

THE EUREKA QUARTZITE OF THE GREAT BASIN REGION.*

EDWIN KIRK.

INTRODUCTION.

Within the Ordovician of the Great Basin region is a persistent quartzite horizon. In central Nevada this formation is known as the Eureka quartzite. Work in the Great Basin region and adjacent areas extending over a period of several years has made it possible to add considerably to our knowledge of this quartzite horizon. Its age, at least in part, is determinable within fairly narrow limits, its known extension considerably increased and correlations with distant points made possible. It is chiefly as bearing on the age of the quartzites, their extension and correlation, that the present paper has been written. Based on reconnaissance work covering large areas the present contribution is intended only to point out features of major interest and serve as a groundwork for future and more detailed investigations.

The Eureka quartzite was described by Hague (1883, 1892) with its type section in the Eureka district, Nev. Very little was known as to the extension of the formation outside the Eureka district, and such additional information as has appeared since that time is widely scattered in the literature. It now appears that the Eureka quartzite, or quartzites holding an equivalent stratigraphic position, are widely developed in the Great Basin region. They are well shown as far south as the Las Vegas quadrangle, Nev. The Eureka or equivalent beds cross the Utah line to the eastward and extend at least as far as Frisco, Utah. Owing to lack of outcrop, they are unknown in Nevada north of a point in the Pinyon Range some 60 miles north of Eureka. Quartzites that may be partially equivalent in age occur in Idaho. To the westward equivalents of the Eureka extend into California.

Instead of being a stratigraphic unit, as thought by Hague and Walcott, the Eureka quartzite proves to be a composite of three distinct divisions within the Eureka district, the type area. Of outstanding interest is the fact that at least one of these quartzites can be shown with reasonable assurance to pass laterally into fossiliferous marine sediments. From a paleogeographic standpoint the results are of interest as dem-

* Published by permission of the Director, United States Geological Survey.

onstrating the presence of a widespread Middle Ordovician (approximately Black River) sea in the Great Basin region where it was formerly unknown and give an approximate delimitation of the eastward extension of the sea in the Nevada-Utah region. Hitherto we have had no definite knowledge of sediments intermediate in age between the Chazyan and Upper Ordovician in this region, barring graptolite faunas of uncertain placement.

At the top of the Eureka quartzite is a thin layer, never over three feet in thickness as seen, of saccharoidal sandstone resting on a somewhat uneven surface of dense quartzite. This thin sandstone, although originally included in the Eureka quartzite, is the initial deposit of the overlying Upper Ordovician. In a section on Pete Hanson Creek in the Roberts Creek Mountains 300 feet of Eureka quartzite are well shown. As seen in cliff exposures one notes that approximately 100 feet of the basal quartzite are of a dark brownish color, while the upper 200 feet are much lighter, tending toward the gleaming white vitreous quartzite that is so characteristic of the typical Eureka. The lower portion also shows a considerable amount of cross-bedding. Subsequently it was noted in other localities that the basal portion of the Eureka quartzite frequently showed cross-bedding, and there was a tendency on weathering for the lower beds to have a sandy texture. Also, below the quartzite proper, as at Lone Mountain, sandy calcareous argillites were found that did not seem to go with the underlying beds of Chazyan age. Where such beds were found the quartzite was thinner than elsewhere. Such observations seemed to show that in the Eureka quartzite the lower portion is a variable lithologic unit and so far as known varies independently of the overlying vitreous quartzite that apparently maintains its thickness and lithologic character throughout the area.

It was not, however, until sections were examined in the Monitor and Antelope Ranges some 30 miles southwest of Eureka that the problem was solved, at least in part. Here resting immediately upon beds of Chazyan age was a heavy ledge of sandstone. Above this came several hundred feet of calcareous beds and capping the whole, vitreous quartzite. In the calcareous beds immediately above the basal sandstone an invertebrate fauna was collected. A few cephalopods were found in the sandstone. Evidence at hand clearly indicates that we have here a lateral change of the basal part of

the Eureka quartzite from quartzite to massive compact sandstone, to sandstone, sandy argillaceous beds, sandy calcareous beds, and finally to fairly pure limestones.

The Ordovician sands collectively embraced under the name Eureka are distributed as known in Nevada and Utah over an area some 300 miles north and south in maximum extension and some 225 miles east and west. The area lies approximately between 36° and 41° north latitude and 113° and 117° west longitude. The maximum known north-south extension lies in about 116° west longitude and the maximum known east-west extension in 38° north latitude. The typical quartzitic Eureka can apparently be bounded on the west by a meridional line at about 117° west longitude. Known sections plotted on a map show the area as approximately fan-shaped, with the northern and southern margins converging eastward. At 114° west longitude the north-south width of the fan is approximately 200 miles. There is no chance of tracing the margins of the structure much farther east than the 114° meridian owing to concealment by younger sediments. Throughout the area as bounded above, exposures of the Eureka are fairly uniformly distributed. Sections are seldom more than 20 miles apart in Nevada. The extension into Utah has greater gaps.

