Cambrian Rocks of the Pioche Mining District Nevada

GEOLOGICAL SURVEY PROFESSIONAL PAPER 469

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By CHARLES W. MERRIAM

With a section on PIOCHE SHALE FAUNULES

By A. R. PALMER

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Stratigraphy of a western zinc-lead district with emphasis on lithology and correlation of ore-bearing strata

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By Charles W. Merriam

ABSTRACT

The Pioche mining district in the Ely Range, southeastern Nevada, is one of several districts in the Great Basin where Cambrian rocks are hosts of important ore deposits. Cambrian strata underlying the Ely Range are intruded by porphyritic granite and other dikes. Tertiary volcanic rocks and Pliocene fresh-water clastic deposits of the Panaca Formation occupy adjacent valleys and extend over the Cambrian strata on the south and east.

The Pioche mining district reached a production peak in 1872, followed by a long interval of decline. In 1924, successful application of the flotation process to previously valueless sulfide ores of zinc, lead, and silver brought about revival of the mining industry, which has continued to recent times.

Mining at Pioche during the initial production period was along fissures in the Lower Cambrian Prospect Mountain Quartzite. Much of the later mining was in the overlying intensely faulted Pioche Shale. Fissures which transect these shales brought about replacement of limestone layers by sulfide ores in such manner as to preserve initial bedding features. To these deposits, the term "bedded ore" has appropriately been applied. In this district a detailed understanding of stratigraphy is essential to mining and ore search, as the richest sulfide ores are in large part confined to specific limestone members.

Cambrian strata of the Pioche area are dissected into multitudes of blocks by high-angle normal faults. Evidence of earlier thrust faulting is adduced from low-angle faults and one outlier of Upper Cambrian on Middle Cambrian strata; but in general late normal faulting obscures the results of thrust movement.

In the Pioche region the Cambrian section, about 10,000 feet thick, includes rocks of Early, Middle, and Late Cambrian age. In the Ely Range the Upper Cambrian was recognized only in a possible thrust outlier, but these strata are well represented, together with Lower Ordovician beds, at nearby Arizona Peak. Siliceous clastic rocks of the Prospect Mountain Quartzite and Pioche Shale are of Early and early Middle Cambrian age; these rocks which compose the lower 3,200 feet of the column, are overlain by 7,000 feet of mainly carbonate sedimentary rocks that are Middle and Late Cambrian.

The Middle Cambrian rocks are about 5,500 feet thick and include the upper part of the Pioche Shale, Lyndon Limestone, Chisholm Shale and Highland Peak Formation, in ascending order. Except for some of the upper part of the Pioche and the Chisholm Shale, the Middle Cambrian is represented mainly by carbonate rocks. Of these the Highland Peak Formation, 4,500 feet thick, is the greater part.

The lowest fossils that have age significance are Early Cambrian olenellid trilobites in the lower part of the Pioche Shale; this fossil-bearing shale grades downward into the barren Prospect Mountain Quartzite.

The Pioche Shale, about 800 feet thick, straddles the Lower Cambrian–Middle Cambrian boundary and embraces the largest number of clearly definable lithologic-paleontologic zones of any single Cambrian formation in the region. Certain of these zones are loci of bedded ore deposits.

Though referred to as shale the Pioche is actually diverse, comprising micaceous and nonmicaceous shale, siltstone, sandstone, and fossiliferous limestone. The limestone members are in part bioclastic, including beds composed largely of trilobite shell material. Disseminated carbonaceous matter is abundant in some of these limestones. Although susceptible to sulfide replacement, almost none of the limestone in the Pioche Shale is dolomitized. Dolomitization seems to have preferred the thick, fairly pure, and fine-textured nonbioclastic carbonate rocks of the higher Middle Cambrian such as the Highland Peak Formation.

Study of the varied Pioche Shale depositional record reveals a fluctuating, more or less cyclic repetition of lithologic units. Features of special interest are alternating micaceous and nonmicaceous shales, and a repeated pairing of a basal quartz sandstone with an overlying limestone. The last is well illustrated by the Combined Metals Member, most important ore unit of the district.

The Combined Metals Member, whose average thickness is about 50 feet, has great lateral continuity and extends at least 12 miles westward through the Highland Range, where it contains replacement sulfide ore. The member lends itself to rather detailed yet fairly consistent lithologic division. Knowledge of its lesser stratigraphic subunits is of practical value to the mining geologist and engineer.

The Combined Metals Member gives unparalleled opportunity to study detailed structure of some of the earliest trilobites. Through much of its extent, the fossil shells are silicified and may be removed in large quantities by acid solution. Especially numerous in the residues are minute larval stages of olenellids.

The Highland Peak Formation comprises 13 principal lithologic units. The lower six of these have been mapped in the Pioche mining district, where they are designated as members. The seven units representing the upper part of the Highland Peak Formation are absent in the productive part of the district; these are assigned reference numbers ranging from 7 through 13.

The designated units of the Highland Peak Formation, although mappable, must be used with caution, for they are largely barren of fossils and nearly identical carbonate facies are repeated vertically. These units are identifiable with assurance only where a fairly large part of the stratigraphic column is exposed.

Stratigraphic study of the thick Highland Peak Formation entails complex facies problems, especially as related to diagenetic dolomitization. The fine-grained unfossiliferous car-

bonate rocks that make up much of the formation are believed to be in large part of chemical rather than organic origin. The lower six carbonate units lend themselves to possible alteration studies in connection with ore search, because they overlie potential ore-bearing ground.

INTRODUCTION

The Pioche mining district is in the Ely Range of southeastern Nevada, 20 miles from the Utah State line (fig. 1). As used in this report, the name "Pioche mining district" is restricted to the Ely Range or "Pioche Hills" vicinity, a natural geographic and geologic unit and a convenient one for use in connection with the mining industry. Pioche district in a broad sense has previously been employed (Westgate and Knopf, 1932) for a much larger area, including several mining districts (pl. 2).

The Ely Range (pl. 2) is a minor geomorphically discordant mountain uplift about 14 miles long. It strikes northwest toward a near-junction with the elongate Highland–Bristol chain, which has the northerly orographic trend more characteristic of the Great Basin.[1] Meadow Valley and Lake Valley flank the range on the south and north. These are exceptions to the Great Basin interior drainage, for they empty south into the Colorado River.

The Cambrian rocks which underlie most of the Ely Range are intruded by diabasic and porphyritic granite dikes. Upper Tertiary volcanic rocks and fresh-water clastic beds of the Panaca Formation occupy adjacent valleys and cover the Cambrian rocks on the south and southeast.

Silver, gold, and base-metal mining reached a peak at Pioche in 1872. There followed a lengthy period of decline and virtual abandonment, lasting until about 1905. A revival in metal production began here in 1924, when the flotation process was introduced to beneficiate zinc-lead sulfide ores previously of no value (Westgate and Knopf, 1932, p. 54).

In the early period of large production, the mines at Pioche were opened on outcropping fissure veins in Prospect Mountain Quartzite, oldest exposed rock of the region. After 1924 during the later period of major production, the principal ores were limestone-replacement sulfide deposits in Cambrian strata (Young, 1948) which overlie the quartzites. These deposits are bedded or blanket ore bodies confined to a few stratigraphic zones. In most places no outcropping indicated their presence, but the existence of feeder veins or fissures was either demonstrated or suspected. Stratigraphic control of ore, coupled with pervasive and exceedingly complex faulting, encouraged the use of geologic techniques in connection with ore search by drilling, and in exploitation of known ore bodies.

[1] Early reports (Howell, 1875, p. 243; Hague, 1883, p. 256) erroneously interpret the Ely Range as a spur of the Highland Range.

PURPOSES AND METHODS

Detailed geologic mapping of the structurally complex Pioche mining district is dependent upon correspondingly detailed subdivision of the stratigraphic column. In this area, pervasive faulting coupled with rapid lateral facies change of some units, and vertical repetition of nearly identical, commonly nonfossiliferous carbonate rocks greatly increase possibilities of misidentifying strata.

The principal aims of this study are description and age classification of rock units for map representation, establishment of superposition, elucidation of facies changes, and, finally, geologic correlation by paleontologic and other means with strata of nearby mountain ranges and with more distant areas of the Cordilleran belt.

At the outset of this investigation preliminary reconnaissance in search for the least faulted sections was unrewarding, the best sections for stratigraphic measurement being disclosed only after geologic mapping and structural interpretation were well advanced. Sections as far removed as the Highland Range, although less disturbed, were in general not wholly satisfactory for reference because of lateral changes in the rocks.

The great number of fault blocks into which the Ely Range is dissected (pl. 1) prevents observation of continuous lithologic change. Accordingly the fieldwork resolved itself into many individual structural-stratigraphic problems. Sequences studied and measured in one block were compared and matched with those in adjacent or more distant blocks for purposes of stratigraphic integration. Some reference sections are therefore composite.

Most reference sections were measured by tape and Brunton compass. Many of the stratigraphic conclusions, however, are based on planetable geologic mapping at field scales ranging from 1 inch equals 100 feet to 500 feet, rather than upon simple one-plane measurement.

Paleontology rendered trustworthy, but relatively minor service; most of the Middle Cambrian carbonate units yielded no significant fossils. Lithologic criteria were relied upon for identification, checked wherever possible by rigid tests of mappability.

The rocks are described mainly in terms of gross hand specimen petrology applicable in the field. Briefly touched upon are thin-section petrology and problems of sedimentation as related to the stratigraphy.

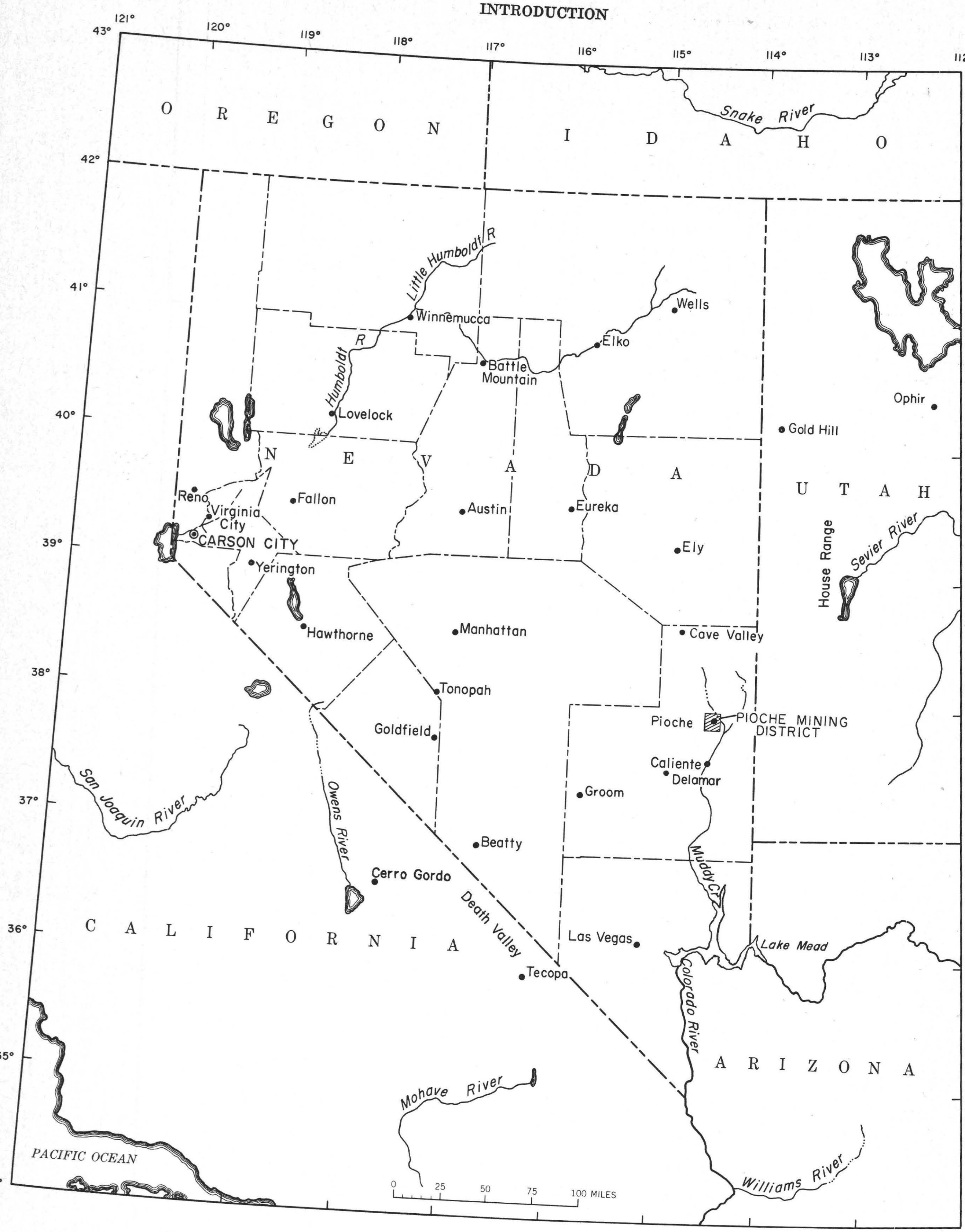

FIGURE 1.—Index map showing location of the Pioche mining district, Lincoln County, Nev.

The Pioche mining district is one of several mining districts in the Great Basin wherein Cambrian rocks are either ore hosts or closely associated with ore bodies. Among these are Delamar (Callaghan, 1937), Groom (Humphrey, 1945), Bristol (Westgate and Knopf, 1932), Comet (Westgate and Knopf, 1932), and Eureka in Nevada (Nolan, Merriam, and Williams, 1956); and Gold Hill (Nolan, 1935), Ophir (Gilluly, 1932), and Tintic (Lindgren and Loughlin, 1919) in Utah. Stratigraphic and paleontologic comparisons are made with several of these, and with the important House Range section of western Utah (pl. 5). Comparisons will be made eventually with the nearby Snake Range, where detailed mapping is now in progress.

STRATIGRAPHY AND ORE DEPOSITS

Though economically inspired, the present undertaking might otherwise be viewed as yielding purely scientific values in terms of Cambrian history. Occurrence of bedded replacement ores of zinc, lead, and other base metals in discrete stratigraphic units, however, gives practical value to stratigraphy in this district. This applies specifically to such ore-bearing units as the Combined Metals and Susan Duster Limestone Members of the Pioche Shale, the Lyndon Limestone, and the Chisholm Shale. But for exploration purposes all stratigraphic details in overlying rocks have value. Much of the exploratory drilling was done from the surface by churn drill and diamond drill, for which predictions of stratigraphic thickness and depth to potential ore-bearing beds are needed. In a theoretical sense, knowledge of the stratigraphy as well as the geologic structure is of value in conjunction with investigation of the little understood petrologic, geochemical, and geophysical factors that affect selective replacement of limestone beds by sulfide ores, as typified by the Pioche occurrences.

HISTORY OF STRATIGRAPHIC INVESTIGATION

Study of the Ely Range Cambrian rocks began in 1871 when G. K. Gilbert of the Wheeler Survey examined the active mines at Pioche and recorded observations on geologic structure. The following year E. E. Howell (1875, p. 259) continued work of the Wheeler party; his published map and cross sections are the first to illustrate stratigraphic and structural relations in the district. Fossils collected by Howell from the lower part of the Pioche Shale fixed the Cambrian age of these beds. Shortly thereafter, the common Lower Cambrian trilobite at Pioche was described as *Olenellus gilberti* by F. B. Meek (in Gilbert, 1875; see also White, 1877).

Discovery of abundant Cambrian fossils at Pioche encouraged C. D. Walcott to visit the area in 1885, shortly after his pioneering study of Cambrian and later Paleozoic rocks at Eureka, Nev. (Walcott, 1884). He collected also from Cambrian sections in the House Range, Utah, at about this time. Thenceforth these three areas together with the Grand Canyon, the Silver Peak area, Nevada, and the Inyo Mountains, California, figured importantly in discussions of western Cambrian history.

Walcott's 1885 fieldwork in the Pioche region included measurement of a section on the west side of the Highland Range (Walcott, 1886, p. 33–35), where the Cambrian rocks are less deformed than at Pioche. Fossil collections that served to correlate the Pioche Cambrian section with that of the Highland Range and more distant parts of the Cordilleran and Appalachian belts were described in part by Walcott (1886). The described fossils came mainly from shale units now recognized as Pioche Shale and Chisholm Shale.

From 1886 to 1916, Walcott's comprehensive paleontologic and stratigraphic studies of the North American Cambrian touched frequently on problems involving Pioche and the Highland Range (Walcott, 1888, p. 162; 1891, p. 317; 1908a; 1908b; 1912, p. 189–192; 1916a; 1916b). His stratigraphic and paleontologic revisions led to the naming of the Pioche Shale (Walcott, 1908a) and the Chisholm Shale (Walcott, 1916b). A geologic study of the Pioche area by Pack (1906a, 1906b) augmented data on the stratigraphic order of lithologic units and faunas. Burling (1914, p. 4–6) reinterpreted observations of both Walcott and Pack in proposing a solution of the Lower Cambrian–Middle Cambrian boundary problem.

In 1922 the U.S. Geological Survey initiated a comprehensive study of the Pioche region. Geologic mapping of the Ely Range and the Highland–Bristol chain continued through four seasons to 1926 (Westgate and Knopf, 1927, 1932). This work resulted in an excellent geologic map delineating the more distinctive stratal and igneous subdivisions. Stratigraphic units adopted for the Cambrian were fully adequate for purposes of a moderately detailed map compiled on a scale of 1 inch equals 1 mile.

Renewed interest in Great Basin Cambrian paleontology and stratigraphy about 1936 drew attention to the geomorphically spectacular Highland Range, which awaited more detailed stratigraphic investigation. At this time Mason (in Grabau, 1936, p. 274–276) studied the Pioche Shale and its trilobite faunules in that area and proposed changes in nomenclature. Also forthcoming were revised correlations of Cambrian faunal zones in the Highland Range and the Ely Range with those of other North American successions (Howell and Mason, 1938; Mason, 1938).

Deiss and Mason (Deiss, 1938) measured and zoned paleontologically the lower part of the Highland Range Cambrian. As a result of these field studies Deiss redefined the Pioche Shale and proposed transfer of type sections from the Pioche area in the Ely Range to the Highland Range.

Work by Wheeler and Lemmon (1939, p. 33–57) related mainly to the previously undifferentiated Highland Peak Limestone of Westgate and Knopf. Detailed measurement and range-to-range comparison demonstrated that many of the unfossiliferous units in this 4,500-foot carbonate section had lateral continuity and could be used effectively in mapping; similar conclusions were being made concurrently by mining company geologists. The lithologic units proposed by Wheeler and Lemmon were assigned informal letter symbols. Wheeler (1940) later proposed restriction of Highland Peak Limestone and applied the new formation names Peasley Limestone and Burrows Dolomite to the bottom part of the interval, as delimited initially by Westgate and Knopf.

By 1941 the Pioche mining district and the Comet district in the Highland Range had come to be regarded as harboring large unproved reserves of zinc, lead, and other base metals (Young, 1948). Moreover, mining company experience had fully demonstrated the technological value of stratigraphy as an ore search tool in this region.

Under stimulus of the war-time strategic minerals program the U. S. Geological Survey in 1943 began detailed structural-stratigraphic studies at Pioche. Areas considered promising for drill exploration in the Ely, Highland, and Bristol ranges (pl. 2) were mapped geologically by planetable. Among areas so covered are the northwest tip of the Ely Range between Mount Ely and The Point (pl. 3), a 3½-mile strip east of the Comet and Pan American mines, Highland Range, and smaller areas near the Bristol mine. This initial mapping was done by C. D. Campbell and J. A. Reinemund, assisted by the late Irvin Gladstone. Planetable geologic mapping was undertaken concurrently in the Mount Ely vicinity by American Metal Co., Ltd., results of which were made available to the U.S. Geological Survey.

From January 1944 through August 1945, geologic mapping of the Ely Range was continued by means of planetable and aerial photographs, the work being carried out by a U.S. Geological Survey party consisting of C. S. Bacon, L. C. Craig, R. L. Griggs, C. W. Merriam, and P. D. Proctor. Surface work was supplemented by mine mapping. In addition small areas at the Shodde mine and the Forlorn Hope mine (pl. 2) in the Highland Range were mapped and studied in detail.

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During the winter of 1945–46, Merriam began compilation and integration of the large volume of map, drill log, and stratigraphic information assembled during the war years by the U.S. Geological Survey and various mining companies. It was planned at that time to complete detailed geologic mapping of the Ely Range when scheduled topographic base maps became available.

During the summer of 1949, members of the U.S. Geological Survey resumed geologic mapping by planetable and completed a preliminary geologic and topographic map of the Ely Range in 1952. During this period the party consisted of C. F. Park, Jr., and C. M. Tschanz, assisted by J. E. Frost and P. D. Proctor. The mapping was carried out in cooperation with Paul Gemmill, of the Combined Metals Reduction Co.

Merriam continued stratigraphic studies in the Ely and Highland Ranges at intervals through 1954. In 1952, A. R. Palmer assumed responsibility for the paleontology of the Cambrian strata and thereafter assembled and studied all Cambrian fossil collections made by the U.S. Geological Survey parties in this region. A reconnaissance of Cambrian and Ordovician rocks at Arizona Peak was made by Palmer in 1954. Upper Cambrian and Ordovician strata of that area had not been differentiated previously.

ACKNOWLEDGMENTS

Mining company officials have been helpful during the course of the Pioche studies in supplying subsurface data, especially drill logs and maps of inaccessible mine workings. Among these are E. H. Snyder, S. S. Arentz, E. B. Young, and Paul Gemmill of Combined Metals Reduction Co., and John Janney of the Ely Valley mine. Valuable geologic maps and drill logs have also been made available by P. A. Lewis, of American Metal Co., Ltd., George Bowen, of Bamberger Brothers, Salt Lake City, and the late W. H. Pitts, of Amalgamated Pioche Mines and Smelters Corp.

Fossil collections from the Ely Range and the results of surface geologic mapping by C. F. Park, Jr., and C. M. Tschanz of the U.S. Geological Survey in collaboration with Paul Gemmill of the Combined Metals Reduction Co. were transmitted for use in connection with the present stratigraphic study.

All determinations of Cambrian fossils were made by A. R. Palmer, and of Ordovician fossils by R. J. Ross, Jr., of the U.S. Geological Survey.

GEOLOGIC STRUCTURE OF THE ELY RANGE

Detailed geologic mapping of the fault-bounded Ely Range has revealed a complex closely spaced network

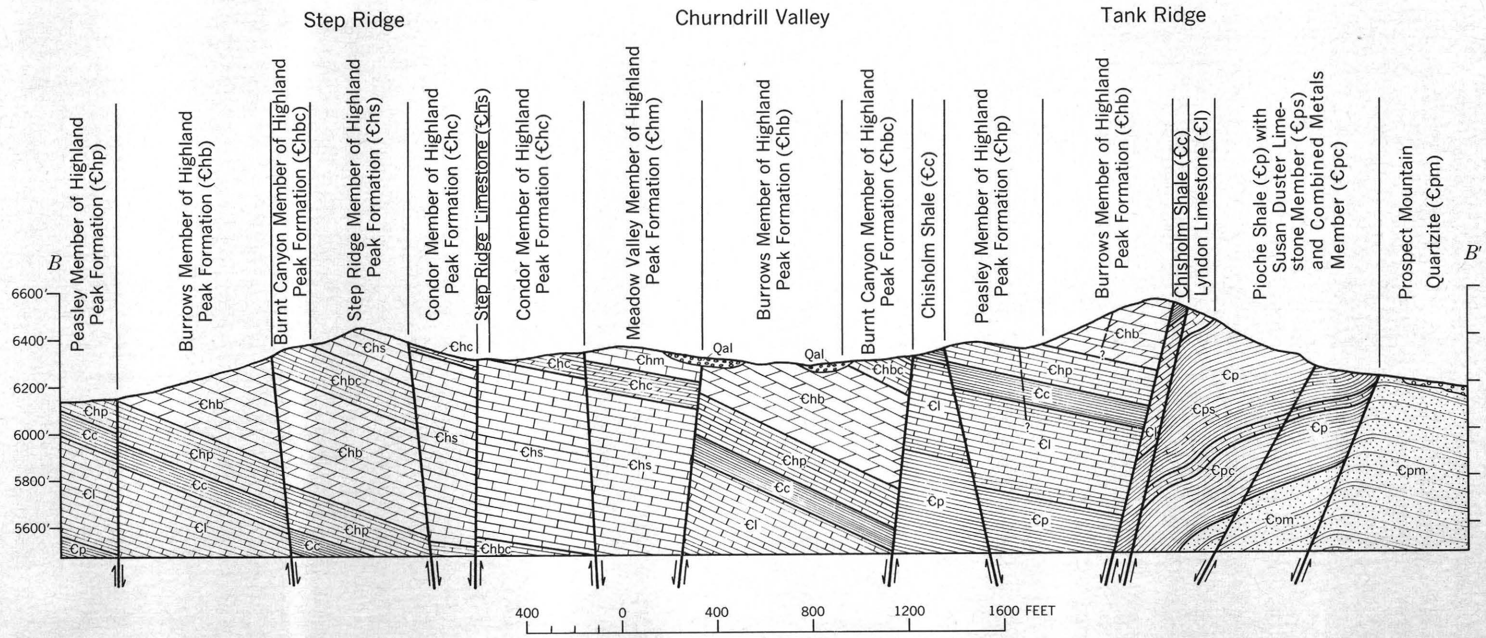

FIGURE 2.—Geologic structure section (*B–B′*) extending northeast across Churndrill Valley through a point near the Pioche No. 1 shaft. Shows intricate normal fault pattern in productive area. See plate 1 for location of section.

of high-angle normal faults (pl. 1). Although the principal structure of the range was once (Walcott, 1886, p. 33–35) believed to be anticlinal, no incontrovertible evidence of major folding in the ordinary sense was recognized. Something of the net effect of broad warping is brought about by distributive throw on great numbers of high-angle faults (fig. 2).

Bedding dips are moderate to low, except where drag has occurred in the immediate vicinity of faults. Magnitude and direction of bedding dip vary from fault block to fault block; but commonly within contiguous blocks of a fault set, the direction of dip is fairly uniform.

NORMAL FAULTS

Normal faults—both frontal and internal—have exerted the principal geomorphic control in the Ely Range. Whereas the neighboring Highland–Bristol chain (pl. 2) extends more nearly northward, the Ely Range trends northwestward in the direction of its predominating normal faults. These northwest longitudinal breaks are more continuous than the northeast transverse faults which intersect or cross them locally. North-south normal faults, less numerous than the others, are present on the south and southeast flanks of the range.

Many faults of the Ely Range occur in distributive sets with downthrown hanging-wall blocks (fig. 2). Sets of this kind are commonly opposed by others of roughly parallel strike, but opposite dip, such that total block displacement is like that of a graben or horst. Some individual blocks in this fault patchwork (fig. 3 and pl. 1) seem to have moved independently almost as monoliths, one bounding fault apparently terminating against another without cutting or displacing it.

Carbonate rocks of this intensely block faulted area reveal closely spaced, concordant, knife-sharp shear surfaces which parallel normal faults through widths of many feet. Sympathetic shears of this kind are commonly mineralized.

THRUST FAULTS

Thrust faults were recognized by Westgate and Knopf (1932, p. 42–43) on the west side of the Highland–Bristol chain. In the Ely Range, structural features of compressional origin are masked and obscured by pervasive late normal faults superposed upon them. Presumptive evidence of thrusting includes low-angle faults and bedding-plane slippage in the Chisholm and in other incompetent shale units. An outlier of Upper Cambrian rocks on Middle Cambrian at Step Ridge (pl. 1) is explainable by thrust displacement. This significant occurrence is discussed below.

Mine workings along the northeast margin of the Ely Range show low-angle faults of possible thrust origin. For example, in the Alps mine (pl. 3) a flat fault dipping 28° E. separates Prospect Mountain Quartzite from Pioche Shale, which is the next overlying formation in depositional sequence. Flat faults were recognized also in the Raymond Ely Extension

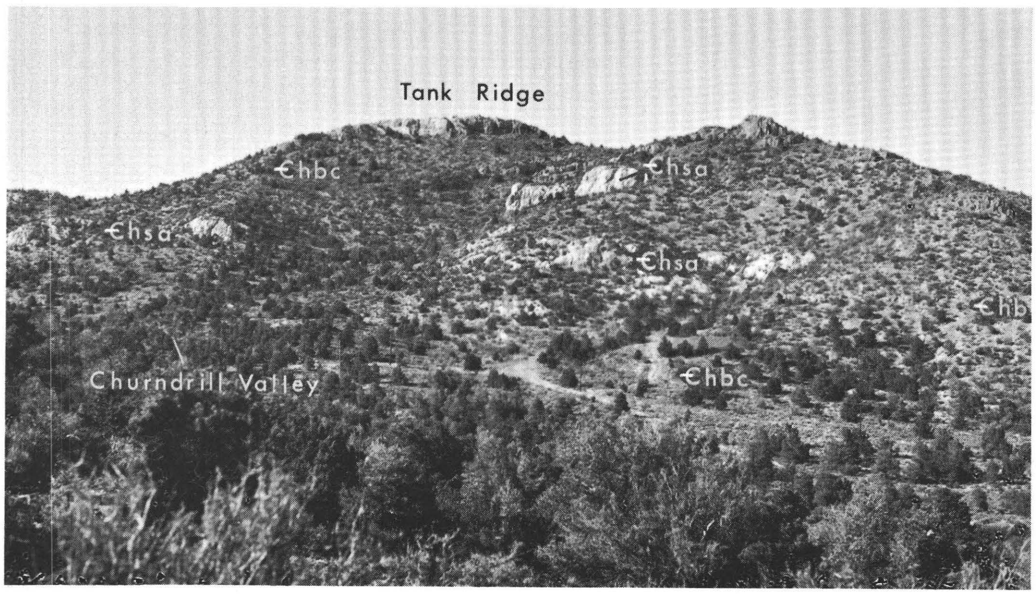

FIGURE 3.—View from Churndrill Valley northeastward to Tank Ridge. White cliffy outcrops are unit *a* (Ꞓhsa) of the Step Ridge Member of the Highland Peak Formation in small fault blocks; top of ridge mainly Burnt Canyon Member (Ꞓhbc) overlying Burrows Member (Ꞓhb) of the Highland Peak Formation The intensely block-faulted terrane overlies important stopes of the Pioche No. 1 mine in Pioche Shale.

mine east of Lime Hill (Young, E. B., written communication, 1946). The Wheeler Monument fault at the west base of Lime Hill (fig. 4) is a thrust. This low-dipping fault brings Middle Cambrian limestone of the Highland Peak Formation into contact with Lower Cambrian Prospect Mountain Quartzite, with nearly 2,000 feet of intervening strata cut out.

According to Paul Gemmill, of Combined Metals Reduction Co. (written communication, 1960), drill holes through valley alluvium west of the Ely Range showed limestone and dolomite of the Highland Peak Formation in flat fault contact upon Tertiary volcanic rocks. This anomalous relation may be interpreted as the result of either late thrusting or major landslides.

