartzite at the Nevada Test Site, Nev., comprises 35 feet of thin-bedded orange- to brown-weathering limestone underlain by 60 feet of brown-weathering indistinctly thin-bedded quartzite (Byers and others, 1961, p. C108). This interval is a Barrel Spring equivalent (Ross, R. J., 1964, p. C18, colln. D680–CO). Interestingly enough, two of the fossil forms (*Valcourea*, *Lonchodomas*) in the limestone there are the same as forms from the shaly upper member of the Barrel Spring Formation. Near the west edge of the Specter Range quadrangle in Nevada, about 1 mile north of U.S. Highway 95, red-weathering thin-bedded quartzite, siltstone, and some shale that also may be the Barrel Spring equivalent are present near the base of the Eureka Quartzite.

These sections east of the Inyo Mountains, though probable correlatives of the Barrel Spring, lack the distinctive red-brown shaly upper member. Most are dominantly carbonate, but this would be expected owing to the seemingly regional trend of increasing carbonate south and east of the Independence quadrangle. However, shaly beds reappear in the basal part of the Eureka Quartzite in the Eureka area of eastern Nevada. Kirk (1933, p. 28) noted that "below the quartzite proper, as at Lone Mountain, sandy calcareous argillites were found." He also noted (1933, p. 32–33) that about 250 feet of mixed carbonate and quartzite in the Antelope Range about 30 miles southwest of Eureka contains *Remopleurides* and *Valcourea*, which are also present in the Barrel Spring Formation. These beds were studied and named the Copenhagen Formation by Merriam (1963a, p. 25), who suggested that the formation is a local lateral equivalent of the lower part of the Eureka Quartzite and that it is correlative with the Barrel Spring Formation.

North and west of the quadrangle, the stratigraphic equivalent of the Barrel Spring Formation may well be present in the fossiliferous Ordovician section in the Mount Morrison roof pendant of the Sierra Nevada (Rinehart and Ross, 1964, p. 17–23), and in the Palmetto Formation in Nevada (Ferguson and others, 1954). In these areas, however, the exposed Ordovician sections are so different from those in the Inyo Mountains that recognition of any of the Inyo formations is virtually impossible. The appearance of dark fine-grained clastic rocks of the Barrel Spring Formation in the lower part of the Eureka Quartzite interval is probably a forerunner of these markedly different Ordovician rocks to the north and west.

JOHNSON SPRING FORMATION

NAME AND DISTRIBUTION

The Johnson Spring Formation was named by Pestana (1960, p. 862) for exposures along the east side of Mazourka Canyon. It is a lateral equivalent of at least part of the widespread Eureka Quartzite. The relation of the Independence rocks to this widely known formation is discussed on page 24.

A thin belt of the Johnson Spring Formation extends virtually unbroken except for minor cross faults from the vicinity of Barrel Springs north to Badger Flat. Northwest of Badger Flat the thin belt is faulted out, but it makes a brief reappearance along the south margin of the Waucoba Mountain quadrangle, the northernmost known occurrence of the formation. South of Barrel Springs the outcrop belt is discontinuous owing to faulting, but segments of the formation occur as far south as the Betty Jumbo mine, the southernmost appearance of the formation. The nearest outcrops of stratigraphically equivalent beds to the southeast in the New York Butte quadrangle are assigned to the Eureka Quartzite (Merriam, 1963b, p. 9). Directly east of the area, in the Waucoba Wash quadrangle, equivalent beds are found in a small area west of the Willow Creek Camp.

The Johnson Spring Formation is thus virtually limited in its distribution to the Independence quadrangle. Pestana (1960, p. 862) wisely gave it a local name to point out its lithologic variation from the Eureka Quartzite.

THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness of the Johnson Spring Formation 13 measured sections ranges from 398 feet near the south end of the outcrop belt to 114 feet near Badger Flat. Thinner sections were measured northwest of Badger Flat (one is only 39 feet thick), but these are suspect owing to faulting. The type section, which is about midway in the outcrop belt, is 210 feet thick; this figure is fairly close to the average thickness of about 225 feet for the formation. In general, the Johnson Spring thins to the north (pl. 3), but it is difficult to say how much of this thinning is due to faulting and how much is due to variation in original thickness. Several subunits of the Johnson Spring are notably lenticular. The sections given in "Stratigraphic Sections" (p. 47–53) were measured in areas where the rocks were least disturbed. Most variation in thickness is due to variations in original depositional thickness, but the subtle effects of strike faulting, such as those observed in the northern part of the area, cannot be completely dismissed anywhere along the outcrop belt.

The beds of the Johnson Spring Formation conformably overlie the Barrel Spring Formation. The readily mappable contact between the dark-colored shale of the underlying Barrel Spring and the light-colored basal quartzite of the Johnson Spring Formation is abrupt, but no break in deposition is noticeable.

LITHOLOGY

The Johnson Spring Formation represents a marked variation from its partial stratigraphic equivalent, the Eureka Quartzite. Good exposures along a strike length of some 15 miles, in steeply dipping but gener-

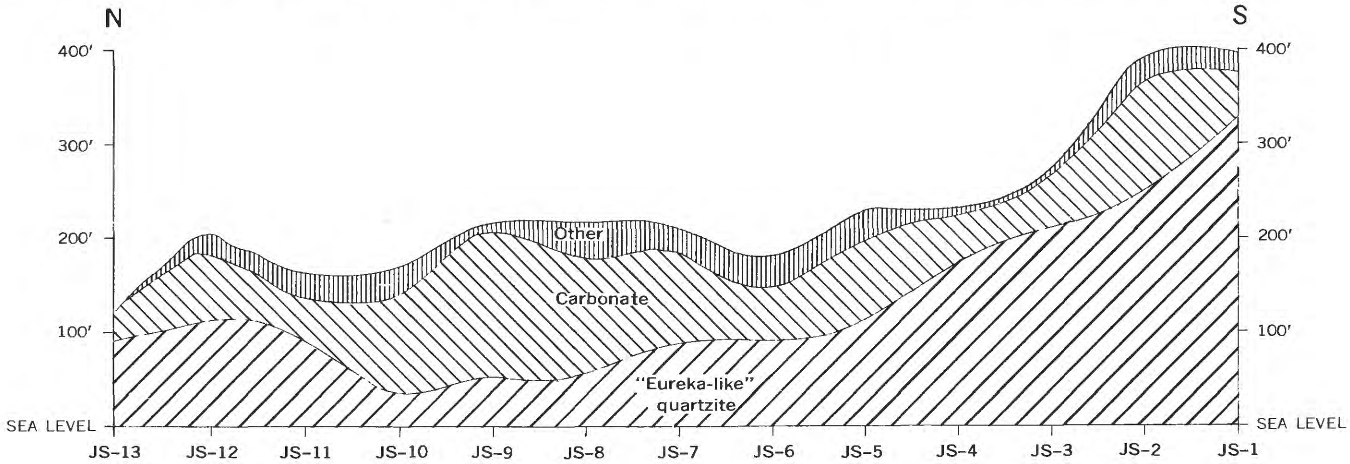


FIGURE 12.—Variation in thickness and lithology of Johnson Spring Formation.

ally unfaulted sections, provide an excellent opportunity to detail these variations. The characteristic rock type of the formation is white to gray orthoquartzite, although in some sections a combination of limestone, dolomite, siltstone, and shale is dominant.

In addition to the decrease in thickness to the north, the percentage of quartzite also decreases in this direction. From sections JS–1 to JS–10 (see p. 47–52) the percentage of quartzite decreases from 85 percent to 20 percent (fig. 12). Northward, in sections JS–11, –12, and –13, the trend is reversed, and quartzite percentage increases to 75 percent.

The subunits of the Johnson Spring, and most notably the quartzites, are lenticular. One of the best examples of this lenticularity is shown by the uppermost quartzite. It is 4 feet thick at section JS–10 and expands to 70 feet at JS–11 along a strike of about 1 mile. Just south of JS–10 the uppermost quartzite seems to lens out completely, but it reappears and continues southward. In this same area the basal quartzite also thickens markedly northward. On the composite cross section (pl. 3) it is apparent that other subunits are also lenticular, particularly the coral limestone lens that extends from sections JS–7 to JS–10. Despite the lenticularity, in most outcrops a distinctive light-colored quartzite at the top of the formation, and another at the base readily identify and delimit the Johnson Spring Formation.

The abundance (or even the dominance) of thin-bedded limestone, dolomite, siltstone, and shale and the preservation of marine fossils leave little doubt about the marine origin of the Johnson Spring Formation. Some of the more massive quartzites, particularly in the upper part of the formation, may very possibly be subaerial deposits; but their intimate association and interbedding with marine beds means that if they were subaerial they were deposited as beach sands.

Although the Johnson Spring Formation is easily mapped because of its distinctive quartzite cap and base, it nevertheless is one of the more lithologically variable formations in the quadrangle. The units shown in the composite section (pl. 3) are all mappable; if a large enough scale had been used they could have been delineated to show in plan view the lenticularity that is evident in cross section (pl. 3.) The following members, in descending order, are distinguishable:

Upper quartzite
Upper dolomite
Coral limestone
Middle quartzite
Lower limestone
Crinoidal dolomite
Mixed lithology
Lower quartzite

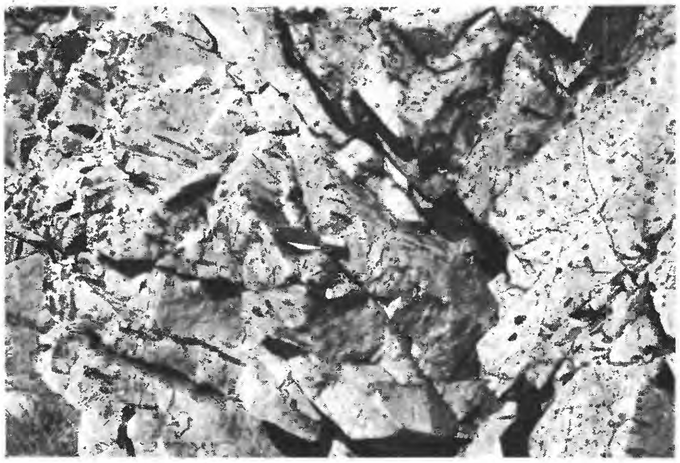
No one section exposes all these units, and some members are probably laterally discontinuous equivalents of the same unit. Some units, as defined, are a composite of different lithologies and may contain several small subunits which further accentuate the variability of the formation.

LOWER QUARTZITE

The light-colored lower quartzite is present throughout the area and stands in contrast with the underlying dark-colored shale of the Barrel Spring Formation. The quartzite ranges in thickness from about 10 feet to 110 feet and is thickest at the northernmost measured section (JS–13).

The quartzite is mostly light colored and pure at the south end of the area, but elsewhere it commonly weathers yellow to red brown and has calcareous cement (fig. 13*A*). Characteristically the beds are thin, and crossbedding is obvious in some outcrops. *Scolithus* is

A



B

FIGURE 13.—Johnson Spring Formation. *A*, Thin-bedded yellowish-weathering calcareous quartz sandstone and quartzite. Pure quartzite layer below hammerhead; most other beds have some calcareous cement. Exposed about 40 feet above base of formation near section JS–13. *B*. *Scolithus* in quartzite showing hackly fracture. Exposed about 1 mile west-northwest of the Betty Jumbo mine in unit 7 of measured section JS–1.

found locally and is particularly abundant in unit 7 of section JS–1 (fig. 13*B* and p. 48).

The quartz grains are as much as 0.75 mm in diameter and are generally well rounded. In some specimens these larger grains are scattered through a mass of less well rounded grains from 0.1 to 0.2 mm in size. The quartzite in some outcrops is generally coarser grained than that higher in the formation. Some specimens have calcite cement, and others contain grains of tremolite and diopside, which attest to the original presence of carbonate cement. Beds a few inches thick of dark-colored shale or siltstone are also present.

At the type section the lower quartzite comprises Pestana's (1960, p. 863) units 1 and 2, which are combined as unit 1 in my description of the same section. (See section JS–7, p. 50.)

MIXED LITHOLOGY

Immediately overlying the lower quartzite in the central part of the area, but lensing out both to the north and south, is a mixed sequence of limestone, dolomite, siltstone, calcareous quartz sandstone, shale, and quartzite. Its maximum thickness is about 60 feet, near the type section (JS–7).

The unit as a whole weathers dark in contrast to the light-colored quartzites above and below. Medium- to dark-gray carbonate rocks and red-brown silty and shaly beds are interspersed with thin beds of light-colored sandstone and quartzite.

The limestone is commonly thin bedded and nodular and contains coral and other fossil fragments. In section JS–8, unit 4, the limestone has grayish-red lenses that give the rock an overall purplish cast. This particular rock type commonly contains abundant corals.

Most of the dolomite is thick bedded, but some is thin bedded and (or) has thin silty and sandy layers; locally, it contains pelmatozoan fragments. Owing to different proportions of quartz and dolomite grains, the unit ranges from clastic dolomite (calcarenite) to sandstone. Some specimens comprise well-rounded quartz grains, as large as 0.5 mm, in a matrix of carbonate or calc-hornfels and are lithologically much like the Ordovician rocks of the Mount Morrison roof pendant of the Sierra Nevada (Rinehart and Ross, 1964, p. 15). In some places laminated calc-hornfels has formed from the carbonate layers, as in section JS–5.

The section of mixed lithology comprises units 3–9 of Pestana's type section (1960, p. 863). In my modified version of the same section (JS–7), units 2–6 make up the mixed lithology.

CRINOIDAL DOLOMITE

At the north end of the area, dolomite rich in pelmatozoan fragments overlies the section of mixed lithology. The crinoidal dolomite ranges in thickness from about 25 to 40 feet. The presence of limy and silty rocks both above and below the crinoidal dolomite in section JS–11 and above the crinoidal dolomite in section JS–12 suggests that the dolomite is a lateral variant of the mixed-lithology unit.

The unit is made up of medium-gray to medium-dark-gray thin- nodular-bedded dolomite containing abundant pelmatozoan fragments and some brachiopod and coral fragments. The fragmental appearance of this rock is borne out in thin sections. Clasts of fossil material as much as 3 mm across are liberally scattered through a matrix of fragmental dolomite grains of various sizes but all much less than 1 mm in diameter.

This unit is truly a calcarenite.

The crinoidal dolomite is not present at the type section; it was noted only from section JS–10 north to section JS–13. At section JS–13, where the upper quartzite bed of the formation is missing, the distinctive dolomite, rich in fossil fragments, is in contact with the overlying Ely Springs Dolomite.

LOWER LIMESTONE

South of the type section and extending from section JS–5 to the southern limit of exposure of the formation, the mixed-lithology unit is overlain by a unit composed mostly of limestone, which is probably also a lateral variant of the mixed-lithology unit. The thickness of the lower limestone is extremely variable but reaches a maximum of 56 feet. To the south the limestone splits into three units that are interbedded with quartzite, and at section JS–1 it comprises only two thin limestone (and calc-hornfels) units; probably the lower limestone lenses out a short distance farther south.

The lower limestone is made up of medium-gray to medium-dark-gray thin- nodular-bedded limestone with irregular lenses and beds of silty material that weather brown and reddish brown. Although limestone is most common, silty and dolomitic mixtures that have been altered to calc-hornfels are also present. Brachiopods are found locally, and pelmatozoan fragments are liberally scattered through the unit.

MIDDLE QUARTZITE

Overlying the belt of nonquartzite rocks is a distinctive marker zone composed mainly of pure quartzite. This unit is more than 200 feet thick in Willow Springs Canyon, but northward it thins and becomes discontinuous and finally disappears near section JS–9.

Most beds in this unit could be referred to as "typical Eureka Quartzite." The quartzite is white to light gray, massive to poorly bedded, and has a blocky to hackly fracture; it is composed of well-sorted and well-rounded very fine to medium-sand-size quartz grains. Locally this unit contains thinly bedded crossbedded quartzite and may have calcite cement. In some sections (JS–2 and –3, for example), particularly in the southernmost sections, the unit includes beds of limestone and dolomite.

The middle quartzite is unit 10 in the type section of Pestana (1960, p. 863), and unit 7 of my modification of the same section (JS–7).

CORAL LIMESTONE

A unit composed mostly of limestone in which coral fragments are locally abundant forms a lens from the type section (JS–7) north to the vicinity of section JS–10. It thins rapidly both north and south from a maximum thickness of about 90 feet.

The limestone is bluish gray to dark gray in thin irregular beds containing scattered black chert nodules. These beds are relatively soft and are poorly exposed in some areas. Grayish-red silty lenses and irregular beds give a purplish cast to some outcrops. The grayish-red lenses, which are commonly coral bearing, are a distinctive feature of this unit. Corals are the most common fossils in the limestone, but brachiopods, gastropods, bryozoans, and pelmatozoan fragments were also seen. The corals are most abundant in the vicinity of sections JS–7 and JS–8.

Though gray limestone is the dominant lithology, dark-colored limy quartzite, dark-gray dolomite in thin nodular beds, and minor silty layers are also present.

The coral limestone member comprises units 11–14 of Pestana's type section and units 8 and 9 of section JS–7.

UPPER DOLOMITE

Overlying the coral limestone member, but more extensive, is a dolomite member that crops out along almost the entire strike length of the formation. This dolomite, together with the coral limestone, forms a carbonate belt separating the upper and middle quartzites. The dolomite is as much as 40 feet thick, and it thickens and thins irregularly along its strike length.

The dolomite is medium gray to dark gray but weathers lighter. Bedding is variable; in some places it is thin and nodular, and elsewhere it is massive or very poorly developed and thick. Black chert nodules are scattered to common, and locally the chert is in ¼- to ½-inch thick beds. Fossil debris—most commonly pelmatozoan fragments but also corals and brachiopods—is scattered through the dolomite.

The upper dolomite is unit 15 in Pestana's type section, which equates to unit 10 of section JS–7.

UPPER QUARTZITE

The formation is capped by a light-colored relatively pure quartzite unit at every measured section except JS–13, the northernmost section measured. The thickest section, about 85 feet thick, was measured near the southern limit of exposure. The unit thins to less than 30 feet thick in less than a mile to the north and remains about 10–30 feet thick for several more miles along the strike. South of section JS–10 the unit lenses out, but it reappears as a thin layer at JS–10; from there it thickens rapidly northward but, just as rapidly, lenses out again south of section JS–13. The upper quartzite is an easily mapped unit, for it forms a prominent white rib (fig. 14) and has the appearance of "typical Eureka Quartzite."

FIGURE 14.—Johnson Spring Formation. Prominent rib of the upper quartzite north of the Blue Stone talc mine. Dark rocks to right on skyline are dolomite and limestone underlain by middle quartzite, which makes white rib on skyline. Dark rocks to left of upper quartzite are lower part of the Ely Springs Dolomite.

The quartzite is white to various shades of gray on fresh surfaces. Locally it weathers to shades of yellow and orange or to a reddish cast along joint surfaces. Most outcrops are boldly massive, but some are thin to thick bedded. The quartz grains are fine to medium sand size and generally are well rounded and well sorted. The quartzite is notably pure, but minor calcite cement is found in some outcrops. The northernmost thick lens (JS–11, JS–12) contains minor dolomite and, locally, soft sandy layers rich in sericite, which reflects argillaceous impurities.

Pestana's (1960, p. 863) unit 16, at the type section, is the upper quartzite (unit 11) in the equivalent section JS–7.

FOSSILS AND AGE

Fossils in the Johnson Spring Formation are of particular geologic importance because the lateral equivalent of this unit is almost exclusively quartzite that is notably unfossiliferous. The carbonate units, particularly the coral limestone unit and parts of the mixed-lithology unit, locally contain abundant corals and, less commonly brachiopods, bryozoans, and gastropods. Undiagnostic pelmatozoan fragments also are widespread and abundant.

The first reported collections from the formation were made by Langenheim and others (1956, p. 2093). They listed a fauna of corals, bryozoans, brachiopods, gastropods, sponges, pelecypods, and cephalopods, which were collected in the canyon where JS–7 was later measured and in the next canyon to the south. They considered that "this fauna has a general Blackriver–Trentonian aspect, although certain elements, such as *Ptychopleurella* n.sp. and *Favistella* cf. *F. discreta*, suggests that it may be Trentonian."

A further collection and study was made in the same area by Pestana (1960), who enlarged on the previous collections and described several new coral species and a new brachiopod species. Pestana (1960, p. 864), chiefly on the basis of the generic ranges of the corals, concluded that the formation appeared to be of Trenton age.

In the present study of the Independence quadrangle, several collections were made, chiefly of corals and brachiopods. The identifications in the following collections were made by R. J. Ross, Jr.

USGS colln. D1008–CO. Collected from unit 8 of section JS–7 about 140 feet above the base of the formation (California coordinates, zone 4; 2,273,500 E., 575,700 N.).
- Streptelasmid corals, small
- *Palaeophyllum*? sp.
- *Lichenaria* sp.
- Dinorthid, smooth, indeterminate (fragment)
- aff. *Nicollella* sp. (immature)
- *Zygospira* sp.
- *Sowerbyella merriami* Cooper

This fauna correlates with the upper Copenhagen Formation and may be of Wilderness age.

USGS colln. D1025–CO. Collected from unit 6 of section JS–7 about 85 feet above the base of the formation (California coordinates, zone 4; 2,273,500 E., 575,700 N.).
- Small streptelasmid corals
- *Zygospira* sp.
- *Sowerbyella* sp.

USGS colln. D1064–CO. Collected from unit 5 of section JS–2 (California coordinates, zone 4; 2,271,300 E., 544,700 N.).
- *Sowerbyella*? sp. (fairly large)
- *Desmorthis*? sp.
- Trilobite fragments

The occurrence in this collection of the specimen which is probably *Desmorthis* was unexpected because *Desmorthis* is considered to be a genus of Whiterock age that occurs below *Rhysostrophia*.

Collected from unit 7 of section JS–2 (California coordinates, zone 4; 2,271,300 E., 544,700 N.).
- *Sowerbyella*? sp.

USGS colln. D1091–CO. Collected 70 feet above base of formation (California coordinates, zone 4; 2,273,000 E., 579,700 N.)
- *Dinorthis*? sp. (mold of a large pedicle? valve)

The following collections were identified and reported on by W. A. Oliver (written commun., 1960).

Collected about 6,000 feet N. 40° E. of Johnson Spring in unit 10 (coral limestone) of section JS–10 (California coordinates, zone 4; 2,273,000 E., 580,200 N.).
- *Palaeophyllum* sp. 1, several blocks
- "*Streptelasma*" *tennysoni* Pestana (20 specimens representing one or several coralla)
- Streptelasmatid corals (two specimens)
- Horn corals, indeterminate (nine specimens)
- Receptaculitid fragment

[Oliver stated that *Palaeophyllum* sp. 1, which forms 50 percent of the collection, may be *P. rugosum* Billings of Pestana (1960) because it fits Pestana's description in all respects.

Neither the specimens at hand nor those illustrated by Pestana would justify comparison with Billings' species. "*Streptelasma*" *tennysoni* Pestana forms 40 percent of the collection; Oliver did not know what genus it should be assigned to but stated that it is not *Streptelasma*. The peripheral budding with loose, phaceloid growth form is characteristic. Oliver believed that this collection is most likely Late Ordovician in age, although he would not rule out Early or Middle Silurian or late Middle Ordovician.]