West of the 117th meridian the Middle Ordovician is represented predominantly by graptolite shales with minor amounts of sandstones, limestones, and calcareous shaly beds. East of the line the Eureka horizon is predominantly a massive quartzite of variable thickness but of characteristic and fairly uniform lithology. Occasional intercalated masses (probably lenticular) of calcareous beds or shales are rarely found.

In order to give a general idea of the distribution and local characteristics of the Eureka a number of sections have been chosen. These fall into four geographical groups. The first group comprises those sections in and adjacent to the type area, that is, within 50 miles of Eureka to the north, west, and southwest. The next group carries the Eureka southward between the 116th and 117th meridians to its most southern known limit. The next group lies between 114° and $115^{\circ} 30'$ west longitude, and the line of sections is followed northward from the approximate margin of the old land that lay to the south. The fourth group constitutes the sections representing the eastward extension of the Eureka into Utah.

FIRST GROUP OF SECTIONS.

Eureka, Nev.—As described by Hague (1883, 1892) the Ordovician section near Eureka, Nev., was given as consisting of Pogonip below, Eureka quartzite, and then Trenton. The upper portion of the Pogonip was rightly said to be Chazyan in age. The so-called Trenton appears to have been included in the Lone Mountain formation for mapping purposes. It was not well known and was considered to have a limited areal distribution. It is now known that this so-called Trenton is of Upper Ordovician age and is one of the most widely extended stratigraphic horizons in the Great Basin, as well as other parts of the western United States. In the reports of Hague and Walcott this zone was often identified as Silurian owing to the presence in it of *Halysites*. As to the age of the Eureka, nothing was known other than as determined by the bounding formations above and below.

Near Eureka, Nev., exposures of the Eureka quartzite are poor. Indeed, exposures of the quartzite though abundant and covering an aggregate of many square miles of surface are either not good or not readily accessible within the area mapped by Hague. The Eureka quartzite is well shown in other parts of Nevada, however, and reasonably accessible outcrops showing the over and underlying beds can be seen at a few points within 50 miles of Eureka, within Eureka County. As described by Hague (pp. 54-57, 1892) the Eureka quartzite was given a possible maximum thickness of 500 feet, with a maximum measured thickness of 300 feet. It is probable that within the Eureka area the latter is the more nearly correct average thickness. Measured sections of the quartzite within a radius of 50 miles of Eureka gave me 225 feet as a minimum and 300 feet as a maximum for the quartzite proper.

Lone Mountain. (About 18 miles northwest of Eureka, Nev. Roberts Mountains quadrangle.)—The southwest face of Lone Mountain gives an excellent section of the upper part of the Pogonip, the overlying Eureka quartzite, and superposed Upper Ordovician. It is the best section I know of this part of the Paleozoic column.

Here the cliff-forming quartzite has a thickness of but 225 feet. The lower portion of the cliff is a sandstone rather than quartzite and shows cross-bedding in places. Below the cliff and above the typical uppermost Pogonip limestones are about 50 feet of brownish-weathering sandy dolomite. These beds

in lithology are very like sediments to be described later that prove to be of Middle Ordovician age. No fossils were found in these sandy beds at Lone Mountain, but they apparently pertain to the Eureka. It should be noted that their thickness added to that of the superjacent cliff-forming sandstones and quartzites give a total thickness about normal for the Eureka as a whole in this general area.

Roberts Creek Range. (About 35 miles northwest of Eureka, Nev. Roberts Mountains quadrangle.)—Along the west front of the range from Pete Hanson Creek northward is a bold line of cliffs formed by the Eureka quartzite. On the north fork of the creek the Eureka quartzite is well shown and can readily be reached. To the northward the quartzite steadily rises until it caps the highest peaks in the northwestern portion of the range.

The Eureka quartzite here is approximately 300 feet in thickness and, as noted above, the basal third is sharply differentiated from the upper portion in color and texture, being much darker and showing cross-bedding. This indicates massive compact sandstone rather than quartzite. The beds immediately under the quartzite are poorly shown, as is usually the case owing to the heavy talus cover.