On the west side of Step Ridge (loc. 17), a small discordant exposure of coarse limestone breccia (pl. 1) includes large jumbled limestone blocks bearing Upper Cambrian fossils of the Mendha Formation. The breccia is surrounded by and is presumably underlain by nearly flat-lying Middle Cambrian strata assigned to the Step Ridge Member of the Highland Peak Formation. A Late Cambrian *Aphelaspis* faunule in this outlier would normally be expected 3,000 feet stratigraphically above contiguous beds of the Step Ridge. No adequate explanation of this phenomenon is provided by the mapping of normal faults in the vicinity; emplacement by thrusting, therefore, seems reasonable. Other, but seemingly more speculative, explanations are surficial transport by mud slides, or downward migration of large blocks of the Mendha in a breccia pipe. Submarine filling of caves or fissures in Middle Cambrian limestone of the Step Ridge by Mendha sediments is improbable, in view of the brecciated and jumbled nature of the erratic materials.

STRATIGRAPHIC COLUMN OF CAMBRIAN ROCKS

No Paleozoic rocks younger than Cambrian were recognized in the Ely Range. Lower Ordovician strata are present at nearby Arizona Peak in the eastern Highland Range (pl. 2). To the west and northwest are rocks of Ordovician, Silurian, and Devonian ages, as in the Ely Springs, Bristol, and West ranges.

Cambrian strata of the Ely Range are divided into 17 map or potential map units (table 1). Of these, 10 are named units; 7 are not employed as map units in connection with this study and therefore are designated by number only. The 10 named units represent the lower part of the stratigraphic column and comprise the country rock in the northwest Ely Range, that is, in the vicinity of the productive mines. These rocks are of Early and Middle Cambrian age. Except for the Mendha outlier at Step Ridge, elsewhere discussed, no Upper Cambrian beds were recognized. There is thus near Pioche a major gap in the Cambrian record, a

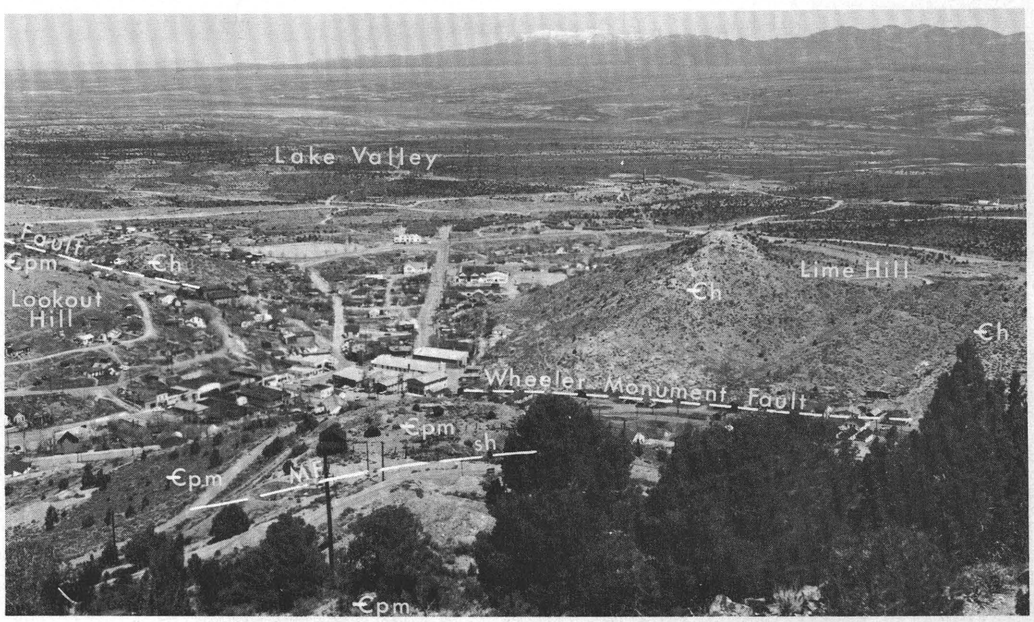

FIGURE 4.—Pioche, Nev., view northward from Treasure Hill. In foreground are dumps of old shaft workings (sh) on the Meadow Valley fissure (MF) in Prospect Mountain Quartzite (€pm). Lime Hill right of center shows limestone of the Highland Peak Formation (€h) in thrust contact overriding Prospect Mountain Quartzite along the Wheeler Monument fault.

hiatus partly filled by more complete sections in the southeastern Ely Range (Panaca Hills) near Warm Spring (pl. 2).

TABLE 1.—*Paleozoic column, Pioche mining district, Nevada*

System		Formation			Thickness (feet)
Ordovician	Lower Ordovician	Mendha Formation (Upper Cambrian and Lower Ordovician at Arizona Peak)			2,000
Cambrian (10,000 ft)	Upper Cambrian				
	Middle Cambrian	Highland Peak Formation (4,500 ft)	Upper part of the Highland Peak Formation (2,430 ft)	Unit 13	125
				Unit 12	170
				Unit 11	245
				Unit 10	240
				Unit 9	840
				Unit 8	500
				Unit 7	310
			Lower part of the Highland Peak Formation (2,130 ft)	Meadow Valley Member	430
				Condor Member	110
				Step Ridge Member	740
				Burnt Canyon Member	190
				Burrows Member	300-500
				Peasley Member	160
		Chisholm Shale			100
		Lyndon Limestone			380
	Lower Cambrian	Pioche Shale			800
		Prospect Mountain Quartzite			2,400

PROSPECT MOUNTAIN QUARTZITE

NAME AND OCCURRENCE

Reddish brown Prospect Mountain Quartzite is the oldest rock exposed in the Ely Range, where it occupies the largest area of any single formation. Present-day exploitation of sulfide ores in stratigraphically higher Cambrian limestone gives this quartzite a less significant economic status than it formerly had; yet as host rock of rich fissure ores worked exclusively in the early days, it deserves more than passing consideration (figs. 4, 5).

The Prospect Mountain Quartzite was named by Hague (1883, p. 253; 1892, p. 34) for exposures on Prospect Peak in the Eureka mining district, Nevada, 140 miles northwest of Pioche (Nolan, Merriam, and Williams, 1956, p. 6). In early all respects the quartzite at Pioche resembles closely that of the type area, and in both districts these strata conformably underlie Lower Cambrian strata containing *Olenellus*. There is little doubt that the name is appropriately applied at Pioche.

Siliceous clastic rocks of Cambrian age that have the appearance of Prospect Mountain Quartzite are widely distributed in the Great Basin, and extend from southeastern California to north-central Nevada and eastward into Utah. Many of the outcrops are small, highly disturbed, and lack an exposed stratigraphic base.

Although the Prospect Mountain Quartzite at Eureka, Pioche, and elsewhere is predominantly quartzite, it includes through its vertical extent an appreciable amount of interbedded micaceous shale, silty shale, and siltstone. Pebbly conglomerate and coarser conglomerate are present locally. In the Ruby Mountains (Sharp, 1942, p. 652) intercalated shale is altered to micaceous schistose deposits.

THICKNESS

Absence of an exposed stratigraphic base in the Ely Range eliminates determination of true thickness. A partial measurement of about 2,400 feet was obtained northwest of Red Hill, along a line extending southwestward from the Alps mine (pl. 3). In that section the outcrop is more than a mile wide and seemingly unbroken by large faults. Exposed Prospect Mountain strata are generally low dipping, and single fault blocks show only a few hundred feet of continuous section. At Eureka, Nev., where again no precise measurement is possible, the Prospect Mountain can be no less than 1,400 feet thick. In the Ruby Mountains, Sharp (1942, p. 652) measured 1,400 feet of this formation.

At the Groom mine, 85 miles southwest of Pioche, a 7,855-foot section of Prospect Mountain Quartzite is reported by Humphrey (1945, p. 15). As noted by Humphrey, further investigation of geologic structure and stratigraphy is needed to confirm this great thickness.

AREAL DISTRIBUTION

Prospect Mountain Quartzite occupies an area of 3½ square miles in the Ely Range, where its surface extent greatly exceeds that in the type area at Eureka, Nev. Outcrops of the Prospect Mountain Quartzite extend for 4 miles southeast of Pioche through Treasure Hill and Red Hill, forming the greater part of the Ely Range within this belt. The quartzite is well exposed in the northeast foothills between Pioche and the Ely Valley mine. In these foothills it forms several flat-topped spurs and hillocks. Float material probably derived from the Prospect Mountain Quartzite occurs near The Point and was traced to a fault breccia.

West of Pioche (pl. 2) where the surface rocks are younger, mine openings have penetrated the topmost Prospect Mountain at depths greater than 1,400 feet. Fissure veins, similar to those that have been followed downward from the surface at the town of Pioche, cut through these deeply buried quartzites to enter overlying Cambrian shale and limestone, thus to feed the blanket ore bodies for which the district is noted.

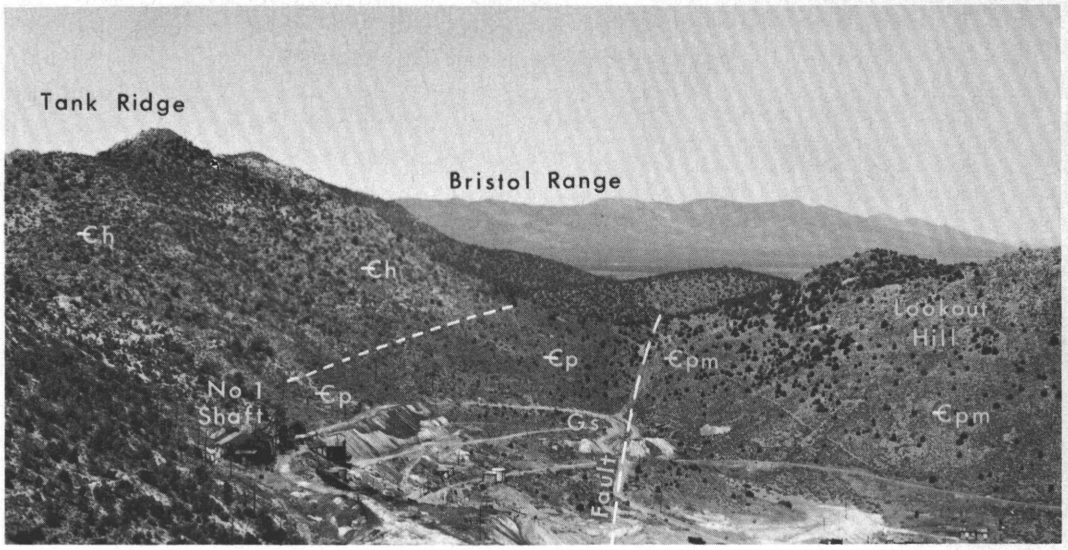

FIGURE 5.—View northwestward from Treasure Hill, Pioche mining district, Nevada, through saddle in which lies a fault contact of Pioche Shale (Ꞓp) and Prospect Mountain Quartzite (Ꞓpm). Tank Ridge on left shows Burrows and Burnt Canyon Members of the Highland Peak Formation (Ꞓh). Pioche No. 1 mine in Pioche Shale left middleground; Greenwood shaft (Gs) center middleground.

LITHOLOGY AND BEDDING FEATURES

The Prospect Mountain Quartzite is typically a rose-colored to reddish-brown dense vitreous orthoquartzite showing moderately good sorting and a wide variation in grain size. Color of fresh surfaces ranges from white and light gray to pale red, grayish red, reddish brown, and limonitic brown. Grayish-red shades are especially characteristic. Shale interbeds vary from grayish red to drab, yellowish tan, and green. The darker reddish brown of weathered quartzite surfaces is generally confined to an outer skin a half-inch thick; internally these rocks are commonly white or light gray. Solutions responsible for iron staining of otherwise light phases commonly followed a plexus of fractures from which they diffused outward. Diffusion-ring patterns of reddish or brown coloration are characteristic.

The quartzite consists mainly of clear quartz grains with rare feldspar. Well-sorted varieties are common; these contain about 30 percent of well-rounded grains, the remainder being subrounded to angular. Grain size of coarse-textured varieties ranges from about 0.5 to 1.5 mm. Finer varieties, with average grain size less than 0.5 mm, have a greater proportion of angular grains. Finely divided angular detrital quartz occurs as interstitial matter in a quartzose cement that contains widely varying amounts of ferruginous pigment. The quartz grains are distinctly sutured in a mosaic texture where recrystallization has taken place.

Arkosic facies of the Prospect Mountain Quartzite occur at Cave Valley, 55 miles north of Pioche. These have a laminated appearance and contain about 10 percent of feldspar grains, many of which are plagioclase and microcline.

Layers of coarser material contain occasional rounded quartz fragments as much as 1 cm in diameter. Although such pebbles are uncommon in this formation at Pioche, they are abundant elsewhere in the Prospect Mountain and in more or less equivalent Lower Cambrian clastic rocks of the Cordilleran belt. Pebble conglomerates and conglomerates with abundant larger rounded quartz fragments make up a considerable part of the comparable Stirling Quartzite in the Spring Mountains of southwestern Nevada. Many of the fragments in the Stirling exceed 1 inch in diameter.

The intercalated shales are commonly reddish or streaked with red, and in general strongly micaceous. Bedding surfaces are usually very uneven or lumpy, and the shiny interfaces reveal coarse sericitic-appearing micaceous flakes. These shales are in places bleached white or light gray, as for example, the punky-appearing beds near the mouth of Slaughterhouse Gulch. The shale beds locally contain a large amount of silty and fine sandy debris.

Micaceous shales similar to those of the Prospect Mountain also occur in the overlying Pioche Shale. Reddish color, though uncommon in the Pioche, occurs sporadically in its upper members. Reddish-brown, near-vitreous quartzite like that of the Prospect Mountain is also present in the "sandstone marker" at the base of the A-shale member of the Pioche.

Because it is brittle, the Prospect Mountain Quartzite has become much jointed, fractured, and brecciated in response to stresses. Talus and surface mantle derived from it are composed of irregular blocks and rubble; breakage to flat slabs or flagstones is uncommon.

Silica-cemented quartzite breccia of the Prospect Mountain forms prominent outcrops near the northeastern margin of the Ely Range. The breccia is well exposed adjacent to frontal faults north of Slaughterhouse Gulch (pl. 3), where northwest-southeast fracture cleavage is developed in massive quartzite. Fractures and gashes are commonly filled with white quartz. Certain of the larger quartz veins are continuous and attain widths as great as 40 feet.

Erosion has sculptured the resistant Prospect Mountain Quartzite into prominent features such as Treasure Hill and Lookout Hill (fig. 5); the more massive beds produce low cliffy rises, or form the caprock of hills and flat-topped spurs. Where the quartzite is intensely shattered, response to erosion differs, and more subdued or even rounded surfaces are developed. In the Ely Range, as is common in the Great Basin, quartzite is less prone to form commanding heights than carbonate rocks.

The bedding of the Prospect Mountain is nonuniform, ranging from thinly laminated shales to massive quartzite layers more than 4 feet thick. The quartzite beds which predominate, normally range from 2 inches to 1½ feet in thickness. Vitreous quartzite layers are characteristically bounded by thin, sometimes paper-thin, bumpy micaceous shale partings.

Color banding and rather coarse color lamination occur within otherwise fairly homogenous quartzite beds. Some color-laminated layers exhibit an almost rhythmic alternation of laminae high in iron with laminae of low iron content, a change possibly related to fluctuating sedimentary conditions. The thicker quartzite beds commonly exhibit well-defined cross lamination. Shale layers show occasional ripple marks and, more rarely, mudcracks; these features indicate a range from shallow water to subaerial conditions.

Mud castings, burrows, pits, tracks, and irregular vermiform lumps of undoubted organic origin are common bedding features. Shiny micaceous shale interfaces and shale-quartzite interfaces show them particularly well.

Burrows and castings are of two types: (1) those which are essentially parallel to bedding and produce an interlaced, anastomosing fabric; and (2) those which are normal to bedding. The first occur in shales or at shale-quartzite interfaces. The vertical type, corresponding to the well-known form genus *Scolithus*, was observed only in reddish vitreous quartzite. The burrows and castings lack annulations. Flat-lying castings are usually thick and heavy, attaining a maximum cross-section diameter in excess of half an inch.

STRATIGRAPHIC RELATIONS

Only the upper limit of the Prospect Mountain Quartzite is definable at Pioche, and this boundary is arbitrary, for the quartzite grades upward into the overlying Pioche Shale. In mapping, the contact was drawn above a vitreous quartzite layer that marks the top of an interval the rocks of which are grayish red. Below this topmost vitreous layer, and classified with the Prospect Mountain, is a transitional zone roughly 50 feet thick, in which vitreous quartzite occurs as 2- to 6-inch beds intercalated within crinkly, lumpy, and only partly red-stained micaceous shales in beds 2 or more feet thick. Passing downward through the transition zone, the amount of vitreous quartzite increases relative to that of shale until it predominates in the lower part.

Exposures of the transition are well shown in flat-topped spurs southeast of the Ely Valley mine. Here the lowest *Olenellus*-bearing strata of the Pioche Shale lie 40 feet stratigraphically above the top of the Prospect Mountain as defined above. Between mines known as the Garrison and the Gold Eagle, 3,000 to 4,000 feet southeast of the Ely Valley mine (pl. 3), a transitional zone 35 to 50 feet thick bridges the gap from massive vitreous Prospect Mountain Quartzite to typical D-shale.

Churn-drill holes on the west side of the Ely Range reveal alternating shale and quartzite in a transition zone as much as 75 feet thick. On the east side of the range at Slaughterhouse Gulch, churn-drill logs indicate a comparable transition zone that is at least 40 feet thick.

No key beds or horizon markers useful in the stratigraphic division of the Prospect Mountain were recognized. *Scolithus* beds have possible stratigraphic value; at Treasure Hill, Lookout Hill, and Red Hill the *Scolithus* beds seem to be in the upper part of the formation.

In general, the thicker sections of this formation exhibit a monotonous repetition of similar lithologic types. Combinations or groupings of beds are definable locally as members, but as these were not traced from one fault block to another, they serve no useful purpose in mapping. These possible unit combinations of beds are as follows:

1. Massive thick-bedded cross-laminated quartzite almost lacking in shaly partings;
2. Thick-bedded cross-laminated quartzite with thin micaceous shaly partings and interbeds as much as 6 inches thick; shale partings pitted and lumpy, of reddish and greenish color; shale less than 2 percent of the rock;

3. Thin-bedded flaggy to platy quartzite in beds 1 to 6 inches thick; shale nearly equal to quartzite in amount; shale, reddish and greenish, rarely bleached light gray and punky.

ORIGIN

Quartzose clastic material forming the bulk of this unit was derived mainly from decomposing crystalline rocks. Coarse, pebbly quartz sands and local conglomerates give evidence of fairly high standing, if not mountainous, crystalline sources situated at no great distance from the depositional sites.

The gross lithologic character of the formation is much the same at exposures hundreds of miles apart; this characteristic suggests that accumulation in very extensive basins near sea level is more likely than deposition in great numbers of small intermontane basins. Tectonic and climatic conditions responsible for this siliceous clastic cycle of deposition affected vast regions, possibly of continental extent.

Students of Cambrian history (Walcott, 1915, p. 183) earlier speculated in terms of continental as opposed to marine origin of the Prospect Mountain Quartzite. In support of this reasoning are ubiquitous presence of cross-laminated red sands, and mudcracks in reddish shale. At present this formation is believed by the writer to be of nearshore, partly subaerial, partly shallow water origin under fluctuating conditions of rise and fall of the strand. The basins were probably joined from time to time with the open sea.

The Prospect Mountain interval foreshadowed one in which advanced shell-bearing marine fossils abruptly became abundant; hence, the little-understood physical and biotic environments under which these sediments accumulated are of special interest to paleontologists. The Prospect Mountain sedimentary record seems to be one of inhospitable biotic environments, ill suited for fossil preservation. Absence of fossil shells and seeming lack of organic matter have been attributed to the grinding action of continually shifting silica sands under aeolian, fluviatile, and deltaic conditions.

In spite of the seeming biologic inhospitability of the normal Prospect Mountain Quartzite, local reddish-brown shale facies with abundant organic castings and burrows remind us that the mud bottoms of this interval were not everywhere inimical to life. Organic material as a food supply must have been abundant initially to sustain this biota. Unfortunately the producing organisms left no trace of taxonomic identity; their burrows and castings give no clue as to whether the mud bottoms underlay fresh, brackish, or marine waters. Similar organically produced mud structures are found in Cambrian rocks above the Prospect Mountain; these higher rocks are known by their trilobites and other fossils to be marine. By analogy the Prospect Mountain shales that contain castings are likewise believed to be marine rather than continental. The analogy may be extended also to organically stirred mud facies in the upper part of the Lower Cambrian Johnnie Formation east of Death Valley. These Johnnie strata, which are considered to be older than the upper part of the Prospect Mountain Quartzite, include shell-bearing fossil beds of undoubted marine origin.

AGE AND CORRELATION

The Prospect Mountain Quartzite has yielded no fossils of definitive age significance. Its provisional classification as Early Cambrian is predicated upon upward depositional intergradation with the *Olenellus*-bearing Pioche Shale. Such *Olenellus*-bearing shales, which rest upon the quartzite at Eureka, Nev., were originally included by Hague (1883, p. 254) in the Prospect Mountain, but in later years these have been assigned to the Pioche Shale (Nolan, Merriam, and Williams, 1956, p. 7).

The Prospect Mountain Quartzite at Pioche, in the Highland-Bristol chain, and at Eureka probably correlates westward toward Death Valley with the Stirling Quartzite and overlying strata that are stratigraphically beneath beds containing *Olenellus*. Correlative quartzites occur also in the House Range of western Utah (pl. 5).

BASAL CAMBRIAN OF THE EASTERN GREAT BASIN

Barren reddish brown quartzites are commonly the lowest Cambrian rocks exposed in the Great Basin. Gradationally overlying shales in the central and western parts of this physiographic section commonly contain Early Cambrian olenellids. Toward the eastern Great Basin and toward the Colorado Plateaus Province, overlying shales appear to become progressively younger, or to rise eastward in the stratigraphic column. Such problems call for the detailed study and comparison of the lowest Cambrian fossils of the eastern part with those of the central and western parts, as at Pioche and Eureka, Nevada, and the Death Valley region.

In the Tintic and Ophir (pl. 5) districts of Utah, where Ophir Shale overlies Tintic Quartzite, contained fossils suggest that the topmost Tintic may be younger than the topmost Prospect Mountain Qaurtzite at Pioche. According to A. R. Palmer, reports of olenellids in the Ophir Shale of both Utah districts have not been confirmed by recent collecting. On the contrary, the Ophir contains faunules linking it, not with the Pioche Shale, but with the Chisholm Shale of Middle Cambrian age at Pioche, and with the lower part of the Bright Angel Shale of the Grand Canyon. If, as suggested, the entire Ophir is Middle Cambrian, the uppermost part of the Tintic Quartzite may likewise be of this age.

McKee's (1945, p. 11–36) findings and the studies of Wheeler (1947; 1948) bear out similar relations in the Grand Canyon region. For the eastern Grand Canyon, McKee showed that olenellids are seemingly absent in the lower part of the Bright Angel Shale, the lowest fossils discovered above the Tapeats Sandstone being Middle Cambrian trilobites of the genera *Glossopleura* and *Alokistocare;* these link the lower part of the Bright Angel of the eastern Grand Canyon with the Chisholm Shale of Middle Cambrian age at Pioche, rather than with the Pioche Shale of Lower to Middle Cambrian age. According to McKee, as the Bright Angel Shale is followed west from the eastern to the western Grand Canyon, the shale-quartzite boundary appears to descend in the column, figuratively transecting imaginary time lines, until in the western Grand Canyon, olenellid trilobites of Early Cambrian age are above the quartzite.

These data suggest progressive landward overlap of basal Cambrian clastic rocks from west to east, accompanied by eastward rise (in time) of the intergradational shale-quartzite boundary and by eastward thinning of the great sandstone wedge.

RELATION TO THEORETICAL BASE OF THE CAMBRIAN

The Cambrian System in a world sense has no objectively definable base. Ideally its oldest beds constitute the *Olenellus* zone, a rock-time-fossil range concept, in accordance with which the first appearance of *Olenellus* or olenellid trilobites (Wheeler, 1947, p. 157; Longwell, 1952) would seemingly provide a theoretical criterion. In the practical sense the base of the system might arbitrarily be indicated immediately below the lowest horizon in any particular section where olenellids happen to have been discovered.

First appearance of olenellids in the rocks unquestionably varies greatly in time from section to section and from region to region, depending upon distributional, environmental, and preservational factors. Absence of these life forms in lower strata of a particular section may involve lag in geographical spread, local facies conditions inimical to bottom life, or conditions of burial unfavorable to shell preservation. In considering this question, factors of chance or probability as related to fossil entombment and fossil discovery should be added to the vagaries of depositional and life environment.

The fact is inescapable that olenellids are an advanced form of invertebrate life and had certainly been in existence long before deposition of the lowest discovered trilobite bed of the Pioche Shale. A theory that these forms possessed no preservable shells until a late evolutionary stage, when protective investment was abruptly acquired, has little appeal. In theory the olenellids could well have flourished in favored spots as shell-bearing arthropods during the entire Prospect Mountain depositional interval without leaving an objective record in rocks of the familiar Prospect Mountain facies.

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Current studies east of Death Valley may be expected to elucidate the question of where the theoretical base of the Cambrian might reasonably be drawn in the Great Basin. The Stirling Quartzite (Nolan, 1929) of the Spring Mountains, Nevada, resembles and is believed correlative with part of the Prospect Mountain. Stratigraphically under the Stirling is a thick quartzite-shale-dolomite sequence which comprises the Noonday Dolomite below and the Johnnie Formation above. The Pahrump Series (Hewett, 1956, p. 25), unequivocally assigned to the Precambrian, underlies the Noonday.

At Bare Mountain, Nevada, (Cornwall and Kleinhampl, 1960) rocks provisionally assigned to the upper part of the Johnnie include a significant fossil bed containing spines and possible head-shield fragments of trilobite origin. These fragmentary remains add support to the theory that the Stirling and correlative parts of the Prospect Mountain are younger than the base of the Cambrian System. How much of the sequence between the Pahrump and the Stirling should eventually be retained in the Early Cambrian remains to be determined.

PIOCHE SHALE

The ore-bearing Pioche Shale (fig. 6), economically the most important rock unit in the district, is actually diverse lithologically, comprising micaceous and nonmicaceous shale, siltstone, sandstone, and limestone. The limestones are varied, being in part dense and barren of fossils, and in part bioclastic, including some beds composed largely of trilobite shell material. Some of the limestones contain an abundance of very finely divided carbonaceous matter. In general, the limestone beds of the Pioche Shale are very impure and almost none are dolomitized. This is true even where these limestones are cut by fissures and fractures which appear to have been responsible for local hydrothermal dolomitization of carbonate strata higher in the stratigraphic column. Dolomitization seemingly preferred the thick, fairly pure, and fine-textured nonbioclastic carbonate rocks like those of the Highland Peak Formation of Middle Cambrian age.

The Pioche Shale depositional record reveals a fluctuating, more or less cyclic repetition of lithologic units. Features of special interest are alternations of micaceous with nonmicaceous shales, and a repeated pairing of a basal quartz sand with an overlying limestone. The last is well illustrated by the Combined Metals Member, most important ore unit of the district.

This formation, which contains the oldest known carbonate rocks and the oldest significant fossils of the region, was investigated paleontologically and named as a formation by Walcott (1908a) before realization of the large replacement ore bodies within it. The Pioche Shale separates two nearly unfossiliferous formations, the Prospect Mountain Quartzite below and the Lyndon Limestone above. Strata of similar lithology and more or less equivalent Cambrian age are known at many localities in the central and southern Great Basin, at least as far east as the House Range, Utah.

PREVIOUS INVESTIGATION

Observations on the Pioche Shale were recorded at Pioche by G. K. Gilbert (1875, p. 257–261) and by E. E. Howell (1875, p. 259), during field work in 1871 and 1872. Discovery of well preserved Cambrian fossils by these pioneers led to more extensive work by Walcott (1886, p. 35) 13 years later. Fossil collections were made by Walcott in the Pioche vicinity, but his detailed Cambrian section was measured in the Highland Range 8 miles west of Pioche. This measured Highland section shows 23 stratigraphic units, of which 20 pertain to the Pioche Shale of present usage. In subsequent contributions Walcott (1888, p. 162; 1891, p. 317; 1908a, p. 11; 1912, p. 189–192) again referred to the measured Highland Range section, giving revised fossil lists.

Pack (1906a, p. 285–312), in discussing stratigraphic and structural relations near Pioche, did not formally name or describe the shales in question, although he estimated their thickness conservatively to be about 400 feet.

The structure of the Ely Range was erroneously viewed as anticlinal at the time of Walcott's early Pioche work. Some of his fossil collections from that area are accordingly referred to localities on "* * * the east side of the anticlinal arch at Pioche 20 miles east of the Highland Section, the strata resting on quartzite * * *". Study of these collections in the light of present understanding indicate that they were made in two or more rather widely separated zones, but the exact localities from which they came remain in doubt.

Areal distribution and broader structural relations of the Pioche Shale were outlined by the U.S. Geological Survey in mapping the Pioche region (Westgate and Knopf, 1927, 1932). Again, the representative Pioche Shale section was measured at Lyndon Gulch, in the Highland Range, rather than at Pioche. Although the potential value of individual limestone members for correlation and structural interpretation was recognized, no attempt was made to divide the formation for mapping purposes. In dealing with problems of mining geology, enlightening details of stratigraphy relative to the economically important Combined Metals Member and other ore-bearing stratal units in the Pioche Shale are given (Westgate and Knopf, 1932, p. 54–55).

During the 1930's, academic students of Cambrian history were attracted by the spectacular Highland Range Cambrian rocks, while at Pioche a more practical interest continued to grow as stratigraphy was successfully applied to search for bedded ore.

Mason in 1936 (in Grabau, 1936, p. 275) restudied the Highland Range succession and proposed Forlorn Hope shale and Comet shale for Lower and Middle Cambrian parts of the Pioche Shale, respectively. Deiss (1938, p. 1152–1156), following joint field studies by Deiss and Mason, likewise proposed adoption of two units in the Highland Range. To these were given the names Pioche shale: restricted for Lower Cambrian and Comet shale for the Middle Cambrian part. Wheeler and Lemmon (1939, p. 34–35), briefly summarized Pioche Shale stratigraphy, rejected the Deiss separation into Comet shale and Pioche shale: restricted in the Highland Range, and concluded that the entire sequence is lithologically best treated as a single formation.

AREAL DISTRIBUTION

In keeping with its lack of resistance to erosion, the Pioche Shale underlies depressions and foothills. Three main areas of outcrop may be defined in the Ely Range as follows (pl. 3): (1) The northeast area extending from Slaughterhouse Gulch along the northeast side of the range almost to The Point, (2) the central area extending from Lookout Hill past the Pioche No. 1 mine and southward over Pioche Divide west of Treasure Hill, (3) the southeast area, a narrow depressed belt extending from the Alps mine 1½ miles southeast of Pioche, past Gray Cone, thence southward across the eastern Ely Range. Small fault-block exposures are found in greatly disturbed terrane along the west base of the Ely Range, beginning 3,000 feet south of The Point, and continuing thence as small more or less isolated segments to the mouth of Buehler Gulch north of Caselton. An isolated, much faulted low-lying exposure is found northeast of the Prince mine. Much of what is known about the Pioche Shale is subsurface information gained through churn-drill exploration and geologic mapping of mines.

The most continuous Pioche Shale exposures of the region lie in the western foothills of the Highland Range (pl. 2), where they may be followed due south without break from a point near Stampede Gap to the union of Black Canyon Range and Highland Range, a distance of 10 miles.

Elsewhere in the Great Basin, strata identified as Pioche Shale extend from Eureka, Nev., on the northwest, southward 200 miles to Frenchman Flat, and eastward at least to the House Range, which lies 140 miles east of Eureka, Nev.