Collected about 4,900 feet N. 60° E. of Johnson Spring in the coral limestone unit near section JS–8 (California coordinates, zone 4; 2,273,300 E., 577,300 N.).

Palaeophyllum sp. 2
Streptelasmatid corals

[According to Oliver, *Palaeophyllum* sp. 2(?) may be the same as *P.* sp. 1, but it is larger and has shorter septa. Neither is comparable to Pestana's other species of *Palaeophyllum*.]

Collected about 7,800 feet S. 59° E. of SE cor. sec. 36, T. 11 S., R. 35 E. Float from near the middle of formation (California coordinates, zone 4; 2,272,400 E., 582,900 N.).

Palaeophyllum? sp. 3
Horn corals (indeterminate)
Favistella sp.
Echinoderm columnals

Palaeophyllum? sp. 3 could be *P. mazourkaensis* Pestana, because it is comparable in size and growth form, but it is so poorly preserved that it cannot be definitely assigned, even to genus. *Favistella* is presumably restricted to rocks of Middle and Late Ordovician age.

Collected about 8,700 feet S. 54° E. of SE cor. sec. 36, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,272,700 E., 581,800 N.).

Streptelismatid corals
Echinoderm debris

[Oliver noted that the streptelasmatid corals are of types common in parts of the Ordovician but that a Silurian age cannot be ruled out on the basis of these corals alone.]

Collected 10 feet above base of unit 8 of section JS–8 (California coordinates, zone 4; 2,273,400 E., 577,400 N.).

Indeterminate coral cf. *Eofletcheria* sp.

The corals, which looked so promising in the field, have not proven to be of much value in dating the Johnson Spring Formation; silicification has apparently destroyed internal structures, which are critical for identification. Externally, the corals from some localities appear remarkably well preserved. Oliver's identifications suggest a Middle or Late Ordovician age, but he was careful to point out that a Silurian age cannot be ruled out on the basis of the corals alone.

R. J. Ross, Jr. (written commun., 1962), placed the Johnson Spring Formation in the Wilderness Stage (immediately below the Trenton) of the Middle Ordovician. Langenheim and others (1956, p. 2093) considered that the "fauna has a general Blackriver-Trentonian aspect," but they seemed to favor a Trenton age. Pestana (1960, p. 864) also favored a Trenton age. The Johnson Spring Formation is thus considered Middle Ordovician, most probably middle or late Middle Ordovician.

CORRELATION AND RELATION TO THE EUREKA QUARTZITE

Probably no formation in the Great Basin is more widely known than the Eureka Quartzite. It is a distinctive relatively homogeneous unit that has a fantastically wide distribution, considering that its thickness is only a few hundred feet at most. Only a few miles southeast of the Independence quadrangle, in the New York Butte quadrangle, a belt of Eureka Quartzite occupies the stratigraphic interval filled by the Johnson Spring Formation in the Independence area. There can be little doubt of the stratigraphic equivalence of these two units, particularly in view of the readily apparent lensing out of carbonate and other nonquartzite lithologies in the southern part of the area in the direction of the Eureka outcrops (pl. 3).

In the New York Butte quadrangle, shaly beds probably correlative with the Barrel Spring Formation are included in the lower part of the Eureka Quartzite (Merriam, 1963b, p. 10). Farther east, in Nevada, the fine-grained clastic and carbonate beds that had been mapped as Eureka Quartzite by Kirk (1933, p. 32) were placed in a new formation, the Copenhagen Formation, by Merriam (1963a, p. 25). The Eureka Quartzite, as defined in the New York Butte quadrangle (Merriam, 1963b, p. 9), would include both the Barrel Spring and Johnson Spring Formations. As currently defined in eastern Nevada (Webb, 1958, p. 2340–2342), the Copenhagen Formation would equate to the Barrel Spring Formation, and the Eureka Quartzite would be grossly equivalent to the Johnson Spring Formation.

Langenheim and his associates (1956, p. 2094) proposed that the term Eureka Group include the Barrel Spring Formation and unnamed overlying rocks, later named the Johnson Spring Formation by Pestana (1960, p. 862). This terminology would fit sections in the western Great Basin, where Copenhagen-like rocks have been included in the Eureka, or where the Copenhagen is not identifiable. In current eastern Nevada usage, however, Langenheim's Eureka Group would include the Eureka Quartzite of Kirk (1933) plus the underlying Copenhagen Formation. Although Langenheim's suggestion probably has logic and historical precedent, its adoption seems improbable. The firmly entrenched name Eureka Quartzite is not likely to be soon replaced by another name so that Eureka can be used for the group.

Correlation of individual sections of the Eureka Quartzite with the Johnson Spring Formation is somewhat difficult. Fossils are virtually nonexistent in the Eureka, and the Johnson Spring Formation is lithologically dissimilar from the "typical" Eureka. In some Eureka sections, a two- or three-fold subdivision is evident, the uppermost unit of which most likely equates to the Johnson Spring Formation.

In the Quartz Spring area (McAllister, 1952, p. 12) the upper 250 feet of white vitreous quartzite of the Eureka may be correlative with the Johnson Spring, and the lower 150 feet of crossbedded darker, hematitic quartzite, platy quartzite, and siltstone may be correlative with the Barrel Spring Formation as suggested by Langenheim and others (1956, p. 2090). Recent examination of this section by J. F. McAllister, R. J. Ross, Jr., and me, however, suggests the alternate possibility that the upper 250 feet of McAllister's section correlates with units 7–11 of section JS–7 of the Johnson Spring type section (the same as units 10–16 of Pestana, 1960, p. 862–863), and that the remainder of the Johnson Spring correlates with McAllister's lower Eureka. The possible relation of the Barrel Spring to this section is discussed on p. 18. A similar two-fold division of the Eureka was noted in the Funeral Mountains east of Death Valley (J. F. McAllister, written commun., 1962), and a similar correlation with the Johnson Spring is suggested.

In the Darwin area (Hall and MacKevett, 1962, p. 10) the Eureka Quartzite is probably a correlative of the Johnson Spring. Here transitional beds between the Pogonip and the Eureka may equate to the Barrel Spring. (See p. 18.)

At the Nevada Test Site, the 300-foot-thick upper unit of the Eureka Quartzite (Byers and others, 1961, p. C107) may be equivalent to the Johnson Spring, but this correlation is very tentative.

Generally the Barrel Spring and Johnson Spring Formations can be equated to the Eureka Quartzite as described by Kirk (1933). Variations in the Eureka Quartzite from pure quartzite considered as "typical Eureka" are most common in the lower part, where carbonate and fine-grained clastic beds like those of the Copenhagen and Barrel Spring occur. The upper part of the Eureka, on the other hand, appears to remain relatively pure. Thus, a significant change in the lithology of the Eureka interval occurs in the Independence area (pl. 3; fig. 12); the Barrel Spring and Johnson Spring Formations together represent the westernmost recognizable stratigraphic equivalent of the Eureka. To the northwest along the strike, equivalent beds may also be present in the Mount Morrison roof pendant about 50 miles away, where clean sand-size clastic material and calcareous quartz sandstone are interbedded with fine-grained clastics and carbonates in a thick interval containing Ordovician graptolites (Rinehart and Ross, 1964, p. 17–23).

ELY SPRINGS DOLOMITE

NAME AND DISTRIBUTION

The Ely Springs Dolomite was named by Westgate and Knopf (1932, p. 15) from exposures in the Ely Springs Range near Pioche, Nev., nearly 200 miles northeast of the Independence quadrangle. The name is widely used in the southern part of the Great Basin for the carbonate rocks immediately overlying the Eureka Quartzite.

A faulted but nearly continuous outcrop belt extends from the Squares Tunnel area to northwest of Badger Flat, where the formation is faulted and cut out by granitic rocks. This is the northwesternmost known occurrence of rocks that are assignable to the Ely Springs Dolomite. South of the Squares Tunnel area, faulted segments of the formation extend almost to Coyote Spring. Beds assignable to the Ely Springs Dolomite are present a few miles farther southeast, in the New York Butte quadrangle, (Merriam, 1963b, p. 10), and in a small area along the east front of the Inyo Mountains in the Waucoba Wash quadrangle near the White Eagle talc mine.

THICKNESS AND STRATIGRAPHIC RELATIONS

The measured thickness of the Ely Springs Dolomite ranges from 591 feet at the southernmost section (ES–1) to 195 feet at the northernmost section (ES–10). The northward thinning of the formation (pl. 4) is a characteristic of the Ely Springs Dolomite and several other formations in the quadrangle. The average thickness, based on nine measured sections, is less than 300 feet, much less than that of presumably correlative rocks southeast of the Inyo Mountains.

Only a few miles to the southeast, in the New York Butte quadrangle, Merriam (1963b, p. 10) assigned at least 240 feet of beds to the Ely Springs. The upper contact there is uncertain because of the similarity of the upper part of the Ely Springs to the overlying Silurian dolomite; thus, the formation may be thicker. Merriam (1963b, p. 8) listed a thickness range from 240 to 550 feet for the Ely Springs, which is comparable to that of sections in the Independence quadrangle.

The Ely Springs Dolomite generally is considerably thicker in the areas southeast of the Inyos. Reported thicknesses are: in the Darwin quadrangle, about 920 feet (Hall and MacKevett, 1962, p. 10); in the Quartz Spring area, 740–940 feet (McAllister, 1952, p. 15); at the Nevada Test Site, about 280 feet (Poole, 1965); and at the north end of the Nopah Range, 800 feet (Hazzard, 1937, p. 325). At Bare Mountain, Nev., Cornwall and Kleinhampl (1961) measured only about 300 feet.

The beds of the Ely Springs Dolomite overlie the Johnson Spring Formation conformably. The contact is generally abrupt, quartzite against the overlying dolomite. The interbedding of dolomite similar to that of the Ely Springs with quartzite in the upper part of the Johnson Spring Formation suggests a lithologic transition. For convenience in mapping, I placed the contact at the top of the uppermost quartzite. In other areas—for example, the Dry Mountain quadrangle—quartzite beds are included in the lower part of the Ely Springs Dolomite (McAllister, written commun., 1962) and the base of the Ely Springs is placed at the bottom of the lowest carbonate above the massive Eureka Quartzite. In the Independence area, the upper dolomite of the Johnson Spring Formation may correlate with the lowermost Ely Springs of such sections. For mapping purposes, however, these differences are not significant. It is a matter of interpretation, through a few tens of feet at most, whether the lowest dolomite or the highest quartzite marks this contact. This interval, then, marked by intertonguing carbonate and clean sand-size clastic materials, represents a zone of continuous deposition but one in which conditions of sedimentation were changing. Such a change is widespread in the Great Basin at this stratigraphic level.

LITHOLOGY

The Ely Springs Dolomite is almost exclusively dolomite, in shades of gray, with varying amounts of nodular and bedded black chert. Throughout the Independence quadrangle the formation is readily separable into three members (pl. 4): (1) a lower thin-bedded dark-gray dolomite containing abundant black chert, (2) a middle massive light-gray dolomite, and (3) an upper thin-bedded dark-gray dolomite with nodular and bedded black chert. These members are not delineated on the geologic map because they are too thin to be shown at the map scale.

In addition to the thinning of the formation to the north, a pronounced lithologic change also occurs in the same direction. Near the north end of the outcrop belt, both the lower and upper members grade into massive black chert; in its northernmost exposures, the Ely Springs Dolomite comprises a lower massive chert member, a middle gray dolomite, and an upper massive chert member. This section is so different from the typical Ely Springs that it properly deserves a new formational name to point out this lithologic variance. Since such a name would apply only to a strike segment about 2 miles long northwest of Badger Flat, this variant is not named but is described as part of the Ely Springs. The trend of increasing chert at the expense of dolomite in the Ely Springs is one more instance of the increase in transitional-assemblage affinities northward in the Paleozoic rocks of the Independence quadrangle.

LOWER MEMBER

The lower member, consisting of dark-gray dolomite and chert, forms a dark belt extending along the entire outcrop length of the formation. It ranges in thickness from 294 feet in Willow Springs Canyon to less than 50 feet near Badger Flat.

The dolomite is mostly medium dark gray to dark gray on fresh surfaces and medium gray on weathered surfaces. Individual beds are generally 1–6 inches thick and somewhat nodular. Laminations are common within many individual beds, but locally the outcrops are massive and poorly bedded.

The chert is black where fresh and unaltered, but metamorphism has lightened much of it (fig. 15*A*). The chert occurs in thin nodular beds as much as 3 inches thick, in scattered nodules, or in trains of nodules that follow bedding.

The overall dark color and the abundance of chert characterize this member. Most outcrops in the southern part of the area are 10–15 percent chert (fig. 15*A*), although some are almost chert free. About 1½ miles southeast of Badger Flat, the amount of chert increases notably, and the rocks are as much as 25 percent black chert, commonly in nodular beds (fig. 15*B*). The lower member is transformed entirely to chert in a strike length of less than 1 mile just south of Badger Flat. Section ES–9 shows this transition; chert beds as much as 1 foot thick are interbedded with dark dolomite overlying a basal unit composed of massive chert. At section ES–10, massive black chert, in part altered to shades of gray, makes up the entire member. This lithology continues across Badger Flat and north to the end of the outcrop belt (fig. 15*C*).

MIDDLE MEMBER

The middle member, composed of light-gray dolomite was traced along the entire strike length of the formation. It forms an easily recognizable light-gray belt that markedly contrasts with the underlying and overlying darker members. The thickness ranges from about 65 feet to somewhat less than 150 feet but does not seem to change systematically along the strike. In contrast with the other two members, the greatest thickness of the middle member is near the center of the outcrop belt.

The dolomite is medium gray to medium dark gray on fresh surfaces, similar to the dolomite of the lower member, and characteristically and distinctively light gray or, locally, dappled gray on weathered surfaces.

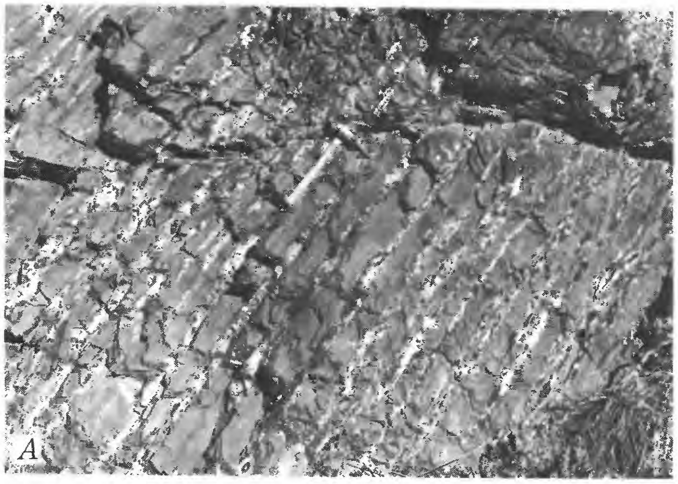


FIGURE 15.—Ely Springs Dolomite. *A*, Black chert nodules and nodular layers in dark-gray dolomite of lower member in Willow Springs Canyon (unit 1 of measured section ES–1). Chert commonly contact metamorphosed to light-colored calc-hornfels minerals. *B*, Dark-gray dolomite and nodular bedded chert. Photograph taken about 10 feet above base of lower member of formation along section ES–8. Hammer used for scale. *C*, Banded chert west of Badger Flat. Lighter layers at least partly a metamorphic effect. Penny used for scale.

Irregularly ridged and spiny surfaces are also present.

From a distance the member appears massive, and it is a good cliff former; blocky, craggy outcrops are common. On close observation, however, most outcrops show some thin to thick irregular bedding.

Clastic beds are generally absent, but a local sandy lens in unit 2 of section ES–5 indicates that sandy material was still being supplied, at least locally. This lens has 15–20 percent of 0.2–0.5-mm well-rounded quartz grains scattered through a dolomite matrix.

UPPER MEMBER

The upper member, composed of dark-gray dolomite and chert, forms a dark, easily recognizable band along the entire strike length of the formation in the quadrangle. This member was not recognized in the Inyo Mountains east and southeast of the Independence quadrangle. The thickness ranges from 166 feet in Willow Springs Canyon to about 30 feet near the north end of the area.

The basal beds of the member are interbedded dark-gray to medium-gray dolomite and black chert in rather regular layers as much as 4 inches thick. These distinctive beds are persistent and best developed in the northern part of the area (fig. 16*A*).

In part, these beds are overlain by thin-bedded to massive dark-gray to light-gray dolomite. Bedding is commonly irregular, and chert nodules, though locally abundant, are missing in many outcrops. The dolomite shows the pitted and ridged weathered surface typical of fine-grained dolomite in arid regions.

The next overlying and most distinctive unit in the member is a massive black chert that is found at almost all outcrops. The chert forms bold outcrops (fig. 16*B*) a few feet to at least 30 feet thick. Lamination or thin bedding is visible in most of the seemingly massive outcrops on close observation. This massive chert unit was cited by Langenheim and others (1956, p. 2095) as an example of a siliceous hardpan marking a post-Ely Springs erosional interval. Nolan, Merriam, and Williams (1956, p. 37) speculated that this unit was the stratigraphic equivalent of a massive bed of black chert that is widespread in the Great Basin and is considered to be the lowermost bed of the Roberts Mountains Formation of Silurian age. At several measured sections of the Ely Springs Dolomite, how-

A

B

FIGURE 16.—Ely Springs Dolomite. *A*, Along measured section ES–10; steeply dipping contact of lighter colored middle member (unit 2) on left with dark dolomite and chert of upper member on right (unit 3 capped by unit 4 at right of massive outcrop). *B*, Massive brecciated black chert at top of upper member; unit 7 of measured section ES–4.

ever, the massive chert unit is overlain by dolomite typical of the rest of the formation. (See p. 54–56). I interpret the massive chert in the Independence quadrangle as being within the Ely Springs Dolomite; in places it is the uppermost unit, and in other places it is below the uppermost dolomite. The massive chert and the overlying dolomite belong with the rest of what I call Ely Springs Dolomite, as a map unit. The much less certain question of the age of these upper beds and their correlation with the upper part of the Ely Springs Dolomite or with Silurian rocks in other areas is discussed in the following section, "Fossils, Age, and Correlation."

Just south of Willow Spring Canyon, along section ES–1, 28 feet of cherty limestone is poorly exposed near the top of the upper member. This is the only known occurrence of limestone in the formation within the quadrangle. It is both overlain and underlain by cherty dolomite of the Ely Springs type, and is considered to be part of the Ely Springs Dolomite, though it may be a precursor of the dominantly limestone strata of the overlying Vaughn Gulch Limestone of Silurian age.

The upper member maintains a general three- or four-fold division as far north as section ES–10 (pl. 4). The transition of this member to massive chert north of section ES–10, is concealed in poor exposures in the Badger Flat area; but northwest of Badger Flat, massive chert similar to that of the lower member is locally well exposed. Presumably the concealed transition zone is much like that of the lower member as shown by section ES–9.

FOSSILS, AGE, AND CORRELATION

No identifiable fossils were recovered from the Ely Springs Dolomite during the mapping of the Independence quadrangle. Fragments of corals were found, and pelmatozoan debris is locally abundant. Some massive chert beds contain oval to rounded spots of somewhat coarser quartz (0.1–0.15 mm in diameter) that probably represent the remains of Radiolarian tests. One massive chert specimen was rich in sponge(?) spicules.

Langenheim and others (1956, p. 2095) reported poorly preserved *Streptelasma* sp. from the formation. A collection of brachiopods and corals from the lower part of the Ely Springs in the Darwin area is Late Ordovician in age (Hall and MacKevett, 1962, p. 11). A fauna of brachiopods and corals from the Quartz Spring area also support a Late Ordovician age (McAllister, 1952, p. 15). On the basis of lithologic comparison with fossiliferous Ely Springs in these areas, the rocks referred to the Ely Springs Dolomite in the Independence quadrangle are probably Late Ordovician in age.

The lower and middle members probably correlate with units 1 and 2, respectively, of the Quartz Spring area (McAllister, 1952, p. 13) and with the lower and upper parts of the Ely Springs Dolomite in both the Darwin area (Hall and MacKevett, 1962, p. 11) and the Nopah Range (Hazzard, 1937, p. 325).

The upper member, on the other hand, does not have an obvious correlative unit in the Ely Springs of the Quartz Spring area or the Nopah Range. At Darwin a 40-foot-thick dark-gray dolomite with little chert is at the top of the formation (Hall and MacKevett, 1962) and may be correlative with the upper member, but this correlation is very speculative.

The upper member may be equivalent to the lower part of the Hidden Valley Dolomite, which was originally described in the Quartz Spring area by McAllister (1952, p. 15) as medium-gray to light-gray dolomite with abundant chert. In the nearby New York Butte quadrangle, a direct lithologic comparison is difficult to make; although dolomite and chert make up the lower part of the Hidden Valley, they are metamorphosed (Merriam, 1963b, p. 11). At Darwin, on the other hand, the Hidden Valley does not match the upper part of the Ely Springs of the Independence area. In the Nopah Range, dolomite containing abundant chert in the lower part of the unnamed Silurian (Hazzard, 1937, p. 326) may equate to the upper Ely Springs of the Independence area. At Lone Mountain (Nolan and others, 1956, p. 37), Bare Mountain (Cornwall and Kleinhampl, 1961), and other places in Nevada, black chert and dolomite that make up the lower part of the Roberts Mountains Formation of Silurian age may also be equivalent to the upper member of the Ely Springs Dolomite of the Independence area. I thought that the contact of the chert and dolomite of the lower unit with the slabby silty limestone of the middle unit of the Roberts Mountains Formation in Chuckwalla Canyon (Bare Mountain) looked very similar to the contact between the Ely Springs and Vaughn Gulch Formations in the Independence quadrangle.

The correlation of the lower and middle members of the Ely Springs Dolomite in the Independence area with the Ely Springs elsewhere is likely, and the assignment of a Late Ordovician age for these members is a strong probability. The correlation and age of the upper member are less certain. The upper member is lithologically compatible with the lower two members of undoubted Ely Springs and is markedly different from the overlying rocks; hence, it belongs with the lower two members as a mappable unit. My presumptions that these three members together are correlative with the Ely Springs and that the top of the formation in the Independence area marks the boundary between the Ordovician and the Silurian should be viewed with some reservations. The upper part of the formation could be Silurian and correlative with the lower part of the Hidden Valley Dolomite.

The age and correlation uncertainties about the upper part of what I call Ely Springs suggest that a new local formational name would be desirable for the entire formation, but retention of the old name is favored for the present to point out the similarity of this formation to the Ely Springs elsewhere. Many formations in the Independence area have been given local names to stress variations from formations of the eastern (carbonate) assemblage. Wherever possible, the "classic" carbonate assemblage names should probably be retained to call attention to the fact that, although transitional, the Independence Paleozoic section is closely related to the carbonate assemblage.[1]

SILURIAN AND DEVONIAN(?) SYSTEMS

Throughout most of the southwestern part of the Great Basin, the Silurian and Lower Devonian are represented by dolomite typified by the Hidden Valley Dolomite (McAllister, 1952, p. 15). In marked contrast, the Silurian and Devonian(?) rocks in the Independence quadrangle consist of thin-bedded argillaceous limestone and bioclastic limestone (the Vaughn Gulch Limestone) rich in coral, sponge, bryozoan, and pelmatozoan debris that grades laterally northward into graptolite-bearing calcareous shale, siltstone, and argillaceous limestone (the Sunday Canyon Formation) penetrated by tongues of bioclastic limestone of the coral-rich facies to the south.