Fossils were collected some 300 feet below the quartzite according to apparent stratigraphic position. These were of lower Pogonip age (approximately Beekmantown) and rather early in that. Loose float above the fossils had the lithology of lower Pogonip. It appears that a minimum of 1,000 feet of Pogonip is not present in this section. The conditions bringing this about are not clear. The beds dip at a low angle, and ordinarily one would assume a fault along the face of the cliff. Evidence of such a fault is, however, not apparent. About 10 miles to the east on the other side of the range are graptolite shales, the locality of which is given in the literature as "Summit," Nev. This name is misleading as there is a Summit in western Nevada, near the California-Nevada boundary, and the locality were better rechristened Garden Pass. This graptolite fauna is of early Chazyan age and fits in the hiatus between the Eureka quartzite and the lower Pogonip beds on Pete Hanson Creek. There are three possible explanations of the absence of these beds on Pete Hanson Creek. They were either not deposited or were removed by erosion prior to Eureka time, or we are dealing with an overthrust of younger beds on older. I believe non-deposi-

tion may be eliminated from consideration. Of the other two explanations either is possible.

Cortez, Nev. (Cortez Range, about $116^{\circ} 40'$ west longitude and $40^{\circ} 10'$ north latitude.)—This locality is approximately 20 miles north and somewhat west of the Roberts Mountains section. As given by Emmons (p. 101, 1910) the Eureka quartzite has a thickness of from 200 to 300 feet. It is underlain by gray limestones and overlain by cherty gray limestones. The latter are probably Upper Ordovician. What part of the Pogonip is represented can not be told. This is unfortunate as this section might throw some light on the Roberts Mountains section where the upper portion of the Pogonip is wanting. The section is of interest as being the last known Eureka outcrop to the northwest.

Ravens Nest, Pinyon Range. (About 116° west longitude and $40^{\circ} 30'$ north latitude.)—Walcott in Hague (p. 200, 1892) gives a "roughly estimated" thickness of 400 feet for the Eureka in the northern portion of the Pinyon (Sulphur Spring) Range. This thickness apparently indicates a former extension to the northward for a considerable distance beyond this point.

Antelope Range. (Northward extension of Hot Creek Range. About 30 miles southwest of Eureka, Nev. Roberts Mountains quadrangle.)—Along the west front of the range a few miles south of Ninemile Canyon is one of the best sections of the Pogonip to be had. Faults parallel to the front of the range should be crossed before beginning the section. Some 2,500 feet of the Pogonip are well exposed together with the overlying beds to the top of the Eureka quartzite. This is perhaps the most interesting known section of the Eureka and the one in which fossils were collected within the Eureka proper.

Overlying the Pogonip limestone (carrying abundant Chazyan fossils) is a ledge of brown sandstone 25 feet in thickness. In this are to be found some poorly preserved cephalopods probably referable to *Endoceras*. Above this sandstone are some 250 feet (estimated) of sediments forming a long receding slope. Capping an isolated peak at the top of the section is a mass of quartzite estimated to have a thickness of about 150 feet. This is the hard vitreous light-colored quartzite which seems universally to characterize the upper portion of the Eureka.

The great interest in this section lies in the 250 feet of beds

overlying the basal sandstone and under the capping vitreous Eureka. The basal portion of this series consists of fairly pure limestones, apparently lenticular and interbedded with sandy beds and sandy dolomites. The higher portion of the series is largely concealed, but judging from float it consists largely of calcareous sediments tending to break down in small angular fragments. Interspersed in the series are sandy beds. In the basal 25 feet or so of this series, immediately overlying the basal sandstone, fossils are abundant, the main difficulty being to find outcrops. The fauna collected, which probably represents but a fraction of that obtainable, is here listed.

Fauna immediately above basal sandstone of the Eureka.

- Stromatotrypa* sp.
- Sowerbyella*, type of *pisum* Ruedemann
- Sowerbyella* near *punctostriata* Mather
- Dinorthis* (*Plaesiomys*) sp.
- Valcourea* cf. *deflecta* Conrad
- Cliftonia* sp.
- Clathrospira* sp.
- Remipleurides* sp.
- Iliaenus* cf. *americanus* (Billings) (punctate type of late Black River age)
- Thaleops* sp.
- Ectenaspis* cf. *homalonotoides* (Walcott)

Monitor Range. (About 35 miles southwest of Eureka, Nev. Roberts Mountains quadrangle.)—Along the east front of the Monitor Range approximately six miles west of the Antelope Range section just described the upper portion of the Pogonip and the overlying Eureka are exposed for several miles. In the line of traverse taken to the crest of the range the basal portion of the Eureka was poorly shown, falling in a saddle on ridge sections and being covered by detrital matter on slopes. No continuous basal sandstone unit was seen. Near the base of the Eureka, however, was a zone of dissociated lenticular masses of brownish sandstone. None of these as seen had a thickness greater than 10 feet. Overlying the sandstone horizon were some 180 feet of beds showing only as float, which consisted of small angular fragments of light-colored limestone. The upper portion of this slope was largely covered by talus of the capping quartzite. The quartzite forming the crest of the range has a thickness of approximately 200 feet. This quartzite is again the light-colored semi-vitreous type characteristic of the upper Eureka. In this section the Eureka is overlain by limestones in which no recog-

nizable fossils were seen but quite unlike the Upper Ordovician. I suspect the limestones to be of Silurian age.