THICKNESS

No unbroken exposures of the entire Pioche Shale were found during mapping of the Ely Range. At Pioche Divide (pls. 1, 4) the Pioche Shale is about 620 feet thick; this is the most nearly complete section recognized. About 130 feet of shale at the top and roughly 75 feet of shale at the bottom are cut out by faulting. Average thickness of composite Pioche Shale sections in the Ely Range is, thus, of the order of 820 feet. The measured Pioche Shale section at Lyndon Gulch, Highland Range, is 975 feet thick; 2¾ miles north of Lyndon Gulch the formation thins to 780 feet at the Forlorn Hope mine (pl. 2). Unrecognized strike faults conceivably account for this discrepancy of nearly 200 feet.

PIOCHE SHALE REFERENCE SECTION

The Pioche Shale section at Pioche Divide (pls. 1, 3, 4 and figs. 6, 7) is proposed as the standard or reference section for this formation. In the past there has been no established Pioche Shale yardstick in the Ely Range. Walcott's only measurement of these strata in the Highland Range rather than at Pioche doubtless explains the tendency among stratigraphers to regard the Highland occurrence as typical.

Walcott (1908a, p. 11) designated no type section when he formally described and named the Pioche Shale in 1908. It is nonetheless fairly clear in context that he intended the Pioche vicinity as the type area, reference being made to exposures "southeast of the town of Pioche, Nev., on the road to Panaca, Utah." Hence, by priority, acceptance of a general type area embracing the shale belt "southeast" of town would seemingly be called for.

That the Pioche Shale belt "southeast" of Pioche is by itself illsuited for purposes of stratigraphic investigation is demonstrated by recent detailed mapping of the U.S. Geological Survey. In fact, the nearest Pioche Shale outcrops of consequence in this direction lie 1½ miles from town along the old Pioche-Panaca foothill road; moreover, all shale exposures in the southeast foothill belt were found to be so badly deformed as to lend themselves poorly to definitive stratigraphy.

Less disturbed shales of this formation occur half a mile "southwest" of town at Pioche Divide (pl. 3) through which another and more devious Pioche–Panaca road passed in Walcott's day.[2] Furthermore

[2] Inadvertent directional confusion is possible in connection with Walcott's reference to Pioche Shale "southeast" rather than "southwest" of town.

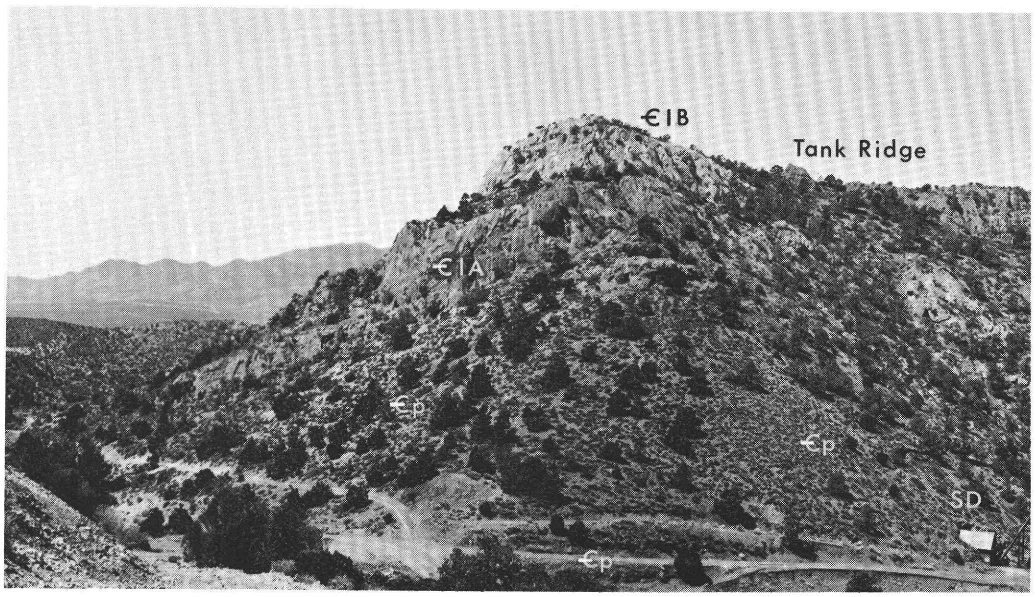

FIGURE 6.—View northwest at Pioche Divide. Susan Duster mine (SD) right foreground. Foreground on road is Pioche Shale (€p); cliffy slopes in middle distance are Lyndon Limestone. The dark gray unit is member A (€LA) and the overlying white unit is Member B (€LB).

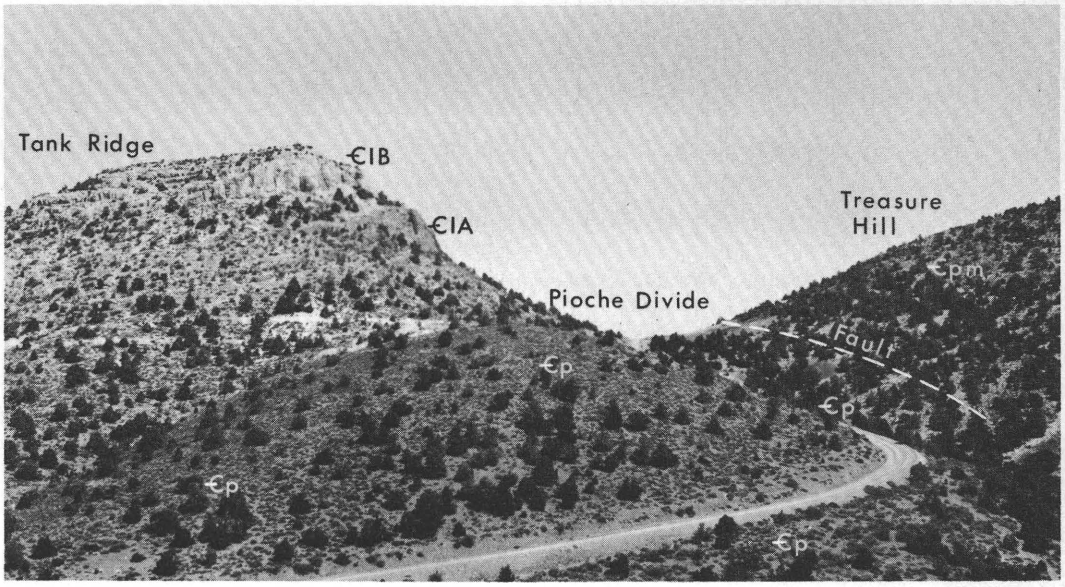

FIGURE 7.—View northeast through Pioche Divide. Treasure Hill on right is Prospect Mountain Quartzite (€pm). Tank Ridge on left shows member A (€lA) and member B (€lB) of the Lyndon Limestone. Foreground and middleground are Pioche Shale (€p) of the reference section.

Walcott (1908 b, p. 184) actually refers in another publication to Pioche Shale fossils collected "southwest of Pioche, Nevada on the Panaca road," probably in the Pioche Divide vicinity. In any event, that Walcott studied and collected in these better exposures of Pioche Shale is a reasonable assumption. Westgate and Knopf (1932, p. 8) concluded that Walcott's original Pioche Shale exposures were "doubtless the shales which are well shown at the west of the pass south of Pioche along the old road (not the present road) to Panaca." The pass alluded to is Pioche Divide.

The Pioche Divide reference section was selected after mapping and stratigraphic appraisal of all exposures of Pioche Shale in the Ely Range. This easily accessible section embraces in continuous and seemingly little broken or duplicated condition about two-thirds of the composite Pioche Shale column (pl. 4). However, the top and bottom relations are better shown in the northwest part of the Ely Range, because the uppermost and lowermost parts of the formation are faulted out in the reference section. Zoned fossil collections made at Pioche Divide include five of the six important Pioche Shale faunules.

Future studies may be expected to prove the less disturbed sections of Pioche Shale in the Highland Range to be better suited on the whole for stratigraphic paleontology than those of the intensely faulted Ely Range. However, no valid necessity would seem to exist for abandoning a type area and appropriate reference sections near the geographic location after which the formation is named.[3]

STRATIGRAPHIC DIVISION

Since the early 1920's, exploration for and development of bedded limestone replacement ores in the Pioche Shale have called for more refined stratigraphic procedures as the economic bearing of stratigraphic ore controls became increasingly more evident. Detailed geologic mapping and exploratory drilling by the mining companies demonstrated that this formation was not, as earlier believed, a monotonous repetition of similar beds.

The mining companies divide the Pioche Shale into six principal lithologic units, each traceable throughout the Ely Range. Of these, the lower four are clearly differentiated to the west, in the Highland Range. Minor subunits have a local utility in parts of the Ely Range, and at least one of these is recognizable also in the western part of the Highland Range. Pioche Shale divisions here adopted (table 2) are virtually those successfully used by the Combined Metals Reduction Co.

The stratigraphic nomenclature which came into being as the ore bodies in the Pioche Shale were exploited is expressive of exploration from the surface downward (table 2). Four of the units are assigned letter symbols

[3] Deiss (1938, p. 1159) seems to have interpreted Westgate and Knopf (1932) as implying transfer of the Pioche Shale type section to Lyndon Gulch, Highland Range. Actually reference is made (Westgate and Knopf, 1932, p. 9–10) to a type locality at Pioche.

A through D in descending order, the uppermost unit being A-shale and the lowermost D-shale. As these letter symbols are firmly established among geologists and engineers in the district, we are hesitant to modify or to reverse them for sake of convention. Table 2 presents the Pioche Shale column here adopted.

TABLE 2.—*Pioche Shale, composite column*

System	Formation	Member	Thickness (feet)
Middle Cambrian	Pioche Shale	A-shale member	310
		B-shale member	170
		Susan Duster Limestone Member	5–20
?		C-shale member	80
Lower Cambrian		Combined Metals Member	40–70
		D-shale member	200

The terms "Forlorn Hope shale" and "Comet shale" proposed by Mason (1936), as well as "Comet shale" and "Pioche shale: restricted" of Deiss (1938) are not adopted herein. Fossil ranges rather than lithology are seemingly the criteria upon which these proposed units depend, and the unrealistic boundaries which separate them in the Highland Range were not recognized in the Pioche mining district.

In addition to the lithologic criteria upon which division of the Pioche Shale is based, paleontology serves effectively in zoning the formation. All members except B-shale and C-shale contain distinctive trilobite faunules. B-shale has yielded no fossils, but C-shale is sparingly fossiliferous; the few trilobites thus far collected from C are not stratigraphically distinctive. The occurrence and distribution of the Pioche Shale fossils are treated below under "Age and Correlation."

D-SHALE MEMBER

OCCURRENCE

Vertically continuous exposures of the entire D-shale member were not found in the Ely Range. Composite columns were therefore compiled from overlapping partial sections measured on the surface, in the mines, and logged in churn-drill holes. Incomplete sections may be studied south and southeast of the Ely Valley mine and in the Pioche Divide area south of Pioche. The D-shale sections three-fourths of a mile southeast of the Ely Valley mine (pl. 3) though attenuated by faulting, show the normal gradational relation with underlying Prospect Mountain Quartzite. The lower part of the member is cut out by faults in the Pioche Divide section.

In the southeast belt of Pioche Shale, the relations of D-Shale to the overlying Combined Metals Member may be observed along the main highway southwest of Gray Cone. All deep mines of the district have penetrated D-shale to get below the productive Combined Metals Member for stoping and exploration purposes.

On the west side of the Highland Range, the D-shale is on the whole poorly exposed, lying in an alluviated foothill belt between upstanding Prospect Mountain Quartzite and, to the east, steeper slopes formed by higher Pioche Shale and the overlying limestones.

LITHOLOGY AND STRATIGRAPHIC RELATIONS

On fresh surfaces the typical D-shale is light olive gray to dusky yellow and has partings of much darker, slightly greenish olive gray. Weathered surfaces are in many places khaki colored or moderate yellowish brown and marked by streaks of limonite brown. Interfaces have a distinct sheen, for D-shale is characteristically micaceous, having in fact been mistaken for mica schist (Pack, 1906a, p. 294). The flakes range from finely divided sericitic material to coarser green chlorite plates more than half a millimeter in diameter. Chlorite flakes are more concentrated in the greener partings and laminae, which are commonly the layers in which trilobites occur. Green layers with coarse chlorite flakes alternate with finer grained layers having fewer flakes visible to the unaided eye.

Bedding tends to be uneven, crinkly, and bumpy. A multiplicity of intersecting minor joint surfaces causes the rock to weather into rather small hackly pieces. Similar lumpy micaceous shales are found also in A-shale and B-shale members, although the percentage of coarse green chlorite in D-shale is somewhat greater.

Innumerable large olenellid carapaces occur in some of the D-shale layers. The trilobites are preserved as smooth limonitic, sometimes reddish-brown coated impressions showing relief. No filmy carbonaceous shell material or silicification of shells like that in the overlying Combined Metal Member was noted in D-shale. In addition to trilobite impressions, the bedding surfaces show various types of tracks and other markings of organic origin. However, the thick, lumpy, interlaced castings so common in the underlying transition zone of the Prospect Mountain Quartzite were not recognized in the D-shale.

The stratigraphic relation of D-shale member of the Pioche to the underlying Prospect Mountain Quartzite was investigated by underground studies, by examination of churn-drill cuttings, and by surface mapping in the area southeast of the Ely Valley mine. All the evidence points to gradual passage from quartzite into D-shale, seemingly without break in sedimentation. The transition zone, varying in thickness from 35 to 75 feet (see p. 11), is arbitrarily included with the Prospect Mountain.

Red iron staining so characteristic of the Prospect Mountain disappears in the lower beds of D-shale and the amount of coarser arenaceous debris decreases upward. Sandy beds in D-shale are of finer grain, lacking the dense vitreous appearance of the quartzites in the Prospect Mountain. Southeast of the Ely Valley mine abundant olenellid trilobites appear about 40 feet stratigraphically above the uppermost reddish brown vitreous quartzite bed which defines the top of the transition zone. In the Pioche Divide reference section similar olenellid trilobites occur in a somewhat higher position, 70 feet stratigraphically below the base of the Combined Metals Member.

Within the upper 25 feet of D-shale there is at some places a thin calcareous fossil bed ranging from less than 1 inch to about 6 inches in thickness. Called the 20-foot marker in the Prince and Caselton mines, this fossil bed is locally mineralized and has served as a useful underground datum. A similar bed is found in the Pioche Divide section, but was not recognized in the Ely Valley mine. In the Prince mine, it is roughly 24 feet below the so-called lower bed (table 3) of the Combined Metals Member; on the 1,400-foot level of the Caselton mine, it was identified about 20 feet below the lower bed.

The contact separating D-shale from the quartz sands, which characterize subunit 1 of the Combined Metals Member, is abrupt but conformable.

THICKNESS

The average thickness of D-shale member is about 175 feet in the Ely Range. Faulted sections southeast of the Ely Valley mine show about 80 feet of the lower part of the D-shale only. Underground in the Ely Valley mine, the member ranges in thickness from 114 to 158 feet; churn-drill logs at Slaughterhouse Gulch give thicknesses ranging from 120 to 175 feet. In the standard Pioche Divide section, only 130 feet of this unit is exposed, but total thickness in that vicinity may exceed 200 feet. Underground in the nearby Pioche No. 1 mine, D-shale is estimated to be between 225 and 250 feet thick (Westgate and Knopf, 1932, p. 54).

Churn-drill records on the west side of the Ely Range give D-shale thicknesses from 170 to 230 feet. Near the Pan American mine (pl. 2) on the west side of the Highland Range, this unit is estimated to be 260 feet in thickness; this increase suggests overall westward thickening.

COMBINED METALS MEMBER

NAME AND OCCURRENCE

Bedded zinc and lead ores have been mined extensively from this predominantly limestone unit by the Combined Metals Reduction Co., and the name "Combined Metals bed" (here changed to Combined Metals Member) is now firmly established among mine operators and geologists.

There are few good exposures of the Combined Metals Member in the Ely Range. Scarcity of surface outcrop is offset, however, by underground access. On the surface the member may be studied to advantage near the Gold Eagle, West End, and Gelder mines, 3,500 to 5,000 feet southeast of the Ely Valley mine (pl. 3). Small exposures occur southeast of the Pioche No. 1 shaft. In the Pioche Divide reference section (pl. 3) the Combined Metals Member shows a nearly continuous outcrop length of 1,000 feet, this being the best surface outcrop recognized in the district. Three miles southeast of Pioche, the member crosses the main highway near Gray Cone; it can be observed at several points between the highway and low limestone ridges south of Gray Cone.

On the lower west slope of the Highland Range are many good exposures of the Combined Metals Member; these may be followed from the Pan American mine north to the Forlorn Hope mine (pl. 2), a distance of 3½ miles. The Pan American inclined shaft is collared in low-dipping beds of the Combined Metals Member.

THICKNESS

The Combined Metals Member ranges in thickness from less than 40 feet to about 70 feet in the Ely Range, the average being about 50 feet. Measurements were obtained from surface exposures, mine openings, and drill holes. Whereas some lateral variation in thickness is due to factors of original deposition, it is the pervasive faulting that accounts for many of the recorded differences in thickness. Some exploratory drill holes were located on faults where the potential ore beds have been partly cut out or apparently thickened. Exaggerated figures of thickness were obtained where the drill followed steeply dipping dragged beds.

Thickness measurements reported by mine operators vary to some extent because the basal sandstone beds were in some places logged with the upper part of the D-shale member rather than with the Combined Metals Member. On the west side of the Highland Range, surface thickness measurements range from 25 feet near the Pan American mine to about 60 feet west of the Forlorn Hope mine.[4]

LITHOLOGY AND STRATIGRAPHIC RELATIONS

The Combined Metals Member may be divided at Pioche into an upper well-bedded argillaceous limestone

[4] Results of drilling by the U.S. Bureau of Mines (Trengove, 1949, p. 3) in Lyndon Gulch give thickness ranging from 80 to 100 feet, which appears excessive, for the Combined Metals Member.

35 to more than 50 feet thick, and a lower heavier bedded part about 17 feet thick, comprising fine calcareous sandstone and arenaceous limestone. In this lower part, calcareous sandstone predominates and shows a varied concentration of micaceous debris from bed to bed. These two units are referred to informally as upper and lower parts of the Combined Metals Member, and are mappable separately throughout the district. Both parts lend themselves to further subdivision into subunits having more than local stratigraphic value (table 3).

Adopted terminology is based on study of the Pioche Divide reference section (pl. 1). The lower arenaceous part of the Combined Metals Member is partitioned into 3 subunits, called subunit 1, subunit 2, and subunit 3 in ascending order. Two lithologic subunits are recognizable in the upper limestone part; these are a lower, thicker bedded part (subunit 4) and an upper thinner bedded part (subunit 5).

TABLE 3.—*Stratigraphic subdivisions of the Combined Metals Member of the Pioche Shale at Pioche Divide, showing equivalent terms used by mining companies*

	Pioche Divide section, C. W. Merriam, this report			Mining company terms
	Subdivisions		Lithology	
Combined Metals Member of Pioche Shale	Upper limestone (53 ft).	Subunit 5 (40 ft).	Thin-bedded nodular limestone of fine grain, with shale partings; dark gray to black; shale partings locally pale to purplish red.	Upper part of upper bed (U.P.U.B.).
		Subunit 4 (8–12 ft).	Heavier bedded, medium-grained limestone of medium to dark gray.	Lower part of upper bed (L.P.U.B.).
	Lower calcareous sandstone and sandy limestone (17 ft.)	Subunit 3 (2½ ft).	Very fine grained gritty calcareous sandstone with abundant micaceous flakes.	Micaceous shale rib.
		Subunit 2 (4 ft.)	Fine-grained calcareous sandstone and sandy lime-limestone.	Lower bed.
		Subunit 1 (8–10 ft).	Fine- to medium-grained calcareous sandstone.	Siliceous shale rib.
				Footwall bed, overlying siliceous footwall shale.

Subunit 1, which is 8 to 10 feet thick, is a fine- to medium-grained slightly calcareous sandstone of yellowish olive brown to light brownish olive; it weathers tan or limonitic brown. The sandstone is well sorted, containing about 90 percent of subrounded to angular grains of clear quartz, 2 to 6 percent of micaceous minerals resembling chlorite and sericite, and about 1 percent of dark ferruginous matter. Calcite fills interstices. Because of its abundant angular quartz grains and mosaic texture the term fine grit is not inappropriate. Normally this sandstone is speckled with micaceous flakes and has on the whole a rather dull nonvitreous appearance. Locally it becomes denser and subvitreous, containing little or no micaceous matter visible to the unaided eye.

Subunit 2, about 4 feet thick, is a fine-grained fairly well sorted highly calcareous gritty quartz sandstone changing here and there to sandy limestone. It is medium gray to light brownish and pinkish gray. Fine to medium clear quartz grains make up 40 to 80 percent; the remainder is turbid calcite. These quartz grains are subrounded to angular, the latter in places predominant. Subrounded detrital grains of reworked turbid calcite enclose quartz grains. Fragments of trilobite and brachiopod shells are common. Subunit 2 is an important ore zone, being quite susceptible to sulfide replacement.

Subunit 3, about 2½ feet thick, is a very fine grained well-sorted gritty calcareous sandstone containing abundant flakes of micaceous minerals. This bed is a useful marker and is termed "micaceous shale rib" by the mining companies. A distinct sparkle imparted by the finely divided micaceous mineral is clearly evident to the unaided eye. The rock is light gray to grayish tan and is composed of subrounded to angular quartz grains (80 percent), chlorite or sericite (8 percent), and calcite as cement (5 to 15 percent). Some calcite is present in the form of turbid detrital grains.

Fine-grained argillaceous and silty carbonaceous limestones about 53 feet thick make up the upper part of the Combined Metals Member in the Pioche Divide section. Two lithologic subunits are recognizable in this interval, subunit 4 below being heavier bedded and subunit 5 above prevailingly thinner bedded. The impure limestones of these two upper subunits prove to be the principal hosts of Pioche zinc-lead ores.

Subunit 4 is a limestone 8 to 12 feet thick, of medium to dark gray color, and speckled with limonite brown. It is of medium grain, showing scattered rather coarse calcite cleavage faces. In thin section this limestone reveals a considerable admixture of very fine sand and silt grains, composed mostly of quartz. These grains are in the main less than 0.1 mm in diameter, are subangular to angular in shape, and make up 10 to 25 percent of the rock. The main body is granular turbid calcite. Locally this rock is essentially bioclastic, organic debris being abundant as spines, needles, and fragments of brachiopod and trilobite shells.

Subunit 5, about 40 feet thick in the Pioche Divide section, consists of dark-gray very fine grained thin-bedded carbonaceous limestone intercalated with argillaceous shale. These strata exhibit a characteristic pinch-and-swell bedding, individual beds ranging in thickness from less than 1 inch to 3 inches. Uneven nodular limestone beds are separated by thin, uneven crinkly shale layers. On the weathered surface, shale partings and intercalations are locally pale red, purplish, or tan.

A decrease in quartz grain content was noted near the top of subunit 4, where the limestone layers become progressively thinner and more argillaceous upward. Accompanying this change, the limestone, as seen in thin section, takes on a detrital texture, exhibiting abundant round to subangular calcite granules that range in diameter from less than 1 to 3 mm. Scattered throughout are larger ovoid limestone bodies that resemble *Girvanella* and are as much as 1 cm in diameter. Although of possible algal origin, none showed concentric lamination. Fossil shell material forms less of the rock in subunit 5 than in the somewhat coarser textured beds of subunit 4. Local beds of subunit 5, however, contain vast numbers of silicified trilobites, including larval growth stages (Palmer, 1957, 1958). These silicified shells weather out on limestone-shale interfaces.

The quantity of finely divided sooty carbonaceous or graphitic matter associated with the upper limestones of the Combined Metals Member in the vicinity of ore bodies is surprising. When freshly exposed, some of the low-grade bedded ores with a good deal of black unreplaced limestone remind one of a low-grade coal seam. Knopf's (1932, p. 55) description is particularly appropriate; he stated that these beds ". . . are commonly so nodular as to suggest that they are made up of layers of more or less flattened potatoes. These nodules are coated with a thin black carbonaceous (?) skin." Not infrequently when the limestone layers in these pinch-and-swell bedded ores are almost completely replaced by sulfides, the more inert clayey interbeds remain essentially unreplaced.

The upper limestone and lower sandy parts of the Combined Metals Member are distinguishable throughout the Pioche district, but the three numbered subunits of the lower sandy part are not everywhere recognizable. Such is the case in the Ely Valley mine. Surface exposures near the Gelder and West End mines (pl. 3) show the well-developed lower sandy part of the member, but details of thickness and lithology in this lower part are slightly at variance with the Pioche Divide reference section. On the other hand, lithologic details of the thick upper limestone division at the Ely Valley mine and neighboring prospects are about the same as in the Pioche Divide standard column.

Where the Pioche Shale is badly faulted and poorly exposed, it is possible to confuse the thicker limestones of A-shale member with those of the Combined Metals Member. The distinction as a rule can be made by detailed lithologic examination. Paleontology is of specific aid in this connection, for Lower Cambrian faunules of the Combined Metals Member are wholly different from Middle Cambrian faunules in the A-shale limestones.

Depositional changes noted in the Combined Metals Member reveal a transition from basal quartz sands upward into impure limestones, concomitant with a more or less progressive decrease in grain size of the admixed siliceous debris and a corresponding increase in the proportions of clayey and carbonaceous matter. The historical meaning of this succession is not understood, but a similar cycle is repeated in the limestone units of A-shale member, some of which have a basal quartz sand.

COMBINED METALS MEMBER AS ORE HOST

The Combined Metals Member is host for the largest manto-type zinc and lead ore bodies of the district. As evidenced by the great number of prospect holes and dumps, this fairly uniform and laterally persistent unit has been extensively prospected through the Ely and Highland Ranges.

Surface studies of the Combined Metals Member were supplemented by underground mapping, and by measurement and sampling of ore-bearing beds in the Caselton, Prince, and Ely Valley mines (pl. 3). Caving and waste-filling of large flat-back stopes in most places prevented satisfactory stratigraphic observations where the member had been most completely mineralized. Details of differential sulfide replacement, however, are well shown in exploratory headings penetrating unmined low-grade ore, where only partial sulfide replacement has taken place.

In addition to structural relations of the bedded ores, attention was given to such factors as bed-by-bed change in ore mineralization through the member and to stratigraphically controlled ore boundaries. The initial depositional differences which make possible subdivision of the member are clearly reflected by change of ore grade and metallurgical character across the section. These vertical differences seem to manifest stratigraphic selectivity on the part of fissure-introduced mineralizing solutions.

Hydrothermal alteration commonly obscures boundaries of subunits in the vicinity of ore bodies, especially the contacts separating the three lower siliceous sandy subunits. But even where the member is in considerable part replaced by sulfides, some gross bedding features, and, to a more limited extent, traces of original sedimentary texture, may survive. Inert shale or clay interlayers are generally unreplaced.

Recognition underground of stratigraphic position within the Combined Metals Member has practical mining significance. Not only is this true with reference to stratigraphic change in ore, but in the engineering sense because of the varied physical strength of beds. During selective mining, certain beds or zones are found to be better adapted than others to support load, and to stand without timbering after the removal of material beneath. In view of these factors, it is not surprising that the exigencies of ore search and mine development have encouraged at Pioche a high consciousness of the significance of stratigraphic details.

Much speculation has been indulged in relative to geochemical, geophysical, and stratigraphic factors that make the Combined Metals Member so favorable a locus for replacement ores in the presence of feeding fissures. Among the more obvious of these is the rather impure carbonaceous nature of the limestone beds, some of which are bioclastic and all of which are seemingly not subject to dolomitization. The limestones are evidently prone to fracturing under stress, and the member is confined above and below by relatively impermeable shale units not at all susceptible to sulfide replacement away from the immediate influence of strong feeding fissures.

Where transecting fissures carry sulfides, the lowest significant carbonate beds of a stratigraphic section are expected loci of abundant replacement ore (Prescott, 1926, p. 247). By virtue of its low position, the Combined Metals Member appears to satisfy these conditions ideally. No stratigraphically or structurally lower carbonate beds of consequence are known in the Pioche region; however, older and deeper carbonate rocks may be inferred in depth even below the Prospect Mountain Quartzite, as is true for the Death Valley region.

Discovery of large, bedded ore deposits at Pioche and presence of ore in the Combined Metals Member as far away as the western Highland Range have encouraged prospecting for zinc and lead in similar beds of more distant areas. Limestones resembling those of the ore-bearing Combined Metals Member in mountain ranges of the central and southern Great Basin have long attracted the attention of prospectors. Such limestones also occur as members in Middle to Lower Cambrian shales; however, they have not been correlated specifically by fossils with the Combined Metals Member or with other potential ore units of the true Pioche Shale. Search in these more distant beds for replacement zinc and lead deposits has not in recent years been rewarded by significant discoveries. Negative results of this kind support the elementary deduction that massive zinc-lead replacement ore bodies of the Pioche type are not reasonably to be expected in supposedly favorable beds unless strongly mineralized fissures are also present.

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C-SHALE MEMBER

OCCURRENCE

This lithologically distinctive and relatively uniform shale is recognizable in most Pioche Shale exposures of the Ely Range and is present likewise along the west slopes of the Highland Range. The C-shale member may be studied to advantage in the Pioche Divide section on the Prince mine road, in the vicinity of Gray Cone near the main highway, and on the slopes of Mount Ely about 2,000 feet northeast of the summit. The C-shale member is separated from the Combined Metals Member below and from the Susan Duster Limestone Member above by sharp conformable contacts.

LITHOLOGY

The C-shale member is more uniform in color and texture than are other members of the Pioche Shale. Its color is normally fairly light, slightly brownish olive gray, ranging to darker shades of grayish olive. Weathered surfaces are tan or light brown. The member is easily recognized by its smooth, even bedding and commonly very fine grain. A high proportion of interfaces or parting surfaces do not show micaceous flakes readily visible to the unaided eye; however, fine micaceous beds with a distinct sparkle do occur rarely in this member. Unlike other members of the Pioche, the C-shale member normally includes no sands or silty interbeds, nor have limestone beds been recognized within it. Crinkly and lumpy interfaces are conspicuously absent.

As occasional interbeds, smooth C-type shale is repeated in the upper part of A-shale member. Because it is fine grained and relatively nonmicaceous, the C-shale member may be confused with the Chisholm Shale. The latter may be distinguished by its reddish color and color banding; it is almost everywhere highly fossiliferous, whereas fossils are exceedingly rare in the C-shale member. Limestone interbeds, absent in the C-shale member, are numerous in the Chisholm.

Although the C-shale member is normally devoid of organic traces, a few poorly preserved trilobite impressions were found in this member at Pioche Divide and near the Pan American mine in the Highland Range.

THICKNESS

The C-shale member is 80 feet in the Pioche Divide section. Its average thickness in the Ely Range is about 100 feet, and its maximum is 120 feet in churn-drill holes. Near the Forlorn Hope mine, Highland Range, 110 feet was measured.

SUSAN DUSTER LIMESTONE MEMBER

OCCURRENCE

This important marker, lying 80 to 100 feet above the Combined Metals Member and separated from it by the C-shale member, is named for the Susan Duster mine near Pioche Divide on the Prince mine road (pl. 4). Contacts with the C-shale member and with the overlying B-shale member are characteristically sharp and conformable.