The Vaughn Gulch Limestone and the Sunday Canyon Formation are virtually limited to the Independence quadrangle. The nearest Silurian and Lower Devonian rocks to the southeast in the New York Butte quadrangle are Hidden Valley Dolomite (Merriam, 1963b, p. 11). To the east the nearest rocks in this time span are near the east base of the Inyo Mountains about 3 miles east of the quadrangle boundary. These rocks are dolomite and are probably correlative with the Hidden Valley. To the north and west, limited outcrops of limy and

[1] Regional studies of the Ely Springs Dolomite from its type section in eastern Nevada to eastern California suggest that the upper part of the Ely Springs Dolomite as used in Mazourka Canyon is Silurian (F. G. Poole, oral commun., 1965). In a field conference in Mazourka Canyon after the completion of this report, Poole suggested to me that at section ES–1 (pl. 4) much of the middle member was correlative with his unit Su_2, and the entire upper member was correlative with his unit Su_3, both of which are Silurian units in the Nevada Test Site area (Poole, 1965), and units which he has recognized widely over the southern Great Basin. Poole also suggested essentially the same correlations for the middle and upper members at sections ES–4 and ES–10. He felt that the middle member is largely equivalent to his unit Su_2 rather than to the type upper Ely Springs, on the basis of rather subtle grain size and color differences in the dolomite, which he believes are diagnostic on a regional scale. If these correlations are valid, it means that (1) the lower dark-gray dolomite and chert member in Mazourka Canyon is correlative with the lower Elk Springs Dolomite at the type section in eastern Nevada, (2) the lowermost beds of the middle member north to about the area of section ES–4 are correlative with the lower part of the upper Ely Springs at the type section, and (3) the rest of the Mazourka Canyon Ely Springs is correlative with Poole's units Su_2 and Su_3, which he considers Silurian.

Poole's regional studies also suggest that the Silurian rocks rest with erosional unconformity on various parts of the Ely Springs Dolomite over the southern Great Basin, and that rocks he believes to be Silurian in Mazourka Canyon were deposited on an erosion surface: at ES–1, on top of about 30 feet of beds correlative with type upper Ely Springs; at ES–4, on top of only a few feet of beds correlative with type upper Ely Springs; and at ES–10, directly on beds correlative with type lower Ely Springs. Poole would thus restrict the name Ely Springs Dolomite to the rocks below this unconformity. No physical evidence of an erosional break has been noted, however, within what was mapped as Ely Springs in the Mazourka Canyon area.

212-460 O—66——3

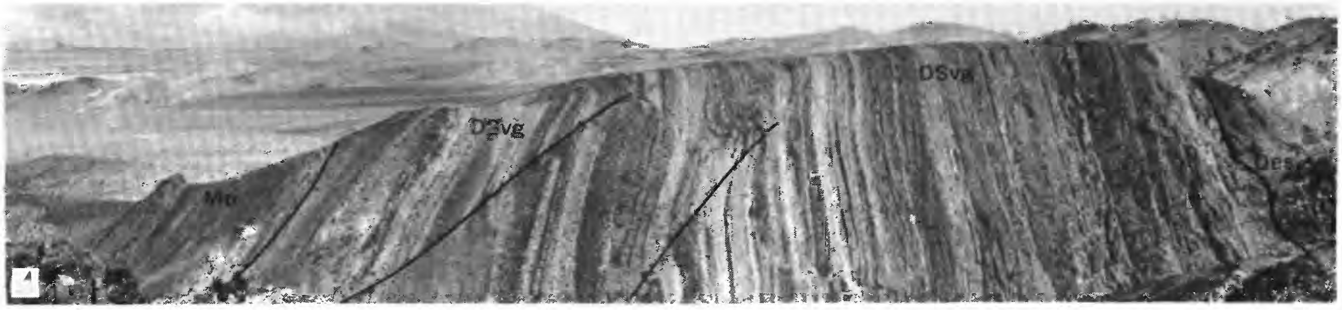


FIGURE 17.—Vaughn Gulch Limestone. *A*, Looking north at type section. On the left, the Perdido Formation (Mp) unconformably overlies the Vaughn Gulch Limestone (DSvg); on the right, the underlying Ely Springs Dolomite (Oes) is in fault contact. *B*, Bioclastic beds on ridge northwest of Vaughn Gulch; 340 feet above base of unit 4 of the type section.

silty rocks that are probably Silurian have been mapped in the Waucoba Mountain quadrangle by C. A. Nelson (oral commun., 1963); beyond this area Silurian rocks have not been recognized, though they could be present in roof pendants in the Sierra Nevada.

Despite their limited known outcrop area, the Silurian and Devonian(?) formations of the Independence area are important because they signal the northwestward change from the carbonate (eastern) assemblage to the transitional assemblage of the Great Basin.

VAUGHN GULCH LIMESTONE

NAME AND DISTRIBUTION

The Vaughn Gulch Limestone was named and the type section designated by Ross (1963, p. B81) for exposures along the ridge northwest of Vaughn Gulch, a small tributary to Owens Valley near the mouth of Mazourka Canyon. At the type section the formation is well exposed in a steeply dipping somewhat faulted and folded homocline (fig. 17*A*).

To the south the formation is considerably faulted and folded, and about 2½ miles southeast of the type section it is cut out by a large granitic mass. This is the southernmost known exposure of the formation. About 12 miles farther southeast, Silurian and lower Devonian rocks reappear, but they are part of the Hidden Valley Dolomite.

The northern limit of the formation is in Water Canyon, about 5 miles north of the type section. Tongues of the Vaughn Gulch Limestone extend several miles farther north into laterally equivalent graptolite-bearing rocks, but the canyon makes a practical though arbitrary mapping break.

THICKNESS AND STRATIGRAPHIC RELATIONS

The measured thickness of the Vaughn Gulch is about 1,500 feet at the type section northwest of Vaughn Gulch. The upper contact is an erosional unconformity; so the thickness measured is something less than the original thickness. A presumably much more eroded section about three-quarters of a mile northeast of Squares Tunnel is only about 260 feet thick. Almost everywhere else, faulting precludes thickness measurements. From the data at hand, all that can be determined with certainty is that the original thickness was at least 1,500 feet.

The contact with the underlying Ely Springs Dolomite is conformable. Dolomite or massive black chert at the top of the Ely Springs generally makes a rather distinctive and abrupt contact with the Vaughn Gulch Limestone. At the type section, a poorly exposed limestone 28 feet thick 18 feet below the top of the underlying Ely Springs could be a tongue of the Vaughn Gulch Limestone. Nowhere else in the area was limestone found in the Ely Springs; this one section could reflect an interbedded transition between the Ely Springs Dolomite and the Vaughn Gulch Limestone.

LITHOLOGY

The Vaughn Gulch Limestone is predominantly thin-bedded argillaceous and silty limestone. (See VG–1, -2, p. 56.) Much of it is medium to dark gray on fresh surfaces; it commonly weathers light gray, but shades of red, orange, and yellow are characteristic of the more impure beds. Bioclastic limestone (fig. 17*B*), the most diagnostic rock type in the formation, is characterized by beds crowded with fragments of corals, sponges, bryozoans, pelmatozoans, and some brachiopods.

Detailed study of some specimens leaves little doubt that most, if not all, of the limestone is fragmental. The widespread presence of fossil fragments, the general abundance of silty impurities, and the evidence of silt- to sand-size calcite clasts identify most of the rocks of this formation as calcarenite or calcilutite. Insoluble residues ranged from 21 to 69 percent in some samples that did not contain visible fossil fragments. Silt- and sand-size quartz fragments made up most of the residue, but finer grained, presumably argillaceous material and black carbonaceous matter were also present. The amount of insoluble residues indicate that some parts of the formation are calcareous siltstone. The specimens selected for insoluble-residue analyses were chosen from the beds that looked most impure, however, and limestone rather than siltstone is predominant in the formation.

Black chert, in nodules and in beds as thick as 3 inches, is common in unit 7 near the top of the type section, less common near the base, and scattered elsewhere.

At the type section, no obvious divisions could be mapped in the formation. The units at the type section (VG–1, p. 56) were distinguished on the basis of gross color differences and the varying ratio of bioclastic limestone to argillaceous limestone. West of the Mazourka Canyon road there is even less opportunity to divide the formation, because thermal metamorphism has affected the section. Division of the type section on the basis of fossil zones might be possible, but this would not yield mappable subunits.

The Vaughn Gulch Limestone is mostly a limestone in the field sense—that is, a calcareous rock. More precisely, the formation is a clastic unit made up of quartz grains, calcite fragments (many of which are fossil fragments), and argillaceous and carbonaceous material. Dominantly the formation is made up of clastic beds ranging from calcilulite to calcirudite and, less commonly, calcareous siltstone.

FOSSILS AND AGE

Fossils are abundant, particularly at the type section. They are commonly silicified and many are broken, but some coral heads more than 1 foot across are preserved.

The first report on fossils from the formation was made by Kirk (in Knopf, 1918, p. 36, 37). He listed genera of corals, brachiopods, trilobites, and one cephalopod and assigned the formation to the Devonian. He later recognized that these beds might be Silurian (Nolan, 1943, p. 153).

The same section where Kirk collected, and presumably the type section of the Vaughn Gulch Limestone, was also examined by Stauffer (1930, p. 86–89). He tabulated an impressive fossil list keyed to the units he distinguished and assigned the rocks to the Middle Devonian.

Waite (1953) in studying this same section, concluded that some of the fossils preclude a Devonian age. He noted particularly the forms *Conchidium*, *Pycnostylus guelphensis* Whiteaves, and *Atrypina* cf. *A. disparilis* (Hall), and further noted that new and better material showed that the *Calceola* of Stauffer was *Rhizophyllum*, a characteristic Silurian genus. Waite concluded that the fossils indicate a late Niagara or early Cayuga age for the formation.

Collections from the type section of the Vaughn Gulch Limestone were also made by C. W. Merriam, who stated (1963b, p. 13):

> The faunas consist very largely of corals, only *Atrypa* and rhynchonellids (*Eatonia bicostata* Stauffer) being at all common among the brachiopods. The large dasycladacean algae (*Verticillopora annulata* Rezak) are most prolific here and provide a tie with the Hidden Valley of the type area as well as with the Roberts Mountains formation of central Nevada and the Laketown dolomite of western Utah.
>
> Among corals of the limestone facies at Mazourka are many conforming to the general features of *Strombodes*. Others are assigned to *Chonophyllum*, *Rhizophyllum*, *Heliolites*, *Alveolites*, and *Cladopora*. Also present are large cyathophyllids and bushy forms of the *Phacelophyllum* and *Disphyllum* types.

Systematic collections were not made from the Vaughn Gulch Limestone during my study. Abundant material is already in the U.S. Geological Survey collections and is currently being restudied by C. W. Merriam. The Vaughn Gulch Limestone at the type section contains some fossils very near the top that may be Devonian forms, but the great bulk of the formation is believed to be Silurian (C. W. Merriam, oral commun., 1964. The fact that the uppermost beds of the Vaughn Gulch may be Devonian in age and that possibly Devonian monograptids are present in the upper part of the laterally equivalent Sunday Canyon Formation suggests that the Vaughn Gulch Limestone should be considered Silurian and Devonian(?) in age.

SUNDAY CANYON FORMATION

NAME AND DISTRIBUTION

The Sunday Canyon Formation was named (Ross, D. C., 1963, p. B83) for Sunday Canyon, a small tributary to Mazourka Canyon about 1 mile west of the outcrop belt of the formation. The Sunday Canyon Formation crops out in a nearly continuous belt from Water Canyon to a point northwest of Badger Flat, where the formation presumably was entirely removed by erosion prior to the deposition of the overlying Mississippian rocks. Relatively poor exposure and faulting northwest of Badger Flat dictate caution for this presumption, however.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Sunday Canyon Formation ranges in thickness from 0 to about 700 feet. The maximum exposed thickness, 683 feet, is at the type section in Bonanza Gulch, about four-tenths of a mile northeast of Barrel Springs, in T. 12 S., R. 36 E. (section SC–1, p. 57). The formation thins to the north and is only 277 feet thick at a measured section south of Badger Flat (section SC–6, p 58). Northwest of Badger Flat the formation thins and wedges out beneath the overlying Mississippian rocks.

The contact with the underlying chert and dolomite beds of the Ely Springs is presumably conformable. It is either covered or poorly exposed, as the Sunday Canyon beds are much less resistant and form a bench which may be partly covered by Ely Springs debris.

LITHOLOGY

The Sunday Canyon Formation consists chiefly of calcareous siltstone, calcareous shale, and argillaceous limestone. Outcrops of the formation are typically thin bedded and weather to poorly exposed slopes littered with thin, shaly to flaggy fragments that are from light gray to shades of yellow and orange. Exposure is normally much better in dry canyons that cut across the strike.

Tongues of clastic limestone rich in fossil fragments (northward extensions of the Vaughn Gulch Limestone) are widespread and locally abundant. They seem to be most abundant near Bonanza Gulch and to decrease in abundance to the north, although some beds of bioclastic limestone are present almost to Badger Flat. A rather prominent rib-forming zone composed mainly of fossil-rich clastic limestone and dense blue-gray limestone in the middle of the formation also contains calcareous quartz sandstone, quartzite, and abundant chert. The siliceous part of this unit is represented by unit 5 in measured sections SC–3 and SC–4 (p. 57).

Chert is locally abundant both as beds and as nodules, but part of what looks like chert in the field is actually fine-grained siltstone, as can be seen on microscopic examination. Most nodules are obviously chert, but some layers that are reported as chert in the measured section may be suspect.

The descriptions of the six measured sections (p. 57) give some idea of the gross lithology of the formation. It is not an easy formation to divide. Some bioclastic beds can be traced for some distance by large-scale mapping, particularly the central, rib-forming unit, which was traced for about 2 miles north of section SC–3. The bulk of the formation, however, is a somewhat featureless and variable mixture of calcareous, siliceous, and argillaceous material.

A gross estimate of the relative amount of calcareous material in this formation was obtained from insoluble residues left when about 30 samples were dissolved in hydrochloric acid. Some of the specimens containing abundant bioclastic material yielded as little as 10 percent insoluble residue. Other light-gray rocks, called fine-grained limestone in field descriptions yielded 20–30 percent insoluble residue. Most samples studied, however, were selected from rocks that were medium dark gray to dark gray on fresh surfaces and effervesced with acid. These rocks generally yielded 55–85 percent insoluble residue, but some yielded more than 90 percent. Much of the insoluble material was fine-grained quartz, but clay and black carbonaceous material were also abundant.

Limited thin-section study revealed that some of the fine-grained limestone is notably clastic; also calcilutites composed of calcite and quartz grains from 0.02 to 0.05 mm in diameter are predominant. In the more silty limestone, quartz clasts 0.03–0.2 mm in diameter are predominant, but the quartz clasts are associated with calcite clasts and set in a calcareous-siliceous matrix.

The distinctive calcareous quartz sandstone and quartzite units are made up of subangular to well-rounded quartz grains and minor feldspar grains from 0.05 to 0.4 mm in diameter set in a calcareous to siliceous matrix.

The generalization can be made that the Sunday Canyon Formation is dominantly a clastic unit. Field mapping further suggests that the proportion of carbonate material decreases toward the north, but more extensive insoluble-residue studies would have to be made to confirm this.

FOSSILS AND AGE

The most significant fossils in the Sunday Canyon Formation are the *Monograptus* graptolites, which have been collected from several localities. They were identified and reported on as follows by W. B. N. Berry (written commun., 1964) and, for localities I-233 and I-235, by R. J. Ross, Jr., (written commun., 1959):

I-233. Collected half a mile south of Badger Flat near the base of the formation (California coordinates, zone 4; 2,265,-800 E., 592,100 N.).
Monograptus spp.

I-235. Collected from south edge of Badger Flat in lower part of formation (California coordinates, zone 4; 2,262,700 E., 596,300 N.).
Monograptus spp.

USGS colln. D165-SD. Collected about 7,600 feet north-northeast of Johnson Spring (California coordinates, zone 4; 2,272,000 E., 582,300 N.).
Monograptus cf. *M. dubius* (Suess)
Age: In span of Wenlock-Ludlow.

USGS colln. D166-SD. Collected from east side of Al Rose Canyon about a mile south of Badger Flat (California coordinates, zone 4; 2,267,100 E., 590,600 N.).
Monograptus dubius (Suess)
Monograptus sp. (of the *M. tumescens* type)
Monograptus sp. (plain thecae and long slender rhabdosome)
Age: Probably Ludlow.

USGS colln. D160-SD. Collected in Al Rose Canyon about 1,500 feet southeast of D166-SD (California coordinates, zone 4; 2,267,500 E., 589,100 N.).
Monograptus? sp. (This could be an *M. vomerinus* type form, but the remains are so twisted that determination is difficult.)
Age: Silurian?.

USGS colln. D161-SD. Collected in Al Rose Canyon about 500 feet southeast of D166-SD (California coordinates, zone 4; 2,267,200 E., 590,200 N.).
Monograptus sp. (slender rhabdosomes with plain thecae)
Age: Silurian.

USGS colln. D162-SD. Collected from about 9,000 feet north-northeast of Johnson Spring (California coordinates, zone 4; 2,271,400 E., 583,600 N.).
Monograptus sp. (of the *M. vulgaris* type)
Monograptus cf. *M. scanius* Tullberg
Monograptus sp. (slender rhabdosomes and plain thecae; could be of *M. dubius* group)
Age: Probably Early Ludlow.

USGS colln. D179-SD. Collected near top of unit 5, measured section SC-2. About 150 feet above the base of the formation (California coordinates, zone 4; 2,272,600 E., 575,800 N.).
Monograptus cf. *M. uniformis* Pribyl
Age: Early Devonian. This form is clearly a Monograptid of the *M. hercynicus* group known to be restricted to beds of Early Devonian (at least clearly post-Ludlow) age. In terms of systemic subdivisions, this form suggests an early Gedinne age for the beds bearing it.

Corals have also been recovered from bioclastic tongues of the Vaughn Gulch Limestone at several localities. The following corals were identified and reported on by W. A. Oliver, Jr. (written commun., 1960, 1962):

Section SC-3, unit 8. Collected about 35 feet below top of formation, about 5,000 feet northeast of Johnson Spring (California coordinates, zone 4; 2,272,100 E., 578,400 N.).
Alveolites sp.
Favosites sp.
Cerioid rugose coral
Cylindrical rugose coral

I-998-1. Collected about 3,000 feet east-northeast of Johnson Spring. Measured section SC-2, unit 11 (California coordinates, zone 4; 2,272,400 E., 575,700 N.).
Alveolites sp.
Thamnopora sp.
"*Cystiphyllum*" sp.
Cylindrical rugose coral

I-2001-1. Collected about 60 feet below top of unit 5, measured section SC-1 (California coordinates, zone 4; 2,272,300 E., 570,000 N.).
Favositoid coral
Alveolitoid coral
Cyathophylloid(?) coral

I-503. Collected from ridge just south of I-998-1 and about 3,000 feet east of Johnson Spring (California coordinates, zone 4; 2,272,400 E., 575,600 N.).
Cladoporoid(?) coral
Favositoid coral
Horn corals (indet.)

Oliver indicated that the age assignment based on these corals can be no closer than Silurian or Devonian.

Other fossils have also been identified and reported by R. J. Ross, Jr. (written commun., 1960, 1961) as follows:

USGS colln. D163-SD. Collected from side canyon east of Mazourka Canyon and about 1½ miles north of Johnson Spring (California coordinates, zone 4; 2,270,600 E., 583,700 N.).
Tentaculites cf. *T. bellulus* Hall

USGS colln. D164-SD. Collected from east side of Al Rose Canyon about 1 mile south of Badger Flat (California coordinates, zone 4; 2,267,100 E., 590,600 N.).
Brachiopods that probably are rhynchonellids. Preservation is so poor that the genus is indeterminate.

USGS colln. D178-SD. Collected near base of unit 4, measured section SC-3 (about 190 ft below top of formation) 4,500 feet northeast of Johnson Spring (California coordinates, zone 4; 2,272,500 E., 578,600 N.).
Tentaculites cf. *T. bellulus* Hall
Ostracodes
Brachiopods
Sponge spicules

The best fossils for use in age determination in the Sunday Canyon Formation are the *Monograptus* graptolites, which have traditionally have been considered to be restricted to the Silurian. Recent work by Berry (1966) has shown that monograptids considered Devonian in Europe are also present in the United States. Berry (written commun., 1964) examined most of the graptolite collections from the Sunday Canyon Formation and concluded that both Silurian and Devonian monograptids are present. The only collection of Devonian age (D179SD) was made about 150 feet above the base of measured section SC-2 (p. 57). The other collections, all of which are considered Silurian, are from very near the base of the formation. Thus, on the basis of the graptolites, the lower 100 feet or so of the formation is most likely Silurian, and the overlying remainder of the formation may be Devonian. Pending further work on other fossil forms in this part of the section, it seems best at present to consider the Sunday Canyon Formation to be Silurian and Devonian(?) in age.

The Silurian graptolites are considered to be Middle to Late Silurian; so the Lower Silurian apparently either is missing or has not been recognized. It has already been suggested (see p. 29) that the Ely Springs Dolomite in the Independence quadrangle could be partly Silurian; but for formational mapping purposes, the base of the Sunday Canyon Formation is the natural break, whether or not it coincides with the boundary between the Ordovician and the Silurian. No physical evidence of a break in deposition or of erosion has been noted at this contact, but poor exposure of the contact precludes much study.

FACIES RELATIONS AND CORRELATIONS

The Silurian and Lower Devonian in much of southeastern California and in parts of southern Nevada is represented by cherty dolomite as typified by the Hidden Valley Dolomite in the Quartz Spring area (McAllister, 1952, p. 15). Generally the dolomite is medium to light gray and contains considerable nodular chert, particularly in the lower part. Grossly similar rocks are also reported in the Nopah Range (Hazzard, 1937, p. 326), at the Nevada Test Site (Johnson and Hibbard, 1957, p. 350), and in the Darwin quadrangle (Hall and MacKevett, 1962, p. 12). The dolomitic facies extends north and west into the New York Butte quadrangle, where chert-bearing dolomite of the Hidden Valley Dolomite is cut off by granitic intrusive rocks about 10 miles southeast of the Independence quadrangle. Only 3 miles to the east, in the Waucoba Wash quadrangle, similar rocks, probably correlative with the Hidden Valley, are also engulfed in granitic rocks. Thus, several miles of granite rocks separate the Silurian and Lower Devonian rocks of the dolomitic facies from the nearest presumably stratigraphically equivalent rocks in the Independence quadrangle, the Vaughn Gulch Limestone.

Although the stratigraphic continuity is broken by the granitic rocks, there can be little doubt of the general stratigraphic equivalence of the Vaughn Gulch Limestone and the Hidden Valley Dolomite, and thus a substantial facies change is evident. A paleontologic tie is also provided by the large dasycladacean algae *Verticillopora annulata* Rezak, which occurs in the Vaughn Gulch Limestone as well as in the Hidden Valley Dolomite of the New York Butte quadrangle (Merriam, 1963b, p. 13).