Some six or seven miles north of the section just described is an outlying hill to the northeast of the mouth of Copenhagen Canyon made up of limestone breaking down into angular fragments which probably represents the limestone horizon underlying the capping quartzite of the Eureka. Fragments of an asaphoid trilobite were found in the limestone, and there is a possibility that a fauna could be collected here.

Toquima Range. (Roberts Mountains and Tonopah quadrangles.)—Less than 20 miles a little south of west of the Monitor Range section, an area of Paleozoic rocks in the neighborhood of Ikes Canyon should have furnished in this latitude the connecting link between the Eureka on the east and the graptolite deposits of equivalent age on the west. The section proved disappointing, however. Here along the front of the range south of Ikes Canyon a plate of Chazyan Pogonip was found overthrust on Devonian. Above the Pogonip, calcareous shaly beds were found that carried Silurian graptolites. So far as seen the evidence pointed to normal sedimentary superposition of the Silurian on the Pogonip. The lack of Middle Ordovician sediments in this portion of the Toquima Range, if they really be wanting, is probably due to pre-Middle Silurian erosion.

The sections given above show the wide range in sedimentary character of the Eureka in Eureka County, Nev., within which lies the type region of the formation. The section at Lone Mountain, which was known to the Hague party and which shows the overlying and underlying formations, is here chosen as the type section, with the approval of the United States Geological Survey. The quartzite proper, as noted above, is somewhat thinner than usual in this section, and its basal portion is probably represented by sandy dolomites and limestones. The section is comparatively easy of access, however, and is the nearest one to the town of Eureka that is satisfactory.

SECOND GROUP OF SECTIONS.

The next series of sections carries the Eureka southward, the outcrops in the Hot Creek Range being essentially continuous with those of the Antelope Range, which is really the northern extension of the Hot Creek Mountains.

Hot Creek, Nev. (Hot Creek Range. About 38° 30' north

latitude and $116^{\circ} 30'$ west longitude.)—Near Hot Creek, Spurr (p. 85, 1903) gives a section in which 400 feet of "massive white quartzite" overlies upper Pogonip, carrying the characteristic Chazyan fauna. This quartzite is the Eureka and is overlain by 200 feet of "thin-bedded dark-blue limestone." This limestone one would expect to be Upper Ordovician, but the fauna quoted on page 86 as coming from "the limestones above the quartzite" contains some fossils that could only be Silurian. It is not stated how far above the quartzite the fossils were collected, and it is possible that both Ordovician and Silurian are represented.

About 15 miles south of Hot Creek at Tybo, Ferguson has found the Eureka varying in thickness from nothing to something over 100 feet and overlain by Silurian. The upper surface of the Eureka is irregular and clearly indicative of an erosion surface.

Kawich Range. (Near Kawich Post Office about $116^{\circ} 15'$ west longitude and $37^{\circ} 30'$ north latitude.)—On Quartzite Mountain, Ball (p. 100, 1907) describes 1,200 to 1,500 feet of Eureka quartzite. This is underlain by "400 to 600 feet of interbedded quartzite, slaty shales, and limestones." Ball notes that although the Eureka is quartzite in the main some beds "are better defined as indurated sandstones." Conglomeratic layers with pebbles up to half an inch in diameter occur in the Eureka. "Cross-bedding is common and ripple marks are locally well developed, while sun cracks are rare and confined to the finer grained arkoses."

This section is of exceptional interest in that it has the thickest recorded Eureka in the western part of the area. It is also interesting because of the sun cracks, ripple marks, and beds of conglomerate. The 400 to 600 feet of beds underlying the massive Eureka may well be the upper portion of the Pogonip as suggested by Ball or may pertain to the Middle Ordovician.

Amargosa Range. (Boundary Canyon, about $36^{\circ} 45'$ north latitude and 117° west longitude.)—Ball describes the Eureka here as having a thickness of about 800 feet. It overlies typical upper Pogonip and is overlain by Silurian limestone. The Eureka here, as at Kawich, has conglomeratic bands with pebbles up to half an inch in diameter. Of interest is the fact that occasional thin layers of "black fine-grained argillaceous quartzite and of olive-green or brown slaty shales are also interbedded with the normal quartzite."