The Susan Duster Member has been recognized throughout the Pioche mining district and is found likewise in the Highland Range. It is replaced heavily by sulfides in the Ely Valley mine, being one of the important ore zones. The member is well exposed 1,500 to 2,000 feet northeast of the summit of Mount Ely (pl. 3) in the vicinity of the West End mine and along the Prince mine road in the Pioche Divide section.

LITHOLOGY

The Susan Duster Limestone Member is a well-bedded medium- to medium-light-gray limestone, which has a few argillaceous partings. The partings are olive colored and weather tan. Bedding tends to be uneven or crinkly, especially as seen at limestone-shale interfaces. Megascopically the Susan Duster Limestone Member may appear medium grained, but in thin section it is usually observed to be very fine grained. Fragmentary trilobite and brachiopod shells are embedded in a matrix of turbid aphanitic limestone with thin seams and spots of clearer crystalline calcite. Locally these beds are bioclastic; shell fragments are so numerous as to constitute a coquina.

This light-colored and very distinctive organic limestone is relatively pure, lacking the admixture of sand grains, clay, and carbonaceous matter that characterizes the dark-gray limestones of the Combined Metals Member. The Susan Duster Limestone Member shows little variation in lithology as far away as the west side of the Highland Range.

This unit contains an abundance of well-preserved fossils, considered below under the heading of age and correlation of the Pioche Shale.

THICKNESS

The Susan Duster Member ranges in thickness from 5 to 20 feet in the Ely Range, averaging about 15 feet. Near the Susan Duster mine (fig. 6) it ranges from 8 to 10 feet; in churn-drill holes at Slaughterhouse Gulch its thickness is 13 feet, and in the Ely Valley mine 14 feet. Average thickness reported in churn-drill holes on the west side of the Ely Range is 20 feet. West of the Forlorn Hope mine, Highland Range (pl. 2), the thickness of the Susan Duster ranges from 7 to 13 feet.

B-SHALE MEMBER

OCCURRENCE

The B-shale member lies between the Susan Duster Limestone Member and the sandstone marker bed generally recognizable at the base of the A-shale member in the Ely Range. The B-shale member is especially well exposed in the Pioche Divide section and near the West End mine (pl. 3) northeast of Mount Ely. Where the sandstone marker bed (pl. 4) is not identifiable with assurance, as in parts of the Highland Range, it is doubtful that B-shale and A-shale members can be differentiated.

LITHOLOGY AND STRATIGRAPHIC RELATIONS

The B-shale member comprises grayish olive brown, crinkly, unevenly bedded, strongly micaceous shales, silty shales, and fine sandstones. Interfaces are lumpy and pitted, some showing organic castings and tracks. Smoother, finer-grained and less micaceous intercalated shales occur near the bottom of the unit. Red-stained patches, the first such recognized above the Prospect Mountain Quartzite, are present in the B-shale member, recurring also in the A-shale member. On the whole the B-shale member is more micaceous, more crinkly and pitted than the D-shale member, and differs also in lacking the numerous green chlorite-rich laminae, especially as noted in the *Olenellus* beds of the D-shale member. No limestone layers were found in the B-shale member, which lacks fossils except for the organic traces mentioned.

The B-shale member is conformable upon the Susan Duster Limestone Member and passes without break into the sandstone marker bed at the base of the A-shale member. In some sections of the B-shale member, sandy and silty intercalations become progressively more numerous from the middle toward the top of the member.

THICKNESS

The B-shale member is 170 feet thick at Pioche Divide but thins to about 135 feet on the west side of the Ely Range as shown by drill cores. This thinning, however, is accompanied by the corresponding increase in thickness of the overlying sandstone marker bed to about 30 feet. Although the sandstone marker is for convenience classified with the A-shale member, its thickening may actually take place at the expense of the upper part of the B-shale member.

Existence of precisely the same basal sandstone marker bed of the A-shale member in the Highland Range is doubtful. A measured section west of the Forlorn Hope mine includes a dense fine-grained sandstone overlain by gray crystalline limestone 95 feet stratigraphically above the Susan Duster Limestone Member. Should this sand actually represent the sandstone marker in question, it must follow that the B-shale member thins westward from 170 feet in the Pioche Divide section to less than 100 feet on the west side of the Highland Range.

A-SHALE MEMBER

OCCURRENCE

The A-shale member, thickest member of the Pioche, is also the most widely exposed in the Ely Range. This heterogeneous member includes sandstone and thick-bedded limestone as well as shale and is more resistant than the other members to erosion, in part owing to protection by the Lyndon Limestone. The A-shale member is commonly the only part of the formation well exposed; as for example, on the east side of the Ely Range near The Point, where a large outcrop was mapped from a position 1,000 feet southeast of The Point nearly to the Alliance mine (pl. 3), 2 miles distant. Outcrops of badly faulted A-shale are present northwest of the Pioche No. 1 shaft, whence they extend south into the Pioche Divide section (pl. 1). The member is fairly well shown in the depressed, much faulted southeastern Pioche Shale belt from Gray Cone southward.

The normal stratigraphic relation of the A-shale member to the underlying B-shale member appears to be gradational through the basal sandstone unit of the A-shale member. Because of faulting, good exposures of the contact of the A-shale with the Lyndon Limestone are uncommon. Near the Forlorn Hope mine, Highland Range (pl. 2), this upper boundary is sharp and suggests disconformity.

THICKNESS

Northwest of the Alliance mine, the A-shale member is 310 feet thick and seemingly unbroken. Because of faulting, only 150 feet of this member is exposed in the Pioche Divide section. At Lyndon Gulch, in the Highland Range, the A-shale member has a possible thickness of 450 feet, but, followed north to the Forlorn Hope Mine, it seemingly thins to 175 feet (pl. 4). However, the accuracy of this deduction rests on correct identification of the "basal sandstone marker." A variation in thickness of the A-shale member as a result of a disconformity between it and the Lyndon Limestone is also possible.

LITHOLOGY AND STRATIGRAPHIC RELATIONS

Lithologic heterogeneity distinguishes the A-shale member from other members of the Pioche Shale. The A-shale member comprises strongly micaceous, as well as nonmicaceous, shales, siltstones, sandstones, and several distinctive varieties of limestone. Micaceous shales, which predominate, resemble those of the B-shale member; they are relatively coarse grained or silty, unevenly bedded, crinkly, lumpy, and pitted and contain organic castings. A noteworthy textural variant of the upper part of the A-shale member is a smooth nonmicaceous phase like that which characterizes the C-shale member.

The normal color of the A-shale member is the grayish olive brown widely noted throughout the formation; it weathers to shades of tan and limonite brown. Patches of red are fairly common, especially in the upper part of the unit, as noted above the Susan Duster shaft and at the Forlorn Hope mine in the Highland Range. Nonmicaceous *Albertella*-bearing A-shale in the northwestern part of the Ely Range lacks the olive shade, being dark gray and streaked with grayish red and limonite brown.

Brown-weathering, commonly fine grained, locally calcareous quartz sandstones are associated with the micaceous shales and limestones. The widespread sandstone marker (pl. 4), lowest bed of A-shale member, is typical of these.

Limestone makes up roughly 23 percent of the A-shale member in the northern Ely Range, occurring mainly in the upper half. The limestone subunits, which range in thickness from 1 inch to 40 feet, may be seen to advantage northwest of the Alliance mine and above the Susan Duster shaft at Pioche Divide. The limestones range in texture and composition from fairly pure dense fine-grained detrital types to oolitic limestones and impure argillaceous and silty limestones. The dense purer limestones usually lack identifiable fossils, whereas the impure and oolitic limestones contain abundant trilobites, brachiopods, and nodules of presumed algal origin (*Girvanella*). No dolomite was recognized.

Mapping of the A-shale member was facilitated by distinctive and laterally persistent subunits within it. Among these, in ascending stratigraphic order, are (pl. 4) (1) basal sandstone marker, (2) blue limestone marker, (3) oolitic zone, and (4) upper fossil zone.

Basal sandstone marker.—This bed is the lowest subunit of the A-shale member and ranges in thickness from 4 feet at Pioche Divide to 35 feet in churn-drill holes on the west side of Ely Range. Though unrecognized in Slaughterhouse Gulch churn-drill holes, it reappears near Alliance mine (pl. 3) at Mount Ely, where it is 16 feet thick. The basal sandstone marker is commonly reddish and is usually paired with an overlying, richly fossiliferous limestone bed into which it grades, as at Pioche Divide.

Blue limestone marker.—This subunit is well shown in the northeastern foothills between Slaughterhouse Gulch and The Point, where it lies near the middle of the member. It ranges in thickness from 40 to 15 feet, thinning as it is traced from Alliance mine toward The Point. As shown by Slaughterhouse Gulch churn drilling, its top is 130 feet below the Lyndon Limestone, whereas near the Alliance mine it is 160 feet below the Lyndon and its base about 100 feet above the sandstone marker. Limestone interbeds are few in the A-shale member below the blue limestone datum, but relatively common above it.

The blue limestone marker is the thickest and most distinctive of the limestone in the A-shale member. It is dense, of medium to fine grain, thick bedded, and dark bluish gray mottled lighter and darker, and in some places shows buff or limonite-brown spots. Oolitic texture was noted near the base. Thin sections disclose a fine detrital structure with rounded and subrounded calcite granules as much as 0.5 mm in diameter. Calcite of the granules is turbid gray and of exceedingly fine grain. Also present are calcareous plates, curved tubular pieces, shreds, and needles as much as 2 mm long. These fragments are assumed to be organic. The limestones of this subunit are fairly pure and relatively uniform, in these respects differing from the Combined Metals Member with which the blue limestone marker has been confused.

That the blue limestone marker of the eastern Ely Range is correlative with the so-called 20-foot lime of the Prince mine is somewhat doubtful. At that mine the limestone is reported to lie 30 to 55 feet beneath the Lyndon and therefore closer to the top of the A-shale member. Conceivably, however, the A-shale member may be thinned here at the top, either by faulting or disconformity.

Limestone beds are common above the blue limestone marker (pl. 4). In general these differ in that they are impure argillaceous or sandy and have coarser texture. Unlike the marker, they may contain identifiable fossils. Some are thin limestone layers that alternate with calcareous shales; others occur in flaggy to fairly thick bedded limestone sequences several feet thick, separated by shales. On fresh surfaces these impure limestones range from medium to light gray or, more rarely, darker bluish gray. They are usually streaked or mottled with limonite brown, buff, or pink and tend to weather to various shades of tan, buff, and brown. The granular texture is medium to rather coarsely crystalline. Most of the individual limestone beds are lenticular and not traceable more than a few hundred feet. Thin sections show some of these limestones to be oolitic, others are oolitic-detrital pellet combinations. Trilobite, brachiopod, and algal remains are abundant in certain layers.

Oolitic zone.—The oolitic zone occupies an interval from 40 to 100 feet above the blue limestone marker and is characterized by an abundance of oolitic limestone interbeds in shale. It has been mapped from Slaughterhouse Gulch toward The Point.

Upper fossil zone.—The upper fossil zone occupies the upper 50 to 75 feet of the A-shale member above the oolitic zone. Thinly layered medium to coarsely granular limonite-stained limestone beds are here associated with calcareous shale. This zone is generally the most fossiliferous part of the A-shale member.

Nonmicaceous smooth C-type shales are present in the oolitic zone and upper fossil zone. The smooth intercalated shales contrast sharply in texture with the crinkly micaceous shales and silty sandstones in these subunits. Smooth C-type intercalated shales appear about 55 feet above the blue limestone marker and the highest observed were about 25 feet below the top of the A-shale member.

Attention is elsewhere directed to characteristic pairing of a basal quartz sand with overlying limestone, as illustrated by the Combined Metals Member. Such pairing is again noted in the A-shale Member, as observed at Pioche Divide near the Susan Duster mine, and in the Highland Range at Lyndon Gulch and the Forlorn Hope mine. A repeated depositional cycle is suggested by this phenomenon. Westgate and Knopf (1932, p. 64) call attention to similar features in the upper part of the Pioche Shale at the Prince mine.

The A-shale interval in the Highland Range contains limestone and sandstone subunits similar to those noted in the Ely Range (pl. 4). Obvious changes in lithologic facies and thickness have, however, taken place within the 8 miles separating the two exposures. In Lyndon Gulch, strata having the character of the A-shale member are 440 feet thick, which is about 140 feet greater than the typical A-shale member of the Ely Range. The base of the A-shale member, however, cannot be established precisely in that area, where the basal sandstone marker is unrecognized. It is possible that the lower part of the 440-foot upper interval in question may embrace a time-stratigraphic equivalent of the Ely Range B-shale member, which is usually devoid of limestone beds. At Lyndon Gulch (Deiss, 1938, p. 1152–1153) a 25-foot limestone unit 178 feet below the Lyndon Limestone probably represents the blue limestone marker. An oolitic zone is present 90 feet above the supposed blue limestone marker.

Ore in limestones of the A-shale member.—Where mineralizing fissures are present, the A-shale limestones have yielded replacement ore. In the Prince mine, ore was extracted from the so-called 20-foot lime and other limestone beds of the A-shale member. On the northeast side of the Ely Range, the A-shale member limestones have been prospected extensively and the blue limestone marker occasionally mistaken for the productive Combined Metals Member. Unlike the Combined Metals Member, the blue limestone marker does not possess a basal sandy zone.

AGE AND CORRELATION

Four of the six members contain diagnostic trilobite assemblages. In ascending order, these are: D-shale, Combined Metals, Susan Duster, and A-shale. C-shale member is sparingly fossiliferous; B-shale member seemingly contains no fossils. Especially well preserved material was collected during this study from limestones of the Combined Metals Member, Susan Duster Member and A-shale member. Upper beds of the Combined Metals Member yielded abundant silicified material amenable to acid preparation. Most of the fossils first collected by Walcott and others came from shale layers; all fossils obtained from D-shale member were in shale, as this basal unit includes very little limestone.

The Pioche Shale faunules range in age from the Early Cambrian *Olenellus* zone to the Middle Cambrian *Albertella* zone. Upward disappearance of olenellid trilobites is the criterion employed for the separation of Early from Middle Cambrian. This trilobite group was not recognized above the Combined Metals Member in the Ely Range. Accordingly D-shale and Combined Metals members are classified as Early Cambrian; the Susan Duster Limestone Member and all younger beds of the formation are Middle Cambrian.

Burling (1914) noted the presence of Middle Cambrian trilobites in the higher part of the Pioche Shale at Pioche; in spite of this announcement there has until recently existed a tendency to place the entire formation in the Early Cambrian. In other districts as at Eureka, Nev. (Nolan, Merriam, and Williams, 1956, p. 8–9), only Early Cambrian fossils have thus far been found in the Pioche Shale.

In the Highland Range, Deiss (1938, p. 1158) drew the Lower Cambrian–Middle Cambrian boundary paleontologically at a horizon where the trilobite *Kochaspis liliana* is reported about 365 feet below the Lyndon Limestone. Walcott's type of *K. liliana* came from the Pioche area, but the type locality and stratigraphic occurrence of this species are unknown. In the Ely Range, the genus *Kochaspis* ranges from the Susan Duster Limestone Member upward to limestone beds in the A-shale member. The contact separating C-shale member from the underlying Combined Metals Member seems to be the physical boundary most nearly approximating that between Lower and Middle Cambrian. Poorly preserved ptychoparioid trilobites from the C-shale member do not controvert this interpretation.

Of six Pioche Shale trilobite faunules identified by A. R. Palmer in the Ely Range (table 4), all but the highest or *Albertella* faunule, are present in the standard reference section at Pioche Divide.

TABLE 4.—*Stratigraphic occurrence of Pioche Shale faunules based on paleontologic studies by A. R. Palmer*

System	Formation		Fossils
	Lyndon Limestone		No fossils
Middle Cambrian	Pioche Shale	A-shale member	6. *Albertella* faunule *Plagiura* 5. *Kochaspis* and *Poliella?*
Middle Cambrian	Pioche Shale	B-shale member	No fossils
Middle Cambrian	Pioche Shale	Susan Duster Limestone Member	4. *Poliella* faunule 3. *Strotocephalus–Mexicella* faunule
Middle Cambrian	Pioche Shale	C-shale member	Ptychoparioids, fossils rare
Lower Cambrian	Pioche Shale	Combined Metals Member	2. *Olenellus gilberti–Paedeumias clarki* faunule
Lower Cambrian	Pioche Shale	D-shale member	1. *Fremontia fremonti–Bristolia bristolensis* faunule
Lower Cambrian		Prospect Mountain Quartzite	*Scolithus* and castings only, no fossil shells

Large collections of fossils from the Pioche Shale have been studied by A. R. Palmer, whose findings in terms of biologic affinity, age, and geologic correlation are set forth below.

PIOCHE SHALE FAUNULES

By A. R. PALMER

EARLY CAMBRIAN FAUNULES

Fremontia fremonti–Bristolia bristolensis *faunule.*—Two species of olenellids characterize this faunule, which occupies the lower part of D-shale member. Both are short-eyed forms, as distinguished from *Olenellus gilberti*, a long-eyed trilobite generally found in younger Early Cambrian beds. The *F. fremonti–B. bristolensis* faunule is also the lowest assemblage of Early Cambrian trilobites in the Pioche Shale at Eureka, Nev. (Nolan, Merriam, and Williams, 1956, p. 8), and in the Cadiz Formation of the Marble Mountains, southeastern California (Riccio, 1952, p. 27). Distinctive but less common associates are *Bristolia insolens*, another short-eyed form, and *Paedeumias nevadensis*, a long-eyed olenellid with long frontal area.

Collections representing the *F. fremonti–B. bristolensis* faunule were made at several localities in the D-shale member. The best of these localities are in the Pioche Divide reference section and on the north slope of Mount Ely (USGS loc. 1398–CO) near the Gold

Eagle mine (pl. 3). The following assemblage was obtained at the last-named locality:

Bristolia bristolensis (Resser)
Bristolia insolens (Resser)
Fremontia fremonti (Walcott)
Paedeumias nevadensis (Walcott)

Olenellus gilberti–Paedeumias clarki *faunule*.—This faunule was found in the Combined Metals Member only. Characteristic elements were obtained throughout the unit, but the greatest numbers of individuals came from the upper few feet. In addition to the olenellids, *Crassifimbra walcotti* is common; less abundant is *Zacanthopsis levis*. Present also are phosphatic brachiopods referable to *Dictyonina*, *Acrothele*, and "*Acrotreta*." Association of the non-olenellid trilobites *Crassifimbra walcotti* and *Zacanthopsis levis* with olenellid forms is considered indicative of late Early Cambrian. Early Cambrian assemblages containing olenellid and non-olenellid trilobites are believed approximately contemporaneous, though the species may differ from one region to another. Approximately correlative assemblages of this nature are recorded from Pioche Shale in the Eureka district, Nevada (Nolan, Merriam, and Williams, 1956, p. 8), the Buelna Limestone of northwestern Mexico (Cooper and others, 1952, p. 71), and the Peyto Limestone member of the St. Piran Sandstone in British Columbia (Rasetti, 1951, p. 82).

Fossils were collected from 2 horizons in the Pioche Divide section of the Combined Metals Member:

Subunit 2, about 10 feet above base of the member (USGS loc. 1391–CO)
Antagmus? sp.
Crassifimbra sp.
Olenellus gilberti Meek
Zacanthopsis sp.

Subunit 5, about 3 feet below the top of the member (USGS loc. 1392–CO)
Acrothele sp.
"*Acrotreta*" sp.
Antagmus sp.
Crassifimbra sp.
Dictyonina sp.
Kutorgina? sp.
Olenellus gilberti Meek
Paedeumias clarki Resser
Zacanthopsis levis (Walcott)

Collections were made also near the West End mine (USGS loc. 1399–CO) on the lower north slope of Mount Ely 5,000 feet southeast of the Ely Valley mine. These are from upper subunit 5 near the top of the Combined Metals Member. Trilobites from this horizon are silicified, with larval stages especially abundant (Palmer, 1957; 1958). The faunule includes the following forms:

"*Acrotreta*" sp.
Crassifimbra walcotti (Resser)
Dictyonina sp.
Olenellus gilberti Meek
Paedeumias clarki Resser

Whether or not the five subunits of the Combined Metals Member can always be distinguished faunually as well as lithologically has not been determined with assurance. It is reasonable to suspect that the sandy beds of subunits 1, 2, and 3 might carry faunas differing in facies from those in limestones of subunits 4 and 5.

MIDDLE CAMBRIAN FAUNULES

Ptychoparioids in C-shale member.—The few poorly preserved trilobites obtained from the C-shale member are questionably Middle Cambrian. These are generalized and flattened ptychoparioids, which at present have by themselves no specific age significance. On the other hand, the apparent absence of olenellids in association points up a post-olenellid, and by definition, post-Early Cambrian age.

Strotocephalus–Mexicella *faunule*.—Elements of this faunule were collected from the lower part of the Susan Duster Limestone Member only. *Strotocephalus* cf. *S. arrojoensis* and *Mexicella* sp. are abundant, while calcareous brachiopods referable to *Diraphora* are common. The phosphatic brachiopod genera listed below occur also in the Combined Metals Member.

A species of *Mexicella*, one of the two abundant trilobites, occurs also in the A-shale member, where it is associated with *Albertella*. The lower Susan Duster faunule lacks *Albertella*, and combined with the faunule from the upper horizon of the Susan Duster, characterizes a pre-*Albertella* early Middle Cambrian faunule with elements of the *Wenkchemnia–Stephenaspis* and *Plagiura–Kochaspis* faunules (both pre-*Albertella*) described by Rasetti (1951, p. 87–92) from the Mount Whyte Formation in British Columbia. *Strotocephalus arrojoensis* is known from the earliest Middle Cambrian Arrojos Formation of northwestern Mexico (Lochman, *in* Cooper and others, 1952, p. 157). A collection from the lower 3 feet of the Susan Duster Limestone Member in the Pioche Divide section (USGS loc. 1393–CO) includes the following:

"*Acrotreta*" sp.
Acrothele sp.
Dictyonina sp.
Diraphora sp.
Kochaspis? sp.
Mexicella sp.
Onchocephalus cf. *O. maior* Rasetti
Strotocephalus cf. *S. arrojoensis* Lochman

Poliella *faunule*.—Elements of this faunule were obtained from the upper few feet of the Susan Duster

Limestone Member. Its affinities are the same as those of the previously discussed faunule.

A collection from the basal limestone bed of the Tatow Limestone of Deiss (1938, p. 1143) in the House Range, Utah, has two genera in common with this assemblage. Collections from the upper part of the Tatow have affinities with those from the upper part of the Pioche Shale, suggesting correlation of A-shale, B-shale, and Susan Duster Members with this House Range unit (pl. 5).

In the Pioche Divide section (USGS loc. 1394–CO) the following fossils were collected near the top of the Susan Duster Limestone Member:

"*Acrotreta*" sp.
Acrothele sp.
Fieldaspis sp.
Kochaspis sp.
Onchocephalus cf. *O. depressus* Rasetti
Poliella cf. *P. denticulata* Rasetti
Schistometopus sp.

Unassigned faunules.—Two collections from the A-shale member of the Pioche Divide section correlate either with the *Plagiura-Kochaspis* faunule from the Mount Whyte Formation in British Columbia or with the *Albertella* fauna widespread in the Cordilleran region. Neither collection contains sufficient well-preserved material to establish its faunal affinities.

Basal limestone of A-shale member, Pioche Divide section (USGS loc. 1395–CO)
Helcionella sp.
Kochaspis sp.
Poliella? sp.

About 40 to 50 feet below top of exposed part of A-shale member, Pioche Divide section (USGS loc. 1396–CO)
Plagiura sp.

Albertella *faunule.*—Elements of this faunule characterize the upper part of A-shale member in the Ely Range and the Highland Range. *Albertella* and other indicators of this zone have been recognized throughout the Cordilleran region and are best known in the Cathedral Formation of British Columbia (Rasetti, 1951), and the Arrojos Formation of northwestern Mexico (Lochman, in Cooper and others, 1952). Closest affinities of the trilobites in this faunule at Pioche are with the *Albertella* faunule of the Arrojos Formation.

The *Albertella* faunule was collected from dark-gray shales of A-shale member on the top of the Ely Range northwest of the Tulloch mine (USGS loc. 1405–CO)

Albertella cf. *A. proveedora* Lochman
Mexicella sp.

LYNDON LIMESTONE

Massive, cliff-making light- and dark-gray limestones (figs. 6, 7, 8) between Pioche Shale and Chisholm Shale were named Lyndon Limestone by Westgate and Knopf (1932, p. 10). The type section of this formation is in Lyndon Gulch (pl. 2) on the west side of the Highland Range near the Shodde mine.

This limestone unit, with an average thickness of about 375 feet in the Ely Range, assumes economic importance as host rock for replacement ores in the Ely Valley and Prince mines. In fact, the name "Prince lime" has long been used for this unit in the Pioche mining district. The disturbed and altered condition of these rocks at the Prince mine, however, make them a poor stratigraphic standard. Throughout the Ely Range all exposures of Lyndon Limestone are considerably deformed, and the less faulted, more continuous sections of this formation in the Highland Range prove more satisfactory for stratigraphic study.

AREAL DISTRIBUTION

The largest Lyndon Limestone exposures in the Ely Range occur to the northwest between the Half Moon mine and The Point. Small discontinuous outcrops occur on the north slopes of Mount Ely, near the Pioche No. 1 mine and at the Prince mine (pl. 3). From Gray Cone southward, a narrow faulted outcrop crosses the range.

In the Highland Range the Lyndon may be traced northward along the west flank from the junction with the Black Canyon Range, through the type area of the formation to Stampede Gap. For 9 miles, limestones of this unit produce a nearly continuous bold cliffy outcrop along the lower front. Less precipitous slopes are formed below and above by the Pioche and Chisholm Shales.

LITHOLOGY AND STRATIGRAPHIC RELATIONS

The Lyndon Limestone is characteristically dense, fine-grained, or porcellaneous limestone ranging in color from white to dark gray or nearly black. The rock commonly has the texture and general appearance of a lithographic limestone, normally containing only a small percentage of such impurities as iron and silica. It varies from platy to heavy bedded and massive, the latter being predominant.

The limestones of this formation fall into two color groups: the purer light-gray or white limestones and the less pure carbonaceous medium-gray to almost black limestones. Most of the thinly bedded limestones are dark gray, whereas the light-colored phases tend to be massive.

In thin section the purer light-gray and white varieties are observed to be partly detrital and rather uniformly composed of round white turbid calcium carbonate granules set in a somewhat clearer calcite matrix.

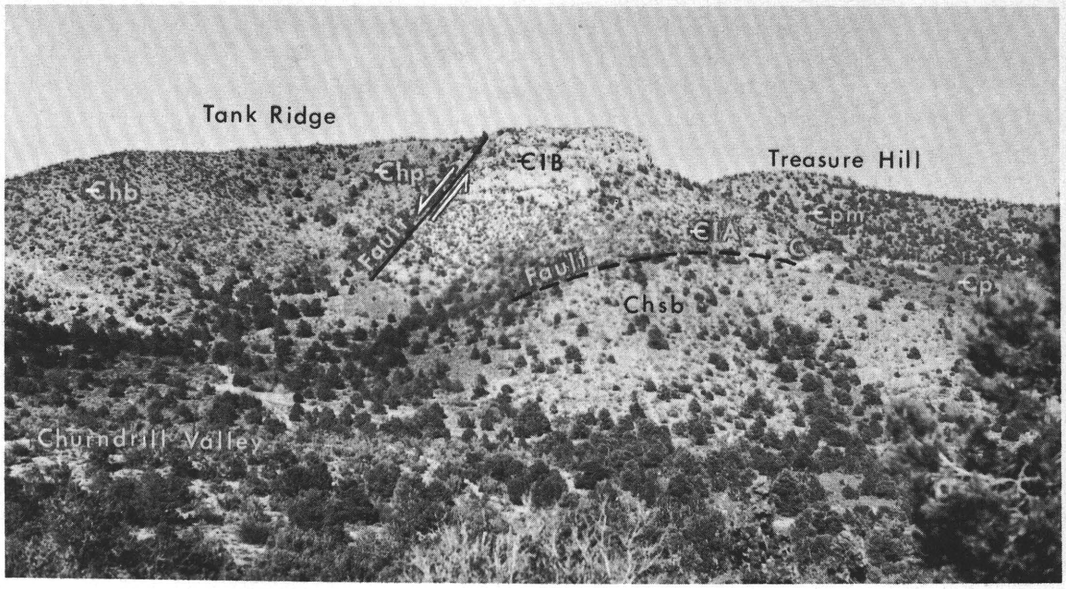

FIGURE 8.—View eastward across Churndrill Valley to Tank Ridge. White colored member *B* (€lB) overlying member *A* (€lA) of the Lyndon Limestone in fault contact with Peasley Member of Highland Peak Formation (€hp) on left. Burrows Member of Highland Peak Formation (€hb) on extreme left. Step Ridge Member of Highland Peak Formation (€hsb) is in fault contact with Lyndon Limestone (€lA) and Pioche Shale (€p) west of California Pioche shaft (C). Prospect Mountain Quartzite (€pm) underlies Treasure Hill.

The round granules are mostly less than 0.3 mm in size and appear to have been mechanically rounded. In general these granules do not exhibit a concentric structure.

The darker-gray carbonaceous limestones are detrital and range from oolitic to nonoolitic; all intermediate gradations are found between them. Nonoolitic carbonaceous types range from medium gray to dark gray, some having a slightly bluish shade. In thin section the dark nonoolitic limestones are observed to be made up of rounded, grayish turbid granules most of which are less than 0.3 mm in diameter, a few exceeding 1 millimeter. All grains, including even the smaller ones, are rounded. Calcite cement, though turbid, is somewhat clearer than the granules, which contain finely divided carbonaceous pigment. Narrow calcite veinlets are numerous, some being less than 1 millimeter in width. A faint pinkish secondary iron staining is common along fractures.

The medium-and dark-gray oolitic limestones commonly have a speckled salt-and-pepper appearance. The oolites show well-defined concentric layering, average about 1 mm in diameter, and are set in a matrix of turbid calcite. Individual oolites have an outer pellicle containing dusty carbon pigmentation. The nucleus is sometimes more coarsely crystalline carbonate than the surrounding matter. Crossbedding, common in other oolitic limestones of this area, was rarely noted in the Lyndon.

A variety of oolitic limestone in the Lyndon shows layers with numerous round or ovoidal dark-gray bodies averaging 5 mm in diameter. These bodies do not, like calcareous algae or the associated oolites, show concentric layering. Some have the appearance of cemented clumps of detrital limestone granules.

Dense, aphanitic fairly pure limestones megascopically like those which characterize the Lyndon are common in the Middle Cambrian of the Great Basin. As noted by Westgate and Knopf (1932, p. 10), the Highland Peak Formation includes lithologic types so similar to parts of the Lyndon as to render distinction difficult or almost impossible in situations where faults obscure the stratigraphy. Most likely to be confused are clean light-gray or white, massive, more or less porcellaneous lithographic limestones, which occur in the Lyndon, in undolomitized portions of the Burrows Member of the Highland Peak Formation, and as a local facies in the Step Ridge Member of the Highland Peak Formation. In thin section white lithographic limestones of the Step Ridge Member show a fairly uniform finely crystalline to aphanitic texture. Surficially similar Lyndon limestones reveal in thin section a less crystalline detrital granular fabric which preserves more of the original depositional features.

Dolomitization in the Lyndon Limestone is uncommon, being confined mainly to the immediate vicinity of faults and fractures. Incipient dolomitic mottling like that characteristic of the Meadow Valley Member of the Highland Peak Formation is noted locally.