In much of the central part of the Great Basin in Nevada, the Silurian is made up of the Roberts Mountains Formation, a thin well-bedded limestone containing abundant fossils, and the overlying Lone Mountain Dolomite, a somewhat massive dolomite and dolomitic limestone (Merriam, 1940, p. 11–14). Descriptions of the Roberts Mountains Formation in the Eureka, Nev., area bear certain similarities to descriptions of both the Vaughn Gulch and the Sunday Canyon Formations. Nolan, Merriam and Williams (1956, p. 37) described the Roberts Mountains Formation as comprising dark-gray flaggy platy to shaly limestone, platy to shaly limestone that is in part silty, and many beds that are highly organic and yield abundant corals. Merriam (1963a, p. 38) described *Monograptus* from the Roberts Mountains Formation at the type locality. Nolan, Merriam and Williams (1956, p. 37) also described limestones from the Monitor Range which contain abundant *Monograptus*. In discussing correlation they stated, "In the Inyo Mountains in California the Silurian dolomites are locally replaced by a highly fossiliferous limestone facies: the fossil evidence indicates that these limestones are equivalent in part to the Roberts Mountains formation." The highly fossiliferous limestone they refer to is the Vaughn Gulch Limestone at its type section. On the basis of the descriptions in the Eureka area, both the coral-rich Vaughn Gulch facies and the graptolite-bearing Sunday Canyon facies are considered to be at least partly equivalent and lithologically similar to what is called Roberts Mountains Formation in central Nevada. As was already noted by C. W. Merriam, the large dacycladacean algae *Verticillipora annulata* Rezak also provides a paleontologic tie between the Roberts Mountains Formation and the Vaughn Gulch Limestone. The middle unit of the Roberts Mountains Formation at Bare Mountain, Nev. (Cornwall and Kleinhampl, 1961), has a strong lithologic resemblance to the Vaughn Gulch Limestone. In the outcrops of the Roberts Mountains that I examined in Chuckwalla Canyon, the slabby-weathering limy, silty layers of the middle unit (some of which are rich in fossil fragments) look very similar to the Vaughn Gulch Limestone at the type section. The upper unit of the Roberts Mountains Formation at Bare Mountain, however, does not resemble the Vaughn Gulch but is more like the Hidden Valley Dolomite. Inasmuch as the possibly correlative rocks in the Independence area are separated from Roberts Mountains Formation by rocks of the Hidden Valley Dolomite and by great distance, it seems best at the present to use local names for the Silurian and Devonian(?) rocks of the Independence quadrangle.

The relation between the Hidden Valley Dolomite and the Vaughn Gulch Limestone may be somewhat similar to the relation between the Roberts Mountains and Lone Mountain Formations in the Roberts Mountains as described by Winterer and Murphy (1960, p. 118). They considered those two formations to be essentially time-stratigraphic equivalents, the Lone Mountain Dolomite representing a reef complex and the Roberts Mountains Formation representing an off-reef, deeper water facies.

Granitic rocks intruded between the Hidden Valley and Vaughn Gulch Formations have blotted out the facies contact, but the Vaughn Gulch Limestone seems to be lithologically and genetically similar to the Roberts Mountains Formation. Hence reef conditions probably existed not far away, for the Vaughn Gulch is rich in off-reef-type bioclastic debris. Traced northward, the Silurian rocks in the Independence quadrangle contain less bioclastic material and more silty material, and the environment becomes more favorable for graptolites. The gradation northward to this Sunday Canyon facies thus seems to reflect an increasing distance from a reef environment. It seems logical to presume, therefore, that a reef zone existed on strike to the south in the position now occupied by granitic rocks. The Hidden Valley facies as now exposed in the New York Butte quadrangle would, by this interpretation, represent the generally shallow-water carbonate deposits inshore from the reef complex whose debris was shed to form the Vaughn Gulch Limestone.

Northwestward the Silurian outcrops terminate in the Badger Flat area owing to the combination of pre-Perdido erosion, granitic intrusion, and Cenozoic overlap. These outcrops are the northwesternmost exposures of fossiliferous Silurian rocks found in the Great Basin; in fact, such rocks have not been found for several hundred miles to the north and west. Silurian beds may be present in the thick stratigraphic section of the Mount Morrison roof pendant (about 50 miles northwest of the Sierra Nevada), where several thousand feet of unfossiliferous beds conformably overlie graptolite-bearing Ordovician rocks (Rinehart and Ross, 1964, p. 21–23).

MISSISSIPPIAN SYSTEM

PERDIDO FORMATION

NAME AND DISTRIBUTION

The Perdido Formation was named by McAllister (1952, p. 22) for exposures in the Quartz Spring area, about 25 miles east of the Independence quadrangle.

A discontinuous belt of the Perdido Formation extends almost the entire length of the quadrangle from Bee Springs north to the quadrangle boundary. Northwest of Badger Flat the Perdido is faulted and is cut out by granitic rocks, but it reappears in fault slices along the front of the Inyo Mountains in the Waucoba Wash quadrangle (C. A. Nelson, written commun., 1961). The only other known occurrence of probable Perdido rocks to the north is on a ridge east of Jackass Flat, about 6 miles northeast of the northeast corner of the Independence quadrangle. There, C. A. Nelson, (oral commun., 1965) mapped and described clastic and carbonate rocks which are lithologically similar to the Perdido exposed in the Independence quadrangle.

Beds assignable to the Perdido Formation are also present in the New York Butte quadrangle, but there they are thin and locally missing (Merriam, 1963b, p. 18).

THICKNESS AND STRATIGRAPHIC RELATIONS

The maximum measured thickness of the Perdido Formation in the Independence quadrangle is 623 feet near Vaughn Gulch. East of Pops Gulch the formation is about 550 feet thick. Near Badger Flat the Perdido is probably somewhat thicker than 600 feet, but near Water Canyon it is considerably thinner. Many units in the formation are lenticular and coarsely clastic; so it is not surprising that the original thickness is variable. Moreover, the Perdido is transitional with the overlying Rest Spring Shale; some vertical range in the upper contact, which is based on the uppermost carbonate-clastic lens against the overlying shale, also accounts for some thickness variation.

The Perdido Formation lies on an eroded surface of Silurian rocks. Near Vaughn Gulch and northeast of Squares Tunnel, the erosional surface is particularly evident; but north of Water Canyon the contact appears remarkably conformable, though presumably also an erosional contact. No cutting out of beds was noted at the contact studied north of Water Canyon, and the concordance of attitudes on both sides of the contact there gives no clue to an unconformity. The contact was particularly difficult to determine where shaly beds in the Silurian were adjacent to shaly beds in the overlying Perdido. The contact was generally placed at the top of the somewhat limy shale assigned to the Silurian; this shale is commonly lighter colored than the overlying noncalcareous shale assigned to the Perdido. Early in the mapping the contact was placed at the lowest appearance of medium- to coarse-grained clastic rocks, but this resulted in much shale being assigned to the Silurian that was similar to the shale above the lowest sand-size clastics of the Perdido. As mapping progressed, the contact of calcareous against essentially noncalcareous shale seemed to be a more significant mappable horizon—though no obvious evidence of erosion was noted at either contact. The thinning out of the Sunday Canyon Formation northwest of Badger Flat, however, does suggest an erosional unconformity if it is not the result of strike faulting.

The amount of time and the thickness of beds represented by the unconformity is difficult to ascertain. Direct comparison with the conformable sections in the New York Butte and Quartz Spring areas is not possible because of probable facies changes (pl. 5). One could speculate that at least the Lost Burro Formation (Middle and Upper Devonian), the Tin Mountain Limestone (Lower Mississippian), and the lower part of the Perdido Formation are missing in the Independence quadrange. But if facies changes like those demonstrable in the Ordovician and Silurian also occurred in the Devonian and Mississippian, facies equivalents of at least parts of the Lost Burro, Tin Mountain, and lower Perdido could be present in the Independence area, particularly north of Water Canyon, and not be recognizable. North of Water Canyon the only fossil control on this erosional gap is based on Silurian and Devonian(?) fossils in the lower part of the Sunday Canyon Formation and Upper Mississippian fossils more than 1,000 feet above the Perdido Formation.

An erosional surface is plainly present beneath the Perdido south of Water Canyon. Though regional relations suggest that some parts of both the Devonian and the Mississippian are missing at this unconformity, the Independence quadrangle could well conceal facies equivalents of either the Lost Burro or Tin Mountain that would considerably narrow down this erosional gap.

LITHOLOGY

In the type area of the Perdido, near Quartz Spring, McAllister (1952, p. 22) noted that "heterogeneity is an outstanding characteristic." This statement applies equally to the Independence area, where the Perdido is predominantly a clastic unit of shale, siltstone, conglomerate, calcarenite, and calcareous quartz sandstone. Limestone and bedded chert, which typify the lower part of the Perdido in the Quartz Spring area, both are subordinate in the Perdido of the Independence area. Whether this difference is due to the absence of the lower part of the Perdido in the Independence area or to a facies change is a moot question. Recognizable changes in other units—for example, the Silurian and Devonian(?)—suggest that a facies change is more probable, and this is shown diagrammatically on plate 5.

Although the Perdido Formation is notably heterogeneous, it has a gross litholgy that makes it easily recognizable as a formation in the Independence area.

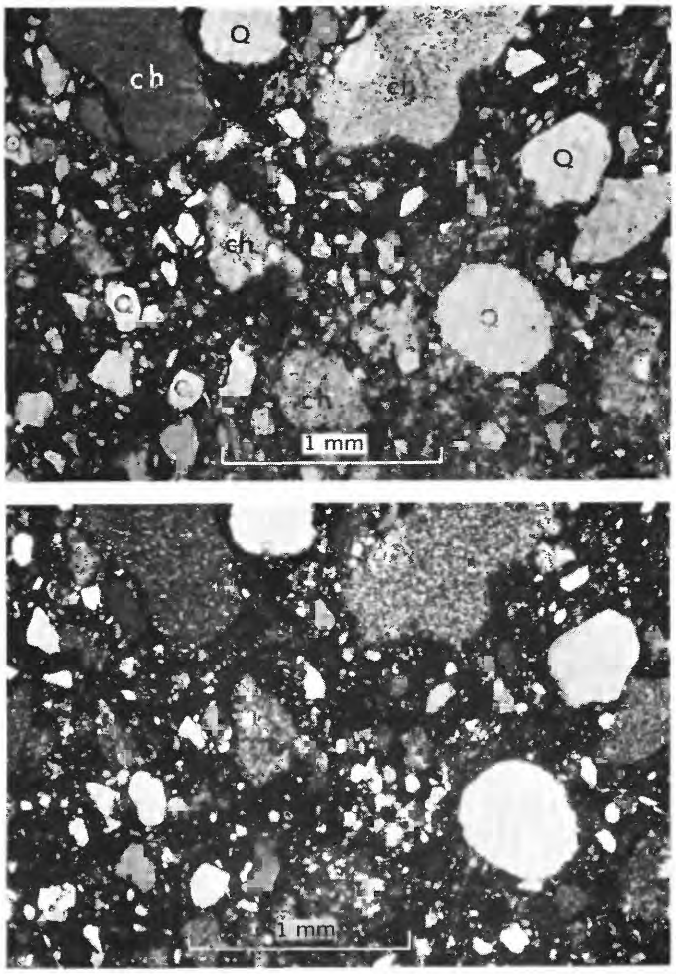


FIGURE 18.—Perdido Formation. Photomicrograph of conglomeratic sandstone about 1½ miles north of Johnson Spring; note abundance of chert fragments (*ch*) and of quartz (Q) in dark dense groundmass. Upper: plane-polarized light. Lower: crossed nicols.

Probably the most obvious single feature of the formation is the abundance of black chert fragments in the coarser clastic rocks (fig. 18). This chert and the generally abundant medium- and coarse-grained clastic rocks make much of the Perdido Formation stand as a resistant rib of outcrop between the bounding less resistant units. North of Water Canyon, however, much of the lower part of the formation is composed of shale, and the contact with the underlying shaly Silurian and Devonian(?) rocks is much less obvious.

No attempt will be made to systematically describe the multitude of rock types in the Perdido. The measured sections (P–1, –2, –3, p. 58–60) are representative and give some idea of the range of rock types. Certain distinctive rock types that are diagnostic of the Perdido in the Independence area are described in the following paragraphs.

As previously noted, chert fragments are diagnostic of the coarser clastic rocks of the Perdido. Particularly distinctive is medium-gray to medium-dark-gray chert granule conglomerate composed largely of rounded chert fragments as much as 10 mm in diameter but containing some fragments as small as a fraction of a millimeter in diameter. Some beds are remarkably well sorted and have chert grains averaging 3–4 mm in diameter. Radiolarian tests are common in some chert fragments. Quartz grains are present, but, characteristically, chert is dominant. Chert fragments also dominate in some coarser conglomerate beds; these chert clasts are well rounded and several inches or more in largest dimension.

Another Perdido rock type, large-boulder conglomerate, is exposed on both sides of Vaughn Gulch. Boulders of quartzite and carbonate as much as 15 and possibly 20 feet in diameter are scattered through a rather thin unit in the lower part of the formation. Smaller boulders are also present. The matrix is a mixture of sandy and limy material. Unit 6 of measured section P–1 (p. 59) is an example of this layer. At other localities farther north where fairly coarse conglomerate is present, few boulders exceed 1 foot in maximum diameter, and most are only a few inches in maximum size. According to Merriam (1963b, p. 19), some of the carbonate boulders in the large-boulder conglomerate are similar to rock types in the Lost Burro Formation (Devonian).

Also in the Perdido is a group of rocks composed of various proportions of sand-size calcite and quartz clasts; fragments of chert and feldspar are subordinate. These beds, which were generally referred to in the field and in some of the measured sections as "sandy-limy layers," are chiefly medium gray (some weather brown) and range from thin bedded to massive; most are lenticular. Locally these beds are made up almost exclusively of quartz grains and are orthoquartzites, but most are composed predominantly of clastic calcite fragments. Generally these rocks could be called calcareous quartz sandstone or calcarenite; calcarenite with 50–75 percent calcite fragments is most common. The calcite fragments as much as 3 mm in diameter are present, but the majority are 0.25–1 mm in diameter; some patterned fragments are obviously fossil fragments. The quartz fragments are as much as 0.75 mm in diameter. Both calcite and quartz grains, as small as 0.05 mm in diameter, make up the groundmass. The clasts range from subangular to well rounded; generally, the coarser fragments are the more rounded.

Bedded chert, which is not common in the formation, forms a distinctive and widespread marker unit in the lower part of the formation. (See unit 4, section P–1, and unit 2, section P–3, p. 59, 60.) This chert is black and thinly and regularly bedded and contains elongate light-gray lenses composed of somewhat coarser material and less carbonaceous material. The origin of the light-gray lenses in unknown, but some lenses contain abundant apatite. Scattered in the chert beds are round areas as much as 0.15 mm across that are apparently devoid of dark, carbonaceous material and contain quartz that is coarser grained than the chert matrix; these areas may be evidence of Radiolarian tests. Shadowy elongate needlelike outlines in the chert may be sponge spicules.

Another rock type that is locally common superficially resembles vesicular basalt, particularly on a weathered surface. This rock is clastic, however. It is composed of sand- to granule-size fragments in a dense groundmass rich in carbonaceous material. The vesicular, porous aspect of this rock is its most diagnostic feature. Presumably the holes resulted from calcite fragments (many of them fossil fragments) being leached out. Commonly the holes are coated with red-brown iron oxide, which preserves fossil imprints, mostly of pelmatozoan fragments. (See fossil colln. I–940, p. 37.) These rocks are most common west of Al Rose Canyon.

In addition to these lithologic types, which, though unusual, serve to characterize the Perdido of the Independence quadrangle, there is an abundance of shale and siltstone. These form dark outcrops that in most places weather red brown and give the formation its predominant reddish-brown weathering color.

In such a heterogeneous formation, it is virtually impossible to assign percentages to the various rock types. The coarse clastics are noticed and sampled beyond their importance, and the prosaic shale and siltstone are apt to lack attention. Approximate calculations from the three measured sections show about 55 percent shale and siltstone, 25 percent calcarenite and calcareous quartz sandstone, 15 percent conglomerate, and 5 percent of sandstone, quartzite, and chert. Although these percentages may not be valid for the whole formation in the Independence quadrangle, they probably show an approximate composition.

FOSSILS, AGE, AND CORRELATION

Fragments of brachiopods, corals, bryozoans, trilobites, and pelmatozoans have been recovered from the Perdido Formation. Most of the fossils are poorly preserved molds, and many are distorted; so the collections made thus far are of little help in determining the age of the Perdido. In addition, evidence of Radiolarian and sponges is found in some of the chert. The following collection was examined and commented on by Mackenzie Gordon, Jr. (written commun., 1964):

I–940. Collected from porous crinoidal clastic rock from near the top of the Perdido Formation, 2,100 feet N. 73° W. of

SE cor. sec. 25, T. 11 S., R. 35 E. (California coordinates, zone 4; 2,263,000 E., 592,800 N.).
Horn coral indet.
Crinoid columnals
Strophomenoid? brachiopod indet.
Reticulariina sp. indet.

All these fossils are distorted. The ribs of the *Reticulariina* are stretched so that they are wide on one side and narrow on the other. The species has four plicae at either side of the fold and may be *R. campestris* (White), which is found in rocks of Chester and Morrow age in the western United States; however, this specimen is too poorly preserved to be identified with any sense of assurance.

Cravenoceras and associated fossils of Late Mississippian age (Chester) were reported from near the top of the formation at its type area, near Quartz Spring (McAllister, 1952, p. 24). In the same reference McAllister also reported on fossils at the base of the Perdido Formation in the southwestern part of the Ubehebe Peak quadrangle that may be late Kinderhook or Osage (Early Mississippian). On the basis of fossils from the upper part of the formation in the type area (rocks which resemble the Perdido of the Independence area) and fossils in the Cerro Gordo area, the Perdido of the Independence area is tentatively considered to be Late Mississippian.

The outcrops of the Perdido Formation closest to Independence exposures are in the New York Butte quadrangle. There the formation is generally less than 100 feet thick and is locally absent (Merriam, 1963b, p. 19). The Perdido is characteristically of diverse lithology at some sections and is entirely fine-grained sandstone and quartzite at others. Merriam (1963b, p. 22) believed that the Perdido in the New York Butte quadrangle has been partly replaced by a shale which he referred to the Chainman Shale of Late Mississippian age. Fossils found in the lower part of Merriam's Chainman are similar to some found in the type section of the Perdido. This relation is certainly in accord with the transitional nature of the upper contact of the Perdido Formation in the Independence quadrangle. The presence or absence of the lenticular coarser clastic beds of the Perdido results in an interfingering contact with the overlying shale (pl. 5). Furthermore, considerable variation in total thickness of a lenticular clastic unit like the Perdido seems probable. A report by Gordon (1964, p. A2–A6) has a detailed discussion of the age and correlation of the Perdido Formation in the Inyo-Panamint region.

The northernmost rocks that are assignable to the Perdido are in the Jackass Flat area, about 6 miles northeast of the Independence quadrangle, and in the fault slices along the front of the Inyo Mountains in the Waucoba Mountain quadrangle. These rocks have the typical coarse to fine clastic diversity of the Perdido and also have abundant chert clasts.

In the Darwin area (pl. 5) Hall and MacKevett (1962, p. 20) described chert and limestone strata, which they considered to be the lateral equivalent of the lower part of the Perdido type section, and the overlying silty Lee Flat Limestone (Upper Mississippian and Pennsylvanian?), which they interpreted to be the lateral equivalent of the upper part of the Perdido and the overlying Rest Spring Shale. This sequence, if the correlation is correct, represents a rather drastic change in the Perdido, and it is another instance of an increase in carbonate southeastward in the section. Such a facies change is in accord with facies changes that occur in other formations in this area.

Farther east and north the Mississippian is again represented by dominantly clastic rocks. Probably a Perdido equivalent is present in the nearly 8,000 feet of argillite, siltstone, quartzite, conglomerate, and limestone of the Eleana Formation (Mississippian to Lower Pennsylvanian) at the Nevada Test Site area (Poole and others, 1961, p. D104). Similar rocks, probably also at least partly correlative with the Perdido, are present in a faulted section more than 3,000 feet thick at Bare Mountain, Nev. (Cornwall and Kleinhampl, 1961). Outcrops of the Meiklejohn Formation (Upper Mississippian) on the east side of Bare Mountain north of Tarantula Canyon have coarse clastic lenses rich in chert fragments interbedded with shale and siltstone and are very similar to Perdido outcrops. Coarse clastic material, which characterizes the lithology of the Perdido Formation, is present throughout nearly all the Meiklejohn Formation (Cornwall and Kleinhampl, 1961). At Bare Mountain, therefore, a clear distinction between a coarser grained facies equivalent to the Perdido and a finer grained facies equivalent to the Rest Spring is not readily made. The overall resemblance of the Meiklejohn to the Perdido plus the Rest Spring leaves little doubt about their general equivalence.

The clastic rocks, both fine- and coarse-grained, which typify the Perdido Formation in the Inyo Mountains appear to be replaced southward by carbonate rocks, as can be seen in the Darwin area. Farther south the Mississippian section is also dominantly carbonate and chert, as reported from the Nopah Range (Hazzard, 1937, p. 275) and in the Ivanpah quadrangle (Hewett, 1956, p. 42). North and east of Independence, the Perdido (and the entire Mississippian section) is predominantly clastic. Poole, Houser, and Orkild (1961, p. D109) considered the Eleana Formation to represent part of a clastic apron shed from the northeast-trending Antler orogenic belt (Roberts and others, 1958) to the northwest. This would explain the southeastward facies trend to more carbonate deposits as a reflection of increasing distance from an orogenic belt.

REST SPRING SHALE

NAME AND DISTRIBUTION

The Rest Spring Shale was named by McAllister (1952, p. 25) at exposures in the Quartz Spring area. In the Inyo Mountains, dark-colored fine-grained clastic rocks now assigned to the Rest Spring were first called White Pine Shale by Kirk (in Knopf, 1918, p. 38). Rocks now considered to be the Perdido Formation were also included in the White Pine Shale by Kirk. In the New York Butte quadrangle, Merriam (1963b, p. 20) used the term Chainman Shale for this same interval. Chainman is a name derived from the Ely district of Nevada (Spencer, 1917, p. 26–27) and is widely used in eastern Nevada.

The Rest Spring Shale crops out in a broad arcuate belt from west of Badger Flat to the mouth of the Mazourka Canyon. Disconnected fault segments continue south to the Bee Springs area. North of the quadrangle, along the front of the Inyo Mountains in the Waucoba Mountain quadrangle, a small amount of the Rest Spring Shale occurs above the Perdido (C. A. Nelson, written commun., 1961); both formations are faulted against Cambrian beds. This is the northwesternmost known occurrence of the Rest Spring Shale.

THICKNESS AND STRATIGRAPHIC RELATIONS

Along a section east of Pops Gulch, 2,475 feet of beds were measured in the Rest Spring Shale. From aerial photographs and the trend of the bounding formations, the section appears to be relatively homoclinal; some folding has been observed along the section (fig. 19), however, and discontinuous beds suggest that the section may also be faulted. Probably 2,500 feet is a fair estimate of the thickness in the Independence quadrangle. In the Quartz Spring area (McAllister, 1952, p. 25–26) the Rest Spring Shale may be considerably thinner (pl. 5), as a maximum of only 400 feet was measured, but the combination of complex structure and an incompetent shale means that little confidence can be placed in this measurement. In the Darwin area (Hall and MacKevett, 1962, p. 19–21) only a small amount of Rest Spring Shale is exposed in fault zones, and the formation is believed to intertongue with and be laterally replaced by the Lee Flat Limestone. In the New York Butte quadrangle (Merriam, 1966, p. 21) about 1,000 feet of shale occupies this interval, but here also the true thickness is doubtful because of structural complications.