Bare Mountain, Nev. (About 25 miles east of the Amargosa Range locality.)—In this area, as described by Ball (p. 154, 1907), the sediments are considerably metamorphosed. The Eureka quartzite is given a thickness of 1,000 feet. In the Eureka are intercalated shales, changed to schists, and limestones. Cross-bedding is common in the quartzite, and ripple marks were seen.

It is evident, as shown by the sections given above, that in the extreme southwestern portion of the Eureka area of deposition we have a region of unusually heavy sedimentation. It is held, as will be more fully stated later, that the source of much of this material lay somewhere to the south or southwest.

THIRD GROUP OF SECTIONS.

The next series of sections lies within a north-south zone bounded in the main by the 115th and 116th meridians, west longitude. As taken in sequence the series starts in the Goodsprings quadrangle, Nev., where the Eureka is wanting, probably owing to non-deposition. The sections are then carried northward as far as they are known.

Goodsprings quadrangle, Nev. (About 36° north latitude and 115° 15' west longitude.)—Hewett (p. 11, 1931) describes the Goodsprings dolomite as having a thickness of some 2,450 feet and probably ranging in age from Upper Cambrian to Devonian. No equivalent of the Eureka seems to be present, which is as might be expected, taking into account the conditions obtaining in the Las Vegas quadrangle a short distance to the north.

Las Vegas quadrangle, Nev. (Section in southern part of quadrangle about 36° 15' north latitude and 115° 30' west longitude. Section in northern part about 40 miles to the north.)—Unpublished information kindly furnished by C. R. Longwell gives us sections in the Las Vegas quadrangle. Used in conjunction with those of the Goodsprings quadrangle these permit us rather definitely to draw the southern boundary of the Eureka sediments between the 115th and 116th meridians.

Longwell's most southern section is near La Madre Spring, approximately 15 miles north of Hewett's section (Goodsprings quadrangle) that contains no Eureka. In this section Longwell found the Eureka represented by 20 feet of sandy shale and sandstone. It overlies typical Chazyan Pogonip and is overlain by Upper Ordovician.

In the northern part of the Las Vegas quadrangle, approximately 40 miles to the northward, Longwell found from 150 feet to 400 feet of Eureka consisting of white and varicolored quartzite and sandstone. This horizon is overlain by Upper Ordovician and rests on Chazyan Pogonip.

Going northward from the Las Vegas quadrangle between the 115th and 116th meridians a line of sections is available as far as 40° north latitude. This gives us a north-south extension in this meridian of more than 250 miles. A few of the ranges will be noted, in sequence, noting merely the thickness of the Eureka. In all cases the stratigraphic succession is normal upper Pogonip, Eureka, and Upper Ordovician.

Hyko and Pahranaġat Ranges, Nev. (About 37° 30' north latitude.)—The Eureka as measured by Walcott (Hague, p. 196, 1892) has a thickness of 400 feet on Quartz Peak in the Pahranaġat Range. It is a hard, white vitreous quartzite.

Quinn Canyon and Grant Ranges, Nev. (About 38° to 38° 30' north latitude.)—Spurr (p. 69, 1903) gives the Eureka a thickness of 200 feet. It is here a hard white vitreous quartzite.

White Pine Range. (Hamilton, about 39° 15' north latitude.)—Walcott (Hague, p. 191, 1892) gives the Eureka a thickness of 350 feet. I did not measure the thickness, but as seen it appeared to run somewhat under this. The quartzite is of the light-colored vitreous type in the main.

Ely, Nev. (About 39° 15' north latitude and 115° west longitude.)—Near Ely, offsetting somewhat to the east from the localities last named, Spencer (1917) found the Eureka but 150 feet thick. Spurr (p. 49, 1903) records the presence of the Eureka in the Egan Range some 50 miles north of Ely. This is the most northern known extension in this meridian, and unfortunately Spurr does not give its thickness. Approximately 50 miles to the east in the Deep Creek Range in Utah (Nolan, 1930) the Eureka is wanting. Approximately 25 miles to the southeast of Ely, near Osceola in the Snake Range, Spurr (p. 30, 1903) gives the Eureka a thickness of 400 feet. It appears that in this portion of Nevada and Utah we have a rapid thinning of the Eureka to the north. It is probable that the northern margin of the Eureka quartzite lay not far north of 40° north latitude in this meridian.