The absence of laterally extensive and uniform dolomite in the Lyndon is not easily explained. Higher in the stratigraphic section the Burrows Member of the Highland Peak Formation is extensively dolomitized, but resembles the Lyndon closely where undolomitized. If we assume the Burrows to have been dolomitized by the action of magnesian solutions which ascended along fissures, the hydrothermal activity might reasonably be expected to bring about similar changes where the same fissures transect the stratigraphically lower Lyndon Limestone. Such does not appear to be so, nor are limestones in the Pioche Shale dolomitized to any extent. Marine-connected diagenetic processes, effective during the Burrows depositional interval, and nonoperative in Lyndon time seem to offer a more logical explanation of the differences noted.

The possibility of disconformity between the Pioche Shale and the Lyndon Limestone is suggested by good exposures of the contact near the Forlorn Hope mine, Highland Range (pl. 2). The boundary is a sharply incised, slightly undulant surface, but no angular discordance was noted. The basal Lyndon at this locality is thick-bedded dark-gray oolitic limestone with limonite brown streaks and parting lines, whereas the topmost Pioche is a bed of brown-mottled argillaceous limestone 1½ feet thick grading downward into limy micaceous shale.

The Lyndon-Chisholm contact is rarely well exposed. The basal Chisholm as observed at the Shodde mine in Lyndon Gulch is a limestone bed 1½ feet thick, of much lighter gray than the topmost Lyndon. Although the change is abrupt, no evidence of disconformity was noted.

Three members are recognized in the Lyndon Limestone (fig. 9); these are designated in ascending order as members A, B, and C. Member B in the middle is distinguished by the light-gray and white limestones within it, whereas the other two members are prevailingly dark gray. The three members are best shown in stratigraphic continuity in the Highland Range type area but are recognizable also in the Ely Range.

Member A of the Lyndon is well exposed in the limestone hill just west of Pioche Divide (fig. 7) and again half a mile northwest of the summit of Mount Ely. It may be observed also at Gray Cone (pl. 3). In the Lyndon type section near the Shodde mine (pl. 2) member A is about 185 feet thick and exhibits a massive ledge-forming dark-gray basal zone 15 to 25 feet thick. The same ledge former is present at the Forlorn Hope mine and is recognizable west of Pioche Divide. It is usually mottled light and dark gray and, though massive weathering, shows faint undulant parting lines ½ to 3 inches apart; these partings are sometimes stained pink or limonite brown. The limestone is markedly oolitic and contains larger ovoidal bodies having the outline of *Girvanella* but revealing none of the internal structure of such calcareous algae. The remainder of member A is prevailingly heavy bedded, medium to dark gray, and, sometimes mottled and forms rough-weathering massive cliffy exposures. Local intercalated argillaceous limestone shows thinner bedding and platy weathering.

A persistent thin-bedded and laminated dark-gray limestone 12 to 35 feet thick occurs at the top of member A. It superficially resembles platy beds in the Condor Member of the Highland Peak Formation, but is not dolomitic like the Condor. This topmost subunit of member A of the Lyndon was recognized also in the Ely Range near Pioche Divide and at Gray Cone.

Dark-gray heavy-bedded limestones of member A of the Lyndon closely resemble the Peasley Member of the Highland Peak Formation, both being partly oolitic and both containing rounded bodies of larger-than-oolite size. However, some of the Peasley inclusions are more specifically algal, having concentric structure, and are on the average larger, attaining a diameter of about an inch. The Peasley nodules, unlike those of the Lyndon, often enclose a fragment of fossil shell. Small patches of striped and mottled oolite of member A resemble the tiger stripe oolitic phase of the Step Ridge Member of the Highland Peak, but crossbedding, so common in the oolite of the Step Ridge, is rare in the Lyndon.

Member B of the Lyndon is generally massive and cliff forming. It varies in color from medium and light gray to white; the conspicuous lighter phases usually show darker patches, mottlings, and bedding streaks. Dense and largely of lithographic texture, this limestone weathers more smoothly than that of member A, and forms rounded outcrop surfaces. The bedding, not everywhere apparent, is normally heavy, thin in very few places, and on the whole not as well defined as that in member A. Member B also differs from A by being more uniform and purer with less of the argillaceous and limonitic mottling and streaking. Pale-pinkish staining of outcrop surfaces is fairly common. Near its base, member B shows a coarse lamination or banding and may intergrade with the underlying thinly bedded zone at the top of member A.

Being dense, brittle, and massive, the limestones of member B are cut by many joints and commonly exhibit cleavage. Recrystallized white calcite as fracture and pocket filling is characteristic. In the field the cliff-forming light-gray or white lithographic limestones of member B are easily confused with those of the Step

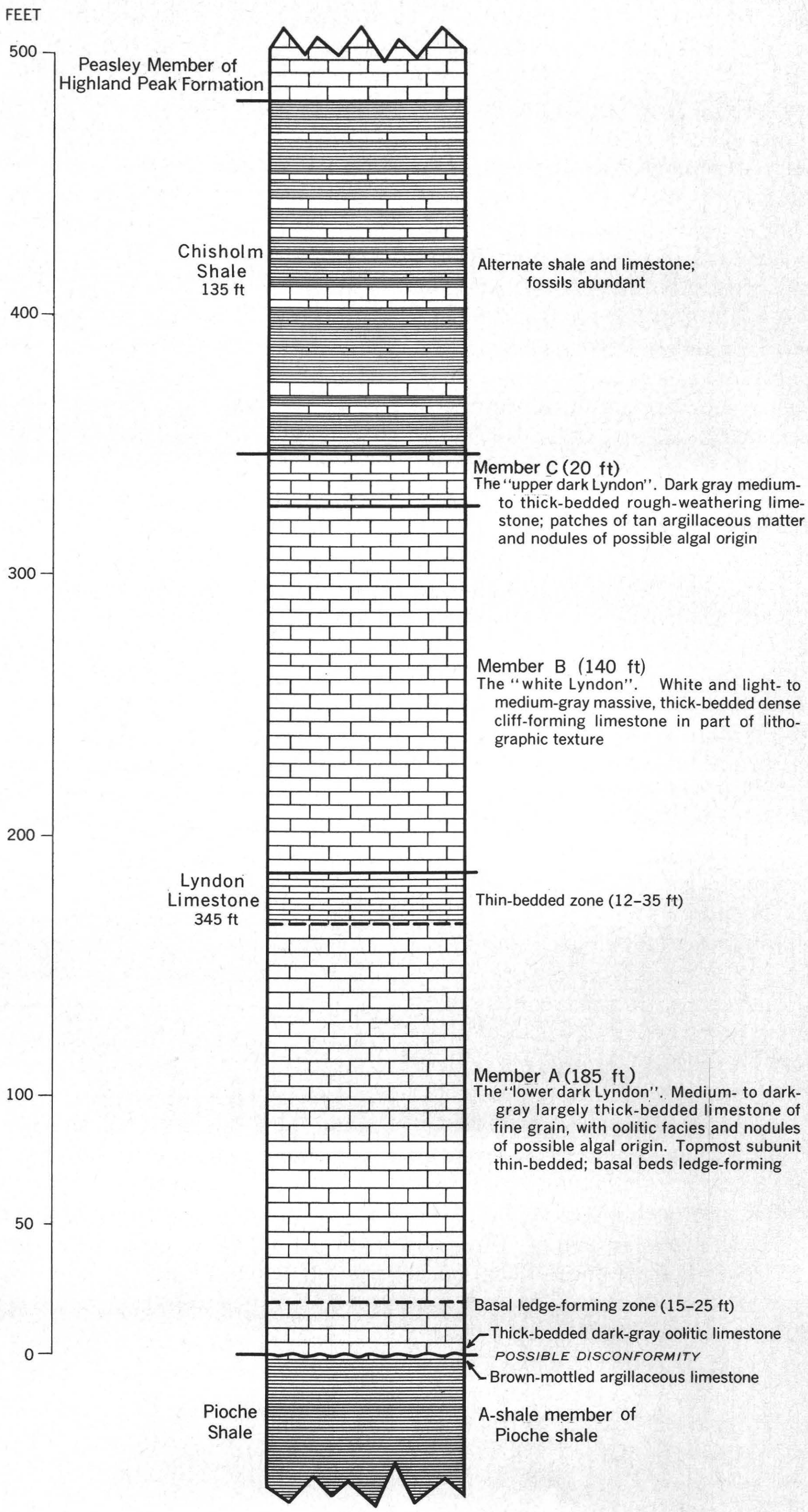

Figure 9.—Columnar section (*K*) of the Lyndon Limestone and Chisholm Shale at the Shodde mine, Lyndon Gulch, Highland Range. See plate 2 for location of section.

Ridge Member of the Highland Peak Formation, and with undolomitized phases of the Burrows Member.

Member C of the Lyndon, the topmost division, is especially well exposed at the Shodde mine in Lyndon Gulch (pl. 2). It may also be studied at Gray Cone in the Ely Range. Topmost Lyndon at the Prince mine, possibly representing this member, is mineralized and has there been called the big bed (Knopf, in Westgate and Knopf, 1932, p. 63). Member C forms a ledge below the less resistant Chisholm shale in the Highland Range.

Limestones of member C resemble those of member A, being dark gray, medium to heavy bedded and rough weathering. Some are mottled, showing patches of limonitic and buff to pinkish-colored argillaceous matter. No oolitic beds were recognized, but the member contains *Girvanella*-like bodies which lack internal structure.

THICKNESS

The Lyndon Limestone as measured near the Shodde mine in Lyndon Gulch (fig. 9) is 345 feet thick, which agrees with the measurement by Deiss (1938, p. 1151) on the south side of Lyndon Gulch. On the north side of the gulch, the formation is thinned somewhat by faulting. In the Shodde mine section, member A is 185 feet thick, member B 140 feet thick and member C at the top of the formation 20 feet thick. Westgate and Knopf; (1932, p. 10) measured 400 feet of Lyndon 1½ miles north of Lyndon Gulch on the ridge south of Peaslee Canyon.

In the Ely Range 380 feet of Lyndon was measured half a mile northwest of the summit of Mount Ely. At Gray Cone, 300 feet of the formation is exposed, of which 160 feet is member A, 115 feet light-gray member B, and 25 feet member C. In the conspicuous white-topped limestone hill west of Pioche Divide (fig. 7), 150 feet of member A is overlain by 80 feet of member B, which is incomplete because of faulting and erosion. No unfaulted sections of Lyndon Limestone were recognized in the Ely Range.

AGE AND CORRELATION

The Lyndon Limestone, like most of the Highland Peak Formation, is singularly barren of fossils.[5] Its early Middle Cambrian age is, however, well established by intermediate position between the fossiliferous A-shale member of the Pioche and the richly fossiliferous Chisholm Shale.

The Lyndon may correlate with part of the Eldorado Dolomite at Eureka, Nev., which is also barren of fossils. The Eldorado differs from the Lyndon by being extensively dolomitized, ranging from nearly pure limestone to nearly pure dolomite (Nolan, Merriam, and Williams, 1956, p. 9–1 In the House Range, Utah (fig. 1), the Lyndon is probably represented in limestone strata overlying the "Pioche shale" and below a fossil-bearing dark-gray argillaceous limestone which is correlated with Chisholm Shale (pl. 5). The House Range beds in question have been called Howell Limestone (Deiss, 1938, p. 1141) and include strata assigned to "Millard limestone" and "Burrows limestone" by Wheeler (1948, fig. 5). Lithologically, they resemble member A and member B of the Lyndon, in addition to occupying about the same stratigraphic interval.

CHISHOLM SHALE

NAME AND OCCURRENCE

The name Chisholm Shale was given by Walcott (1916b, p. 409) to strata between the Lyndon Limestone and the Peasley Member of the Highland Peak Formation of present usage. The type area of the formation is the Chisholm mine vicinity (pl. 3), 1,000 feet west of the summit of Mount Ely. This lithologically distinctive and highly fossiliferous unit provides a valuable Middle Cambrian datum. Despite thinness and structural incompetency, the Chisholm is one of the discrete and readily mappable units of the region.

The total Chisholm outcrop is relatively small, for as a thin and structurally weak unit it became a locus of movement and was more or less completely faulted out locally. Not uncommonly its former presence is indicated only by pinkish tan or gray clay gouge.

The largest exposures of Chisholm Shale in the Ely Range lie on the flanks of Mount Ely, especially the west side in the vicinity of the Chisholm, Whale, Blue Eagle, and Half Moon mines. These mines were partly developed in the Chisholm Shale, and their dumps have long been a fruitful ground for fossil collecting. On the north side of Mount Ely, the Alliance and Lost Treasure mines are likewise in Chisholm. Smaller exposures are found near the Prince mine, on Tank Ridge above the Pioche No. 1 mine, and in the west foothills about the Whiskey Barrel and Demijohn mines. Chisholm Shale is well exposed at Gray Cone and occupies a narrow discontinuous belt stretching south from Gray Cone and thence across the Ely Range.

The most continuous Chisholm exposures and those best suited for stratigraphic study are on the west side of the Highland Range. A nearly unbroken belt of these strata may be followed from the junction of the Black Canyon Range and the Highland Range north-

[5] Mr. Paul Gemmill of the Combined Metals Reduction Co. (oral communication, 1954) reports a small fossil collection from Lyndon Limestone near the Bristol mine, 20 miles north of Pioche. The fossils were referred to Dr. Christina Lochman Balk, who identified *Nisusia* and *Hyolithes*, together with indeterminate trilobite fragments. A Middle Cambrian age was indicated.

ward to Stampede Gap (pl. 2). No Chisholm outcrops are known north of this gap.

THICKNESS

An undisturbed section of Chisholm Shale in the Highland Range at the Shodde mine, Lyndon Gulch, is 135 feet thick (fig. 9). In the Ely Range the thickness ranges from 55 feet north of Mount Ely to about 100 feet at Gray Cone. Thickness measurements of Chisholm in the Ely Range are generally unreliable because of faulting.

LITHOLOGY AND STRATIGRAPHIC RELATIONS

The Chisholm Shale consists of very fine textured, smooth noncalcareous clay shales, calcareous shales, and limestones. Clay shale predominates, but locally as in Lyndon Gulch, 30 percent of the formation consists of limestone (fig. 9). In color the shales are characteristically a pale, slightly pinkish brown, ranging to shades of grayish red, moderate brown, tan, buff, and in very few places pale grayish green. When weathered and bleached the beds become very light tan, cream colored, or even white. Concentric color diffusion rings of grayish red, tan, and light greenish gray are common features. The surface mantle over Chisholm Shale is usually pink or reddish in color. Joints, fractures, and weathered surfaces are sometimes coated with dark-brown or reddish limonitic matter. Fossils stand out sharply in the light-colored shales by reason of their contrasting dark limonitic brown color.

Fresh exposures of Chisholm Shale commonly appear massive and homogeneous, with only an occasional color band to reveal bedding. Weathering develops the shaly layering, though evidence of very thin lamination is seen in very few places. The shale breaks down on weathering to form thin irregular plates as much as 10 inches long, shapes of which are determined in part by intersecting joint surfaces. Chisholm Shale commonly forms topographic saddles.

To the unaided eye Chisholm Shale does not as a rule appear micaceous, differing in this respect from nearly all Pioche Shale except the C-shale member. The C-shale member of the Pioche may be distinguished by the lack of the pinkish Chisholm color; the C-shale member tends to be greenish and shows a small amount of micaceous material. Lumpy or bumpy interfaces are uncommon in the Chisholm. In thin section Chisholm Shale reveals a large amount of reddish brown and orange ferruginous pigment in the form of irregular granules scattered through an exceedingly fine grained nearly colorless matrix.

The Chisholm includes many limestone interbeds ranging in thickness from a few inches to about 8 feet (fig. 9). Where thick, the limestone beds have argillaceous partings. At the Shodde mine about 30 percent of the formation is limestone; it includes 12 limestone units within a total formation thickness of 135 feet. The limestone beds are fine grained and range from light olive gray to medium gray, usually mottled or stained pink and limonite brown. Fossils are abundant in limestone interbeds as well as in the shales. In addition to shell material, these limestones contain ovoidal bodies which suggest *Girvanella.*

The Chisholm is conformable with the Lyndon Limestone below and the Peasley Member of the Highland Peak Formation above; lithologic change at both contacts is abrupt and seemingly without intergradation. Because of the structural weakness and intermediate position of the Chisholm Shale between two rigid limestone units, both top and bottom contacts may show evidence of slippage parallel to bedding.

CHISHOLM SHALE AS ORE HOST

Limestone interbeds of the Chisholm Shale were evidently very susceptible to replacement by sulfide, as were those of the Pioche Shale. Around Mount Ely are several small mines where these limestones contain gossany iron matter and sporadic pockets of rich silver-bearing sulfides. The Chisholm has been much prospected throughout the district, its narrow outcrop being studded by pits, adits, and pinkish-tan-colored dumps. Presence of Chisholm ore has encouraged deeper exploration in the Pioche Shale, on the theory that the same feeding fissures might be reasonably expected to have mineralized limestone beds of the Pioche Shale at depth.

AGE AND CORRELATION

Fossils are nearly everywhere abundant and well preserved in the Chisholm Shale of the Pioche vicinity. In spite of extensive collecting by amateur and professional collectors, the weathered Chisholm continues to yield fossils. Most of the material, however, has come from shales, whereas the limestone members have been neglected. The Chisholm fauna remains an excellent subject for monographic study.

Studies of Chisholm faunas were initiated by Walcott (1886), who established their position in the early Middle Cambrian. Subsequently, Pack (1906b), Walcott (1916b), Resser (1935, 1937, 1942), and Palmer (1954) described and illustrated some of the Chisholm species. To date, most of these studies were based on float material from shales, and zoned collections have not been made.

Most abundant Chisholm fossils are *Zacanthoides typicalis* (Walcott), *Alokistocare piochensis* (Walcott) and *Alokistocare packi* Resser. Presence of *Glossopleura packi* Resser places the formation in the *Glossopleura* zone.

Beds probably equivalent to the Chisholm in age are known in the Abercrombie Formation at Gold Hill, Utah, in the Ophir Formation of the Tintic and Ophir districts, Utah, and in the Langston Limestone of the Wasatch Range. The Chisholm is correlated also with beds of the Cadiz Formation of southeastern California and part of the Bright Angel Shale at Grand Canyon. In the House Range, Utah, argillaceous limestone beds just below the Dome Limestone contain a *Glossopleura* fauna and are probably correlative with the Chisholm.[6] Shales which might be confused lithologically with the Chisholm in complex structural situations occur sparingly in the Burnt Canyon Member and in the lower part of the Mendha Formation at Arizona Peak near the Highland Queen mine (pl. 2).

Lists of common Chisholm Shale fossils identified by A. R. Palmer are given below.

USGS colln. 1403–CO; 8 feet above base of Chisholm Shale on south side of Burrows Canyon, Highland Range:
- *Alokistocare* cf. *A. subcoronatum* (Hall and Whitfield)
- *Athabaskia howelli* (Walcott)
- *Diraphora* sp.

USGS colln. 1406–CO; from dump of Abe Lincoln mine, west side of the Ely Range:
- *Alokistocare packi* Resser
- *Alokistocare piochense* (Walcott)
- *Eocrinus longidactylus* (Walcott)
- *Glossopleura packi* (Resser)
- *Glyphaspis kempi* (Pack)
- *Zacanthoides typicalis* (Walcott)

USGS colln. 1410–CO; on east side of Lime Hill on dump of prospect pit:
- *Alokistocare piochensis* (Walcott)
- *Athabaskia howelli* (Walcott)
- *Glyphaspis kempi* (Pack)
- *Zacanthoides typicalis* (Walcott)

USGS colln. 1414–CO; canyon south of Ely Valley mine, dump high on slope:
- *Alokistocare packi* Resser
- *Zacanthoides typicalis* (Walcott)

USGS colln. 1415–CO; dump at Half Moon mine.
- *Alokistocare packi* Resser
- *Alokistocare piochense* (Walcott)
- *Athabaskia howelli* (Walcott)
- *Glossopleura packi* Resser
- *Zacanthoides grabaui* Pack
- *Zacanthoides typicalis* (Walcott)

HIGHLAND PEAK FORMATION

Carbonate rocks 4,500 feet thick lie between the Chisholm Shale and the Mendha Formation and form the highest peak of the Highland Range (pl. 2). To these geomorphically prominent rocks, Westgate and Knopf (1932, p. 11) gave the appropriate name Highland Peak Limestone, here changed to Highland Peak Formation. To the uninitiated observer this thick and largely massive formation gives a first impression of stratigraphic monotony; closer examination, however, shows it to be a diverse limestone-dolomite sequence having for the most part highly variable facies composition. An added deterrent to stratigraphic division is the absence of fossils in most Highland Peak beds.

As mineral exploration continued near Pioche, it was found that Highland Peak strata occupied much of the surface where blanket deposits of zinc and lead were known or expected in depth. More detailed investigation of these strata demonstrated that the original Highland Peak Limestone can be divided into 13 lithologic units. Six of these have been mapped throughout the Ely Range, and most can with fair assurance be traced or correlated throughout the region of the Highland and Bristol Ranges. It is nonetheless recognized that the almost wholly lithologic criteria as applied here have definite limitations where correlation is concerned, and must be used with caution in a facies-variable carbonate sequence of this type. Only where sections are sufficiently continuous to reveal established vertical groupings, distinctive sets of beds, or sedimentary cycles, are these criteria dependable. Where the Highland Peak sections are short, as in isolated fault blocks, known repetition of similar carbonate facies through the column entails the obvious risks attending strictly lithologic identification and correlation.

A sixfold subdivision of the lower part of the Highland Peak has been used successfully by the mining profession in the Pioche and Bristol districts since the 1930's. The classification here adopted is virtually in agreement with that of the mining companies, except for the objectionable geologic names. Geologic names used by the mining companies are as follows in stratigraphic order:

6. Bristol lime
5. Platy dolomite
4. Newport lime
3. Black Davidson lime
2. Gray Davidson dolomite
1. Blue Davidson lime

Davidson, Newport, and Bristol have previously been used as formation names in other areas; "platy dolomite," being a lithologic term, is inappropriate.

An informal division of the Highland Peak was proposed by Wheeler and Lemmon (1939). In this scheme, 17 lithologic units were described, and each was given a letter designation, A to Q inclusive. With reference to the lower part of the formation, table 5 shows equivalence of the present scheme to those of Wheeler and Lemmon and of the mining companies:

[6] Wheeler (1948, p. 38) assigned these House Range beds to the "Burnt Canyon limestone" of the Pioche column. The true Burnt Canyon Member of the Highland Peak Formation is herein correlated with the lower part of the Swasey Formation of the House Range.

TABLE 5.—*Stratigraphic names for the lower part of the Highland Peak Formation, compared with equivalent terms proposed by Wheeler and Lemmon (1939) and those used by mining companies*

Formation	C. W. Merriam, this report	Wheeler and Lemmon, 1939	Mining company terms
Lower part of Highland Peak Formation	Meadow Valley Member	Highland Peak G	Bristol lime
	Condor Member	Highland Peak F	Platy dolomite
	Step Ridge Member	Highland Peak E Highland Peak D	Newport lime
	Burnt Canyon Member	Highland Peak C	Black Davidson lime
	Burrows Member	Highland Peak B	Gray Davidson dolomite
	Peasley Member	Highland Peak A	Blue Davidson lime

Wheeler (1940, 1948) in subsequent contributions named the Peasley Limestone, Burrows Dolomite, and Burnt Canyon Limestone with designated type sections on the west side of the Highland Range. Except for Highland Peak units A, B, and Q, all originally lettered divisions of Wheeler and Lemmon are typified by exposures in the Warm Spring section northeast of Panaca. These divisions include the Condor or "Highland Peak F." The name Condor was initially applied (Wheeler, 1948, p. 39) to "Condor member" of the "Swasey limestone," a House Range, Utah, formation. However, the type section of the Condor proposed by Wheeler is near Pioche, Nevada, in the Warm Spring vicinity. This unit is here designated as a member of the Highland Peak Formation. Type sections of the new Step Ridge Member and the Meadow Valley Member are proposed in the Ely Range, where each is well exposed and readily accessible.

For this study the Highland Peak is preserved with original content as a geologic formation, and its principal units are classified as members. Such a course seems preferable at present to removal of six or more formational units from the lower part of the original formation, thereafter retaining the term Highland Peak solely for the upper residuum. The named members occur in the productive part of the Pioche mining district where detailed mapping has been done. Group rather than formation status would be appropriate when all members are named and their type sections designated, at which time elevation of member to formation may be in order.

The fairly continuous Highland Peak section at Warm Spring provides a valuable yardstick (pl. 6), especially for those units above the Burnt Canyon Member. However, this section, like all others in the district, is considerably faulted and thickness measurements of some divisions are unreliable.

In the course of this investigation, the six named members that make up the lower part of the Highland Peak Formation were studied intensively with respect to stratigraphy, gross petrology, and geologic structure. In the northwestern Ely Range, these units occupy a large part of the surface above potentially ore-bearing ground (pls. 1, 2). Because of faulting and erosion, the seven upper divisions of the Highland Peak are seemingly absent from this area. In connection with drill exploration from the surface, correct identification of the thick Highland Peak units is especially important in estimating the position of deeply buried potential ore beds.

Rocks of the Highland Peak Formation extend through the Ely, Highland, and Bristol ranges and continue northward into the southern Shell Creek Range, north of the area shown in pl. 2. Certain of its members such as Peasley and Burrows Members are reported (Humphrey, 1945, p. 22–23) in the Groom district 75 miles southwest of Pioche. Middle Cambrian carbonate rocks having the general character of this formation are present over a much larger territory in the central and eastern Great Basin, where they attain a thickness of several thousand feet, and generally form prominent geomorphic features. In most places these strata are sparsely fossiliferous and in general are too poorly known at present for meaningful detailed comparison with the Pioche section. During the course of these studies, field comparisons were made with similar rocks of the House Range, Utah, and the Eureka district, Nevada (pl. 5). Preliminary comparisons have been made by others (Drewes and Palmer, 1957) with the Snake Range. The results seem to indicate that members of the Highland Peak Formation are not traceable with assurance into these outlying districts, although sporadic and nearly identical carbonate facies characteristic of the Highland Peak are recognized throughout. As the formation is traced into outlying districts, individual members tend to lose lithologic individuality or discreteness, with shift of depositional facies. Lithologic units wedge out and local units of limited extent are introduced as the overall content of the formation changes appreciably. How far the name Highland Peak Formation should be carried laterally from the Highland Range belt remains to be determined by areal mapping and facies analysis.

Paleontologic correlation of some Highland Peak units at Pioche with House Range units (pl. 5) indicate that nearly matching carbonate facies and even comparable stratigraphic sequences can be misleading in point of time equivalence. Peculiar carbonate facies which characterize the lower part of the Highland Peak near Pioche are recognizable also in the House Range Middle Cambrian, but in differing vertical order. Paleontologic control, while still inadequate, serves in this case to emphasize the risks of wholly lithologic correlation with distant sections in these facies-variable carbonate rocks.

LOWER PART OF THE HIGHLAND PEAK FORMATION

PEASLEY MEMBER

NAME AND OCCURRENCE

The Peasley Member takes its name from "Peaslee Canyon" [7] on the west side of the Highland Range (pl. 2), where it rests upon Chisholm Shale and is overlain by Burrows Member. As indicated by Wheeler (1940, p. 17), the type section is on the spur of Comet Peak south of "Peaslee Canyon". Westgate and Knopf (1932, p. 12), in the original description of the Highland Peak Formation, distinguished this unit as "dark-blue limestone" 90 feet thick above the Chisholm Shale south of "Peaslee Canyon". As here delimited, Peasley Member is essentially "Highland Peak A" of Wheeler and Lemmon (1939, p. 47), originally described at Comet Peak as "dark-gray, medium grained, thickly bedded massive limestone with numerous calcite stringers." In the Pioche mining district these beds have been known as "blue Davidson lime."

The outcrop area of this relatively thin unit is small in the Ely Range, the narrow band forming a somewhat cliffy slope above the subdued and even narrower Chisholm Shale. The Peasley Member is exposed in small fault blocks near The Point and has been mapped discontinuously along both sides of the Ely Range to Gray Cone, thence southward across the hills toward Panaca. Fault contacts with the incompetent Chisholm Shale, coupled with uncertainty as to the exact position of the upper depositional boundary with the Burrows, make most sections of the Peasley unsatisfactory for stratigraphic study. Good exposures are found on the north, west, and south sides of Mount Ely and at Gray Cone (pl. 3). Less continuous faulted sections lie north and northeast of the Prince mine and south of the Pioche No. 1 mine (fig. 8). The Peasley is poorly exposed in the Warm Spring section. By far the most continuous outcrops of this unit follow the Chisholm along the west side of the Highland Range.

THICKNESS

The type section of the Peasley Member is 150 feet thick. In the Ely Range the member is 152 feet thick at Gray Cone, 160 feet north of Mount Ely, and 98 feet at Warm Spring, where it is faulted at the valley edge. Faulting along the Chisholm-Peasley boundary commonly reduces the measureable thickness of both units. The Peasley seems to thicken and thin appreciably along the strike because the Peasley-Burrows contact undulates. To some extent the waviness of the contact may reflect the mapper's uncertainty as to where from point to point the actual boundary should be drawn.

LITHOLOGY

The Peasley Member is medium-dark- to medium gray limestone that is slightly bluish gray, detrital, less commonly oolitic, and medium to fine grained. It tends to be heavy bedded, massive, rough weathering, and more or less cliffy, with local intervals of thin bedding or color banding that range from half an inch to more than an inch in thickness. Light- and dark-gray mottling and streaking is characteristic, and in places, an alternation of light and dark color bands. In the lower 10 feet, a maroon or limonitic brown mottling is noted in some places. Three principal types of limestone intergrade and show various intermediate phases; these are detrital limestone, oolitic limestone, and algal limestone.

The detrital limestone is composed largely of well-rounded granules of very fine textured calcium carbonate, ranging from silt size to about 2 mm in diameter; scattered oolites and a few algal bodies are present.

The oolites in thin section average less than a millimeter in diameter. Only rarely do they show good concentric structure. Associated with the oolites are larger and smaller, much more irregularly rounded detrital granules of non-oolitic calcareous matter. The matrix is whitish, somewhat turbid calcite. The principal impurity is finely divided carbonaceous material, present in both oolites and detrital granules, but not in the calcite matrix.

Oolitic Peasley resembles oolitic phases of the Step Ridge Member and the lower part of the Lyndon Limestone. It exhibits the peculiar "tiger stripe" color differentiation like that of the Step Ridge. Only locally, however, is crossbedding, so characteristic of the oolitic limestones of the Step Ridge, noted in the Peasley.

The algal limestone is composed in large part of ovoidal bodies averaging about 10 mm in greatest diameter, a few exceeding 25 mm. In the interstices are scattered oolites and numerous rounded calcium carbonate granules ranging from less than 0.1 mm to about 1 mm. The cement is whitish turbid calcite. Although the texture of the cement, carbonate granules, and algal bodies is in general extremely fine, spots of medium to rather coarsely crystalline granularity are found in the calcite cement. The algal bodies do not as a rule show well-defined concentric structure. Many have formed around a piece of brachiopod or other shell which served

[7] On the Highland quadrangle (1916) and Highland Peak quadrangle (1953), this canyon is shown as "Peaslee Canyon." The spelling Peasley is probably correct.

as a nucleus. Fragmentary shell remains, some possibly *Hyolithes*, are likewise scattered through the matrix.