FIGURE 19.—Rest Spring Shale. Exposed in bluff east of Pops Gulch. Note rather tight folding near skyline. Boy in white shirt at base of cliff for scale.

Despite the uncertainty about the true thickness of the Rest Spring Shale and its equivalents, the formation seems to thicken notably to the northwest.

The contact with the underlying Perdido Formation is gradational and transitional. The close relation of the two formations is shown by the intertonguing of the coarser clastics of the Perdido with the finer clastics of the Rest Spring. The contact is arbitrarily placed at the top of the uppermost medium- to coarse-grained clastic rock, although its stratigraphic level probably varies somewhat throughout the quadrangle. The upper beds of the Rest Spring Shale appear to be conformably overlain by the carbonate beds of the Keeler Canyon Formation.

LITHOLOGY

The Rest Spring Shale crops out in a dark-colored band for almost the entire length of Mazourka Canyon. The color of fresh faces ranges from medium dark gray to black, and that of weathered surfaces also is generally dark. Some black layers weather to light-gray, almost silvery, surfaces; dark-reddish-brown weathering is also common, particularly on smooth, desert-varnished surfaces.

Much of the formation has been hornfelsed by the action of the large granitic mass to the west along the front of the Inyo Mountains. Originally the Rest Spring Shale had been a rather monotonous sequence of shale, mudstone, siltstone, minor fine-grained sandstone, and rare limestone. Where less hornfelsed as in the eastern part of the outcrop belt, the rocks are laminated to very thin bedded. Parting is generally shaly to flaggy but is slabby to blocky in some places, particularly where the rocks are more hornfelsed. East of Pops Gulch, where the section is relatively homoclinal, the beds in the upper part of the formation are more massive. Though some bedding and parting may reflect differences in original sediments, much is the result of the alteration to hornfels; metamorphic minerals are more abundant in the more massive part of the formation, which is nearer the granitic body.

Andalusite hornfels and spotted hornfels rich in sericite, which is at least partly the result of alteration of andalusite, are the most common rock types in the formation. Andalusite crystals from a fraction of a millimeter to several millimeters long are liberally sprinkled through many specimens. Some of the andalusite is fresh and exhibits the typical crosslike alinement of inclusions (chiastolite), but more commonly it is partly altered to sericite or completely pseudomorphed by sericite.

Many rocks contain scattered sericite that cannot be attributed to alteration of andalusite. This sericite presumably formed from the metamorphism of clay minerals. Phlogopite and chlorite are also widespread.

The metamorphosed siltstones are composed of rounded to subangular quartz clasts from 0.05 to 0.25 mm in diameter scattered through a denser groundmass of various proportions of quartz, sericite, phlogopite, and chlorite. Locally the percentage of quartz increases and the rock is fine-grained quartzite, but this is not common.

Black organic material is common and widespread. One zone near the middle of the formation is particularly rich in carbonaceous material. This zone, which is several hundred feet wide, has been mapped for about 2 miles along the strike. It is probably lenticular, as it is not mappable beyond this segment and seems to merge with the other rocks of the formation. Within this carbonaceous layer goniatite fragments were recovered. A sample of this organic-rich layer from the principal goniatite locality (I–10) was submitted for semiquantitative spectrographic analysis. The following results were reported (J. D. Vine, written commun., 1963):

[Results are reported in percent to the nearest number in the series 1, 0.7, 0.3, 0.2, 0.15, 0.1, and so on, which represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30 percent of the time]

Ti	1	Cr	0.05	Pb	0.005
Mn	.003	Cu	.0015	Sc	.003
Ag	.0002	Ga	.003	Sr	.03
B	.03	La	.015	V	.05
Ba	.15	Nb	.0015	Y	.003
Be	.0005	Nd	.007	Yb	.0005
Ce	.03	Ni	.001	Zr	.02

Several other specimens of black shale from this goniatite-bearing layer and other nearby localities in the Rest Spring were also spectrographically analyzed, and the concentrations of minor elements were about the same as in I–10 (J. D. Vine, written commun., 1963).

FOSSILS, AGE, AND CORRELATION

Fossil remains are scarce in the Rest Spring Shale, partly owing to the metamorphism of the formation, but a variety of forms have been recovered from two localities; plant-stem remains and possible worm borings (fucoids) have been found elsewhere.

Cravenocerid goniatite fragments were found about 1,300 feet east-northeast of Johnson Spring in a carbonaceous-rich zone about 800 feet above the base of the formation (loc. I–10, California coordinates, zone 4; 2,270,500 E., 575,500 N.). These fossils were assigned a Late Mississippian age by Mackenzie Gordon, Jr. (written commun., 1961):

Two cravenocerid genera are already known in the Inyo Range in the Cerro Gordo area (New York Butte quadrangle), California. These are *Cravenoceras* and *Cravenoceratoides*. *Cravenoceras* is known at many localities in the United States, but *Cravenoceratoides*, a British genus, is known in the United States only in the Inyo Range, Calif., and the Diamond Range, Nev. It differs from *Cravenoceras* principally in the bifurcation of transverse lamellae on the inner part of the flanks.

Most fragments collected in the Independence quadrangle are from the ventral part of the shell and would not show bifurcation even if the genus were *Cravenoceratoides*. One specimen appears to show bifurcation in one place, but this is not enough to go on. As *Cravenoceratoides* is the common cravenocerid in the Chainman Shale in the Cerro Gordo area, the present fragments may also belong in this genus.

Some carbonate-rich specimens from the cravenocerid zone were disaggregated—using Schulz's Solution, sodium hypochlorite, and hydrofluoric acid—in an attempt to recover spores. Black organic particles were separated, but no spores were found (R. A. Scott, written commun., 1961).

The other fossil collection was made about 285 feet below the top of the formation at the mouth of Pops Gulch. Most of the material is fragmental and poorly preserved, but considering that the matrix is andalusite hornfels, the collection is proof that fossils can survive metamorphism, at least locally. Mackenzie Gordon, Jr., reported as follows on this collection (written commun., 1963):

USGS colln. 20588–PC. Collected at mouth of Pops Gulch about 285 feet below the top of the Rest Spring Shale (California coordinates, zone 4: 2,266,700 E., 581,200 N.).

Fenestella sp.
Crinoid plates
Crinoid columnals
Choneted indet.
Heteralosia (?) sp.
Semicostella (?) sp.
Inflatia (?) sp. indet.
Flexaria sp.

Linoproductus (?) sp. (small species)
Spirifer aff. *S. increbescens* Hall
Spiriferoid, indet.
Pelecypods, indet.
Gastropod, indet.
Goniatites, indet. (evolute form)
Fossil plant

This assemblage appears to have more in common with the Late Mississippian fauna than with the Early Pennsylvanian one. But, because of the preservation of these fossils as distorted molds, which precludes positive identification of species, one can only speak in general terms. The surprising thing is that they are as well preserved as they are in this thoroughly metamorphosed matrix.

The forms upon which a probable Mississippian age determination is based include the supposed *Heteralosia*, recognized by its shape and scattered short semiprostrate spines. A similar form, as yet undescribed, occurs in the Upper Mississippian beds in western Utah. The avoniid here identified as *Semicostella?* likewise is indicative of Mississippian age, as no similar forms are known in the Pennsylvanian in this region. Also, the *Flexaria* resembles an undescribed Late Mississippian species. This genus is also represented in the Early Pennsylvanian by a large undescribed species, but this does not appear to be it. The goniatites, although they cannot be identified even as to order, in the absence of sutures and clear external features, resemble several Mississippian forms superificially. They do not resemble any of the known Pennsylvanian species in the Great Basin, most of which are gastrioceratids. Finally characteristic Early Pennsylvanian brachiopods, such as *Rugoclostus* and large linoproductids, are absent.

Southeast of the Independence quadrangle Kirk (in Knopf, 1918, p. 38–39) made a collection about 1½ miles north of the Cerro Gordo mine from fissile black shale that is referred to the Chainman by Merriam. This collection comprises mostly pelecypods and cephalopods. G. H. Girty (in Knopf, 1918, p. 39) made the following comment about that early collection: "* * * an interesting and peculiar fauna of the Caney Shale of Oklahoma and the related but less well known fauna of the White Pine Shale of Nevada. These faunas I refer to the Upper Mississippian."

Abundant fossils have also been collected and reported on from the lower 400 feet of the Chainman Shale in the New York Butte quadrangle (Merriam, 1963b, p. 22); so far no fossils have been found in the upper 600 feet. Most distinctive are the cravenocerid goniatites, which are regarded as of Late Mississippian age (Merriam, 1963b, p. 23). Merriam thus regarded the Chainman Shale of the New York Butte quadrangle as Upper Mississippian, although he acknowledged the possibility that the upper, unfossiliferous part may be Lower Pennsylvanian.

In the Quartz Spring area, where the Rest Spring Shale was named, McAllister (1952, p. 26) reported that fossils are very scarce but include impressions of reedlike leaves, bryozoan fragments, and poorly preserved microfossils. In the southwest corner of the Ubehebe Peak quadrangle, fossils were collected from metamorphosed shale at only one locality. J. S. Williams reported as follows on those fossils (McAllister, 1952, p. 26):

Impressions or fragmentary remains suggest brachiopods belonging possibly to the genera *Chonetes*, *Marginifera*, and *Composita*, but even the generic identifications are uncertain. The fragmentary remains have slightly, but very slightly, more resemblance to Pennsylvanian species of these genera than to Mississippian species, but the age might as well be Mississipian as Pennsylvanian.

McAllister further noted that the uncertain identification of these poorly preserved fossils cannot be used to determine the age of the Rest Spring Shale. Arbitrarily, but provisionally, he placed the boundary between the Mississippian and the Pennsylvanian at the base of the Rest Spring Shale, chiefly because, as he stated (1952, p. 26), "the formation lies above the Late Mississippian fauna in the uppermost part of the Perdido Formation and below the moderately early Pennsylvanian fauna in the lowest part of the Tihvipah Limestone." Further discussion of the age and correlation of the Rest Spring and Chainman in the Inyo-Panamint region is found in a report by Gordon (1964, p. A2–A6).

The fossil collections from the Mazourka Canyon area support the assignment of a Mississippian age to the Rest Spring Shale in the Inyo Mountains. Absence of fossils in the uppermost 600 feet of the 1,000-foot-thick Chainman Shale in the New York Butte quadrangle and in the uppermost 285 feet of the 2,500-foot-thick Rest Spring Shale in the Independence quadrangle suggests that the upper part of the formation may include Pennsylvanian strata, but the only diagnostic fossils from this shale are Upper Mississippian. Following the convention of assigning an age to a formation on the basis of available fossil data, even though fossils are absent in part of the formation, it is preferable at present to restrict the age of the Rest Spring to the Late Mississippian.

The Rest Spring Shale of the Independence quadrangle undoubtedly has lithologic correlative counterparts in the Eleana Formation of the Nevada Test Site (Poole and others, 1961, p. D104) as well as the clastic Meiklejohn Formation at Bare Mountain, Nev. (Cornwall and Kleinhampl, 1961).

Although specific correlations cannot be made because of distances involved and the variability of these clastic units, the Rest Spring, together with the Perdido and the correlative units mentioned above is considered to be part of a vast late Paleozoic clastic blanket which is typified by the Chainman Shale and the Diamond Peak Formation of eastern Nevada (Nolan and others, 1956, p. 59–61).

GREAT BASIN STRATIGRAPHIC AND STRUCTURAL BACKGROUND AND SETTING

The Paleozoic stratigraphy of the western part of the Great Basin can be generalized by grouping the rocks into major assemblages that have lithologic continuity and great geographic extent. An excellent summary of this stratigraphic picture and an interpretation of the structural development of this area in the Paleozoic was published by Roberts and others (1958). That report is the basis for the following summary. Deposition in this area during the Cambrian through the Devonian is represented by three assemblages, one of which is lithologically and geographically transitional between the other two. The first assemblage, which is widespread in eastern Nevada and southeastern California, is predominantly carbonate, comprising limestone and dolomite and smaller amounts of shale and quartzite. It has variously been called the eastern facies, the carbonate facies, and the miogeosynclinal eastern assemblage, but it is now generally refered to as the carbonate assemblage.

In central and western Nevada, correlative strata are mostly fine- to medium-grained siliceous clastic sedimentary rocks, chert, and volcanic rocks. These rocks have been called the western or eugeosynclinal, facies or assemblage and the clastic facies, but they are now called the siliceous assemblage (R. J. Roberts, oral commun., 1963). This assemblage was deposited in a eugeosynclinal environment, in contrast to the carbonate assemblage, which represents miogeosynclinal deposition (Stille, 1940, p. 15).

In some places in Nevada, particularly in the Osgood Mountains, an assemblage transitional between the carbonate and siliceous assemblages has been recognized (Hotz and Willden, 1955). This assemblage is a mixture of carbonate, clastic, and volcanic rocks.

The deposition of these three assemblages continued in their respective areas in the Cordilleran geosyncline until near the end of Devonian time, when orogenic movements began to affect a broad region (the Antler orogenic belt) generally coincident with the area of deposition of the transitional assemblage. Intense folding and faulting, including major thrusting along this emergent belt, lead to the deposition of a coarse clastic apron that spread both east and west. This coarse clastic apron, which grades laterally into fine-grained clastics and limestone, comprises Mississippian, Pennsylvanian, and Permian strata and is termed the overlap assemblage, as it was deposited over deformed strata of the carbonate, siliceous, and transitional assemblages.

PALEOZOIC SECTION OF THE INDEPENDENCE QUADRANGLE AS RELATED TO PALEOZOIC HISTORY OF THE WESTERN GREAT BASIN

The Independence quadrangle and the Paleozoic roof pendants in the eastern Sierra northwest of the Independence quadrangle are in line with the north-northeast-trending Antler orogenic belt (fig. 1). In addition, the Independence Paleozoic section exposes the westernmost recognizable outcrops of several Great Basin formations. Thus, this quadrangle is stratigically located, both structurally and stratigraphically, for studies of the Paleozoic history of the western part of the Great Basin.

Cambrian, Ordovician, Silurian, and Devonian(?) deposits in the Independence area are characterized by thin-bedded and well-bedded fine- to medium-grained clastic rocks and carbonate (both dolomite and limestone) and clean quartz sand that is extremely well rounded and well sorted; sand with carbonate cement is common in the Lower Cambrian and Middle Ordovician strata. Much of the carbonate in the Ordovician, Silurian and Devonian(?) rocks is calcarenite and calcilutite, and many of the carbonate formations contain abundant silt-size quartz fragments. Crossbedding and ripple marks were seen at several localities. Clastic rocks, including the calcarenite, make up nearly half the Cambrian to Devonian(?) section.

These Cambrian to Devonian(?) sedimentary rocks have general characteristics that would class them as shelf or platform deposits; such characteristics are associated with sediments deposited above wave base or in the foreland facies. Such sediments would have been deposited in an environment such as that of Stille's (1940) miogeosyncline. Though miogeosynclinal in general character, these strata differ somewhat from the carbonate assemblage of eastern Nevada and southeastern California. Clastic material is more common in the Lower Ordovician rocks, chert becomes predominant in the Upper Ordovician rocks, and clastic material, including graptolitic beds, is significant in the Middle Ordovician rock and dominates in the Silurian and Devonian(?) rocks. Details of these regional variations are cited under the individual formations described in this report. Only a few miles southeast of the Independence quadrangle, the lower Paleozoic of the New York Butte quadrangle is a typical carbonate assemblage (W. C. Smith, written commun., 1961). Similar typical carbonate-assemblage rocks make up the lower Paleozoic strata in the Darwin area (Hall and MacKevett, 1962, p. 6) and the Quartz Spring area (McAllister, 1952, p. 8), as well as large areas to the south and east. The Independence quadrangle thus stands near the east margin of the transitional assemblage and has close geographic and stratigraphic ties to the carbonate assemblage.

On a strike continuation northwest of the Independence area, the nearest rocks in the age range of Cambrian through Silurian and Devonian(?) are 50 miles away, in the Mount Morrison roof pendant of the Sierra Nevada. There, possibly 25,000 feet of mostly Ordovician strata, chiefly fine-grained clastic rocks and calcareous quartz sandstone, have been mapped. These rocks are also part of the transitional assemblage, but they have more aspects of the siliceous assemblage and were presumably deposited deeper in the geosyncline than the Independence rocks.

The folding and faulting which characterized the middle Paleozoic Antler orogeny in Nevada did not extend into the Independence area. However, a major stratigraphic break marked by Upper Mississippian clastic rocks deposited on the eroded surface of the Silurian and Devonian(?) rocks probably reflects this orogeny. The contact between the Mississippian and Silurian and Devonian(?) rocks is obviously marked by erosion where Silurian and Devonian(?) beds have been cut out, but in many places it appears conformable and shows little evidence of a break. To the southeast at Darwin, New York Butte, and Quartz Spring (fig. 1), sedimentation continued uninterrupted throughout the middle Paleozoic. Apparently the effects of the Antler orogeny are not reflected southeast beyond the Independence area. In the Candelaria Hills of southern Mineral County, Nev. (fig. 1), strongly folded Ordovician rocks of the siliceous assemblage are unconformably overlain by Permian clastic rocks (Ferguson and others, 1954). There the effects of the Antler orogeny include folding, whereas at Independence only uplift and erosion are evident. In the Mount Morrison pendant in the Sierra, which lies northwest of the Independence area and southwest of the Candelaria Hills, fine-grained clastic rocks of Pennsylvanian age are in fault contact with Ordovician rocks and unfossiliferous rocks that are lithologically similar to the Ordovician rocks (Rinehart and Ross, 1964, p. 84). Though structural complications preclude any definite statement, it is possible that an erosional gap is present in this area also.

The Perdido Formation—a variety of coarse clastic rocks, siltstone, shale, and calcareous quartz sandstone—and the overlying Rest Spring Shale total about 3,000 feet of strata that probably belong to the overlap assemblage of the Great Basin. The Perdido, which is characterized by abundant chert pebbles, cobbles, and boulders, probably reflects a source area north or west of the Independence quadrangle. Chert in beds thick enough to yield boulders the size of those present in the Perdido is rare in the Independence area (only in the Ely Springs Dolomite near Badger Flat) and is likewise rare south and east of the quadrangle. Southward from the Independence quadrangle the thickness of clastic rock in the Perdido–Rest Shale interval decreases rapidly, and the proportion of coarse siliceous clastic rocks in the Perdido likewise decreases. Hall and MacKevett (1962, p. 20) suggested that in the Darwin area, a limestone unit (Lee Flat Limestone) laterally replaces the clastic interval of the upper part of the Perdido Formation and the Rest Spring Shale. Thus the coarse-grained overlap-assemblage rocks of the Upper Mississippian grade out rapidly to the south. Thick sequences of clastic rocks of Mississippian age are recognized in the Bare Mountain, Nev. (Cornwall and Kleinhampl, 1961) area, about 55 miles east of Independence, and at Quartzite Mountain (Poole and others, 1961), about 100 miles northeast of the quadrangle. The suggestion is that the general facies boundary between clastic and carbonate rocks of the Mississippian has more of an easterly trend than a northerly trend in this region.

The Pennsylvanian and Permian strata are not discussed in this report, but they are probably part of the overlap assemblage. The Keeler Canyon Formation (Pennsylvanian and Lower Permian) reflects a period of chiefly carbonate deposition between the periods of Mississippian and Permian clastic deposition. The Owens Valley Formation (Permian) is predominantly fine-grained clastics but is overlain by at least 500 feet of sand- to cobble-size clastic rocks in which quartzite and chert clasts are dominant. These coarse clastic beds, which grade out rapidly to the southeast and are not known in the Mount Morrison roof pendant, may reflect some fairly local uplift.

STRATIGRAPHIC SECTIONS

BK–1. *About ½ mile east of Blue Bell mine, NE¼ sec. 24, T. 11 S., R. 35 E.*

Lead Gulch Formation.

Conformable contact.

Bonanza King Dolomite:

	Feet
5. Dolomite, medium-gray to medium-dark-gray; weathers light gray to yellowish gray; massive; poorly bedded; fetid; some coarse grained and sugary	205

BK–1. *About ½ mile east of Blue Bell mine*—Continued

Bonanza King Dolomite—Continued

	Feet
4. Dolomite, dark-gray; weathers medium gray; laminated irregular nodular bedding; platy to flaggy parting; overall aspect of slope is varied gray beds as much as several feet thick; minor black chert near base; coarser grained, lighter, irregular patches of dolomite weather out, in some beds, leaving a darker dolomite matrix	524
3. Dolomite; higher proportion of darker colored beds (evident both on ground and in aerial photographs); upper and lower contacts rather sharp in aerial photographs; scattered mica and tremolite(?); some chert; *Girvanella*(?) about 160 ft below top; irregular nodular bedding and "dappled gray" surface common	564
2. Dolomite, various shades of gray; laminated to very thin, irregular bedding; platy to flaggy parting; much higher proportion of lighter beds; rather abrupt color break with overlying unit in aerial photographs; fucoidal beds locally prominent; color bands from few inches to several feet thick	1,026
1. Dolomite, about same as unit 2 but has more dark beds; distinction of this unit is abundance of *Girvanella*(?) from ¼ to 1 in across, as well as fucoids and other worm-trail-like markings, some of which are filled with coarser, lighter dolomite	504
Total Bonanza King Dolomite	2,823

Contact covered, presumably conformable.

Monola Formation.

LG–1. *Type section of the Lead Gulch Formation, in spur along east wall of Mazourka Canyon, 7,500 feet S. 85° E. from SE cor. sec. 36, T. 11 S., R. 35 E.*

Tamarack Canyon Dolomite.

Conformable contact.

Lead Gulch Formation:

	Feet
7. Limestone, medium-dark-gray; interbedded with orange-weathering silty beds; both types in beds ½–1 in. thick	52
6. Covered	15
5. Dolomite, medium-dark-gray; very thin bedded; irregular beds	44
4. Covered	35
3. Dolomite, medium- to dark-gray; thin platy beds	5
2. Covered (scattered platy dolomite float; fragments of *Lingula*)	50
1. Limestone, medium-bluish-gray; laminated to very thin bedded; interbedded ½-in.-thick layers of weathering gray to orange siltstone; some black chert in nodular beds as much as 4 in. thick; *Lingula* present; beds near base folded; contact contorted	79
Total Lead Gulch Formation	280

Covered contact; presumably fault cutting out originally conformable shale.

Bonanza King Dolomite.

TC–1. *Type section of Tamarack Canyon Dolomite, 6,000 ft northeast of SE cor. sec. 36, T. 11 S., R. 36 E.*

Al Rose Formation.

Conformable contact.