It is probable that in the foregoing line of sections we can fairly accurately locate the northern and southern boundaries of the Eureka sediments in this meridian. The evidence avail-

able seems to indicate that the present limits of the Eureka in these cases practically coincide with the old land margin. Going eastward into Utah as shown by the next group of sections we find the north-south extension of the Eureka becoming progressively less.

FOURTH GROUP OF SECTIONS.

Dugway Range, Utah. (About 40° north latitude and 113° west longitude.)—In the Dugway Range and underlain by sediments of Chazyan age and overlain by Upper Ordovician (Fish Haven dolomite in the Wasatch Range) are some 300 feet of Eureka quartzite. The section is complicated by faulting, but this may be taken as an approximate thickness for the quartzite. The quartzite is reddish-brown in the basal portion, becoming lighter in color higher up, and the upper part is white vitreous quartzite.

This occurrence of the Eureka is of considerable interest. It is tied to the Frisco section, about 100 miles to the south, by intermediate outcrops in the Fish Springs and Confusion Ranges. About 35 miles almost due west, in the Deep Creek Mountains, the Eureka is wanting, as it also is some 25 miles to the northeast in the northern portion of the Stansbury Range. It also is wanting in the Lakeside Mountains about 50 miles to the northeast. No other sections are known in the Great Salt Lake Desert or along the northern shores of Great Salt Lake.

Frisco, Utah. About 38° north latitude and 113° west longitude.)—According to Butler (pp. 31-33, 1913) some 2,000 feet of quartzite overlie the Grampian limestone (of upper Pogonip (Chazyan) age in its upper part) in the San Francisco Range. This formation he named the Morehouse quartzite. To the east, in the Star Range, a quartzite series 2,500 feet or more in thickness probably represents the same horizon. Butler considered the Morehouse quartzite to be at least in part of Ordovician age but assumed that the boundary between the Ordovician below and supposed Silurian above fell within the quartzite. Fitting the Frisco section into the general pattern of the Great Basin sediments it is improbable that the Morehouse quartzite consists of other than Ordovician sediments. Furthermore, it is undoubtedly the approximate equivalent of the Eureka quartzite, the exact upper and lower boundaries being of necessity uncertain.

The lithologic character of the Morehouse quartzite is of considerable interest. Included in the formation are lenses of shale and conglomerate.

Tintic district, Utah. (About 40° north latitude and 112° west longitude.)—Lindgren and Loughlin (p. 34, 1919) have described the Bluebell dolomite as ranging in age from possibly Beekmantown, and almost certainly from Chazy, to Upper Ordovician. At any rate, within the stratigraphic range of this dolomite lies the time interval represented by Eureka deposits. Within this area there seems to be no representative of the quartzite horizon, nor does it appear in sections to the northward. The hiatus is best explained as due to non-deposition.

The extension of Eureka deposits to the southeast of Frisco is unknown, the country being under a heavy cover of later sediments. No equivalent of the Eureka is present in the Grand Canyon sections, and it is probable that the Eureka did not extend far south along this meridian. The nearest Eureka known south of Frisco is near Pioche, Nev., about 75 miles to the southwest. Here Westgate (p. 15, 1932) gives the Eureka an average thickness of 200 feet with a measured variation in thickness of from 150 to 250 feet. Westgate describes the formation as a pure quartzite, varying in color from white to pale-red. Portions of the Eureka are quartzitic sandstone clearly showing individual grains. As described the Eureka is distinctly bedded in layers ranging from six inches to six feet in thickness. The major portion of the Eureka is the white gleaming vitreous type, and as I saw it the reddish coloration was restricted to the basal portion.

In attempting to reconstruct the Ordovician sea in which the Eureka sediments were laid down there are conditioning factors that must be taken into account. The factor of erosion in erasing evidence of prior sedimentation is common to all paleogeographic studies and is difficult in the extreme properly to evaluate. In most studies of this sort erosion has not been taken into account and in some cases has been stated to be a negligible factor. In western North America Paleozoic erosion plays a very important rôle. In the present problem we have to deal with pre-Upper Ordovician, pre-Middle Silurian, pre-Middle Devonian, pre-Mississippian, and pre-Permian periods of erosion, each of which is known to have been effective to a greater or less degree. Fortunately, in the present instance Upper Ordovician sediments overlie the Eureka

in most sections, except along the far western margin, and the later periods of erosion may be eliminated as not affecting the Eureka except in marginal areas and in the possible southward extension of the seaway. Another factor which for practical purposes need only be considered in the western part of the area is thrust-faulting, resulting in lateral displacements of sedimentary masses. It should be noted that throughout Nevada horizontal distances of the present do not actually represent original distances during the period of deposition. This is an area of overthrusting, of unknown but considerable magnitude. The thrust-faults are of the low angle type.