Fairly large algal nodules containing a shell fragment as the nucleus appear to be a distinctive feature of the Peasley. Some of these nodules exceed one inch in diameter. Algal nodules in the Lyndon do not, so far as known, attain such size, and all the many nodules examined from the Lyndon were devoid of the shelly material.

The coloration of the Peasley is very similar to that in parts of the Step Ridge and to the darker-gray phases of the Lyndon Limestone. The Peasley exhibits throughout, however, a slightly more bluish shade than the Lyndon and is rarely as dark as the darker-gray Lyndon. None of the Peasley as here defined is light gray or white like the light-colored phase of the Lyndon Limestone.

STRATIGRAPHIC RELATIONS

Good exposures of the normal Chisholm-Peasley contact are uncommon in the Ely Range because faults are localized in the incompetent shale of the Chisholm. On the west side of the Highland Range an abrupt but conformable contact may be seen near the Shodde mine in Lyndon Gulch (pl. 2). The lower few feet of Peasley at this locality has a pinkish mottling and contains edgewise limestone breccia. At Peaslee Canyon the type Peasley is conformably overlain by dolomite of the Burrows Member. Limestones interpreted by Wheeler (1940, p. 17, 19) as lowermost Burrows in this section and at Warm Spring near Panaca are regarded by the author on lithologic grounds as uppermost Peasley rather than lowermost Burrows. Slight local angular discordance within these upper limestones of the Peasley (emended) is probably the result of subaqueous scour and fill [8] rather than an unconformity of regional importance.

The Peasley-Burrows boundary is difficult to recognize where the upper part of the Peasley is dolomitized, or where the lower part of the Burrows is limestone rather than dolomite. In some places where both Peasley and Burrows are limestone, the boundary is seemingly gradational. At many points the contact is undulant, or markedly uneven, suggesting disconformity.

The upper part of the Peasley is more or less dolomitic northwest of the Pioche No. 1 shaft (loc. 26), in upper Buehler Gulch (loc. 27), and on the east side of Slaughterhouse Gulch at Tank Ridge (loc. 28). At the first-mentioned locality (26) dolomite interbeds occur in the bluish-gray upper part of the Peasley and are overlain with seeming gradation by mottled saccharoidal dolomite of the Burrows containing algal nodule ghosts. The Peasley-Burrows contact relations are further discussed under the Burrows Member.

AGE AND CORRELATION

The lower age limit of the Peasley is fixed as early Middle Cambrian by the abundantly fossiliferous Chisholm Shale, which conformably underlies it. Fragmentary fossil material in the Peasley itself provides nothing of age significance. Peasley and Burrows together may well be roughly correlative with the Dome Limestone of the House Range, Utah (pl. 5). The similarity of the Peasley to the House Range Millard Limestone of Wheeler (1948, p. 35) is probably deceiving, for paleontologic evidence in higher strata (see "Lyndon Limestone") suggests that the Millard Limestone and superjacent light-gray carbonate rocks are best alined with the Lyndon Limestone of the Pioche district, with which they agree in stratigraphic position.

BURROWS MEMBER

NAME AND OCCURRENCE

The name Burrows Member applies to dolomite and limestone between the Peasley and Burnt Canyon Members. Type sections of both Burrows and Peasley (Wheeler, 1940, p. 27) were designated in the same sequence on the northwest spur of Comet Peak south of "Peaslee Canyon." The exposures are continuous southward from the type section to Burrows Canyon, from which the name is taken. Dolomite of the Burrows changes laterally to limestone at many exposures; hence, the term "member" is more appropriate than a lithologic modifier.

The Burrows Member is virtually Highland Peak B of Wheeler and Lemmon (1939, p. 47). As presently interpreted the Burrows is, however, slightly less inclusive than the original definition, for 30 feet of limestone regarded by Wheeler (1940, p. 27) as lowermost Burrows is herein viewed as part of the underlying Peasley. Thus restricted, the Burrows type section is almost exclusively dolomite. Although Westgate and Knopf do not specifically differentiate and name this unit, it is probably the "gray limestone" 560 feet thick measured by them south of "Peaslee Canyon." In the Ely Range, strata of the Burrows interval are known to the mining companies as "Gray Davidson dolomite."

Discontinuous fault-block exposures of the Burrows occur along the west flank of the Ely Range from a position 1,500 feet south of The Point to the vicinity of Caselton, thence southward to the hills northeast of the Prince mine (pl. 3). The intermediate slopes of Mount

[8] In a later contribution, Wheeler (1948, p. 33, 36) deemphasized the stratigraphic importance of these minor discordances, considering them "diastems."

Ely are underlain by interfingering limestone and dolomite of the Burrows. In this belt of lateral facies change, the stratigraphy is complex and confusing. Dolomite of the Burrows forms large blocky outcrops on Tank Ridge west and south of the Pioche No. 1 mine, and the formation is exposed on the east slope of Lime Hill and in the southeast foothills near the Alps mine. Burrows outcrops may be followed southward from Gray Cone across the Ely Range in several fault blocks, the most southerly being that at Warm Spring (pl. 2). Continuous exposures of dolomite of the Burrows are found in the Highland Range, being especially well shown from Burnt Canyon southward to the slopes east of the Pan American mine.

Factors of thickness and resistance to erosion make the Burrows, like the Step Ridge Member, a geomorphically prominent and areally extensive unit.

THICKNESS

The type Burrows (Wheeler, 1940, p. 28–29) as redefined is about 370 feet thick. Elsewhere in the Highland Range greater thicknesses were measured, for example, both north of Lyndon Gulch and along the first spur north of Burrows Canyon where it is about 520 feet thick.[9] The section north of Burrows Canyon however, is thickened somewhat by faulting. In the Highland Range, Westgate and Knopf (1932, p. 12) measured 560 feet of the "gray limestone" which seemingly corresponds to the Burrows Member.

Faulting makes most measurements of the Burrows in the Ely Range untrustworthy, but in general the thickness is extremely variable from one locality to another. For example intertonguing dolomite and limestone of the Burrows at Mount Ely is only about 300 feet thick, but the seemingly unbroken section south of Gray Cone measures about 490 feet (fig. 10). Because of faulting, only about 90 feet of Burrows was measurable at Warm Spring. In view of the faulting it can not be concluded that the variations in thickness are related to conditions of deposition.

LITHOLOGY

Dolomite predominates in the Burrows Member but here and there changes to fairly pure, generally very fine grained limestone. Locally in the Highland Range, the section of this member is almost entirely dolomite, but in the Ely Range, it is commonly limestone over a considerable extent. In few places is the Burrows section wholly limestone.

Typical dolomite of the Burrows is light to medium gray and medium dark gray. Bedding is usually thick, and the outcrops massive and blocky with a ragged cliffy expression at many points. Like most rigid dolomites subjected to deformation, the Burrows is generally much jointed and fractured. Texture is saccharoidal, ranging from medium to coarse crystalline. Some weathered surfaces show a faint limonitic brownish stain, but in general the iron content is low. Silica in the form of chert or jasperoid is seemingly negligible.

At Gray Cone and the first hill to the south (fig. 11), the Burrows is represented in considerable part by fine-textured or lithographic limestone, which is light gray or almost white to medium and medium dark gray in color. Streaks and patches of dark gray occur in the light phases, while in the darker areas the opposite is true. The limestone facies of the Gray Cone area is in general thick bedded, massive, and not uncommonly shows a banded color differentiation parallel to bedding. The bands range in thickness from less than 1 inch to several inches. Such massive limestones develop smooth knobby exposures which contrast with the ragged, blocky surfaces formed on normal dolomite of the Burrows.

Common features of the Burrows limestone facies are irregular white calcitic inclusions for which the term "bluebird structure" is adopted. The name is derived from the Bluebird Dolomite of Middle Cambrian age at Tintic, Utah, wherein these peculiar structures were first described (Lindgren and Loughlin, 1919, p. 28). As observed in limestone facies of the Burrows at Gray Cone the bluebird structure (fig. 11) exhibits a great variety of shapes, sizes, and patterns, ranging from highly irregular branching and vermiform bodies to those which were originally globular or tubular before collapse. The diameter of tubular forms ranges from 2 mm to about 5 mm. Locally the collapsed tubes exhibit a median partition in longitudinal section. On both sides of the partition, calcite crystals form thick walls with long crystal axes oriented perpendicular to the outer surface of the tube. Certain of the ramifying calcite networks associated with bluebird structure suggest "Stromatactis-like frame builders" described by Lowenstam (1950, p. 440–441) in Niagaran reef bodies.

Bluebird structure is especially characteristic of dark-gray limestone patches in the Burrows limestone facies, where the white calcitic material of the structure stands out in sharp contrast. In thin section the dark-gray limestone matrix shows traces of rounded granules and is presumably detrital. It is possible that localization of abundant bluebird structure in the more highly carbonaceous dark facies indicates a locus of more vigorous organic growth than in surrounding areas of light-gray limestone. That bluebird structure is itself a product of organic activity has not, however, been demonstrated.

[9] Measurements scaled from mapping by C. D. Campbell and J. A. Reinemund, U.S. Geological Survey, in 1943.

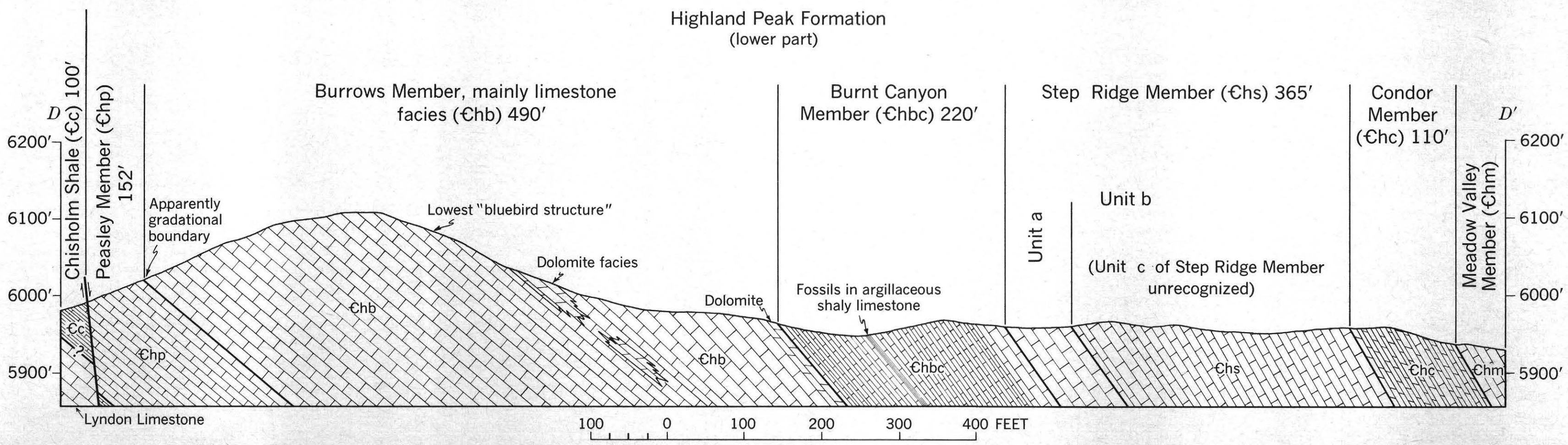

FIGURE 10.—Measured section (*D–D′*) of Highland Peak Formation south of Gray Cone. See plates 2 and 3 for location of section.

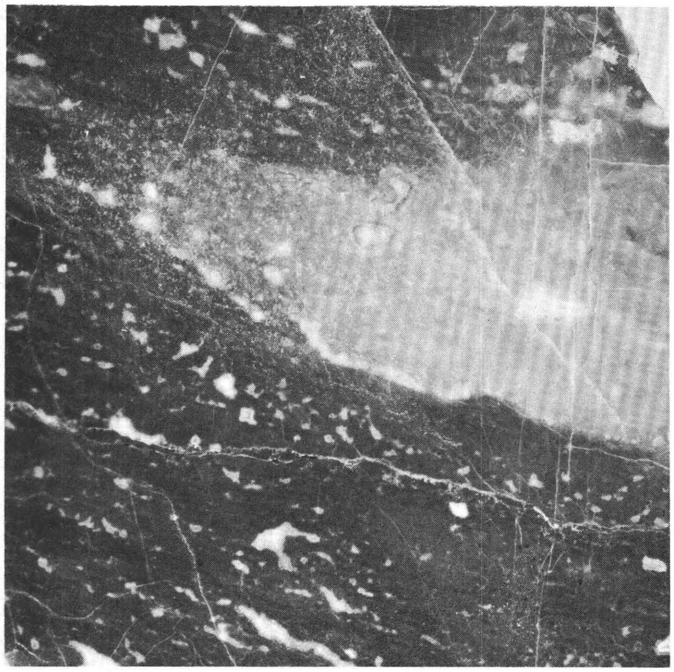

FIGURE 11.—Limestone facies of the Burrows Member of the Highland Peak Formation. Smoothed surface of specimen from the measured section south of Gray Cone shows mottled and fine texture. White patches are bluebird structure. Natural size.

Bluebird structure occurs also in dark limestones of the Step Ridge Member. It is present in the Lynch Dolomite of the Ophir area, Utah (Gilluly, 1932, p. 16), in the Young Peak Dolomite at Gold Hill, Utah (Nolan, 1935, p. 11), and in the Eldorado Dolomite at Eureka, Nev. (Nolan, Merriam, and Williams, 1956, p. 10). Although most occurrences of this structure in the Pioche area are in limestone, the commonest environment elsewhere would seem to be dolomite. At Gold Hill, Utah (Nolan, 1935, p. 11), bluebird structure is reported in both limestone and dolomite.

Thin sections of the light-gray or white lithographic limestone facies reveal indications of detrital origin, although no oolites or fragments of organic origin were recognized. Present are numerous minute seams and irregular inclusions of clear calcite that resulted from partial recrystallization.

Many small fault block exposures of lithographic and oolitic carbonate rocks were recognized during the course of detailed mapping; these commonly occur in structural situations that leave their correct stratigraphic identity uncertain. Confusing situations of this kind were found in upper Slaughterhouse Gulch (pl. 3) and near the head of Churndrill Valley, especially where the Step Ridge Member and lithologically similar undolomitized Burrows Member are in fault contact. Much confusion stems from the fact that the Burrows lithographic limestone facies are megascopically indistinguishable from those of the upper part of the Lyndon and the Step Ridge. Moreover, bluebird structure occurs in dark-gray carbonaceous limestone patches of both the Step Ridge Member and the undolomitized Burrows. Factors to be considered in distinguishing these carbonates are the scarcity of oolites in the undoubted Burrows, and the general absence of dolomitization in the unquestioned Step Ridge. Neither Lyndon nor Step Ridge seem greatly susceptible to dolomitization in the Pioche area, whereas the Burrows is more often dolomite than not. Fault blocks of crossbedded oolitic dolomite texturally reminiscent of the Step Ridge Member are therefore perplexing.

STRATIGRAPHIC RELATIONS

Stratigraphic problems which arose during mapping of the Burrows relate especially to the position and character of its boundaries, to much variation in thickness, and to complex facies change from dolomite to limestone within the member. To these must be added the possibility of confusion with other carbonate units of the Pioche area, facies of which resemble those of the Burrows.

Lack of marker beds eliminates division of the member or determination of stratigraphic position within it by lithology alone. The lower part of the Burrows, however, may sometimes be distinguished from higher beds by abundant ghosts of ovoidal algal nodules and by its light- and dark-gray mottled pattern.

Three sets of local conditions were recognized as the Peasley-Burrows contact was mapped through the Ely Range: (1) normal limestone of the Peasley overlain by normal dolomite of the Burrows, (2) limestone of the Peasley overlain by Burrows limestone facies, (3) both the upper part of the Peasley and the lower part of the Burrows dolomitized. Where dolomite is in contact with dolomite or limestone with limestone, delineating the precise boundary between the two members becomes difficult or impossible.

Limestone of the Peasley is overlain by dolomite of the Burrows at Gray Cone. In its lower part this dolomite includes tongues and patches of limestone, the amount of limestone increasing upward. Only 1,000 feet away in the hill south of Gray Cone, the Peasley Member is directly overlain by the Burrows limestone facies (fig. 10). For mapping purposes the Peasley-Burrows boundary here was arbitrarily placed at the base of the lowest light-gray lithographic limestone body; the boundary relation appears to be transitional. Limestone persists upward to make about 85 percent of the member. In this section, which is 490 feet thick, the lower 300 feet exhibits an irregular patchy distribution of massive light-gray, medium-gray, and medium-dark-gray lithographic and fine-grained limestones with color bands that follow bedding. Bluebird structure appears 290 feet above the base. In this predominantly limestone column, irregular pods of saccharoidal dolomite occur 320 feet above the base, and the upper 15 feet of the member is mainly dolomitic.

Possible existence of unconformities between the Burrows and members above and below is suggested by variations in thickness from point to point, and locally by contact features.[10] At the mouth of Buehler Gulch (pl. 3) 1,600 feet north of Caselton (locs. 29, 30), the limestone of the Peasley is overlain by dolomite of the Burrows with so undulating a contact as to invite suspicion of disconformity. At one exposure (loc. 30) a pinkish stain on the contact surface might be interpreted as evidence of emergence and weathering. A similar highly uneven Peasley-Burrows contact was recognized on the east side of Lime Hill (loc. 31). In Churndrill Valley (loc. 32) the same contact shows no appreciable relief. Close study of these uneven contacts actually reveals no unequivocal evidence of erosion, but on the contrary suggests rapid gradational passage from limestone below to dolomite above.

Although an unconformity between the Burrows and the overlying Burnt Canyon Member has previously been postulated (Wheeler, 1940, p. 28), the mapping of this contact gave no compelling evidence of a break. Normally this boundary is characterized by a change upward from thick-bedded saccharoidal dolomite, or less commonly massive fine-textured limestone, to thin-bedded rather fine grained dark-gray locally fossiliferous limestone. Not uncommonly, however, dolomitization did not cease abruptly with the topmost Burrows, but also affected the lowermost Burnt Canyon, which is a zone of alternating and interfingering dark-gray limestone and dolomite. Northwest of the Pioche No. 1 shaft (loc. 33) and near the head of Buehler Gulch (loc. 34), this partly dolomitic basal Burnt Canyon zone is about 25 feet thick. It is well exposed on Tank Ridge (loc. 35), comprising interbedded limestones and magnesian limestones, which change abruptly upward to well-bedded dark-gray limestones. At other points in this vicinity (loc. 36), the lower part of the Burnt Canyon shows only patches of dolomite in the limestone. On the whole, detailed study of the boundary of this member gives the impression of transition or intergradation rather than disconformity.

DOLOMITIZATION

Stratigraphic study of the Burrows Member unavoidably leads into familiar but as yet unresolved structural, geochemical, and oceanographic problems of dolomite origin. Capricious lateral intertonguing of limestone and dolomite is present in all parts of the member. Where the rock is prevailingly dolomite, one finds sporadic islands or tongues of lithographic limestone 30 feet or more across. Conversely, in predominantly lithographic limestones, there are bodies of saccharoidal dolomite.

Limestone-dolomite relations were mapped and studied in some detail at Mount Ely, at Gray Cone, and at the north end of Tank Ridge. The contacts behave fantastically, following a bedding plane for perhaps several feet, then swinging diagonally through a bed to a higher bedding plane.

Where the Burrows Member is limestone rather than dolomite, the limestone is generally dense, fine-textured or lithographic. From this it is reasoned that the primary carbonate which altered to dolomite was also of the same general lithographic character; however, it is possible to reason that the initial pre-dolomite carbonate facies differed texturally and chemically from the lithographic phase and because of these differences was the part which became dolomite. By the same token, the finer and denser limestone survived as such because it was less susceptible to the change.

Behavior of the Burrows dolomite-limestone boundaries in the Ely Range brings to mind similar phenomena noted by Gilluly (1932, p. 16) in the Lynch Dolomite of the Ophir district and by Nolan (1935, p. 10) in the Young Peak Dolomite at Gold Hill, Utah. In all three there is abrupt change from limestone to dolomite within a single bed. According to Gilluly the changes at Ophir are apparently unrelated to fissures, a conclusion which seems inescapable for many of the abrupt changes in the Burrows at Pioche.

Among geologic factors considered in connection with the present stratigraphic study were the presence or the absence of fracturing or brecciation of the dolomitized rock, the presence or the absence in the dolomite of ferruginous matter and silica (jasperoid), the sharpness of the limestone-dolomite contact, and structural or bedding control. At many observed exposures the lateral boundaries of unfractured massive limestone with dolomite are knife-edge sharp, jagged and have zigzag configuration. These reaction contacts seem to represent the advancing front of a magnesium-rich zone.

Many Burrows exposures reveal that fracturing has a definite bearing upon the dolomitization problem, whether the dolomite be clearly hydrothermal and related to fissuring or whether it be of supposedly primary or diagenetic origin. For example, relatively iron-free and silica-free, homogeneous, and presumably diagenetic dolomite was followed at one outcrop to a

[10] Evidences of Peasley-Burrows unconformity cited by Wheeler (1940, p. 27–28) are not relevant here; they occur locally within what is presently regarded as the upper part of the Peasley Member and are seemingly manifestations of subaqueous scour.

point where it terminated against a sharp fracture on which no evident displacement was noted. At other points, fractures seem to have played a role in facilitating secondary or late movement of magnesum-bearing solutions. Supposedly primary dolomite masses which adjoin limestone have locally been subjected to leaching, and the derived magnesian solutions have migrated along fratures into contiguous limestone. In this manner secondary and nonhomogeneous dolomitic alteration took place in rocks which escaped the initial additive diagenetic reaction.

Near the mouth of Buehler Gulch (pl. 3) the uneven Peasley-Burrows contact previously mentioned (loc. 29) gives evidence of dolomite control by minor fractures. At this contact numerous steeply dipping fractures, which show no clear evidence of displacement, cross from the dolomite above into limestone of the Peasley below. Magnesium derived by leaching from the Burrows apparently moved downward along these fractures to various depths within the limestone of the Peasley, bringing about secondary dolomitization therein. As a result, the uneveness and irregularity of the Peasley-Burrows contact is accentuated.

Most of the dolomite of the Burrows is evidently a product of additive alteration which affected a wide area of buried sea bottom during one rather specific interval of geologic time. The extent or the intensity of the dolomitization process varied greatly with geographic position and was influenced by the character and initial structure of the original carbonate sediment and by local differences in chemical, physical, and biologic factors of marine environment. At the one extreme, dolomitization of the member approaches completeness in the Highland Range. To the east in the Ely Range, the sections at Mount Ely and Gray Cone illustrate the opposite extreme, in which sporadic dolomite, makes up only about 15 percent of the rock, with various intermediate stages.

In theory the additive diagenetic changes came about shortly after accumulation of the carbonate mud, but quite probably after initial consolidation. Sea water is assumed to have been the source of magnesian solutions responsible for the reaction. These solutions may, to be sure, have circulated at considerable depths in the solidifying sediment, well below the interface between sea and mud. Given proper conditions of porosity and permeability, trapped or connate waters high in magnesium might continue to bring about dolomitization long after lithification.

The predominance of diagenetic or primary dolomitization in the Burrows does not rule out the possibility that local dolomite bodies in this unit may be the result of fissure activity. Late hydrothermal dolomitization was recognized in the overlying limestone of the Burnt Canyon; locally in the Burrows such dolomitization may well be superimposed upon earlier formed diagenetic dolomite.

AGE AND CORRELATION

Undiagnostic algal nodules (*Girvanella*) and bluebird structure provide no evidence of age. However, the Burrows is conclusively Middle Cambrian, being bracketed by overlying fossiliferous Burnt Canyon and by the richly fossiliferous Chisholm Shale below, from which it is separated by the Peasley Member.

The Burrows probably correlates with the Dome Limestone in the House Range, Utah (pl. 5), as suggested by faunal ties between the Burnt Canyon Member at Pioche and the lower part of the Swasey Formation in the House Range.[11] Lithologic similarities invite comparison of the Burrows with the Lynch Dolomite at Ophir, Utah, the Young Peak Dolomite at Gold Hill, Utah, the Bluebird Dolomite at Tintic, and portions of the Eldorado Dolomite at Eureka, Nev. Absence of fossils, however, obviates direct correlation.

BURNT CANYON MEMBER

NAME AND OCCURRENCE

The name Burnt Canyon Member is adopted for dark-gray well-bedded fossiliferous limestones that lie between the Burrows Member and the Step Ridge Member. Described by Wheeler and Lemmon (1939, p. 47) as "Highland Peak C," these rocks were later designated as "Burnt Canyon limestone" by Wheeler (1948, p. 36) with the type section on the west side of the Highland Range between "Peaslee Canyon" and Burnt Canyon.

In the Ely Range this unit has long been known as "Black Davidson limestone," so named for its occurrence together with underlying "Gray Davidson dolomite" and "Blue Davidson limestone" at the Davidson shaft. The Burnt Canyon Member with its well-preserved fossils and distinctive lithology proves to be a reliable stratigraphic datum and a valuable unit for correlation with distant Cambrian sections.

Large exposures of the Burnt Canyon Member occur at Mount Ely a short distance below the summit and at the head of the north fork of Slaughterhouse Gulch. Faulted and incomplete sections are found on Tank Ridge, west and south of Pioche No. 1 mine, and along the east side of Churndrill Valley near its head. Discontinuous badly faulted exposures on the west side of the Ely Range extend from the area east of Caselton southward to hills east of the Golden Eagle mine (pl. 3). Isolated Burnt Canyon exposures have been

[11] This interpretation is somewhat at variance with that of Wheeler (1948, p. 36, fig. 5), who regards the Burrows as correlative with limestones herein alined with the light-gray Lyndon Limestone.

mapped north of Pioche at Williams Hill and southeast of town in conspicuous Lime Hill. The member crops out in the southeastern part of the Ely Range northwest and south of Gray Cone. For purposes of stratigraphic study, the sections at Mount Ely, the hill south of Gray Cone (fig. 10), and Warm Spring north of Panaca (pl. 6) are most satisfactory. In the Highland Range, the Burnt Canyon is much less faulted than it is near Pioche, and the sections are more continuous laterally.

THICKNESS

Burnt Canyon Member of the type area (Wheeler, 1948, p. 47) is about 300 feet thick. Measured sections in the Ely Range give the following thicknesses: Mount Ely, 200 feet; Gray Cone, 220 feet; Warm Spring, 162 feet. Average thickness of 190 feet in the Pioche area thus implies thickening westward toward the Highland Range type area.

LITHOLOGY AND STRATIGRAPHIC RELATIONS

The Burnt Canyon Member is predominantly thin-bedded medium-dark-gray to dark-gray commonly very fine grained limestone similar to that of the upper part of the Combined Metals Member of the Pioche Shale. Individual beds commonly range in thickness from 1/8 inch to more than 1 inch, averaging about half an inch. Locally, thin beds show laminations no more than a millimeter thick; at the other extreme a few beds attain a thickness of 1½ feet. Bedding ranges from fairly even to undulating and nodular, with marked pinch and swell features. On the weathered surface, some of the highly carbonaceous beds are medium light gray. Characteristic features are grayish-red to moderate-red splotches and partings of argillaceous matter. Fossils are abundant locally in thin reddish clayey intercalations, which at some points thicken to several inches of shale. In such argillaceous zones the limestone beds weather in platy fashion, showing extremely bumpy interfaces with highly irregular, sometimes vermiform depressions filled by the reddish clay material.

Oolitic limestone beds and lenses contain ovoidal nodules of probable algal origin (*Girvanella*). The algal bodies average about 3 mm in diameter and are larger than oolites but smaller than the comparable algal bodies in the Lyndon and other Cambrian units of the region.

By reason of its thin-bedded and locally shaly character the Burnt Canyon weathers in somewhat subdued fashion as compared with the massive limestones above and below. Such is particularly true of the lower half, which not uncommonly forms depressions and saddles, whereas the upper part may show greater relief, together with the overlying Step Ridge.

As elsewhere noted, the Burnt Canyon lies conformably upon the Burrows Member, being gradational with it at some places. A precise contact is not everywhere definable by reason of the alternating dark-gray limestone and dolomite beds which locally occupy this boundary zone. Nowhere in the Ely Range was clear evidence of disconformity recognized (Wheeler, 1940, p. 28; 1948, p. 37). Burnt Canyon Member is conformably overlain by unit *a* of the Step Ridge Member. Although the change to light-gray lithographic limestone of unit *a* is abrupt, close examination of the actual boundary gives the impression of gradation in some places.

At least three lithologic zones are recognizable within the Burnt Canyon Member. A lower zone about 25 feet thick is characterized by interbedded dark-gray limestone and light-gray dolomite. The overlying zone some 75 feet thick shows reddish mottling and argillaceous partings or interbeds with fossils. Edgewise limestone conglomerate occurs in this zone (locs. 37, 38). An upper zone about 90 feet thick is somewhat thicker bedded and in part is medium to light gray. The Burnt Canyon tends to be oolitic and crossbedded especially in the upper 25 feet and resembles the tiger stripe facies of Step Ridge unit *b*.

Good exposures of the reddish tan fossil-bearing shales of the Burnt Canyon Member are found near the head of Churndrill Valley on the east side (loc. 18), on the east side of Lime Hill (loc. 22), and south of Gray Cone. At locality 18 the reddish tan clayey material occurs as thin interbeds in dark-gray fossiliferous limestone. At the Lime Hill locality a 10-foot bed of fossiliferous shale suggests Chisholm Shale lithology. The excellent shaly fossil bed south of Gray Cone lies 80 feet stratigraphically above the base of the member. The precise horizon of the other fossil occurrences is unknown; presumably they fall near the middle of the Burnt Canyon Member.

The limestone of the Burnt Canyon Member was susceptible to dolomitization throughout its entire thickness. In this respect it resembles the underlying Burrows, but differs from the overlying Step Ridge. Laterally continuous primary or diagenetic dolomite appears to be more or less restricted, however, to the lower 25 feet of the member. In the higher part, discontinuous, patchy, and irregular dolomitization was noted at many points. In several places these patches are clearly related to feeding faults or fissures, from which magnesian solutions passed outward along favorable beds. Shattering of the dolomite is characteristic of these occurrences, and magnesian solutions usually failed to penetrate far along bedding from the highly disturbed rock. Local fissure-fed dolomites of this sort include jasperoid and ferruginous matter. Limestone of the Burnt Canyon has been brecciated and dolomitized along a fault on the east side of Churndrill Valley just north of the Prince mine road.

AGE AND CORRELATION

According to A. R. Palmer, fossil assemblages collected from the Burnt Canyon Member in Churndrill Valley (loc. 18), at Lime Hill (loc. 22), and in the vicinity of Gray Cone (loc. 25) contain undescribed species of *Kootenia* and ptychoparioid trilobites. This distinctive assemblage is known only from Burnt Canyon Member of the Ely Range.

The unit identified as "Burnt Canyon" in the House Range by Wheeler (1948, fig. 5) contains species of *Glossopleura* and is here considered correlative with Chisholm Shale (Palmer, 1956, p. 672). The Ely Range true Burnt Canyon Member seemingly correlates with the shaly lower part of the Swasey Formation in the House Range (pl. 5), to which Wheeler erroneously applied the name "Condor Formation."

STEP RIDGE MEMBER

NAME AND OCCURRENCE

Here named for Step Ridge (pl. 1), this limestone member (fig. 12) occupies the stratigraphic interval between the Burnt Canyon Member and the Condor Member. In the type area along Step Ridge, and on the east side of Churndrill Valley, the unit is widely exposed but discontinuous, being broken by many high-angle faults. The Step Ridge is fully exposed in the southern part of the Ely Range near Warm Spring, where it embraces the combined "Highland Peak D" and "Highland Peak E" of Wheeler and Lemmon (1939, p. 47). The preoccupied name "Newport lime" has been used for this unit by mining companies.