Tamarack Canyon Dolomite:

	Feet
3. Dolomite, medium-dark-gray; weathers medium light gray; generally massive, but partly very thin bedded; rilled weathering surface accentuates the thin bedding	272
2. Dolomite, medium- to dark-gray; weathers medium light gray to light gray; very thin bedded to laminated; some weathered surfaces rilled; flaggy to slabby parting; some black chert near base	123
1. Dolomite; same as overlying unit but black chert nodules and lenses (as much as 4 in. thick and 2 ft long) are more abundant	515
Total Tamarack Canyon Dolomite	910

Conformable contact.

Lead Gulch Formation.

AR–1. *Type section of the Al Rose Formation, about 2 miles NNE of Johnson Spring, T. 12 S., R. 36 E.*

Badger Flat Limestone.

Conformable contact.

Al Rose Formation:

	Feet
3. Shale and mudstone, medium-dark-gray to olive-gray; weathers light brown to moderate reddish brown; in beds as much as 2 in. thick; interbedded gray limestone beds as much as ½ in. thick; forms distinctive dark outcrop; graptolites near top	52
2. Siltstone and mudstone, medium-gray; weathers dark yellowish orange to light brown; very irregularly interbedded thin-bedded medium-gray limestone; where silty beds are predominant, limestone lenses weather out, leaving diagnostic "eyes"; outcrops have an overall brown appearance; fossil fragments found locally; structural contortions in this relatively incompetent unit preclude accurate thickness measurements	300–400(?)
1. Limestone, medium-gray, very thin bedded to laminated; black chert near base; 6-in.-thick bed of edgewise conglomerate associated with sandy bioclastic layers about 3 ft below top	13
Total Al Rose Formation	400(?)

Conformable contact.

Tamarack Canyon Dolomite.

BF–1. *About ¾ mile northeast of Squares Tunnel, T. 12 S., R. 36 E.*

Barrel Spring Formation.

Conformable contact.

Badger Flat Limestone:

3. Limestone, medium-gray to medium-bluish-gray; thin nodular beds and laminae; abundant argillaceous-siliceous irregular lenses and nod-

BF–1. *About ¾ mile northeast of Squares Tunnel*—Continued

Badger Flat Limestone—Continued

	Feet
ules which weather dark yellowish orange to light brown and in relief; lower 70 ft of unit has scattered large gastropods (*Palliseria*?); one orthocone cephalopod found	165
2. Limestone, medium-gray to medium-bluish gray; thin nodular beds; brownish argillaceous-siliceous beds abundant, as in unit 3; scattered black chert nodules; large gastropods (*Palliseria*?) 45 ft below top of unit	95
1. Limestone and brown beds as in unit 2; black chert, in nodules and in lenses as much as 4 in. thick, more abundant than in unit 2; locally chert makes up 50 percent of unit, but generally about 10 percent; near base of unit, chert and brown layers make up about 50 percent of the unit and are interbedded in relatively even layers 1 to 3 in. thick with bluish limestone	297
Total Badger Flat Limestone	557

Conformable contact.
Al Rose Formation.

BF–2. *About ½ mile south of Barrel Springs, T. 12 S., R. 36 E.*

Barrel Spring Formation.
Conformable contact.
Badger Flat Limestone:

	Feet
7. Limestone, medium-bluish-gray to medium dark-gray; irregular lenticular bedding, accentuated by irregular nodules, lenses, and beds as much as 1 in. thick of dark-yellowish-orange to light-brown siliceous-argillaceous material	81
6. Same as unit 7; gastropod outlines	1
5. Same as unit 7	90
4. Same as unit 7; small chert nodules about 25 ft from top of unit; gastropod outlines about 45 ft below top	65
3. Same as unit 7; orange-brown material replaced by concentrations of amphibole crystals, which are also present, but less abundant, in the limestone. (This feature has been increasing downward from about 100 ft above this unit)	70
2. Same as unit 7; orange-brown beds common, abundant amphibole; very minor black chert as nodules and thin lenses	99
1. Same as unit 7; chert nodules, lenses, and nodular beds locally make up as much as 20 percent of unit, but occurrence is sporadic; orange-brown beds also locally abundant	105
Total Badger Flat Limestone	511

Conformable contact.
Al Rose Formation.

BF–3. *In Water Canyon about 7/10 mile east of Barrel Springs, T. 12 S., R. 36 E.*

Barrel Spring Formation.
Conformable contact.
Badger Flat Limestone:

	Feet
Limestone, blue-gray, in thin irregular beds; variable amounts of gray argillaceous-siliceous material in irregular interbeds that in places stand out in relief as reddish-brown-weathering ribs; these interbeds make up as much as 20 percent of unit and contain numerous amphibole crystals; other argillaceous beds (less siliceous?) weather black and give dappled appearance to unit; minor black chert nodules (several subunits could be designated on the basis of percentage of argillaceous interbeds, but their gross lithology is very similar)	532

Conformable contact.
Al Rose Formation.

BF–4. *Type section of the Badger Flat Limestone, about 2 miles north-northeast of Johnson Spring, T. 12 S., R. 36 E.*

Barrel Spring Formation.
Conformable contact.
Badger Flat Limestone:

	Feet
7. Limestone, medium-gray, very thin and irregular bedded; interbedded lenses and nodular beds of brown-weathering silty material; rare chert beds as much as ½ in. thick; abundant fossil fragments	41
6. Quartzite, dark- to light-gray; beds 6 in. to 1 ft thick; weathers to brownish-gray knobby surface; some limy cement	5
5. Limestone, medium-gray, silty; weathers distinctive dark yellowish orange to light brown; pelmatozoan fragments	12
4. Limestone, medium-gray, very thin and irregular bedded; abundant nodules and lenses of yellow-weathering silty material; pelmatozoan fragments	23
3. Quartzite, medium-gray; weathers brown and knobby; some limy cement and lenticular limestone layers	8
2. Limestone, medium- to dark-gray; irregular lenses of yellow- to brown-weathering silty material give distinctive irregular nodular appearance to outcrops; fossils locally abundant	489
1. Limestone, gray, silty(?), very thin bedded; some black chert	8
Total Badger Flat Limestone	586

Conformable contact.
Al Rose Formation.

BS–1. *About 6/10 mile northeast of Bee Springs*

Johnson Spring Formation.
Conformable contact.
Barrel Spring Formation:

	Feet
2. Covered	11
1. Siltstone and hornfels, medium- to dark-gray; weathers light brown to moderate reddish brown; much spotted hornfels, some calc- hornfels(?); commonly laminated; basal few feet of calc-hornfels makes up lower member in some places but has not been differentiated in this section; coarsely crystalline limestone at contact suggests fault, but attitudes are conform-	

BS–1. *About 9/10 mile northeast of Bee Springs*—Continued

Barrel Spring Formation—Continued — Feet

able, so may just be minor bedding-plane movement or recrystallization along permeable contact — 60

Total Barrel Spring Formation — 71

Conformable contact.
Badger Flat Limestone.

BS–2. *In Willow Springs Canyon, T. 13 S., R. 36 E.*

Feet

Johnson Spring Formation.
Conformable contact.
Barrel Spring Formation:

Upper member:

4. Shale (altered to hornfels), dark-gray to greenish-gray; partly calcareous; well laminated in places — 30
3. Limestone, medium-gray, thinly laminated, interbedded with lenses and irregular layers of light-brown-weathering argillaceous material — 10
2. Shale (altered to hornfels), medium-light-gray, siliceous — 10

Lower member:

1. Dolomite, white, coarse-grained; weathers pale yellowish orange — 20

Total Barrel Spring Formation — 70

Conformable contact.
Badger Flat Limestone.

BS–3. *About 3/4 mile northeast of Squares Tunnel; T. 12 S., R. 36 E.*

Feet

Johnson Spring Formation.
Conformable contact.
Barrel Spring Formation:

Upper member:

2. Shale (altered to hornfels), medium- to dark-gray; weathers moderate reddish brown to moderate brown; commonly speckled with white spots of metamorphic minerals — 109

Lower member:

1. Calc-hornfels, white; some beds laminated, other beds massive; hackly fracture — 80

Total Barrel Spring Formation — 189

Conformable contact.
Badger Flat Limestone.

BS–4. *About 3/4 mile northeast of Squares Tunnel, T. 12 S., R. 36 E.*

Johnson Spring Formation.
Conformable contact.
Barrel Spring Formation:

Feet

Upper member:

4. Shale (altered to hornfels), medium-gray, thin-bedded; weathers moderate reddish brown; poorly exposed interval of rubbly float — 64

BS–4. *About 3/4 mile northeast of Squares Tunnel*—Continued

Barrel Spring Formation—Continued — Feet

Lower member:

3. Limestone, sandy, impure, thin-bedded; contains thin reddish-brown argillaceous beds — 15
2. Calc-hornfels, white; weathers partly to moderate reddish brown; massive; hackly fracture — 15
1. Calc-hornfels, medium-gray, laminated to thin-bedded; weathers grayish orange to dusky brown; weathering accentuates bedding by creating ribbed surface; some limestone and dolomite(?) — 60

Total Barrel Spring Formation — 154

Conformable contact.
Badger Flat Limestone.

BS–5. *About 1/2 mile south of Barrel Springs, T. 12 S., R. 36 E.*

Johnson Spring Formation.
Conformable contact.
Barrel Spring Formation:

Upper member: — Feet

7. Siltstone and shale; hornfelsed; mostly dark colored; weathers moderate reddish brown to dark yellowish orange; poorly exposed, but color of rubbly outcrop very distinctive — 56

Lower member:

6. Mostly covered; float and scattered exposures of light-colored calc-hornfels and impure quartzite — 26
5. Limestone, medium-gray, nodular; irregular beds as much as 1 in. thick; interlayered lenses and beds of reddish-brown-weathering siliceous-argillaceous material in anastomosing patterns — 11
4. Calc-hornfels, yellowish- to light-gray, laminated — 31
3. Dolomite, medium-gray, massive to poorly bedded — 68
2. Limestone, medium-gray, massive to poorly bedded; locally has reddish-brown-stained zones; abundant metamorphic minerals — 11
1. Calc-hornfels, light-gray, massive; weathers light brown; some limestone — 3

Total Barrel Spring Formation — 206

Conformable contact.
Badger Flat Limestone.

BS–6. *Type section of the Barrel Spring Formation, about 3/4 mile northeast of Barrel Springs in Mexican Gulch (next canyon north of Bonanza Gulch), T. 12 S., R. 36 E.*

Johnson Spring Formation.
Conformable contact.
Barrel Spring Formation:

Upper member:

3. Shale (altered to hornfels?), grayish-black; most weathers moderate to dark reddish

BS–6. *Type section of the Barrel Spring Formation, about ¾ mile northeast of Barrel Springs in Mexican Gulch*—Continued

	Feet
Barrel Spring Formation—Continued	
brown but some weathers silvery gray; thinly laminated with shaly to flaggy parting; sandy and silty layers near top; brachiopods, trilobites, graptolites, and ostracodes in lower 5 ft; brachiopods also common 18 ft above base	78
Lower member:	
2. Limestone, medium-dark-gray: weathers medium gray to medium bluish gray; irregular nodular beds ½–3 in. thick; interbedded light-brown lenticular beds that stand in relief on weathered surfaces but are not noticeable on fresh surfaces	29
1. Calc-hornfels, impure sandstone and carbonate; thin bluish-gray limestone beds near base; impure quartzite near top	50
Total Barrel Spring Formation	157

Conformable contact.
Badger Flat Limestone.

BS–7. *About ¾ mile east of Johnson Spring, T. 12 S., R. 36 E.*

[Section measured by Langenheim and others (1956)]

Johnson Spring Formation.
Conformable contact.
Barrel Spring Formation:

	Feet
Upper member:	
3. Shale to mudstone, medium- to olive-gray; weathers light brown to moderate reddish brown; shaly to flaggy parting; fragments of brachiopods and trilobites (Langenheim units 9, 10, 11)	86
Lower member:	
2. Limestone, dark-gray; weathers medium gray; in irregular beds ¼–3 in. thick; interbedded dark-gray argillaceous beds that weather out in relief as orange-brown ribs (Langenheim unit 8)	25
1. Limestone, medium-gray to light-olive-gray, sandy; weathers light gray to pale yellowish orange; nodular, irregular bedding; some fucoids near top (Langenheim unit 7)	30
Total Barrel Spring Formation	141

Conformable contact.
Badger Flat Limestone.

BS–8. *About 1²⁄₁₀ miles northeast of Johnson Spring, T. 12 S., R. 36 E.*

Johnson Spring Formation.
Conformable contact.

	Feet
Barrel Spring Formation:	
5. Shale, black to olive-gray; weathers dark yellowish orange to moderate reddish brown; papery to shaly parting	34
4. Limestone, gray to light-brown, silty, impure; abundant silty beds; some fossil fragments	4
3. Shale, same as unit 5	8

BS–8. *About 1²⁄₁₀ miles northeast of Johnson Springs—Con.*

	Feet
Barrel Spring Formation—Continued	
2. Limestone, gray to light-brown, silty, impure; abundant fossil molds, mostly pelmatozoan, some brachiopods	3
1. Shale, same as unit 5	41
Total Barrel Spring Formation	90

Conformable contact.
Badger Flat Limestone.

BS–9. *About 2 miles north-northeast of Johnson Spring, T. 12 S., R. 36 E.*

Johnson Spring Formation.
Conformable contact.
Barrel Spring Formation:

	Feet
Upper member:	
2. Siltstone, dark-gray shale, and impure quartzite in very thin bedded to laminated sequence; siltstone and shale most abundant and weather to distinctive reddish brown	73
Lower member:	
1. Limestone, dark-gray, impure; weathers light brown to moderate reddish brown; rich in fossil fragments, pelmatozoan predominate, some trilobite fragments; thin interbeds of black shale in lower part of unit	34
Total Barrel Spring Formation	107

Conformable contact.
Badger Flat Limestone.

BS–10. *About 1 mile northeast of Pops Gulch, T. 11 S., R. 36 E.*

Johnson Spring Formation.
Conformable contact.
Barrel Spring Formation:

	Feet
Upper member:	
2. Shale and siltstone, gray-black to dark-gray, thinly laminated; weathers moderate reddish brown	59
Lower member:	
1. Limestone, medium-gray; beds ½–4 in. thick; interbedded with gray silty and shaly layers as much as 4 in. thick; weathers moderate reddish brown	41
Total Barrel Spring Formation	100

Conformable contact.
Badger Flat Limestone.

JS–1. *About ⁶⁄₁₀ mile northeast of Bee Springs, T. 13 S., R. 36 E.*

Ely Springs Dolomite.
Conformable contact.
Johnson Spring Formation:

	Feet
Upper quartzite:	
17. Quartzite, very light-gray to yellowish-gray; weathers white to dark yellowish orange; beds 3–4 in. thick; some beds laminated; some calcareous cement	3

JS–1. *About 6/10 mile northeast of Bee Springs*—Continued
Johnson Spring Formation—Continued

Upper quartzite—Continued	*Feet*
16. Dolomite, medium- to light-gray; weathers light gray	1
15. Quartzite, white to yellowish-gray; part weathers dark yellowish orange to light brown, but overall color is white to cream; thick to thin bedded; forms bold outcrops; some is coarser than most Ojs quartzite and is probably recrystallized; calcareous cement near base	82
Upper dolomite:	
14. Dolomite, medium-gray; 1- to 4-in.-thick irregular beds interlayered with ¼- to ½-in.-thick black chert beds	12
Middle quartzite:	
13. Quartzite, generally light-gray; yellowish tints weather darkish brown; thin to very thin bedded, crossbedded locally; some calcareous cement	27
12. Quartzite, white to light-gray, thick- to thin-bedded; looks very massive in contrast to overlying well-bedded quartzite unit; small iron-stained spots cause speckling and accentuate bedding	72
11. Limestone, medium- to dark-gray, laminated; nodular bedding; possibly sandy; contains one 6-in.-thick bed of calcareous quartz sandstone	21
10. Quartzite, gray; weathers reddish-gray and brownish-gray; some calcareous cement; some silty and calc-hornfels beds near base	39
Lower limestone:	
9. Limestone, medium-gray, crystalline	2
8. Calc-hornfels, greenish-gray, dense, laminated; abundant epidote; weathers reddish-gray and brownish-gray	5
Lower quartzite:	
7. Quartzite, white to light-gray, poorly bedded; forms massive outcrops; *Scolithus* very abundant near center of unit	33
6. Quartzite, impure, and siltstone, limy quartzite, and minor calc-hornfels; light- to dark-gray; weather reddish-gray and yellowish-gray. Poorly exposed; commonly very thinly bedded to laminated	30
Lower limestone:	
5. Limestone, medium-gray; weathers pale reddish brown and gray; very thin irregular bedding; irregular thin beds and lenses of reddish-gray-weathering argillaceous or siliceous material	10
Lower quartzite:	
4. Quartzite; calcareous cement common; some calc-hornfels	9
3. Quartzite, light-gray, pure; much crossbedding	11
2. Siltstone, dark-gray, laminated, and impure quartzite; weathers moderate to dark reddish brown	8

JS–1. *About 6/10 mile northeast of Bee Springs*—Continued
Johnson Spring Formation—Continued

Lower quartzite—Continued	*Feet*
1. Quartzite, white to gray; some crossbedding; massive outcrops	27
Total Johnson Spring Formation	392

Conformable contract.
Barrel Spring Formation.

JS–2. *In Willow Springs Canyon, T. 13 S., R. 36 E.*

Ely Springs Dolomite.
Conformable contact.
Johnson Spring Formation:

Upper quartzite:	*Feet*
21. Quartzite, very light gray to medium-light-gray, massive; local wispy bedding	30
Upper dolomite:	
20. Dolomite, medium-dark-gray; weathers medium gray to medium light gray; generally massive, but locally bedded	40
Middle quartzite:	
19. Quartzite, white to light-gray; massive; grains fine- to very fine sand size; locally bedded; blocky fracture	30
18. Dolomite, dark-gray; weathers medium gray; crinoid debris	2
17. Quartzite, white to light gray; in part well-bedded with layers ¼–1 in. thick, but generally massive; minor calcite cement in some beds	22
16. Limestone, dark-gray; weathers medium gray; nodular beds as much as 4 in. thick; some purplish-pink beds that contain fossil fragments (possibly a lens of the coral limestone unit of sections JS 7–10)	30
15. Quartzite, white, massive	5
14. Dolomite, medium- to dark-gray; crinoid fragments	1
13. Quartzite, white, massive	2
12. Dolomite, medium- to dark-gray; crinoid fragments	1
11. Quartzite, white, massive	6
10. Dolomite, medium- to dark-gray; scattered crinoid fragments	4
9. Quartzite, white to light-gray; generally massive, but locally bedded; blocky fracture	103
Lower limestone:	
8. Calc-hornfels, splotchy gray; abundant calcite; rosettes of tremolite(?)	3
7. Limestone, dark- to medium-gray, in nodular beds 1–6 in. thick; some beds laminated; interbedded light-brown to moderate-reddish-brown argillaceous lenses, which are more abundant in lower 13 ft of unit; scattered crinoid debris and brachiopod fragments	34
Lower quartzite:	
6. Quartzite, white to light-gray, massive	10

JS–2. *In Willow Springs Canyon*—Continued

Johnson Spring Formation—Continued

	Feet
Lower limestone:	
5. Limestone, dark-gray; laminated dark shale and siltstone beds common near top of unit; some crinoid debris and brachiopod fragments	10
Lower quartzite:	
4. Quartzite, white, massive	12
Lower limestone:	
3. Limestone, dark-gray; nodular beds from less than ½ in. to as much as 6 in. thick; partly argillaceous; crinoid, trilobite(?), and brachiopod fragments locally	12
2. Calc-hornfels, varied green and tan laminated beds; some dark-colored siltstone, sandstone, and quartzite beds	16
Lower quartzite:	
1. Quartzite, white to light gray; well bedded near top, but generally massive (seems somewhat thicker on ridge to northwest where less structually disturbed)	25
Total Johnson Spring Formation	398

Conformable contact.

Barrel Spring Formation.

JS–3. *About ¾ mile northeast of Squares Tunnel, T. 12 S., R. 36 E.*

Ely Springs Dolomite.

Conformable contact.

Johnson Spring Formation:

	Feet
Upper quartzite:	
8. Quartzite, white, fine-grained, massive; hackly fracture	11
Upper dolomite:	
7. Dolomite, medium-gray; mostly covered	14
Middle quartzite:	
6. Quartzite, white, fine-grained, massive; hackly fracture	106
5. Limestone, medium-gray	2
4. Quartzite, white, massive; hackly fracture	8
Lower limestone:	
3. Limestone, bluish-gray; thin irregular beds; some fossil debris	33
2. Dolomite, medium-gray; nodular beds	6
Lower quartzite:	
1. Quartzite, white, crossbedded; yellow-to brown-weathering cement; well bedded in layers as much as several inches thick; somewhat coarser grained than upper and middle quartzite units	82
Total Johnson Spring Formation	262

Conformable contact.

Barrel Spring Formation.

212-460 O—66——5

JS–4. *About ¾ mile northeast of Squares Tunnel, T. 12 S., R. 36 E.*

Ely Springs Dolomite.

Conformable contact.

Johnson Spring Formation:

	Feet
Upper quartzite:	
8. Quartzite, white, fine-grained	13
Upper dolomite:	
7. Dolomite, medium-gray, massive; some nodular beds	36
Middle quartzite:	
6. Quartzite, white, fine-grained, massive; hackly fracture	79
Lower limestone:	
5. Limestone, bluish-gray; nodular beds a fraction of an inch to 2 in. thick; fossil debris	20
Lower quartzite:	
4. Quartzite, white, impure, thin-bedded; weathers grayish orange; flaggy parting	1
3. Shale, dark-gray	1
2. Quartzite, white, impure, thin-bedded; weathers grayish orange; flaggy parting	53
1. Quartzite, white, fine-grained; some weathers dark yellowish orange to light brown; hackly fracture; partly crossbedded; some calcite cement	24
Total Johnson Spring Formation	227

Conformable contact.

Barrel Spring Formation.

JS–5. *About ½ mile south of Barrel Springs, T. 12 S., R. 36 E.*

Ely Springs Dolomite.

Conformable contact, but covered.

Johnson Spring Formation:

	Feet
Upper quartzite:	
15. Quartzite, white, fine-grained; hackly fracture; breaks in pieces no more than a few inches across	16
Upper dolomite:	
14. Interval mostly covered; some coarse-grained dolomite about 20 ft below top of unit	25
Middle quartzite:	
13. Quartzite, white, fine-grained, massive to poorly bedded; intensively fractured	60
Lower limestone:	
12. Limestone, medium-bluish-gray to medium-dark-gray; in beds as much as several inches thick; interbedded siliceous-argillaceous material that weathers moderate reddish brown to light brown and is in irregular nodular beds as much as 3 in. thick; abundant fossil fragments, mostly pelmatozoan	56
Mixed lithology:	
11. Calc-hornfels, yellowish-gray to light-gray, well-bedded; beds from fraction of an inch to 3 in. thick	3
10. Shale, hornfelsed, dark-gray, very thin bedded to laminated; flaggy to shaly parting	2

JS-5. *About ½ mile south of Barrel Springs*—Continued

Johnson Spring Formation—Continued

Mixed lithology—Continued	*Feet*
9. Calc-hornfels, yellowish-gray to light-gray, well-bedded; beds from fraction of an inch to 3 in. thick	7
8. Dolomite, medium-gray; weathers light to moderate brown; sugary texture; laminated to beds several inches thick; flaggy to slabby parting	11
7. Calc-hornfels, gray, well-laminated	4
6. Dolomite, medium-gray; weathers light brown; sugary texture; laminated to beds several inches thick	8
5. Shale (altered to hornfels), grayish-black	2
4. Covered	6
Lower quartzite:	
3. Quartzite, light-gray to white; somewhat coarser grained than quartzite in overlying units; beds 1–2 ft thick; some *Scolithus*	10
2. Quartzite, silty, impure; some shale layers; weathers light brown to moderate reddish brown; very thin bedded; some pure gray quartzite interbeds as much as 6 in. thick	8
1. Quartzite, light-gray to white; somewhat coarser grained than overlying quartzites; crossbedded	11
Total Johnson Spring Formation	229

Conformable contact.
Barrel Spring Formation.