In a broad view perhaps the most interesting outcome of this synthesis of information in regard to a limited portion of the stratigraphic column is the reconstruction of a broad north-south-trending seaway in the Great Basin region, in which were laid down clastic sediments derived from land masses both to the east and south and possibly to a minor degree from the west. The eastern moiety of the basin can be described with fair accuracy now, and much supplemental information can be obtained in the future. The western portion of the basin is abruptly cut off by the Sierras, and its further extension to the west must forever be a subject of speculative interest. Careful study of the sediments, however, should yield information of value. The eastern margin of the Middle Ordovician sea, of which the area of Eureka sedimentation was a part, can be outlined with a fair degree of assurance. As reconstructed it follows a somewhat sinuous course between the 113th and 114th meridians from at least 45° north latitude nearly to $39^{\circ} 30'$. Here there seems to have been an embayment carrying eastward, with a width of probably not less than a degree of latitude. South of the embayment the land margin took a southwesterly course, crossing the 115th meridian at about 36° north latitude. From this point westward no information is probably to be had. My own belief is that the land margin continued in a westerly direction, possibly out into the Pacific. If this be the case we may picture the present continental area west of the Rocky Mountains as invaded by an epicontinental sea extending not less than 800 miles from north to south and probably not less than 500 miles from east to west. That there was a wide connection with the Pacific goes without saying. It is conceivable but not probable that a connection with the Pacific was had by way of southern California. The more probable

location of the opening to the westward was between what is now central California and Oregon. Such evidence as we now have favors the view that this sea did not extend north of 47° north latitude and south of 35° north latitude, thus occupying only a portion of so-called Rocky Mountain geosyncline.

It appears from the foregoing account that during Middle Ordovician time the southern portion of this Ordovician sea, having an area of some 50,000 square miles, accumulated clastic sediments to an average depth of more than 200 feet. This enormous amount of material could only have been derived from the land areas lying to the east and south. To the west the sandstones change to limestones and shales, with shales predominating. Obviously the source of material could not have been in that direction. North of the 40th parallel the old land was surfaced with non-clastic sedimentary rocks back for a distance of at least 200 miles. It is the marginal lands to the south of the 40th parallel that must have furnished the sands and pebbles. If we picture the land margin as outlined and in connection with this take into account the local areas of heavy sedimentation, we may postulate two major sources of the clastic material. One of these lay in north-eastern Utah and the other in southern California.

In the reëntrant or embayment noted above as lying approximately along the 39th parallel we have 2,000 to 2,500 feet of quartzite near Frisco, Utah. This thickness is greater than any other known and when plotted with sections to the westward and to the north and south gives us a delta-like structure with its apex somewhere in northeastern Utah and with its source of material to the north and east. Here in the general area of the Uinta Mountains we have an abundant supply of sand. The early Paleozoic clastics of this area, reworked, would furnish us exactly the material we find in the Eureka. The thick sections of Kawich, Amargosa, and Bare Mountains in the southwestern portion of the known area of the Eureka quartzite seem to indicate a second major source of supply of clastic material. These sections, as those near Frisco, have beds of conglomerate and show cross-bedding and ripple marks. Considering all the known facts, one may well postulate a second major delta-like deposit with the source of material lying to the south and southwest, somewhere in southern California.

Although in the discussion the Eureka is spoken of as laid

down in a sea it may have been essentially a continental deposit. The widespread occurrence of cross-bedding, ripple marks, and sun cracks clearly indicates shallow water and emergent conditions over large areas. The lack of fossils in the quartzite proper is not conclusive evidence, but their presence in other Ordovician sandstones of the same general region is suggestive. So far as I know no casts of salt crystals have been found. The presence of conglomerates far from the source of material points to current action extending to considerable distances and confined to fairly narrow channels. It may well be that except for the marginal zone along the western border of the area the Eureka was subject to only partial and intermittent marine transgressions. It is in this sense that the term sea is used, and the bounding land margins or shores represent the higher land that was subject to erosion rather than aggradation. The thick deposits of the eastern and southwestern portions of the area would in this case be viewed as fans, built up by torrential intermittent streams.

Of the three units originally comprised within the Eureka the age of two is known within fairly narrow limits. The thin quartzitic sandstone at the top is in reality the basal sandstone of the overlying Upper Ordovician. Nowhere in the Great Basin is this sandstone known to reach a thickness of more than a few feet. The lower portion of the Eureka quartzite, as shown by the fauna collected within it in the Antelope Range, Nev., is of approximately Black River age.