The Step Ridge Member occupies large areas in the northern Ely Range, where it makes prominent geomorphic features. The unit has been mapped from Mounty Ely southeastward through upper Slaughterhouse Gulch (pl. 3), thence along both sides of Churndrill Valley. In the east foothills north of Pioche, it crops out at Williams Hill and southeast of the town in conspicuous Lime Hill (fig. 4) where the summit and west slope are made by resistant, cliffy portions of the member. Good outcrops are found in the foothills northwest and south of Gray Cone and again farther south in the Condor Canyon–Warm Spring vicinity.

THICKNESS

In the mapped area at Step Ridge (pl. 1), this member is about 740 feet thick; at Warm Spring it is 775 feet thick (pl. 6). Initial variation in thickness of some magnitude is suggested by the fact that a measured section (fig. 10) in the hill south of Gray Cone reveals only 365 feet of Step Ridge Member. This part of the section does not seem badly faulted. At most exposures where faulting is not an important factor, the thickness probably exceeds 600 feet. Unit *a* of the Step Ridge ranges in thickness from 35 feet in Churndrill Valley to about 70 feet south of Gray Cone and at Warm Spring. Unit *c* ranges from less than 30 feet to 50 feet as it is followed along the crest of Step Ridge.

LITHOLOGY AND STRATIGRAPHIC RELATIONS

The Step Ridge exhibits a wide range of lithologic types, from white and dark-gray dense lithographic limestones to mottled oolitic limestones. Most prevalent and distinctive is a striped oolitic variety to which the name "tiger-stripe limestone" is given (fig. 13). Commonly a dull medium bluish gray, these oolitic limestones are generally crossbedded, showing long sweeping foreset beds. To a lesser extent, nearly identical limestones occur in the Peasley and the Lyndon. Mottling is common in all phases of the Step Ridge; where the rock is very light gray, patches are darker gray, or the converse is true. Bedding on the whole is obscure or thick and the outcrops are generally massive and cliffy. Dense resistant beds of the Step Ridge are the cap rock of prominent geomorphic features such as Mount Ely. Bluebird structure is characteristic of the Step Ridge Member as well as of the Burrows Member.

In the vicinity of Churndrill Valley (pl. 1), it was feasible to divide the Step Ridge into three map units, which from bottom to top are called unit *a*, unit *b*, and unit *c*. Units *a* and *c*, the thinner subunits, consist mainly of light-gray and white, massive lithographic limestones very similar to the white limestone member B of the Lyndon Limestone, and white undolomitized lithographic lime of the Burrows Member. Both units *a* and *c* are dense and resistant to weathering and form bold cliffy exposures.[12] Unit *a* is well exposed at the summit of Mount Ely and on the east side of Churndrill Valley near its head. Unit *c* occurs in a series of discontinuous light-gray cliff exposures along Step Ridge (fig. 12) from Mount Ely southward. At the top of this unit just beneath the contact with the overlying Condor Member is a massive 3- to 5-foot dark-gray limestone containing an abundance of bluebird structure. Scattered darker-gray phases occur in the light-gray limestone of unit *c*. Unit *c* of the Step

[12] The mining companies refer to unit *c* of the Step Ridge Member as "false Prince A" and unit *a* of the Step Ridge Member as "false Prince B". The dense lithographic limestones in each are quite similar to the "white Prince lime" of the mining companies which is member B of the Lyndon Limestone of present usage.

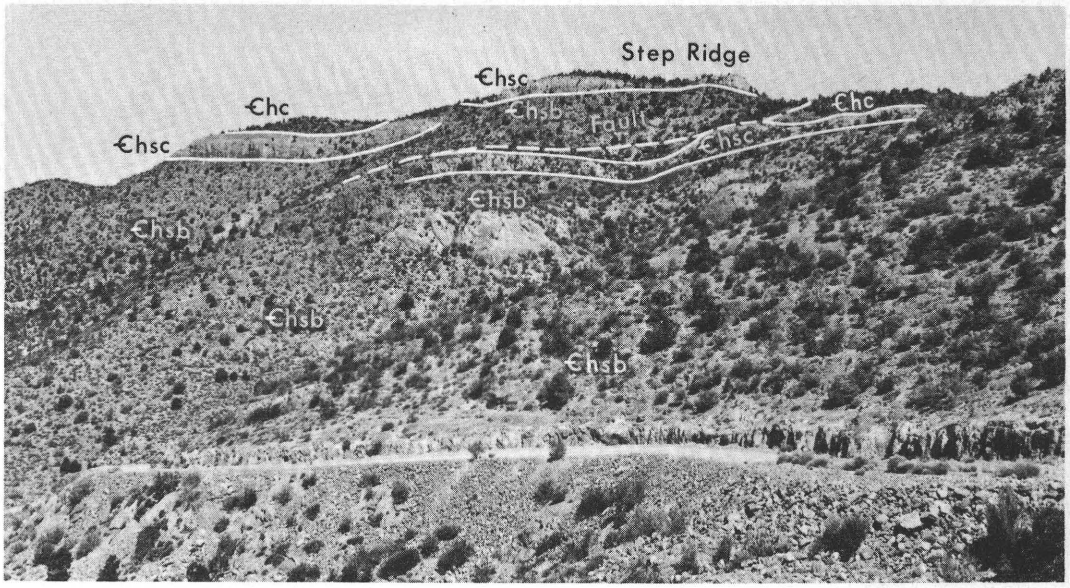

FIGURE 12.—View northward across Prince mine road toward the crest of Step Ridge. Light gray cliffy unit c (Ꞓhsc) of the Step Ridge Member of the Highland Peak Formation stepped down by northeast faults. Condor Member of Highland Peak Formation (Ꞓhc) at ridge crest on left. Foreground is unit *b* (Ꞓhsb) of the Step Ridge Member.

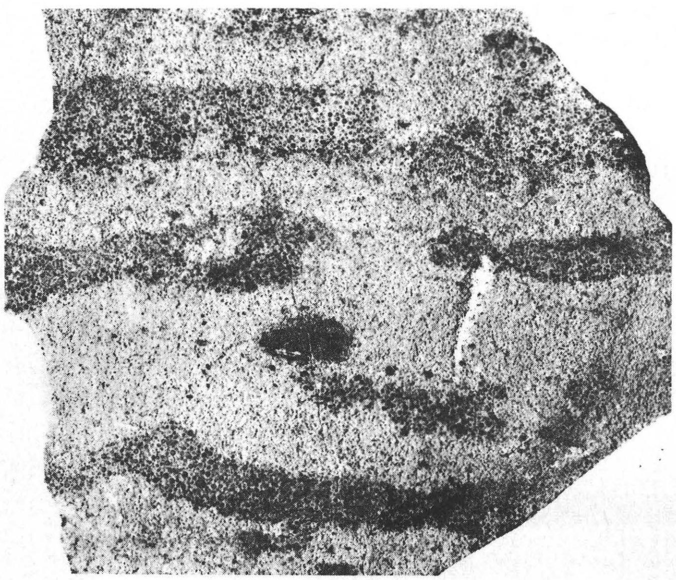

FIGURE 13.—Typical mottled oolitic tiger stripe limestone facies in unit *b* of the Step Ridge Member of the Highland Peak Formation. Weathered surface. Natural size.

Ridge was not recognized in the more southerly outcrops of this member at Gray Cone and Warm Spring.

The greater part of the Step Ridge Member falls in unit *b*, which is characterized by large lenticular bodies of crossbedded tiger-stripe oolitic limestone. Unlike Lyndon oolitic limestone, these bodies seldom include algal nodules. Also present in unit *b* are massive light- and dark-gray-mottled fine-grained limestones having the appearance of magnesian limestone of the Meadow Valley Member. Bold lenticular masses of light-gray lithographic limestone like those of units *a* and *c* are uncommon in unit *b;* however, on Step Ridge west of upper Churndrill Valley small lithographic bodies as much as 20 feet thick are present in the upper 80 feet of this middle unit.

Unit *a* of the Step Ridge is "Highland Peak D" of Wheeler and Lemmon (1939, p. 47). "Highland Peak E" is approximately equivalent to combined units *b* and *c* of the Step Ridge Member.

Very little dolomite was found in the Step Ridge. Near Warm Spring a weak incipient dolomitization was noted locally in the lower part. Scarcity of dolomite in the Step Ridge is rather surprising, for light-gray lithographic limestones of the Burrows were quite susceptible to magnesian replacement. Exposures of dolomitized oolitic tiger-stripe limestone at the head of Slaughterhouse Gulch have the appearance of the Step Ridge oolites. In this intensely faulted area, identity remains uncertain and the dolomitic rocks in question may be part of either Peasley, Burrows, or Step Ridge. Whereas the Step Ridge Member is readily distinguishable when top and bottom contacts or a considerable part of the member are exposed, identity may remain in question when only small segments of the member are in view. Incomplete fault block exposures (fig. 3) may easily be confused with Lyndon, uppermost Burnt Canyon, Peasley, Burrows, or Meadow Valley, all of which include facies indistinguishable from parts of the Step Ridge.

The Step Ridge is conformable upon the Burnt Canyon Member and is overlain by the Condor Member with apparent conformity. Uppermost beds of the Burnt Canyon in places closely resemble the mottled middle Step Ridge facies.

AGE AND CORRELATION

The Step Ridge Member has yielded no fossils, but its lower age limit is firmly established by the fossiliferous limestone of the Burnt Canyon Member which lies conformably beneath.

Paleontologic correlation of the Burnt Canyon Member at Pioche with the lower shaly part of the Swasey Formation in the House Range, Utah, suggests that Step Ridge and the upper part of the Swasey are also correlative (pl. 5). Moreover the upper limestone of the Swasey shares lithologic features of the Step Ridge, such as the oolitic tiger-stripe facies and the cliff-forming tendency. But lithologically the Step Ridge even more closely resembles the House Range Dome Limestone, which is quite probably older. Both are unfossiliferous massive cliff-forming limestone comprising dark mottled facies with lighter gray lithographic phases. Both are characterized by oolitic tiger-stripe cross-bedded limestone and bluebird structure.

CONDOR MEMBER

NAME AND OCCURRENCE

The Condor Member is named for Condor Canyon (pl. 2), 2½ miles north of Panaca (Wheeler, 1948, p. 39). This is the most distinctive map unit of the Highland Peak Formation. Mining-company geologists refer to it as the platy dolomite because of the dolomitic nature and platy weathering of some beds. Actually the Condor is diverse lithologically, containing calcareous sandstone and limestone as well as impure siliceous dolomite. Westgate and Knopf (1932, p. 12) recognized the potential value of this member in interpretating the complexly faulted structure. Although unnamed by them, its occurrence north of the Prince mine was correlated with that near Gray Cone and with a 98-foot unit east of Panaca.

This member was first designated as "Highland Peak F" by Wheeler and Lemmon (1939, p. 47), it was later assigned the name "Condor member" by Wheeler (1948, p. 39) and considered by him a member of the "Swasey limestone," a House Range, Utah, formation. But in naming the Condor, Wheeler stated that the type section "* * * is in the Panaca Hills, Pioche district, Nevada * * *." However, the unit "* * * takes its name from Condor Canyon about two miles north of the type section where it is exposed on the north wall near the canyon mouth." In accord with this definition the Condor Member as here interpreted is typically exposed in the Warm Spring reference section measured by Wheeler and Lemmon and remeasured in connection with this study.

The Condor Member is represented in the central part of the Pioche district, where it serves well as a key unit in mapping the stepped-down fault blocks along Step Ridge (pl. 1). At several points in this vicinity, it is either the youngest bedrock exposed or is overlain by only a capping of Meadow Valley Member. Small Condor outcrops occur northeast of the Golden Eagle mine (pl. 3) and at lower elevation in minor fault blocks near the mouth of Churndrill Valley. South of Gray Cone the Condor reappears at the surface, whence it may be followed discontinuously southward toward Warm Spring and Panaca.

THICKNESS

The Condor Member varies little in thickness throughout the district. Three measured sections give the following: Warm Spring, 105 feet; Gray Cone, 110 feet; Step Ridge, 120 feet.

LITHOLOGY AND STRATIGRAPHIC RELATIONS

The Condor Member is nonuniform, showing a considerable range of lithologic types. Among these are impure silty dolomites and dolomitic limestones, calcareous silty sandstones, and fine-grained limestones. Fairly pure, clean uniform saccharoidal dolomites so characteristic of the Burrows and other carbonate units of the district are uncommon. Dark-gray and black chert nodules are present, though not in abundance.

The fine silty dolomite is light or medium light gray on weathered surfaces. Limestone interbeds usually weather darker gray, although the calcareous siltstones and sandstones weather tan or light limonitic brown. On fresh fracture the silty dolomites are medium to dark gray, the limestone interbeds usually medium-dark gray, and siltstones and sandstones range from pale pink or reddish brown to very light tan gray.

Thin bedding and fine lamination are characteristic of the member; as a consequence weathered surfaces tend to be platy or flaggy. Although the light-gray-weathering platy beds predominate, these layers are separated here and there by darker limestone and sandstone beds ranging from less than 1 inch to more than a foot thick. A few fairly uniform, almost unlaminated dolomite beds as much as 2 feet thick were noted. Weathering of the laminated rocks imparts a rilled or grooved pattern like weatherbeaten wood where resistant laminae stand sharply in relief.

The black chert does not occur in continuous layers, but as scattered nodules and lenses as much as 2 feet long and 8 inches thick.

Of interest with respect to conditions of accumulation are the fine bedding laminae, ripple marks, pits, and castings. Many of the laminae are less than 1 mm thick, and some exhibit the alternation of dolomite with fine limestone layers. These alternations appear to be primary or diagenetic, rather than results of selectivity during late magnesian additive hydrothermal action. Highly undulating and broken laminae are common, giving evidence of flowage and slumping prior to lithification. At one exposure the laminae were observed to be molded concentrically around a chert nodule.

Ripple marking noted in brown-weathering silty beds is of the oscillation variety having nearly symmetrical ridges, wave length of about 30 mm and amplitude of 2½ mm. A ripple index of 12 suggests that these features formed by wave action in a partly inclosed body of shallow water, little affected by currents or tides (Pettijohn, 1949, p. 131).

Interfaces show pits and mud castings that suggest organic activity. Supposed worm castings are abundant just beneath the 4-foot tan sandstone which caps the member near Warm Spring. No other fossils were found in the Condor.

Thin sections of average dolomite of the Condor Member reveal a finely crystalline texture generally lacking traces of rounded carbonate granules, oolites, pellets, or organic structures of any kind. Laminated varieties range in character from dolomite or dolomitic limestone, of which 65 percent is carbonate and 35 percent quartz grains, to what is virtually fine quartz sandstone, of which about 80 percent is quartz. The quartz grains are angular or subangular, almost never rounded, are concentrated in the coarser quartz-rich laminae, and are for the most part larger than average grain size. Intervening carbonate laminae are finer grained and contain only an occasional angular quartz granule. Flakes of a micaceous mineral are present. The fine-grained more or less magnesian limestones show coarser dolomite rhombs in a finely granular calcite matrix. Also present are a few angular quartz grains. In these limestone layers are abundant traces of rounded and subrounded carbonate granules, but no organic shapes were recognized.

The Condor Member rests conformably upon the Step Ridge Member and is overlain concordantly by Meadow Valley Member.[13] Massive dark-gray limestone with abundant bluebird structure at the top of the Step Ridge gives way abruptly to laminated dolomite of the Condor. The top of the Condor is marked by a conspicuous bed of light-brown-weathering fine dolomitic sandstone, which was traced south from the Pioche area to the vicinity of Warm Spring.

Across the Condor section, the lithologic sequence shows a more or less rhythmic repetition of similar layers. The dark-gray chert nodules are limited mainly to the upper half; platy character and tan coloration on weathering are better defined in the lower half. The Condor is one of three units of the Highland Peak Formation in which chert is characteristic. The others are unit 7 and unit 9 in the upper part of the Highland Peak Formation.

The Condor Member is the lowest unit of the Cambrian section in this area that is typified by the rather uncommon finely laminated dolomites. Similar rocks are repeated in units 7, 9, and 13 in the upper part of the Highland Peak Formation. Platy laminated beds at the top of member A of the Lyndon Limestone resemble the Condor, but are not dolomitic. Elsewhere in the Great Basin, laminated Middle Cambrian carbonate rocks, recalling those of the Condor, occur at Gold Hill and in the Ophir district, Utah. Condor lithology also resembles that of the fine-textured Lower Devonian dolomites of the Sevy Dolomite, which occur widely in the Great Basin.

AGE AND CORRELATION

Identifiable fossils have not been found in the Condor Member. The lower part of the Swasey Formation of the House Range, Utah, with which the Condor has been correlated (Wheeler, 1948, p. 39) does not possess the lithologic peculiarities of the Condor. Fossils in the lower part of the Swasey, moreover, suggest a correlation of that unit with the Burnt Canyon Member of the Pioche district (Palmer, 1956). At present it would be hazardous to suggest that the Condor of the Pioche area is correlative with any of the Middle Cambrian units elsewhere in the Great Basin which include similar fine-grained laminated dolomitic strata.

MEADOW VALLEY MEMBER

NAME AND OCCURRENCE

The Meadow Valley Member is here named for beds that are conformably underlain by the Condor Member and conformably overlain by unit 7 of the Highland Peak Formation. In the past this unit has been called "Bristol lime" by the mining companies, in reference to its occurrence at the Bristol Silver mine. The type section of the Meadow Valley Member lies in the measured Warm Spring section northeast of Panaca (pl. 6) on the edge of Meadow Valley. The Meadow Valley Member is virtually equivalent to "Highland Peak G" of Wheeler and Lemmon (1939, p. 47).

The Meadow Valley Member is the youngest Cambrian unit of areal importance, known to be exposed in

[13] A minor unconformity between the Condor and Step Ridge is reported at a locality about 2,000 feet west-northwest of the Pioche No. 1 shaft (Park, C. F., Jr., Gemmill, Paul, and C. M. Tschanz, written communication, 1955).

the northern Ely Range near Pioche.[14] In this vicinity the member is represented by several fault-bounded erosion remnants on the crest of Step Ridge from the head of Slaughterhouse Gulch southeastward for about one mile. A large exposure is found on west-facing slopes 2,400 feet northeast of the Caselton shaft; a remnant caps a knoll 2,600 feet northeast of the Golden Eagle mine (pl. 3).

Meadow Valley Member is exposed over a larger area in the southeastern Ely Range where it reappears 3 miles southeast of Pioche in the hill south of Gray Cone; from this locality it has been followed discontinuously southward toward the type section at Warm Spring.

THICKNESS

No complete section of Meadow Valley suitable for measurement was found in the northern part of the Ely Range where the greatest thicknesses remaining after erosion are of the order of 200 feet. The type section east of Warm Spring is 430 feet thick, which agrees with the measurement by Wheeler and Lemmon (1939, p. 47) for "Highland Peak G." [15]

LITHOLOGY AND STRATIGRAPHIC RELATIONS

The Meadow Valley Member comprises medium-gray to dark-gray medium-grained to exceedingly fine grained mottled limestones, which are in the main thick bedded and massive. In several zones, however, bedding becomes thin, yielding platy debris on weathering. The limestone has a characteristic and peculiar mottling (fig. 14). Weathered surfaces reveal a decided textural difference between irregular or vermiform splotches of medium grain and the intervening aphanitic limestone matrix. The medium-grained splotches, being less soluble, weather in sharp relief, producing a rough, pitted, and pointed surface recalling that of a bath sponge. Granular texture of the coarser material is that of saccharoidal dolomite, and is evidently due to patchy incipient dolomitic recrystallization. On freshly broken surfaces the coarser spotches commonly are lighter gray than the enclosing aphanitic limestone. On weathered faces the reverse may be true, for the dark fine-grained material bleaches to a rather light gray, as is common with weathered sedimentary rocks rich in carbonaceous matter. Medium-grained mottlings occasionally show a limonitic or pinkish coloration. Where the Meadow Valley becomes more argillaceous and platy, it tends to exhibit pinkish mottling and buff or pink argillaceous

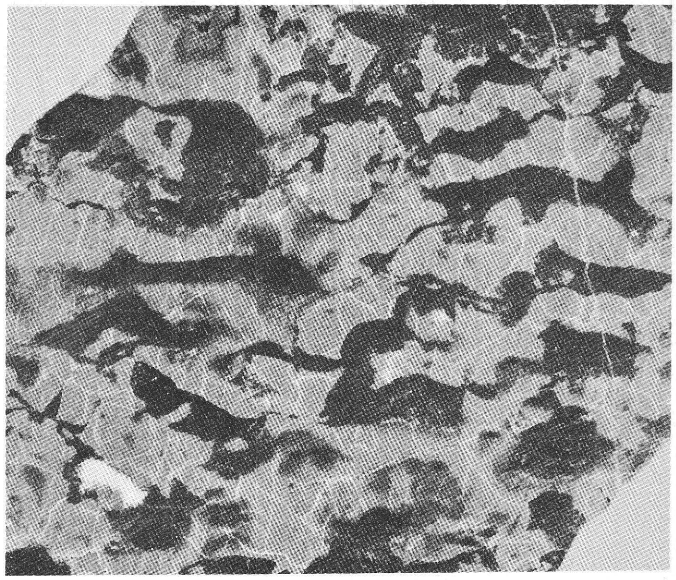

FIGURE 14.—Smoothed surface of typical limestone in the Meadow Valley Member of the Highland Peak Formation showing mottled character. Lighter areas are limestone; darker, coarser grained areas are dolomite. Specimen from measured section south of Gray Cone. Natural size.

partings. Edgewise limestone conglomerate was noted where the Meadow Valley is well bedded.

In thin section the irregular dolomitic parts are relatively coarse internally; the size of rhombs decreases outward toward the boundaries with very fine textured calcite matrix. The calcitic matter contains clearly defined invertebrate shell fragments, which are absent in the completely recrystallized dolomitic patches.

At Warm Spring the type section of the Meadow Valley is divided into two parts by a 30-foot zone of thinly bedded, somewhat pinkish more or less platy argillaceous limestone, the base of which lies 178 feet above the bottom of the member. Above the argillaceous zone, through a thickness of about 140 feet, the higher part of the Meadow Valley shows better defined bedding than the lower part of the member, as in places it is rather thinly bedded.

The Meadow Valley Member rests conformably upon the brownish silty sand bed which caps the Condor member. At Warm Spring the unit is terminated sharply above by the basal 22-foot light-gray laminated dolomite of Highland Peak unit 7.

AGE AND CORRELATION

Two small collections made by A. R. Palmer in 1952 and 1953 from the Meadow Valley Member in the Panaca Hills are not sufficiently distinctive for assignment to a named faunule. According to Palmer (written communication, 1955), these collections contain ptychoparioid trilobites and *Glyphaspis*. No fossils

[14] Jumbled blocks at locality 17 contain Upper Cambrian fossils but have only small areal extent.

[15] In the southeastern Ely Range an average thickness of 340 feet was measured by Park, Gemmill, and Tschanz (written communication, 1955), which suggests a possible thinning of the Meadow Valley north of the type area.

have been found in the Meadow Valley strata of the northwestern Ely Range. Wheeler's (1948, p. 39–40) correlation of "Highland Peak G" or Meadow Valley Member with the upper part of the Swasey Formation of the House Range, Utah (Deiss, 1938, p. 1133), is contingent upon his correlation of the lower part of the Swasey with the Condor, which is improbable. It seems more likely, on paleontologic evidence, that the lower part of the Swasey is of Burnt Canyon age and the upper part of the Swasey roughly equivalent to the Step Ridge Member, rather than the Meadow Valley (pl. 5).

UPPER PART OF THE HIGHLAND PEAK FORMATION

Of 13 major stratigraphic units representing the Highland Peak Formation in the Ely Range, 6 have been given member names. These comprise the lower part of the formation, crop out over a large area in the productive part of the Pioche mining district, and have withstood the practical test of mappability. The remaining seven units, which constitute the upper part of the Highland Peak Formation, are well exposed at Warm Spring near Panaca (pls. 2, 6) and in the Highland-Bristol chain but were not recognized in the northern part of the Ely Range. These upper divisions have received only cursory stratigraphic study in the Highland Range itself.

Because of interpretive differences, the contacts separating the three upper units of the Highland Peak in the Warm Spring measured section of this report do not agree with comparable unit boundaries in the Wheeler and Lemmon (1939) section. To avoid confusion it therefore seems appropriate to designate units by number. Table 6 gives the provisional scheme here adopted, in comparison with the Wheeler and Lemmon informal letter designations. Units 10 through 13 agree with divisions M through P of Wheeler and Lemmon. The interval of units 7 through 9 inclusive corresponds to the stratigraphic range of Wheeler and Lemmon divisions H through L, but constituent unit boundaries differ somewhat.

The seven units comprising the upper part of the Highland Peak Formation have not all been used as map units; whether they are mappable and worthy of eventual member or formation status remains to be determined.

UNIT 7

This unit, which is 310 feet thick (pl. 6) near Warm Spring, includes division H of Wheeler and Lemmon plus the lower part of division I. It is characterized by fine-grained, medium- to dark-gray mottled limestone beds, which alternate with dolomite and dolomitic limestone. The dolomite and dolomitic limestone is in part finely laminated, very fine grained, and weathers light gray to almost chalky white. On fresh fracture the distinctive laminated beds are commonly medium gray tinted slightly pinkish. The laminae are closely spaced, varying from one per millimeter to about 3 per millimeter. The laminated lower 22 feet of the unit is composed mainly of dolomite containing small amounts of quartz and calcite.[16] Some dolomite laminae are speckled with finely divided calcite.[17] These fine-grained dolomites differ in texture from the coarser saccharoidal types so characteristic of the lower Paleozoic column in this region.

TABLE 6.—*Stratigraphic units of the upper part of the Highland Peak Formation, Warm Spring, Nev.*

Formation	C. W. Merriam, this report		Wheeler and Lemmon (1939)
	Unit	Thickness (feet)	
Upper part of the Highland Peak Formation (2,430 ft)	Unit 13	125	Highland Peak P
	Unit 12	170	Highland Peak O
	Unit 11	245	Highland Peak N
	Unit 10	240	Highland Peak M
	Unit 9	840	Highland Peak L
			Highland Peak K
			Highland Peak J
	Unit 8	500	Highland Peak I
	Unit 7	310	Highland Peak H

The laminated dolomite of unit 7 is similar to that found in the Condor Member, and in units 9 and 13 of the Highland Peak Formation. Similar strata are reported in the Trippe Limestone of Middle Cambrian age at Gold Hill, Utah (Nolan, 1935, p. 12, pl. 5, B.) and in the Lynch Dolomite of Middle(?) and Upper Cambrian age in the Stockton and Fairfield quadrangles, Utah (Gilluly, 1932, p. 16, pl. 6, C.).

Unit 7 of the Highland Peak is conformable with the Meadow Valley Member below and unit 8 above; the relation at both contacts is gradational. Wheeler and Lemmon (1939, fig. 11) have identified rocks of this interval in the Bristol Range. The presence of black chert in the lower part (see below), and the large amount of light-gray laminated dolomite are factors which should facilitate local correlation on a lithologic basis. Absence of fossils obviates correlation with strata in more distant areas.

Following is a detailed section of unit 7 of the Highland Peak Formation as measured near Warm Spring:

[16] Determined by X-ray powder analysis.

[17] Shown by staining with copper nitrate solution, following the technique devised by Rodgers (1940).

Measured section, unit 7 of the Highland Peak Formation near Warm Spring, Nev.

Subunit	Thickness (feet)
7i. Limestone, dark-gray, mottled; thinly laminated interbeds; some laminae and bands are light gray	34
h. Limestone, dark-gray mottled, thin-bedded	38
g. Limestone, dark-gray, well-bedded; alternating with light-gray laminated dolomite	60
f. Dolomite, light-gray, laminated; similar to subunit 7a	39
e. Limestone, dark-gray, mottled, like subunit 7c	40
d. Dolomite, light-gray-weathering laminated, similar to subunit 7a	28
c. Limestone, dark-gray mottled, fine-grained	37
b. Limestone, medium- to dark-gray, mottled, fine-grained; intercalated light-gray dolomite; black chert nodules	12
a. Dolomite, light-gray-weathering, laminated, of fine grain; color medium gray and pinkish on broken surface	22
	310

UNIT 8

This unit, having a thickness of 500 feet (pl. 6), consists largely of dark-gray, mottled rather thick bedded limestone and a few intervals of thinner bedded limestone. Its relation to unit 7 below and unit 9 above is gradational. Unit 8 embraces most of division I and the lower part of division J of Wheeler and Lemmon, both of which were recognized also in the Bristol Range.

UNIT 9

This well-bedded unit is 840 feet thick (pl. 6) and comprises dark-gray, mottled, thick-bedded limestones and intercalated thin-bedded laminated dolomite and dolomitic limestone; the dolomitic strata tend to weather very light gray, providing a strong color contrast. Chert or jaspery silica occurs in at least three zones within the lower 350 feet as follows: (1) A 2-foot bed of light-brownish-gray laminated jaspery matter 50 feet above the base, (2) large concentrically laminated spheroids of dark-gray and black chert weathering brown in a light-gray bed 162 feet above the base, (3) scattered chert nodules about 350 feet above the base.

Except for the upper 70 feet of this unit, the dark-gray, mottled limestone predominates greatly over light-gray laminated dolomite or dolomitic limestone, intercalations of which range in thickness from a few inches to about 7 feet. Near the top of the unit, light-colored laminated beds (fig. 15) become so numerous that in the upper 70 feet they constitute about one-third of the rock; nine such beds range from less than 2 feet to 5 feet in thickness.

Unit 9 includes most of division J and divisions K and L of Wheeler and Lemmon. Relations to units 8 and 10 of the Highland Peak Formation are gradational. Rocks of unit 9 have been recognized in the Bristol Range by Wheeler and Lemmon.

FIGURE 15.—Flat-pebble mud-breccia pocket in laminated calcitic dolomite 95 feet below top of unit 9 of the Highland Peak Formation. Some of the coarser patches and laminae are partly calcitic. Warm Spring measured section northeast of Panaca, Nev. Natural size.

Fossils identified by A. R. Palmer from the middle part of unit 9 (basal part of division K of Wheeler and Lemmon; U.S.G.S. colln. 1808–CO, Warm Spring area) include the distinctive upper Middle Cambrian trilobite *Eldoradia*. This genus is known from many localities in the Great Basin. Among these localities is the Eureka mining district, Nevada (pl. 5), where it is found in the upper part of the Secret Canyon Shale (Nolan, Merriam, and Williams and others, 1956, p. 16). In the Gold Hill area, Utah, *Eldoradia* occurs in the upper part of the Trippe Limestone; in the Tintic district, Utah, it is present in the upper part of the Cole Canyon Dolomite. According to Palmer (in Gilluly, 1956, p. 22, 23) *Eldoradia* has also been recognized in the lower part of the Abrigo Limestone of southeastern Arizona and in the House Range, Utah, where its horizon has not been determined. Presence of *Eldoradia* in unit 9 indicates that up to the horizon of its occurrence, the Highland Peak Formation is Middle Cambrian. Whether some of the overlying beds in this formation are Upper Cambrian has not been ascertained. Palmer concludes that the lowest fossils from the Mendha Formation are well up in the *Crepicephalus* zone of early Late Cambrian age, and are thus not the oldest fossils of the Late Cambrian to be expected.