JS-6. *About ⁸⁄₁₀ mile northeast of Barrel Springs, T. 12 S., R. 36 E.*

Ely Springs Dolomite.
Conformable contract.
Johnson Spring Formation:

Upper quartzite:	*Feet*
5. Quartzite, medium-dark-gray to white, massive; unit contains one irregular dolomite pod	13
Upper dolomite:	
4. Dolomite, dark-gray; weathers medium gray; poor nodular bedding; some black chert nodules near top; strongly fetid; flecked with metamorphic minerals and and pelmatozoan debris	34
Middle quartzite:	
3. Quartzite, white to light-gray, massive	43
Mixed lithology:	
2. Poorly exposed interval; north of section, interval contains dark-gray shale and siltstone underlain by limestone and dolomite containing pelmatozoan debris. Near middle of covered interval is about 10 ft of calcareous sandstone and quartzite underlain by about 2 ft of black shale. Below this are more cabonate rocks	51

JS-6. *About ⁸⁄₁₀ mile northeast of Barrel Springs*—Continued

Johnson Spring Formation—Continued

Lower quartzite:	*Feet*
1. Quartzite, white to medium-gray, massive; weathers to yellow and red tints; intensely fractured	31
1. Siltstone and hornfels, medium- to dark-gray; Total Johnson Spring Formation	172

Conformable contact.
Barrel Spring Formation.

JS-7. *Type section of the Johnson Spring Formation, about ¾ mile east of Johnson Spring; T. 12 S, R. 36 E.*

Ely Springs Dolomite.
Conformable contact.
Johnson Spring Formation:

Upper quartzite:	*Feet*
11. Quartzite, white to gray, fine-grained, massive; markedly thins to south	17
Upper dolomite:	
10. Dolomite, dark-gray; weathers medium light gray, massive to poorly bedded; scattered black chert nodules and fossil debris	20
Coral limestone:	
9. Limestone, dark-gray, with scattered chert nodules and gastropod fragments	4
8. Limestone, dark gray; irregular, nodular bedding accentuated by dark-gray argillaceous layers that weather medium gray; some dark-gray shaly mudstone about 20 ft below top; corals and bryozoans about 10 ft above base	43
Middle quartzite:	
7. Quartzite, very light gray to white, massive; locally weathers to yellow and red tints; blocky fracture; calcareous cement in part	34
Mixed lithology:	
6. Limestone, dark-gray; weathers medium to light gray; thin nodular beds; minor reddish-brown-weathering argillaceous lenses; many coral and other fossil fragments	20
5. Mixture of calcareous sandstone, red-brown-weathering thin-bedded siltstone, medium-gray fossiliferous limestone, medium-dark-gray dolomite, and minor white quartzite; makes a red-brown unit on the ridge	26
4. Quartzite, white, massive	2
3. Dolomite, sandy(?), medium-light-gray, massive to thick-bedded; much fossil debris (mostly pelmatozoan)	5
2. Silty siliceous bed; light-olive-gray to medium-light-gray; weathers light brown to moderate reddish brown; laminated to very thin bedded	6
Lower quartzite:	
1. Quartzite, white to yellowish-gray, partly well-bedded and crossbedded; coarser	

JS-7. *Type section of Johnson Spring Formation, about 3/4 mile east of Johnson Spring*—Continued

Johnson Spring Formation—Continued

	Feet
grained than overlying quartzite units; limy cement near base	35
Total Johnson Spring Formation	210

Conformable contact.
Barrel Spring Formation.

JS-8. *About 9/10 mile northeast of Johnson Spring, T. 12 S., R. 36 E.*

Ely Springs Dolomite.
Conformable contact.
Johnson Spring Formation:

	Feet
Upper quartzite:	
10. Quartzite, white to very light gray, fine-grained, poorly bedded to massive; weathers moderate yellow to moderate reddish brown on many joint surfaces	21
Upper dolomite:	
9. Dolomite, dark-gray, thick- to thin-bedded; weathers medium light gray; black chert nodules common	14
Coral limestone:	
8. Limestone, bluish-gray; irregular thin bedding; many grayish-red streaks and lenses of argillaceous material cause unit to resemble Badger Flat Limestone locally; coral fragments common near base	74
7. Covered	10
Middle quartzite:	
6. Quartzite, white to light-gray, massive, much fractured; some calcareous cement	23
Mixed lithology:	
5. Dolomite, dark-gray; weathers medium gray; beds 1 ft or more thick; massive appearance	7
Coral limestone:	
4. Limestone, medium-gray; irregular very thin nodular beds; grayish-red lenses give purplish cast to rock in places; coral, crinoid, and brachiopod fragments	14
Mixed lithology:	
3. Quartzite, light-gray to white; much calcareous matrix (locally unit is a calcareous quartz sandstone)	5
2. Poorly exposed slope of mixed siltstone, shale, limestone, and impure quartzite; fragments commonly weather to shades of red and brown	37
Lower quartzite:	
1. Quartzite, medium- to light-gray, medium- to fine-grained, massive	9
Total Johnson Spring Formation	214

Conformable contact.
Barrel Spring Formation.

JS-9. *About 1 2/10 miles northeast of Johnson Spring, T. 12 S., R. 36 E.*

Ely Springs Dolomite.
Conformable contact.
Johnson Spring Formation:

	Feet
Upper quartzite:	
13. Quartzite, white to medium-gray; thick to thin bedded near base; locally calcareous	21
Upper dolomite:	
12. Covered, probably like underlying dolomite (unit 11)	11
11. Dolomite, dark-gray; thin nodular bedding; minor black chert nodules; pelmatozoan fragments and corals(?)	26
Coral limestone:	
10. Limestone, medium-gray to dark-yellowish-brown; flaggy fracture; argillaceous; poorly exposed; many coral fragments, some brachiopods	22
9. Quartzite, dark-gray to moderate-reddish-brown; limy interbeds	5
argillaceous beds; similar to unit 10	37
7. Dolomite, medium-dark-gray; weathers medium light gray; thin nodular bedding	12
6. Limestone, medium-dark-gray, bioclastic; generally massive, but bedding is shown by dark-gray siliceous laminated layers as much as 2 in. thick; pelmatozoan fragments common; brachiopods also present	16
Mixed lithology:	
5. Quartzite, white to medium-gray; massive but strongly jointed; metamorphic minerals common near top, suggesting original calcareous cement	7
4. Limestone, gray and dark-gray; weathers moderate reddish brown; argillaceous layers; poorly exposed	17
3. Quartzite, light- to medium-gray, very thin to thin-bedded; some calcareous cement	8
2. Dolomite, dark-gray, laminated to very thin bedded; weathers dark yellowish orange; poorly exposed	18
Lower quartzite:	
1. Quartzite, medium-gray; near top of unit is thin bedded and has some layers of siltstone and shale, rest of unit is massive, pure, and poorly bedded; crisscrossed with white veinlets	12
Total Johnson Spring Formation	212

Conformable contact.
Barrel Spring Formation.

JS-10. *About 1 2/10 miles northeast of Johnson Spring, T. 12 S., R. 36 E.*

Ely Springs Dolomite.
Conformable contact.
Johnson Spring Formation:

	Feet
Upper quartzite:	
12. Quartzite, medium-gray, massive	4

JS–11. *About 1²⁄₁₀ miles northeast of Johnson Spring*—Con.

Johnson Spring Formation—Continued

	Feet
Upper dolomite:	
11. Dolomite, dark-gray to grayish-black, thick- to thin-bedded; appears massive	21
Coral limestone:	
10. Limestone, medium-gray to grayish-orange and grayish-red; very thin nodular bedding; some black chert nodules; corals and brachiopods locally abundant	38
Crinoidal dolomite:	
9. Dolomite, medium-gray; very thin bedded near base, but generally massive; abundant pelmatozoan debris which gives rock a nodular, bumpy surface	26
Mixed lithology:	
8. Mixture of siltstone, dark-gray dolomite, and thin dark-gray bioclastic limestone layers	23
7. Dolomite, same as unit 5	6
6. Sandstone, medium-gray, very thin bedded; well-rounded grains seem coarser than average in this formation; calcareous cement	8
5. Dolomite, medium-gray; weathers grayish yellow to grayish orange; laminated to very thin bedded; irregular argillaceous interbeds as much as ¼ in. thick	17
Lower quartzite:	
4. Quartzite, medium-gray; thin- to very thick-bedded; weathers to slightly brown	5
3. Shale, dark-gray to black; weathers moderate reddish brown	1
2. Quartzite, medium-gray, thin- to thick-bedded; faint crossbedding	9
1. Quartzite, brown-weathering, silty, very thin bedded	3
Total Johnson Spring Formation	161

Conformable contact.
Barrel Spring Formation.

JS–11. *About 2 miles north-northeast of Johnson Spring, T. 12 S., R. 36 E.*

Ely Springs Dolomite.
Conformable contact.
Johnson Spring Formation:

	Feet
Upper quartzite:	
8. Quartzite, medium-gray to white, thick- to thin-bedded; some beds as much as a few feet thick; weathers "soft"; little calcareous cement; lower part tends to weather to shades of red	70
Upper dolomite:	
7. Dolomite, medium-dark-gray; poor nodular bedding; coral fragments; some black chert nodules	21
6. Quartzite, medium-gray; weathers to knobby grayish-orange to light-brown surface	10
5. Shale and siltstone, black; weathers moderate reddish brown; laminated; thin gray limestone near top of unit contains brachiopods and coral fragments, may be lens of coral limestone unit	5
Crinoidal dolomite:	
4. Dolomite, medium-gray, knobby; irregular thin bedding; some crinoidal debris and coral and brachiopod fragments	23
Mixed lithology:	
3. Quartzite, light-gray, as one massive bed; though contact with overlying dolomite is fairly sharp, dolomite is obviously sandy for at least 1 ft above the quartzite; also quartzite has some calcareous cement	3
2. Impure quartzite, siltstone, and black shale; thin-bedded to very thick bedded; weathers moderate to dark reddish brown; about 1 ft of gray limestone near base	16
Lower quartzite:	
1. Quartzite, medium- to light-gray; locally very thin bedded	10
Total Johnson Spring Formation	158

Conformable contact.
Barrel Spring Formation.

JS–12. *About 1 mile northeast of Pops Gulch, T. 11 S., R. 36 E.*

Ely Springs Dolomite.
Conformable contact.
Johnson Spring Formation:

	Feet
Upper quartzite:	
7. Quartzite, white to light-gray, massive; some calcareous cement	5
6. Dolomite, grayish-black, very thin nodular bedding; local pelmatozoan fragments	7
5. Quartzite, white to light-gray, massive, typically fine-grained, well-sorted, even-grained; some calcareous cement	56
Upper dolomite:	
4. Dolomite, medium-gray to medium-dark-gray, fine-grained; very thin irregular poor bedding; some black chert nodules; minor pelmatozoan debris	35
3. Poorly exposed grayish-orange silty, limy bed	9
Crinoidal dolomite:	
2. Dolomite, medium-gray to medium-dark-gray; knobby weathered surface; very thin irregular poor bedding; many pelmatozoan fragments cause surface to appear clastic; some black chert as nodules and thin nodular beds	38
Lower quartzite:	
1. Quartzite, medium- to light-gray, some yellowish-orange; weathers light brown to moderate reddish brown; beds ½–1 in. thick; commonly has thin partings of gray to green shale with fucoid markings; black shale locally has interbeds a few inches thick; some clastic layers are more properly	

JS–12. *About 1 mile northeast of Pops Gulch*—Continued

Johnson Spring Formation—Continued — Feet

siltstone; some crossbedding; basal 4 ft of unit is clean massive light-grey quartzite; overlying 3 ft has much limy cement — 52

Total Johnson Spring Formation — 202

Conformable contact.
Barrel Spring Formation.

JS–13. *In SE¼ sec. 25, T. 11 S., R. 35 E.*

Ely Springs Dolomite.
Conformable contact.
Johnson Spring Formation:

Crinoidal dolomite: — Feet

2. Dolomite, medium-gray; thin nodular bedding; many pelmatozoan fragments and some coral(?) fragments — 29

Lower quartzite:

1. Quartzite, medium- to light-gray; weathers to shades of yellow and brown; thin irregular beds, in places crossbedded; calcareous cement common in lower 30 ft — 85

Total Johnson Spring Formation — 114

Conformable contact, but covered.
Barrel Spring Formation.

ES–1. *In Willow Springs Canyon, T. 13 S., R. 36 E.*

[Units 10, 11, 12, 13 m asured on top of ridge south of canyon]

Vaughn Gulch Limestone.
Conformable contact.
Ely Springs Dolomite:

Upper member: — Feet

13. Dolomite, medium-gray to medium-dark-gray; irregularly thin bedded; rilled weathered surfaces; some black chert nodules — 18
12. Limestone, dark-gray to gray-black; laminated to very thin bedded; some bedded chert; poorly exposed — 28
11. Dolomite, like unit 13 but laminated and has more pronounced rills — 23
10. Chert, black to medium-gray; predominantly dark colored; bedding ranges from regular laminae to nodular beds as much as 2 ft thick, two 6-in.- to 1-ft-thick medium-gray dolomite beds and some lenses interbedded with chert; much brecciation — 30
9. Dolomite, light-gray to medium-dark-gray, color banded; bands are ¼–1 in. thick and are internally laminated; lenses and thin nodular beds of black chert make up about 10 percent of this unit — 8
8. Dolomite, medium-gray; weathers light gray; in massive beds as much as 3 ft thick, within which are nodular beds ¼–1 in. thick; scattered black chert nodules — 18
7. Chert, black, and interbedded medium- to dark-gray dolomite; beds are ¼ to 4 in.

ES–1. *In Willow Springs Canyon*—Continued

Ely Springs Dolomite—Continued

Upper member—Continued — Feet

thick; chert makes up more than half of unit; lower 2 ft is massive black chert; some brecciation of chert and contortion of dolomite bedding — 7

6. Dolomite, medium-dark-gray; weathers light gray; generally massive; some wispy bedding; fetid — 5
5. Dolomite, dark-gray; weathers medium gray; thinly laminated ½- to 2-in. thick beds; interbedded black chert layers from ¼ in. to several inches thick make up about 15 percent of the unit — 29

Middle member:

4. Dolomite, medium-gray; weathers light gray; bedding indistinct within massive beds several feet thick, but thin to very thin near middle of unit; coral fragments locally — 131

Lower member:

3. Dolomite, medium-gray, and black chert in brecciated sequence of thin interbeds — 12
2. Dolomite, medium- to dark-gray, brecciated — 38
1. Dolomite, medium-gray to medium-dark-gray; laminated to very thin nodular beds; interbedded with nodules and nodular beds of black chert that are commonly metamorphosed to a white mass; chert and dolomite more regularly bedded near base; dolomite beds are 1–6 in. thick, and chert beds ½–3 in. thick; locally chert makes up 25 percent of unit, but more commonly 15–20 percent — 244

Total Ely Springs Dolomite — 591

Conformable contact.
Johnson Spring Formation.

ES–2. *About ¾ mile northeast of Squares Tunnel, T. 12 S., R. 36 E.*

Vaughn Gulch Limestone.
Conformable contact.
Ely Springs Dolomite:

Upper member: — Feet

5. Chert, medium-dark-gray to black, in nodular beds from a fraction of an inch to 1 in. thick; much is bleached, altered, and brecciated — 22
4. Dolomite, light-gray, massive — 22
3. Dolomite, medium-dark-gray to dark-gray, and black chert in interbeds 1–4 in. thick that are commonly nodular; contacts of chert and dolomite commonly have reaction zone of talc — 34

Middle member:

2. Dolomite, medium-dark-gray; weathers medium gray; forms massive, blocky outcrops but is in part well bedded in thin layers; parts of some layers nodular; metamorphic minerals scattered throughout unit — 103

ES–2. *About ¾ mile northeast of Squares Tunnel*—Continued

Ely Springs Dolomite—Continued	*Feet*
Lower member:	
1. Dolomite, medium-dark-gray, massive; weathers medium gray; irregular nodules of black chert (mostly metamorphosed to light-colored metamorphic minerals) make up as much as 10 percent of the unit; locally chert is in trains of irregular nodules, which accentuates well-bedded but nodular appearance of this unit	114
Total Ely Springs Dolomite	295

Conformable contact.
Johnson Spring Formation.

ES–3. *About ½ mile south of Barrel Springs, T. 12 S., R. 36 E.*

Vaughn Gulch Limestone.
Conformable contact.
Ely Springs Dolomite:

Upper member:	*Feet*
9. Dolomite, grayish-black; weathers medium light gray; part is well bedded in layers ¼ in. to several inches thick, and partly massive; flaggy to slabby parting; irregular pits and sharp points and ridges on weathered surfaces; irregular black chert nodules as much as 3 in. across throughout unit but most abundant near base; chert nodules commonly have white altered rims	49
8. Chert, grayish-black; altered to various shades of gray; nodular, irregular beds as much as 1 in. or more thick; some beds brecciated	17
7. Dolomite, dark-gray; weathers medium gray; poorly bedded to massive; black chert nodules (as large as several inches) and nodular beds (as thick as 2 in.) make up about 10–20 percent of the unit; weathers as a prominent rib	20
6. Dolomite, medium-gray and interbedded grayish-black chert; beds mostly 1–5 in. thick; some dolomite is laminated and some chert is nodular, though generally regularly bedded; dolomite and chert in about equal amounts	36
Middle member:	
5. Dolomite, medium-gray, massive; beds locally from 1 in. to several inches thick; weathers to a dappled gray; texture is sugary in contrast to aphanitic in overlying dolomite units	54
4. Dolomite, dark-gray; weathers medium gray; bedding ranges from laminae to beds 4 in. thick	7
3. Dolomite, medium-gray to medium-dark-gray, massive to poorly bedded, weathers dappled gray, ridged and pitted	18

ES–3. *About ½ mile south of Barrel Springs*—Continued

Ely Springs Dolomite—Continued	
Lower member:	*Feet*
2. Dolomite, dark-gray to medium-dark-gray, massive to poorly bedded, fetid; scattered irregular black chert nodules as much as several inches long, commonly altered along rims; abundant pelmatozoan fragments locally	56
1. Dolomite, dark-gray to medium-dark-gray; irregular beds 1–4 in. thick; nodular interbeds of black chert as much as 1 in. thick at intervals of 4–5 in. make up about 10 percent of the unit, near base increases to 20 percent; also near base are chert-rich layers several feet thick; pelmatozoan debris abundant in places	85
Total Ely Springs Dolomite	342

Conformable contract.
Johnson Spring Formation.

ES–4. *About ¾ mile east of Johnson Spring, at end of road at Bluestone talc mine, T. 12 S., R. 36 E.*

Sunday Canyon Formation.
Conformable contact.
Ely Springs Dolomite:

Upper member:	*Feet*
7. Chert, dark-gray to black, massive; some altered to lighter shades of gray; brecciated	10
6. Dolomite, medium-gray; weathers light gray; very thin bedded, somewhat irregular; weathers to a varied gray-banded appearance	13
5. Dolomite, dark-gray, dark- to light-gray-weathering, and somewhat nodular black chert regularly interbedded in layers 1–4 in. thick	15
Middle member:	
4. Dolomite, medium-gray; weathers light gray; thin to thick bedded, but massive appearance; some pelmatozoan fragments; scattered metamorphic minerals common	64
3. Dolomite, dark-gray, massive; weathers medium dark gray; scattered black chert nodules and thin nodular beds	57
2. Dolomite, dark-gray; nodular beds 1–5 in. thick; interlayered with nodular black chert beds 1–3 in. thick; pelmatozoan fragments	22
1. Dolomite, dark-gray, fetid; massive beds several feet thick and some irregular dark lenses and wispy layers that accent bedding and are themselves laminated to thin bedded; scattered fossil fragments	19
Total Ely Springs Dolomite	200

Conformable contact.
Johnson Spring Formation.

ES–5. *About 1 mile northeast of Johnson Spring, T. 12 S., R. 36 E.*

Sunday Canyon Formation.
Conformable contact.
Ely Springs Dolomite:

	Feet
Upper member:	
5. Chert, black, massive, brecciated	12
4. Covered (probably same as unit 3)	5
3. Dolomite, grayish-black, very thin bedded; laced with very thin white carbonate stringers; interbedded nodular black chert layers as much as 1 in. thick	28
Middle member:	
2. Dolomite, medium-dark-gray; weathers light gray; poorly bedded thick to thin beds; massive outcrops; olive-gray sandy dolomite lens 35 ft from top	145
Lower member:	
1. Dolomite, dark-gray; thin, irregular bedding; black chert nodules and nodular beds as much as 2 in. thick; chert less abundant upward	61
Total Ely Springs Dolomite	251

Conformable contact.
Johnson Spring Formation.

ES–6. *About 1 2/10 miles northeast of Johnson Spring; T. 12 S., R. 36 E.*

Sunday Canyon Formation.
Conformable contact.
Ely Springs Dolomite:

	Feet
Upper member:	
6. Chert, black, massive, brecciated	9
5. Dolomite, medium-gray, laminated; weathers varied gray	15
4. Dolomite, dark-gray, in thinly laminated beds as much as a few inches thick interbedded with black chert in beds as much as 3 in. thick	19
Middle member:	
3. Dolomite, medium-gray; weathers light gray; some very thin irregular bedding; forms massive bluffs	97
Lower member:	
2. Dolomite, dark-gray to medium-dark-gray; very minor chert stringers; very thin irregular bedding, shown by wispy varied-gray color bands on weathered surface	39
1. Dolomite, dark-gray, in irregular nodular beds as much as 4 in. thick interbedded with irregular nodular black chert layers as much as 3 in. thick; some pelmatozoan debris	56
Total Ely Springs Dolomite	235

Conformable contact.
Johnson Spring Formation.

ES–7. *About 2 miles NNE of Johnson Spring, T. 12 S., R. 36 E.*

Sunday Canyon Formation.
Conformable contact—covered.
Ely Springs Dolomite:

	Feet
Upper member:	
6. Dolomite, varied gray; thin irregular beds	6
5. Mostly covered; massive black chert striking into this interval from south of section	5
4. Dolomite, grayish-black, thin-bedded, laced with thin white dolomite stringers and interbedded with black chert beds 1–2 in. thick	28
Middle member:	
3. Dolomite, medium-light-gray, weathers light gray; irregular thin to thick beds; some crinoid fragments	69
Lower member:	
2. Dolomite, medium-dark-gray; weathers medium gray; thin irregular bedding, darker and thinner bedded in lower part, some crinoid fragments	43
1. Dolomite, medium-dark-gray, thin- to very thin-bedded, with irregular, nodular interbeds of chert as much as 3 in. thick; both partly laminated	64
Total Ely Springs Dolomite	215

Conformable contact.
Johnson Spring Formation.