This leaves the correlation of the upper portion of the Eureka somewhat uncertain. This upper division is as a rule a gleaming white vitreous quartzite and seems stratigraphically to be distinct from the lower beds. The Upper Ordovician overlying the Eureka is probably not later than Maysville in age and correlates with a part of the upper members of the Bighorn dolomite of the type area. Considering the stratigraphic units represented in the western United States the possibility remains that the upper portion of the Eureka is to be correlated with the lower Bighorn. The latter I consider of pre-Maysville, post-Trenton age, and probably represents a stratigraphic unit not present in the eastern United States. Sections on the Salmon River in Idaho favor such an interpretation. Here, underlying an Upper Ordovician zone to be correlated with the post-Eureka beds, is a great quartzite series. Within these quartzites are beds of dolomite of characteristic lower Bighorn lithology. Carrying sections

eastward into eastern Idaho and Wyoming all available evidence points to the conclusion that we are dealing with horizons of lower Bighorn age. The correlation of this horizon with the upper portion of the Eureka can probably never be demonstrated, but such a correlation seems most nearly to explain all the observed facts.

The similarity of the Black River faunas of the Great Basin and those of like age in the eastern United States bespeaks an inter-communication of seaways. Whether there was a direct connection between the Great Basin sea and the inland waters is questionable. Along the eastern front of the Rockies in Colorado and extending northward into Wyoming and South Dakota are deposits of approximately Black River age, represented by the Harding sandstone and the lower part of the Fremont limestone at Canyon City, Colo., and a quartzite equivalent of the Harding to the northward (Kirk, 1930). As traced westward in Colorado there is a progressive thinning of the Harding, suggestive of approach to land, and neither to the north or south is there evidence of a channel across the land mass. It is probable that the Pacific and Interior seas were in communication across what is now Alaska and possibly to the south across Mexico or northern South America.

Carrying the Eureka westward into the zone of graptolite shales is a separate problem that will only briefly be noted here. The Toquima formation of Nevada carrying a graptolite fauna of derived Normanskill type is almost certainly to be correlated with the lower Eureka. The same is true of the upper portion of the Palmetto formation of the Silver Peak region. The lower portion is probably of late Beekmantown or Chazyan age. In Idaho an equivalent graptolite horizon is represented, but here the graptolite fauna progressively modified continues upward well into the Upper Ordovician.

BIBLIOGRAPHY.

- Ball, Sydney H. 1907. A geological reconnaissance in southwestern Nevada and eastern California. U. S. Geol. Survey Bull. 308, 1907.
- Butler, B. S. 1913. Geology and ore deposits of the San Francisco and adjacent districts, Utah. U. S. Geol. Survey Prof. Paper 80, 1913.
- Emmons, William H. 1910. A reconnaissance of some mining camps in Elko, Lander, and Eureka Counties, Nev. U. S. Geol. Survey Bull. 408, 1910.
- Hague, Arnold. 1883. Abstract of report on the geology of the Eureka district. U. S. Geol. Survey Third Ann. Rept., 1881-1882, pp. 241-288, 1883.

- Hague, Arnold. 1892. Geology of the Eureka district, Nev. U. S. Geol. Survey Mon. 20, 1892.
- Hewett, D. F. 1931. Geology and ore deposits of the Goodsprings quadrangle, Nev. U. S. Geol. Survey Prof. Paper 162, 1931.
- Hill, James M. 1912. The mining districts of the western United States. U. S. Geol. Survey Bull. 507, 1912.
- Kirk, Edwin. 1930. The Harding sandstone of Colorado. *This Journal*, 20, 456-466, 1930.
- Lindgren, Waldemar, and Loughlin, G. F. 1919. Geology and ore deposits of the Tintic mining district, Utah. U. S. Geol. Survey Prof. Paper 107, 1919.
- Nolan, T. B. 1930. Paleozoic formations in the Gold Hill quadrangle, Utah. *Washington Acad. Sci. Jour.*, 20, No. 17, 1930.
- Spencer, A. C. 1917. The geology and ore deposits of Ely, Nev. U. S. Geol. Survey Prof. Paper 96, 1917.
- Spurr, J. E. 1903. Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California. U. S. Geol. Survey Bull. 208, 1903.
- Walcott, C. D. 1884. Paleontology of the Eureka district. U. S. Geol. Survey Mon. 8, 1884.
- Westgate, L. G., in Westgate, L. G., and Knopf, Adolph. 1932. Geology and ore deposits of the Pioche district, Nev. Part 1. General geology, by Westgate, L. G. U. S. Geol. Survey Prof. Paper 171, 1932.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.