UNIT 10

This unit, with a thickness of 240 feet (pl. 6), consists of medium- to fine-grained dark-gray, mottled, thick-bedded limestone, which lacks the light-gray laminated interbeds. It is gradational with unit 9 below and with unit 11 above, and corresponds to division M of Wheeler and Lemmon.

UNIT 11

This unit is almost entirely dolomite (pl. 6), differing in this respect from all others in the upper part of the Highland Peak Formation. One measured section 245 feet thick consists of a lower dark-gray mottled, mostly saccharoidal, thick-bedded dolomite 198 feet thick and an upper light-gray saccharoidal dolomite 47 feet thick. Another section of unit 11 measured only 110 feet. The difference may be due to unrecognized faults or to dolomitization having affected only the lower part of the unit. Theoretically, undolomitized carbonate rock of unit 11, like undolomitized Burrows Member, could well be a fine lithographic limestone indistinguishable from the lithographic limestone of overlying unit 12. Division N of Wheeler and Lemmon corresponds to this unit.

UNIT 12

Unit 12 is about 170 feet thick in the measured Warm Spring section (pl. 6) and consists of fine-grained, porcellaneous or lithographic limestone ranging from white and light gray to dark gray. Locally it exhibits a faint pinkish staining. The beds are rather thick. The limestone of this division resembles white limestone of the Lyndon and is similar to the undolomitized lithographic facies of the Burrows Member. Unit 12 is conformable with underlying and overlying units. Unit 12 corresponds to division O of Wheeler and Lemmon, and has been recognized also in the Bristol Range.

UNIT 13

Unit 13 comprises dark-gray, mottled saccharoidal dolomite, fine-grained medium- to dark-gray limestone, and light-gray laminated fine-grained dolomite like that in units 7 and 9. No true thickness can be given as this division is faulted in the measured section (pl. 6); it is believed to be at least 125 feet thick. Following is the order of beds in the measured section, partly repeated in a fault block to the east at the top of the column:

Top.	*Thickness (feet)*
Dolomite, dark-gray, mottled, sugary, blocky-weathering	60
Limestone, medium- and light-gray thick-bedded, fine-grained; interbeds of light-gray, laminated dolomitic limestone	37
Limestone, fine-grained, medium- to dark-gray, with interbeds of fine white-weathering dolomitic limestone having pinkish tinge	28
	125

Unit 13 corresponds to division P of Wheeler and Lemmon, recognized also by them in the Bristol Range.

UPPER CAMBRIAN AND LOWER ORDOVICIAN ROCKS

Strata of Late Cambrian age are represented in the Ely Range by a small outlier at Step Ridge (pl. 1). This occurrence has been discussed above under Geologic Structure. Rocks of the same interval are present to the west in Arizona Peak (pl. 2), where they were described by Westgate and Knopf (1932, p. 13) as Mendha limestone, named for the Mendha mine. As now understood the Mendha type area includes beds of both Early Ordovician and Late Cambrian age. Until the structurally complex Arizona Peak area is mapped in detail geologically, a satisfactory differentiation of these rocks is not possible. Eventually it may be expedient to establish new formations and treat the Mendha as a group. In this report the strata in question are referred to as the Mendha Formation of Late Cambrian and Early Ordovician age.

It is probable that the Mendha Formation extends eastward beneath valley alluvium and volcanic rocks between the east spur of Arizona Peak and the Ely Range. Limestone pieces in fault breccia near The Point (pl. 3) suggest a facies of the Mendha lithologically, but unlike the occurrence at Step Ridge, have yielded no fossils.

Geologic mapping by Merriam and Proctor at the Highland Queen mine in 1945 pointed up the structural and stratigraphic complexity of the Arizona Peak vicinity, and fossils collected in that area by A. R. Palmer show that Ordovician as well as Late Cambrian strata are represented.

MENDHA FORMATION

The original definition of the Mendha given by Westgate and Knopf (1932, p. 13) is as follows:

> The Mendha limestone, named from the Mendha mine, on the west side of Arizona Peak, which is entirely composed of these rocks, includes nearly 2,000 feet of limestones and dolomites which lie with apparent conformity above the Highland Peak limestone. The formation is not seen in normal position under the Ordovician, as the contact with the Ordovician is everywhere a fault contact.

If, in keeping with the original definition, Arizona Peak is the type area, the Mendha Formation may now be interpreted as comprising not only a lithologically diverse and rather complex sequence of Upper Cambrian rocks, but strata of Early Ordovician age as well.

LITHOLOGY AND STRATIGRAPHIC RELATIONS

The contact between the Mendha and the Highland Peak Formation is not exposed at Arizona Peak.

Farther south along the east slope of the Highland Range the two are reported to be conformable (Westgate and Knopf, 1932, p. 13). The lower beds of the Mendha are described as follows by Westgate and Knopf:

The basal beds of the Mendha formation are thin-bedded gray limestones, in places stained yellow or rusty-red on weathering, which in the hand specimen are rather coarsely crystalline, locally oolitic and rusty-specked. They contain abundant fossil debris, almost wholly fragments of trilobites, most of which are specifically unidentifiable. By reason of their contrast with the underlying Highland Peak limestone these beds mark an easily recognizable horizon, which has helped greatly in working out the structure of the main Bristol-Highland Range.

South of Dead Deer Canyon, Westgate and Knopf measured a section across the lower part of the Mendha, as quoted below:

	Feet
White massive dolomite in beds as much as 8 feet thick. The beds show close-spaced parting planes but break into large blocks	85
Gray limestone, thinly parted, making the lower part of the cliff at the top of the hill. Layers throughout more or less oolitic and mottled. White chert in sheetlike lenses is found from the base up	235
Thin sandstones and layers of alternating sandstone and limestone, weathering to flat rusty debris	10
Gray thick-bedded crystalline limestone	230
Gray limestone, some beds 5 feet thick, most of it crystalline, oolitic and mottled	220
Gray, rather thick-bedded limestone, 60 feet thick, passing up into well-bedded limestone in beds 1 or 2 feet thick. Layers commonly oolitic, rarely conglomeratic and yellow streaked. Breaks down easily into slaty debris	165
	945

As at present understood the Mendha embraces at least seven principal lithologic divisions; three of these are limestones and four are dolomites. The lowest unit is a limestone of Late Cambrian age above which apparently follows the sequence of four dolomite units. A second Upper Cambrian limestone overlies the dolomite sequence. Stratigraphic relations of the Lower Ordovician limestones are unknown, for they occupy an inlying belt of fault-bounded rocks.

Limestones of the lower part of the Mendha Formation are exposed about 1 mile southeast of the Mendha mine. They crop out on a northwest-trending spur half a mile northeast of the mine and at various points northwest of Arizona Peak. At the Highland Queen mine in Sheridan Canyon, the lower part of the Mendha includes brownish-weathering medium- to fine-grained medium- to light-gray limestone resembling the white limestone of the Lyndon. This rock, which is similar to the Lyndon Limestone, is mottled with limonitic spots or patches, exhibits a pinkish staining and contains a small amount of chert. Argillaceous shale interbeds of light tan to greenish color in this predominantly limestone unit resemble Chisholm Shale, with which they have been confused. Near the Highland Queen, these older Upper Cambrian limestones appear to be overlain normally by medium- and light-gray, mottled dolomites. A drill hole (Stone, J. B., in Wheeler and Lemmon, 1939, p. 43–44) in this area disclosed several hundred feet of limestone with oolitic facies and reddish-brown shale partings. The unexposed beds may represent lower, partly oolitic Mendha, like that near Dead Deer Canyon described by Westgate and Knopf.

Dolomites are present at the Mendha mine on the west side of a north-south fault. The higher part of Arizona Peak is also dolomite, which is estimated to be more than 600 feet thick. On the south side of hill 7771 (in the Highland Peak quadrangle) three-quarters of a mile south of the Arizona Peak summit, the dolomite sequence comprises four lithologic divisions in the following stratigraphic order:

4. Light-gray dolomite (capping hill 7771)
3. Dark-gray cherty dolomite
2. Mottled light- and medium-gray thick-bedded dolomite
1. Dark-gray dolomite

The lower dark-gray dolomite contains concentrically laminated stromatolites or algal bodies, some of which have diameters of several inches. Brachiopod fragments and *Hyolithes* occur in mottled beds of unit 2. In unit 3, chert lenses and nodules are more abundant than in any of the cherty units of the Highland Peak Formation with which it might be confused.

The youngest fossil-dated Cambrian limestones recognized crop out on the west slope of Arizona Peak south of the Highland Mary mine and cap hill 7569 a mile southwest of the summit of Arizona Peak. Whereas these beds resemble limestones beneath the dolomite sequence, of hill 7771, latest Cambrian trilobites identified by A. R. Palmer as *Eurekia* and *Dikelocephalus* suggest that they are younger. Moreover, on hill 7569 these younger limestones conformably overlie dolomites probably equivalent to those of hill 7771.

Strata of Early Ordovician age occur east of the Mendha mine and extend southeast to the Highland Mary mine. Consisting of well-bedded fossiliferous fine-grained bluish gray cherty limestones, these isolated Ordovician strata are separated by north-south faults from dolomites at the Mendha mine and from the main Arizona Peak dolomite body to the east. Their stratigraphic relations to the latest Cambrian limestones are obscured by a disturbed zone paralleling the road to the Highland Mary mine.

MENDHA OUTLIER AT STEP RIDGE

Jumbled limestone blocks occur with red gougy matter in a breccia on the west side of Step Ridge (pl.

1, loc. 17); the larger blocks are several feet long. Surrounding and presumably underlying the breccia is unit *b* of the Middle Cambrian Step Ridge Member of the Highland Peak Formation. According to A. R. Palmer, fossils in the breccia blocks are of Late Cambrian (Dresbach) age and strongly suggest derivation from the Mendha. Stratigraphic separation between the horizon of the Dresbach faunule and unit *b* of the Step Ridge would normally be of the order of 3,000 feet. As discussed under geologic structure these outlying blocks are believed to represent a possible upper plate thrust remnant.

Fossiliferous limestones of the breccia blocks are medium dark gray, very fine textured, and contain argillaceous inclusions and reddish-brown to tan mottlings. Some limestone blocks have a dull, chalky reddish-tan laminar incrustation of caliche where exposed to weathering. Oolites are present but uncommon in these breccia limestone blocks.

AGE AND CORRELATION

Fossils indicate that the rocks described as Mendha Formation range in age from early Late Cambrian to Early Ordovician.

A. R. Palmer reported early Late Cambrian trilobites of the *Crepicephalus* zone in limestones near the Highland Mary mine, and at a locality about 1 mile south-southwest of the summit of Arizona Peak. Between this summit and hill 7203, half a mile northeast, *Elvinia* occurs in shale layers in limestone. These *Elvinia*-bearing strata are probably correlative with Dunderberg Shale of Eureka, Nev. (Nolan, Merriam, and Williams, 1956, p. 19), which is of early to middle Late Cambrian age.

Limestones with *Eurekia* occur in the upper part of the Mendha on the west slope of Arizona Peak. The *Eurekia*-bearing strata are uppermost Cambrian, correlative with Windfall Formation, which overlies the Dunderberg at Eureka, Nev.

Fossils from the Mendha outlier on Step Ridge (pl. 1, loc. 17) are of early Late Cambrian (Dresbach) age and include the trilobites *Aphelaspis* sp., *Glaphyraspis* sp., and *Coosina* sp. A. R. Palmer (written communication, 1955) referred to collections from this locality as follows:

> All except one piece of rock contain abundant specimens of *Aphelaspis* sp., and *Glaphyraspis* sp., both widespread guides to the latest Dresbach. The presence of *Glaphyraspis* further indicates the very basal part of the *Aphelaspis* zone. This agrees well with a single piece of slightly oolitic limestone with a cranidium of *Coosina* sp., the characteristic guide to the beds immediately preceding *Aphelaspis*. These collections should have come from the interval above the sublithographic oolitic limestones of the lower part of the Mendha and below or associated with the thin interval of succeeding sandy beds.

Lower Ordovician fossils of the Mendha at Arizona Peak were submitted to R. J. Ross, Jr., of the Geological Survey, who provided the following report:

> All these are of early Early Ordovician age. I am unable to give ages of the collections relative to one another, which would be desirable in a structurally complex area. All four are correlative with the interval zones A–D [Ross, R. J., Jr., 1951] of the Garden City Formation. The presence of *Kainella* suggests zone D, but in Nevada this genus may range lower than elsewhere.
>
> Locality 39 (APN–1–54), southwest slope of Arizona Peak near Highland Mary mine, altitude about 7,400 feet.
>
> *Symphysurina* sp. (rounded genal angle)
> Syntrophid brachiopod
>
> Locality 40 (APN–2–54), near top of southwest spur of Arizona Peak northwest of Highland Mary mine, in noncherty limestone.
>
> *Apheoorthis*? sp.
> *Nanorthis*? sp.
> *Symphysurina* sp.
> *Kainella* sp.
> *Hystricurus* sp.
>
> Locality 41 (APN–4–54), west end of southwest-trending spur one-quarter of a mile west-southwest of Highland Mary mine. Same fauna and lithology as Locality 40.
>
> Locality 42, west side of Arizona Peak, 200 yards west of Highland Mary mine.
>
> *Leiostegium*? sp.
> *Symphysurina* sp.
> *Nanorthis* sp.

Lower Ordovician cherty limestones provisionally included with the Mendha are correlative with the Goodwin Limestone of the Eureka, Nev., region. The Goodwin (Nolan, Merriam, and Williams, 1956, p. 25–27) is the lowest formation of the Pogonip Group. Like the Ordovician part of the Mendha, it contains abundant chert, which tends to be light gray or white. However, cherts of the Lower Ordovician beds at Arizona Peak differ in being dark gray or black. In the section given by Westgate and Knopf south of Dead Deer Canyon the higher cherty limestone includes lenses of white chert reminiscent of the Goodwin.

LOCALITY REGISTER

Important localities in the Ely Range and Arizonia Peak to which reference is made. (See pls. 1, 2 and 3)

Locality No.	
12	Pioche Shale, A-shale member, *Albertella* collections. One mile southeast of The Point on crest of ridge near trail and near Evans mine. Altitude 6,359 ft.
13	Pioche Shale, D-shale member, *Olenellus* collections. Half a mile southeast of Ely Valley mine, near Garrison mine. Alt 6,480 ft.
14	Pioche Shale, D-shale member, *Olenellus* collections. Three-fourths mile southeast of Ely Valley mine, near Gold Eagle mine. Alt 6,450 ft.
15	Pioche Shale, D-shale member, *Olenellus* collections. One mile southeast of Ely Valley mine, 600 ft north of West End mine. Alt 6,350 ft.

16---- Chisholm Shale fossil collections in saddle. On Tank Ridge 400 ft southwest of Pioche No. 1 shaft.

17---- Upper Cambrian fossil locality, outlier of Mendha Formation. West side Step Ridge three-fourths of a mile west of Pioche No. 1 shaft. Jumbled blocks of fossiliferous limestone may represent remnant of thrust sheet.

18---- Burnt Canyon Member of Highland Peak Formation, fossil-bearing shaly bed. West side Tank Ridge near head of Churndrill Valley.

19---- Pioche Shale, Combined Metals Member with fossils. Pioche Divide section.

20---- Pioche Shale, D-shale member with *Olenellus*. West of Pioche Divide section.

21---- Pioche Shale, Susan Duster Limestone Member with fossils. Near edge of road in Pioche Divide section.

22---- Burnt Canyon Member of Highland Peak Formation, fossil-bearing shale bed. Northeast side Lime Hill near tramline.

23---- Prospect Mountain Quartzite, *Scolithus* bed. Southeast side Lookout Hill. Alt 6,340 ft.

24---- Prospect Mountain Quartzite, *Scolithus* bed. West side Treasure Hill, 1,300 ft southeast of Pioche Divide. Alt 6,620 ft.

25---- Burnt Canyon Member of Highland Peak Formation, fossil-bearing shaly beds. Near road 1,350 ft southeast of top of Gray Cone. Alt 5,925 ft near measured section *D–D'*.

26---- Upper part of Peasley Member of Highland Peak Formation; 1,200 ft northwest of Pioche No. 1 shaft. Alt 6,500 ft.

27---- Upper part of Peasley Member of Highland Peak Formation. Buehler Gulch, half a mile north of Caselton. Alt 6,520 ft.

28---- Upper part of Peasley Member of Highland Peak Formation. East side Slaughterhouse Gulch, 3,000 ft northwest of Pioche No. 1 shaft. Alt 6,480 ft.

29---- Undulating Peasley-Burrows contact. Mouth of Buehler Gulch.

30---- Undulating Peasley-Burrows contact. Mouth of Buehler Gulch.

31---- Undulating Peasley-Burrows contact. Southeast side Lime Hill.

32---- Peasley-Burrows contact. East side Churndrill Valley 1,300 ft southwest of Pioche No. 1 shaft. Alt 6,370 ft.

33---- Lower part of Burnt Canyon Member of Highland Peak Formation; 2,000 ft northwest of Pioche No. 1 shaft. Alt 6,780 ft.

34---- Lower part of Burnt Canyon, Member of Highland Peak Formation. Near head of Buehler Gulch 1,400 ft east of Abe Lincoln mine. Alt 6,960 ft.

35---- Lower part of Burnt Canyon Member of Highland Peak Formation. On Tank Ridge 1,250 ft west of Pioche No. 1 shaft.

36---- Lower part of Burnt Canyon Member of Highland Peak Formation. West side Tank Ridge near head Churndrill Valley on east side. Alt 6,760 ft.

37---- Burnt Canyon Member of Highland Peak Formation with edgewise limestone conglomerate. On Tank Ridge 1,400 ft west of Pioche No. 1 shaft.

38---- Burnt Canyon Member of Highland Peak Formation with edgewise limestone conglomerate. Near head Churndrill Valley.

39---- Lower Ordovician beds. Southwest slope of Arizona Peak near Highland Mary mine. Alt about 7,400 ft (APN–1–54). *Symphysurina*.

40---- Lower Ordovician beds. Near top of southwest spur of Arizona Peak northwest of Highland Mary mine, in noncherty limestone (APN–2–54). *Kainella*, *Symphysurina*.

41---- Lower Ordovician beds. At west end of southwest-trending spur a quarter of a mile west-southwest of Highland Mary mine, Arizona Peak (APN–4–54). Same lithology and fauna as loc. 40.

42---- Lower Ordovician beds. On west side of Arizona Peak, 600 ft west of Highland Mary mine. *Symphysurina*.

43---- Churndrill hole No. 2, Combined Metals Reduction Co.; 1,400 ft northeast of Prince shaft.

U.S. Geological Survey fossil localities, Ely Range and Highland Range, Nevada

USGS 1213–CO, Ely Range, Warm Spring measured section near Panaca. Meadow Valley Member of Highland Peak Formation, probably above middle.

1214–CO, Ely Range, Warm Spring measured section. Meadow Valley Member of Highland Peak Formation, near top.

1391–CO, Pioche Divide section, Combined Metals Member of Pioche Shale, subunit 2, about 10 ft above base of member. Lower Cambrian faunule with *Olenellus gilberti*.

1392–CO, Pioche Divide section, Combined Metals Member of Pioche Shale, subunit 5, about 3 ft below top of member. Lower Cambrian faunule with *Olenellus gilberti* and *Paedeumias clarki*.

1393–CO, Pioche Divide section, lower 3 ft of Susan Duster Limestone Member of Pioche Shale. Middle Cambrian *Strotocephalus-Mexicella* faunule.

1394–CO, Pioche Divide section, near top Susan Duster Limestone Member of Pioche Shale. Middle Cambrian *Poliella* faunule.

1395–CO, Pioche Divide section, basal limestone of A-shale member of Pioche Shale. Middle Cambrian faunule with *Kochaspis* and *Poliella*.

1396–CO, Pioche Divide section, 40 to 50 ft below top of exposed part of A-shale member of Pioche Shale. Middle Cambrian with *Plagiura*.

1398–CO, lower north slope of Mount Ely near Gold Eagle mine, about 4,000 ft southeast of the Ely Valley mine. Lower Cambrian *Olenellus fremonti–O. bristolensis* faunule.

1399–CO, lower north slope of Mount Ely about 5,000 ft southeast of the Ely Valley mine, near West End mine. In upper part of subunit 5 of Combined Metals Member of Pioche Shale. Lower Cambrian faunule with *Olenellus gilberti* and *Paedeumias clarki*. Silicified larval trilobites.

1403–CO, Highland Range, south side of Burrows Canyon. Chisholm Shale 8 ft above base.

1405–CO, Pioche Shale, A-shale member with *Albertella*. Same as loc. 12.

1406–CO, west side Ely Range on dump of Abe Lincoln mine. Chisholm Shale.

1407–CO, west side Ely Range on dump of Half Moon mine. Chisholm Shale.

1408–CO, Ely Range, east side of Lime Hill. Chisholm Shale.

1410–CO, Ely Range, east side of Lime Hill on dump of prospect pit. Chisholm Shale.

1414–CO, Ely Range, canyon south of Ely Valley mine, dump high on slope; probably at Alliance mine. Chisholm Shale.

1415–CO, Ely Range, dump at Half Moon mine. Chisholm Shale.

1808–CO, Ely Range, Warm Spring measured section. Highland Peak Formation of unit 9, about 370 ft above base and below middle of unit. *Eldoradia.*

REFERENCES CITED

Burling, L. D., 1914, Early Cambrian stratigraphy in the North American Cordillera, with discussion of the Albertella and related faunas: Canada Dept. Mines, Mus. Bull. no. 2 (Geol. ser. no. 17), p. 1–37.

Callaghan, Eugene, 1937, Geology of the Delamar district, Lincoln County, Nevada: Nevada Univ. Bull., v. 31, no. 5, 72 p.

Cooper, G. A., Arellano, A. R. V., Johnson, J. H., Okulitch, V. J., Stoyanow, Alexander, and Lochman, Christina, 1952, Cambrian stratigraphy and paleontology near Caborca, northwestern Sonora, Mexico: Smithsonian Misc. Colln., v. 119, no. 1, 183 p.

Cornwall, H. R., and Kleinhampl, F. J., 1960, Preliminary geologic map of the Bare Mountain quadrangle, Nye County, Nevada: U.S. Geol. Survey Mineral Inv. Prelim, Map MF–239, 1: 48,000.

Deiss, Charles, 1938, Cambrian formations and sections in part of Cordilleran trough: Geol. Soc. America Bull., v. 49, p. 1067–1168.

Drewes, Harald, and Palmer, A. R., 1957, Cambrian rocks of southern Snake Range, Nevada: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 104–120.

Gilbert, G. K., 1875, Report on the geology of portions of Nevada, Utah, California, and Arizona: U.S. Geog. Geol. Survey, W. 100th Meridian (Wheeler), v. 3, p. 17–187.

Gilluly, James, 1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U.S. Geol. Survey Prof. Paper 173, 171 p.

——— 1956, General geology of central Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 281, 169 p.

Grabau, A. W., 1936, Paleozoic formations in the light of the pulsation theory; v. 1, Lower and Middle Cambrian pulsations: 2d. ed., Natl. Univ. Peking Press, 680 p.

Hague, Arnold, 1883, Geology of the Eureka district, Nevada: U.S. Geol. Survey Ann. Rept. 3, p. 237–290.

——— 1892, Geology of the Eureka district, Nevada: U.S. Geol. Survey Mon. 20, 419 p.

Hewett, D. F., 1956, Geology and mineral resources of the Ivanpah quadrangle: U.S. Geol. Survey Prof. Paper 275, 172 p.

Howell, B. F., and Mason, J. F., 1938, Correlation of Middle Cambrian faunas of North America: Jour. Paleontology, v. 12, p. 295–297.

Howell, E. E., 1875, Report on the geology of portions of Utah, Nevada, Arizona, and New Mexico: U.S. Geog. Geol. Survey, W. 100th Meridian (Wheeler), v. 3, p. 227–301.

Humphrey, F. L., 1945, Geology of the Groom district, Lincoln County, Nevada: Univ. Nevada Bull., v. 39, no. 5 (Geol. and Mining Ser. no. 42), 53 p.

Knopf, Adolph, 1932, Part 2. Economic geology, *in* Westgate, L. G., and Knopf, Adolph, Geology and ore deposits of the Pioche district: U.S. Geol. Survey Prof. Paper 171, p. 45–75.

Lindgren, Waldemar, and Loughlin, G. F., 1919, Geology and ore deposits of the Tintic mining district, Utah: U.S. Geol. Survey Prof. Paper 107, 282 p.

Longwell, C. R., 1952, Lower limit of the Cambrian in the Cordilleran region: Washington Acad. Sci. Jour., v. 42, no. 7, p. 209–212.

Lowenstam, H. A., 1950, Niagaran reefs of the Great Lakes area: Jour. Geology, v. 58, no. 4, p. 430–487.

Mason, J. F., 1936, *Communication quoted in* Grabau, A. W., Paleozoic formations in the light of pulsation theory, v. 1, Lower and Middle Cambrian pulsations: 2d ed., Natl. Univ. Peking Press, p. 274–276.

——— 1938, Cambrian faunal succession in Nevada and California: Jour. Paleontology, v. 12, p. 287–294.

McKee, E. D., 1945, Cambrian history of the Grand Canyon region: Carnegie Inst. Washington Pub. 563, 168 p.

Nolan, T. B., 1929, Notes on the stratigraphy and structure of the northwest portion of Spring Mountain, Nevada: Am. Jour. Sci., 5th ser., v. 17, p. 461–472.

——— 1935, The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 177, 172 p.

Nolan, T. B., Merriam, C. W., and Williams, J. S., 1956, The stratigraphic section in the vicinity of Eureka, Nevada: U.S. Geol. Survey Prof. Paper 276, 77 p.

Pack, F. J., 1906a, Geology of Pioche, Nevada and vicinity: Columbia Univ., School of Mines Quart., v. 27, p. 285–312, 365–386.

——— 1906b, Cambrian fossils from the Pioche Mountains, Nevada: Jour. Geology, v. 14, p. 290–302.

Palmer, A. R., 1954, An appraisal of the Great Basin Middle Cambrian trilobites described before 1900: U.S. Geol. Survey Prof. Paper 264–D, p. 55–86.

——— 1956, The Cambrian system of the Great Basin in western United States, *in* Rodgers, John, ed., El Sistema Cambrico, su paleogeografia y el problema de su base—symposium, Pt. 2: Internat. Geol. Cong., 20th, Mexico, D.F., 1956, p. 663–681.

——— 1957, Ontogenetic development of two olenellid trilobites: Jour. Paleontology, v. 31, no. 1, p. 105–128.

——— 1958, Morphology and ontogeny of a Lower Cambrian ptychoparioid trilobite from Nevada: Jour. Paleontology, v. 32, no. 1, p. 154–170.

Park, C. F., Jr., Gemmill, Paul, and Tschanz, C. M., 1958, Geologic map and sections of the Pioche Hills, Lincoln County, Nevada: U.S. Geol. Survey Mineral Inv. Field Studies Map MF 136.

Pettijohn, F. J., 1949, Sedimentary rocks: New York, Harper and Brothers, 526 p.

Prescott, Basil, 1926, The underlying principles of the limestone replacement deposits of the Mexican province: Eng. Mining Jour., v. 122, no. 7, p. 246–253; no. 8, p. 289–296.

Rasetti, Franco, 1951, Middle Cambrian stratigraphy and faunas of the Canadian Rocky Mountains: Smithsonian Misc. Colln., v. 116, no. 5, 277 p.

Resser, C. E., 1935, Nomenclature of some Cambrian trilobites: Smithsonian Misc. Colln., v. 93, no. 5, p. 1–46.

——— 1937, Third contribution to nomenclature of Cambrian trilobites: Smithsonian Misc. Colln., v. 95, no. 22, p. 1–29.

Resser, C. E., 1942, Fifth contribution to nomenclature of Cambrian fossils: Smithsonian Misc. Colln., v. 101, no. 15, 58 p.

Riccio, J. F., 1952, The Lower Cambrian Olenellidae of the southern Marble Mountains, California: Southern California Acad. Sci. Bull., v. 51, pt. 2, p. 25–49.

Rodgers, John, 1940, Distinction between calcite and dolomite on polished surfaces: Am. Jour. Sci., v. 238, no. 11, p. 788–798.

Ross, R. J., Jr., 1951, Stratigraphy of the Garden City formation in northeastern Utah, and its trilobite faunas: Peabody Mus. Nat. History, Yale Univ. Bull. 6, 161 p.

Sharp, R. P., 1942, Stratigraphy and structure of the southern Ruby Mountains, Nevada: Geol. Soc. America Bull., v. 53, p. 647–690.

Trengove, R. R., 1949, Investigation of Comet Coalition lead-zinc deposits, Lincoln County, Nevada: U.S. Bur. Mines, Rept. Inv. 4541, 6 p., 8 figs.

Walcott, C. D., 1884, Paleontology of the Eureka district, Nevada: U.S. Geol. Survey Mon. 8, 298 p.

——— 1886, Second contribution to the studies on the Cambrian faunas of North America: U.S. Geol. Survey Bull. 30, 369 p.

——— 1888, Cambrian fossils from Mt. Stephens: Am. Jour. Sci., 3d ser., v. 3, p. 161–166.

——— 1891, Correlation papers; Cambrian: U.S. Geol. Survey Bull. 81, p. 317.

——— 1908a, Cambrian geology and paleontology; no. 1, Nomenclature of some Cambrian Cordilleran formations: Smithsonian Misc. Colln., v. 53, p. 1–12.

——— 1908b, Cambrian geology and paleontology; no. 5, Cambrian sections of the Cordilleran area: Smithsonian Misc. Colln., v. 53, p. 167–230.

Wallcott, C. D., 1912, Cambrian Brachiopoda: U.S. Geol. Survey Mon. 51, Part I, 872 p.

——— 1915, The Cambrian and its problems in the Cordilleran region, *in* Problems of American geology: Yale Univ. Press, New Haven, p. 162–233.

———1916a, Evidences of primitive life: Smithsonian Inst. Ann. Rept. 1915, p. 235–255.

——— 1916b, Cambrian Trilobites: Smithsonian Misc. Colln., v. 64, no. 5, p. 409–410.

Westgate, L. G., and Knopf, Adolph, 1927, Geology of Pioche, Nevada and vicinity: Am. Inst. Mining and Metall. Engineers Trans., v. 75, p. 816–836.

——— 1932, Geology and ore deposits of the Pioche district, Nevada: U.S. Geol. Survey Prof. Paper 171., 79 p.

Wheeler, H. E., 1940, Revisions in the Cambrian stratigraphy of the Pioche district, Nevada: Univ. Nevada Bull., v. 34, no. 8 (Geology and Mining ser. no. 34), 42 p.

——— 1947, Base of the Cambrian system: Jour. Geology, v. 55, no. 3, pt. 1, p. 153–159.

——— 1948, Late pre-Cambrian - Cambrian stratigraphic cross section through southern Nevada: Univ. Nevada Bull., v. 42, no. 3 (Geol. and Mining ser. no. 47), 61 p.

Wheeler, H. E., and Lemmon, D. M., 1939, Cambrian formations of the Eureka and Pioche districts, Nevada: Univ. Nevada Bull., v. 33, no. 3 (Geol. and Mining ser. no. 31), 60 p.

White, C. A., 1877, Report upon geographical and geological explorations and surveys west of the one-hundredth meridian: v. 4, pt. 1, paleontology, 219 p.

Young, E. B., 1948, The Pioche district [Nevada], *in* Dunham, K. C., ed., Symposium on the geology, paragenesis and reserves of the ores of lead and zinc: Internat. Geol. Cong., 18th, London, p. 98–106.

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