ES–8. *About 1 mile northeast of Pops Gulch, T. 12 S., R. 36 E.*

Sunday Canyon Formation.
Conformable contact.
Ely Springs Dolomite:

	Feet
Upper member:	
8. Dolomite, medium-dark-gray; weathers light gray; abundant pelmatozoan debris	1
7. Covered	7
6. Dolomite, medium-dark-gray; weathers medium gray; irregular thin beds; irregular black chert nodules	5
5. Chert, black, massive, brecciated; thin dolomite lenses	2
4. Dolomite, medium-dark-gray to medium-gray; irregularly laminated to very thin bedded	1
3. Dolomite, dark-gray, and interbedded black chert; dolomite beds as much as 4 in. thick and internally laminated; chert beds 1 in. thick; chert makes up 25–50 percent of unit; pelmatozoan debris in dolomite near top of unit	15
Middle member:	
2. Dolomite, medium-dark-gray to medium-gray; weathers light gray; irregular beds a few inches to a few feet thick (overall massive appearance); sharp color contrast with overlying darker dolomite and chert	141
Lower member:	
1. Dolomite, gray-black to dark-gray, and interbedded black chert; dolomite in beds as	

ES–8. *About 1 mile northeast of Pops Gulch*—Continued

Ely Springs Dolomite—Continued

Lower member—Continued *Feet*

much as 1 ft thick with varied gray laminations; chert in fairly regular beds as much as 4 in. thick; chert makes up about 25 percent of unit; top 3 ft composed of black chert beds as much as 1 ft thick with thin dolomite interbeds … 61

Total Ely Springs Dolomite … 233

Conformable contact.
Johnson Spring Formation.

ES–9. *About 1 mile northeast of Pops Gulch, T. 11 S., R. 36 E.*

Ely Springs Dolomite. *Feet*

Middle member: gray, massive dolomite.

Lower member:

2. Chert, black, and interbedded dark-gray to grayish-black dolomite; dolomite beds as much as 1 ft or more thick; chert beds a few inches to 1 ft thick … 28
1. Chert, black; some very thin irregular bedding; massive bold outcrops … 15

Total Ely Springs Dolomite … 43

Conformable contact.
Johnson Spring Formation.

ES–10. *In SE¼ sec. 25, T. 11 S., R. 35 E.*

Sunday Canyon Formation.
Conformable contact.
Ely Springs Dolomite:

Upper member: *Feet*

5. Dolomite, dark-gray, knobby, irregularly bedded; minor black chert … 10
4. Chert, black, massive, brecciated … 5
3. Dolomite, dark-gray to grayish-black, and interbedded black chert; very thin bedded … 25

Middle member:

2. Dolomite, light- to medium-gray; very thin nodular beds; sharp color contrast with overlying dark cherty beds … 105

Lower member:

1. Chert, black, massive, brecciated; gray where altered … 50

Total Ely Springs Dolomite … 195

Conformable contact.
Johnson Spring Formation.

VG–1. *Type section of the Vaughn Gulch Limestone, about 2 miles north-northeast of Kearsarge, T. 13 S., R. 35 E.*

Perdido Formation.
Erosional unconformity.
Vaughn Gulch Limestone:

7. Limestone, dark-gray; generally weathers medium gray; in 1- to 6-in.-thick laminated beds; interbedded with $\frac{1}{10}$- to 3-in.-thick black chert

VG–1. *Type section of the Vaughn Gulch Limestone, about 2 miles north-northeast of Kearsarge*—Continued

Vaughn Gulch Limestone—Continued *Feet*

layers; some limestone beds weather grayish orange to moderate reddish brown, which suggests argillaceous impurities; chert decreases near top of unit, and limestone becomes bioclastic; coral fragments abundant at upper contact … 96

6. Limestone, medium- to dark-bluish-gray, dense, laminated; minor argillaceous limestone … 70
5. Argillaceous limestone and siltstone, dark-gray; weathers light gray to grayish orange; platy to shaly fracture; generally poorly exposed; few fossils … 105
4. Limestone, argillaceous, laminated; red weathering surfaces; shaly parting; interbedded bioclastic limestone and dense bluish-gray limestone abundant but not as common as in unit 3 … 484
3. Limestone, medium-dark-gray to medium-bluish-gray; 6-in. to 1-ft.-thick coral-rich bioclastic beds predominant; orange-weathering argillaceous beds subordinate; minor chert … 215
2. Limestone, like unit 1, but greater proportion of argillaceous limestone; bioclastic beds subordinate; slope has yellowish tint; some black chert in lenticular beds and nodules … 363
1. Limestone, medium-dark-gray to medium-bluish-gray, laminated to thin-bedded; alternating sequence of bioclastic limestone and dense blue limestone; thin-bedded orange-weathering argillaceous limestone subordinate; thin black chert beds and nodules present … 185

Total Vaughn Gulch Limestone … 1,518

Conformable contact.
Ely Springs Dolomite.

VG–2. *About ¾ mile northeast of Squares Tunnel, T. 12 S., R. 36 E.*

Perdido Formation.
Erosional unconformity.
Vaughn Gulch Limestone: *Feet*

6. Limestone, medium-gray, dense; some thinly laminated argillaceous layers; crinoid debris … 26
5. Limestone, medium-gray, and interbedded dark-gray argillaceous layers that weather moderate reddish brown to light brown; beds are from a fraction of an inch to 1 in. thick and have a flaggy parting; commonly metamorphosed to calc-hornfels; minor crinoid debris … 51
4. Limestone, medium-gray, thinly laminated; minor argillaceous stringers which weather moderate reddish brown … 23
3. Calc-hornfels, weathers light brown to moderate reddish brown, commonly thinly laminated; much of this interval is covered … 60
2. Limestone, medium-gray, beds from fraction of an inch to several inches thick; flaggy parting; minor argillaceous beds; crinoid debris locally … 79

VG–2. *About ¾ mile northeast of Squares Tunnel*—Continued

Vaughn Gulch Limestone—Continued *Feet*

1. Limestone, argillaceous, dark-gray; weathers grayish orange; thinly laminated ____ 25

Total Vaughn Gulch Limestone ____ 264

Conformable contact.

Ely Springs Dolomite.

SC–1. *Type section of the Sunday Canyon Formation, in Bonanza Gulch, about 4/10 mile northeast of Barrel Springs, T. 12 S., R. 36 E.*

Perdido Formation.

Erosional Unconformity.

Sunday Canyon Formation: *Feet*

5. Limestone, dark-gray, dense, argillaceous(?) weathers grayish orange to light brown; commonly studded with metamorphic minerals (chiefly amphibole?); massive to poorly bedded in 1- to 2-ft-thick beds; interbedded black chert layers as much as 8 in. thick; 1-ft-thick blue bioclastic limestone bed about 60 ft from top contains favositid, alveolitoid, and cyathophylloid corals; mudstone interbedded near top of unit ____ 166
4. Mudstone and chert, dark-gray to black; weathers light gray to moderate reddish brown; very thin bedded; some dark-gray limestone ____ 27
3. Limestone, dark-gray; weathers light gray; very thinly bedded; flaggy parting; some bioclastic beds as much as 1 ft thick, including a particularly coral-rich bed 114 ft from top of unit; some flaggy beds weather to shades of yellow, orange, or red, which suggests argillaceous impurities; "brown dashed-line" beds near top ____ 217
2. Limestone and argillaceous limestone, dark-gray; weathers light gray; beds a foot or more thick; alternates with blue-gray limestone beds that are about the same thickness and rich in fossil debris, particularly pelmatozoan, but also corals and bryozoans; argillaceous limestone beds dominant in the upper 100 ft, elsewhere they tend to be covered and bioclastic limestone layers stand out in relief on slopes ____ 140
1. Limestone, dark- to medium-gray; weathers light gray; platy splitting; very thin bedded, probably argillaceous; clastic fossil fragments in lower 55 ft; forms platy gray outcrops that might be called typical of the Silurian to the north ____ 133

Total Sunday Canyon Formation ____ 683

Conformable contact, but covered.

Ely Springs Dolomite.

SC–2. *Section 6/10 mile east of Johnson Spring, T. 12 S., R. 36 E.*

Perdido Formation.

Erosional unconformity.

Sunday Canyon Formation:

11. Shale, black; weathers light to medium gray, some with reddish shades; thinly laminated; mostly noncalcareous; upper 10 ft has three 1- to 2-ft-thick blue-gray limestone beds containing abundant fossil debris, mostly pelmatozoans; shale poorly exposed on rubbly slope ____ 122
10. Limestone, argillaceous, black to dusky-yellow, generally laminated to very thin bedded; beds as much as 1 ft thick near top of unit; platy to to flaggy splitting; nodular black chert interbeds as much as 6 in. thick make up as much as 10 percent of unit ____ 71
9. Shale, limy, dark-gray; weathers light gray; shaly parting; poorly exposed in rubbly slope ____ 33
8. Limestone, blue-gray, fine-grained; poorly defined thin irregular beds; few fossil fragments ____ 10
7. Siltstone(?), limy, light-olive-gray; weathers grayish orange with small reddish spots ____ 45
6. Limestone, argillaceous, medium to dark-gray; weathers light gray; laminated; platy parting ____ 96
5. Limestone, argillaceous, medium- to dark-gray, weathers light gray; laminated; platy parting; several 1- to 3-ft-thick beds of blue-gray bioclastic limestone; *Monograptus* near top ____ 76
4. Limestone, bluish-gray, irregular beds 1/10–1 in. thick; bioclastic (calcarenite), rich in corals and crinoids ____ 4
3. Limestone, argillaceous, medium-gray; weathers dark yellowish orange to light brown; thinly laminated; platy and flaggy parting ____ 23
2. Covered ____ 38
1. Limestone, argillaceous; dark- to medium-gray, massive; weathers medium light gray; locally thin irregular beds; blocky fracture; abundant metamorphic amphibole ____ 6

Total Sunday Canyon Formation ____ 524

Conformable contact.

Ely Springs Dolomite.

SC–3. *About 1 mile northeast of Johnson Spring, T. 12 S., R. 36 E.*

Perdido Formation.

Erosional unconformity.

Sunday Canyon Formation: *Feet*

9. Platy and shaly beds, calcareous, argillaceous; some black chert; poorly exposed ____ 32
8. Limestone, blue-gray, with abundant crinoidal and coral fragments ____ 9
7. Limestone, blue- to dark-gray, interbedded with flaggy argillaceous beds; calcareous beds 2–3 ft thick separated by several feet of argillaceous beds; black chert nodules ____ 42
6. Same as unit 7, but no chert ____ 36
5. Quartzite and calcareous quartz sandstone, medium-gray; minor calcareous layers; lenticular ____ 7
4. Limestone, blue-gray to medium-dark-gray, interbedded with flaggy argillaceous layers; lime-

SC-3. *About 1 mile northeast of Johnson Spring*—Continued

Sunday Canyon Formation—Continued

	Feet
stone beds 2-3 ft thick separated by several feet of argillaceous beds; *Tentaculites* and graptolites near base	62
3. Limestone, medium-dark-gray, laminated to thinly laminated; scattered altered pyrite crystals; platy parting	41
2. Limestone, argillaceous (or limy shale and siltstone); platy to flaggy splitting; red-brown spots and streaks ("brown dashed-line beds") present; some blue-gray bioclastic limestone layers; scattered poor exposures in slope	246
1. Covered	19
Total Sunday Canyon Formation	494

Conformable contact, but covered.
Ely Springs Dolomite.

SC-4. *About ¾ mile east of mouth of Pops Gulch, T. 12 S., R. 36 E.*

Perdido Formation.
Erosional unconformity—contact uncertain.
Sunday Canyon Formation:

	Feet
9. Limestone, dark-bluish-gray, fine-grained, bioclastic(?); abundant tiny pyrite crystals on some surfaces	2
8. Shale, mostly in shades of dark gray; some is slightly calcareous; poorly exposed	87
7. Limestone, blue-gray, very thin bedded; partly bioclastic	3
6. Limestone, shaly (or limy shale), medium-gray to light-olive-gray; limy; dark-gray siltstone or chert float suggests thin interbeds of these materials	83
5. Limestone, medium-gray, sandy, and thin beds of dark-gray quartzite and black chert; one 6-in.-thick bed composed of chert fragments as much as ½ in. across in cherty matrix	7
4. Limestone, grayish-black, mostly very thin bedded, partly massive; irregular beds	9
3. Shale, medium-gray to light-olive-gray, partly calcareous	27
2. Limestone, dark- to light-gray, laminated to very thin and irregularly bedded; some fossil debris; some limy shale	20
1. Shale, calcareous, medium-gray; weathers light olive gray, with red to brown spots and "dashed lines" in some layers; blue-gray bioclastic limestone layers as much as a few feet thick scattered throughout the interval; poorly exposed rubbly outcrop; scattered graptolites from 50 ft to 270 ft above base, brachiopods about 300 ft above base, one trilobite fragment about 190 ft above base	389
Total Sunday Canyon Formation	627

Conformable contact.
Ely Springs Dolomite.

SC-5. *About 1 mile northeast of Pops Gulch, T. 11 S., R. 36 E.*

Perdido Formation.
Erosional unconformity (covered).
Sunday Canyon Formation:

	Feet
5. Limestone, grayish-black, poorly bedded but partly laminated; bioclastic, abundant pelmatozoan fragments	7
4. Shale, limy, medium-gray; weathers light olive gray	91
3. Limestone, medium-dark-gray; very thinly and irregularly bedded; interbedded black chert layers as much as 5 in. thick; limestone beds 1 ft or more thick	25
2. Shale, limy, medium-gray; weathers grayish orange with light-brown spots and "dashed lines"; laminated; shaly parting; some blue-gray limestone beds ¼-½ in. thick; fossil fragments	246
1. Covered	5
Total Sunday Canyon Formation	374

Conformable contact.
Ely Springs Dolomite.

SC-6. *In SE¼ sec. 25, T. 11 S., R. 35 E.*

Perdido Formation.
Erosional unconformity.
Sunday Canyon Formation:

	Feet
3. Shale, various shades of gray; some weathers olive gray; weakly calcareous in part	66
2. Limestone, dark-gray, dense, very thin bedded to laminated, interbedded with black chert beds as much as 4 in. thick	17
1. Shale, calcareous, medium-gray; weathers light gray to light olive gray or yellowish gray; reddish and brownish spots and "dashed lines" abundant; some 1- to 2-ft-thick beds of blue-gray bioclastic limestone	194
Total Sunday Canyon Formation	277

Conformable contact.
Ely Springs Dolomite.

P-1. *Northeast cor. SE¼ sec. 8, T. 13 S., R. 35 E.*

Rest Spring Shale.
Conformable contact.
Perdido Formation:

	Feet
19. Sandstone, calcareous, medium-gray; much pelmatozoan debris	5
18. Shale, dark-gray to black; fucoids locally	30
17. Sandstone, like unit 19	2
16. Shale, like unit 18	16
15. Sandstone, like unit 19	12
14. Shale, like unit 18	22
13. Sandstone, like unit 19	5
12. Shale, dark-gray to black; some calcareous sandstone beds; fucoids locally	81
11. Limestone, medium-gray, laminated; flaggy parting	5

P–1. *Northeast cor. SE¼ sec. 8*—Continued

Perdido Formation—Continued	*Feet*
10. Conglomerate, chert, quartzite, and limestone; chiefly calcareous fragments, including much pelmatozoan debris in a bluish-gray calcite matrix (calcirudite); quartzite and chert fragments angular to well rounded and as much as several inches across	12
9. Limestone (mostly calcarenite), medium-gray laminated; splits flaggy; interbedded dark-gray argillaceous-calcareous beds as much as 6 in. thick that weather dark brownish and stand out in relief; minor crossbedding in some limestone layers; abundant pelmatozoan fragments; forms prominent cliff	134
8. Shale, black to dark-gray; weathers medium gray; thin calcareous sandstone and calcarenite beds; fucoids abundant locally	85
7. Siltstone; weathers olive gray to light brown; weakly calcareous; poorly exposed; seems to fill irregularities in underlying coarse conglomerate unit	49
6. Conglomerate; boulders of quartzite and limestone as much as several feet across; some well rounded; quartzite most abundant; both calcareous and siliceous matrix; south of the section, boulders 10–15 ft across were seen	48
5. Limestone, bluish-gray, very thin bedded; some chert as fragments and thin beds	35
4. Chert, siltstone, and some sandstone; dark colored; very thin bedded and lenticular; some limy beds; chert to the north along the south side of Vaughn Gulch contains light-colored lenses typical of chert in lower Perdido	42
3. Conglomerate; angular to rounded chert fragments as much as 2 in. across scattered in medium-bluish-gray limestone matrix; sandy lenses and some siltstone	15
2. Siltstone, medium- to dark-gray, very thin bedded	6
1. Mostly covered; some chert-pebble conglomerate beds with calcareous matrix	19
Total Perdido Formation	623

Erosional unconformity.
Vaughn Gulch Limestone.

P–2. *About 9/10 mile northeast of Johnson Spring, T. 12 S., R. 36 E.*

Rest Spring Shale
Conformable contact.

Perdido Formation:	*Feet*
20. Sandy, limy layer, gray	6
19. Shale, black; weathers light gray	43
18. Chert conglomerate with siliceous matrix; poorly exposed	47
17. Chert conglomerate, like unit 2	23
16. Shale, black; weathers light gray	14
15. Sandy, limy beds, very thin bedded in part; crinoidal debris common; matrix generally calcareous but partly siliceous; some pebbly beds made up predominantly of chert clasts	36

P–2. *About 9/10 mile northeast of Johnson Spring*—Continued

Perdido Formation—Continued	*Feet*
14. Chert granule conglomerate, granules as much as ½ in. in diameter	7
13. Limestone with abundant crinoidal and chert fragments (calcarenite to calcirudite?); sandy, limy beds present; locally, chert-granule conglomerate; some brown siltstone	21
12. Shale, black; looks "coaly"	15
11. Siltstone, medium-gray; weathers light brown, partly thinly laminated	15
10. Conglomerate and sandstone with limestone matrix; conglomerate a few feet thick at base, grades up to very thin bedded medium-gray sandy beds	26
9. Chert, black, massive; overlain by pebble and granule conglomerate in which chert clasts are predominant; both chert and quartzite clasts well rounded and as much as several inches across; weathers dark gray	5
8. Covered, probably shale	14
7. Conglomerate; limy matrix; black chert clasts as much as several inches across; quartzite clasts also present	4
6. Shale, dark-gray	3
5. Cherty conglomerate, like unit 2	6
4. Covered	9
3. Limestone, sandy, medium-bluish-gray, irregularly bedded; black chert as nodules and irregular beds; some crinoidal debris	10
2. Conglomerate, dark-gray, poorly bedded; argillaceous-siliceous matrix with scattered fragments and pebbles as much as 2 in. in diameter; clasts mostly chert; some gray quartzite	22
1. Shale and siltstone, medium-gray; shaly to papery parting; many joint faces and silty layers weather moderate reddish brown, in contrast to gray-weathering shales; calcareous shale bed about 140 ft above base	224
Total Perdido Formation	550

Erosional unconformity.
Sunday Canyon Formation.

P–3. *About ¾ mile east of mouth of Pops Gulch; T. 12 S., R. 36 E.*

Rest Spring Shale.
Conformable contact.

Perdido Formation:	*Feet*
23. Limy sandstone (or sandy limestone(?)), medium-gray, massive; some pelmatozoan debris	5
22. Shale, mudstone, and chert(?); black, very thin bedded; chert and mudstone layers as much as 1 ft thick separated by shale partings as much as 2 in. thick; 1- to 2-ft thick limy sandstone beds	29
21. Limestone, medium-gray, very thinly and irregularly bedded; weathers to yellowish and brownish shades; some thin chert layers	15
20. Mudstone and siltstone, dark-colored; weathers moderate reddish brown	13
19. Sandy limestone and some fine-grained quartzite in a structurally disturbed bed	12(?)

P–3. *About ¾ mile east of mouth of Pops Gulch*—Continued

Perdido Formation—Continued

	Feet
18. Mudstone and shale, dark-gray to black, very thin bedded; weathers moderate reddish brown; shaly to flaggy parting; some chert conglomerate in lenticular beds as much as 1 ft thick; some limy sandstone; fucoids locally	28
17. Sandy limestone, medium-gray	4
16. Mudstone, siltstone, conglomerate, and sandy limestone, interbedded; includes 2-ft-thick bioclastic limestone bed having abundant pelmatozoan fragments	25
15. Conglomerate and sandstone; grayish-black matrix; partly calcareous, partly siliceous; pelmatozoan fragments and other clasts weather out leaving a pitted surface ("cinder rock"); scattered but prominent chert clasts as much as 3 in. across	8
14. Mudstone and siltstone, poorly exposed	9
13. Sandy limestone, thin-bedded to laminated; some mudstone and chert beds	41
12. Siltstone, mudstone, and shale, black to dark-gray; some weathers light gray, but most weathers to red and brown shades; subordinate limy sandstone beds; rubbly exposure	28
11. Sandy limestone, medium-gray, and lesser black mudstone; much variation in grain size and carbonate content of sandy beds; some chert beds as much as 6 in. thick, and some granule and pebble conglomerates composed of limestone fragments in sandy limestone matrix	33
10. Mudstone, black, and lesser sandy limestone; limestone beds from 6 in. to several feet thick (some discordance of the sandy beds, which appear to have "squirted" around in the muddy matrix)	28
9. Sandy limestone, medium-gray to medium-dark-gray; abundant clastic carbonate and lesser fragments of chert and mudstone; black mudstone interbeds as much as a few feet thick; upper 9 ft is a massive sandy limestone containing abundant well-rounded well-sorted quartz clasts	33
8. Mudstone, gray-black to black, very thin bedded; weathers dark reddish brown; some of unit may be chert	26
7. Sandstone and conglomerate; mostly chert clasts in gray-black siliceous mudstone matrix; commonly weathers reddish brown	31
6. Shale, black	1
5. Conglomerate, medium-gray limestone matrix; clasts mostly chert, but some quartzite and carbonate; some slabby chert fragments as much as 2 ft long and medium-gray quartzite clasts as much as 6 in. long; clasts angular to well rounded and range from coarse sand to pebbles in a limy matrix; some chert grit and shale near top	9
Erosional unconformity.	
4. Shale, mudstone, and chert(?), gray-black; weathers light gray to moderate reddish brown; very thin bedded, but partly irregular slabs and flags; one sandy limestone lens 1 ft thick and 3 ft long	24
3. Conglomerate; mostly well-rounded chert clasts as much as 2 in. thick in dense black matrix	3
2. Shale, dark-gray to black; weathers light gray to dark red-brown; some shale fucoidal and interbedded with nodular beds of black chert as much as 8 in. thick; prominent white lenses are present in this unit to the south on ridge crest	22
1. Shale, various shades of gray-black to light-gray, laminated to very thin bedded; some finely laminated dark-gray siltstone; some beds richly sprinkled with metamorphic minerals, mostly tremolite; these beds are dark gray but commonly weather red or brown; shales are partly fucoidal	130?
Total Perdido Formation	557

Erosional unconformity.

Sunday Canyon Formation.

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INDEX

[Italic page numbers indicate major references]

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