Stratigraphy of the Pando area, Eagle County, Colorado

by

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STRATIGRAPHY OF THE PANDO AREA, EAGLE COUNTY, COLORADO[1]

By

OGDEN TWETO[2]

ABSTRACT

The sedimentary section in the southern part of the Gore Range, Colorado, comprises about 8,500 feet of Paleozoic rocks, almost 8,000 feet of which is Pennsylvanian and Permian(?). The Upper Cambrian Sawatch quartzite, the lowest of the Paleozoic formations, is conformably overlain by, and locally grades into, the Peerless formation, also of Cambrian age. The Peerless is unconformably overlain by the Ordovician Harding quartzite at some places and by the Devonian Chaffee formation at others. The Harding quartzite forms lenses only a few feet thick and is unconformably overlain by the Parting quartzite member of the Chaffee formation. The Dyer dolomite, the upper of the two members of the Chaffee formation, is overlain unconformably by the Gilman sandstone member of the Leadville dolomite, and this is unconformably overlain by the dolomite member of the Leadville.

The thick section of Pennsylvanian and Permian(?) rocks is here divided into three formations. The lowest is the Belden shale, as defined by Brill. It comprises about 125 feet of black shale and limestone and lies unconformably on the Leadville dolomite. The Belden grades upward into a sequence of grits, shales, sandstones, and conglomerates about 6,000 feet thick, here called the Minturn formation. Several beds of limestone and dolomite are interbedded with the clastic rocks in the upper two-thirds of the Minturn formation, and seven of the most persistent and distinctive limestone and dolomite beds or zones are here designated members of the formation. The Jacque Mountain limestone, the uppermost of these members, marks the top of the formation. Most of the Minturn formation is known to be of Des Moines (middle Pennsylvanian) age, and the absence of any stratigraphic break above the dated rocks suggests that the entire formation is Pennsylvanian.

About 2,000 feet of unfossiliferous Pennsylvanian or Permian redbeds overlying the Minturn formation immediately east of the Pando area and in the Kokomo district is assigned to the Maroon formation as here restricted.

The lithologic character, distribution, and stratigraphic relations of all the formations except the Leadville reflect the influence of the Paleozoic Front Range highland, which lay only a few miles to the east of the Pando area. These same features also suggest that a positive area existed on the northeast flank of the Sawatch Range at times from the Cambrian through the Devonian.

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[1]Published by permission of the Director of the Geological Survey, United States Department of the Interior, in cooperation with the State of Colorado through the Colorado State Geological Survey Board and the Colorado Metal Mining Fund.

[2]Geologist, U. S. Geological Survey.

INTRODUCTION

Three of the most productive mining districts of central Colorado—Leadville, Gilman, and Kokomo or Tenmile—are located in the sedimentary rocks of the Mosquito and Gore Ranges where these ranges are crossed by the well-known northeastward-trending Colorado mineral belt. Although these districts have been the subject of intensive and continuing geologic studies,[1] the area between them has remained almost unknown geologically. This area, a triangle with sides of 19, 12, and 13 miles (see fig. 1), contains the same rocks as the productive districts, but through most of it the Leadville dolomite, highly productive in the Leadville and Gilman districts, is deeply buried beneath Pennsylvanian rocks, and the continuity of Pennsylvanian limestone beds productive at Kokomo has been destroyed by faulting and intrusion, so that presence of these beds in this area has not been generally recognized. In order to correlate the rocks and structure of the three mining districts, as well as to appraise many showings of hydrothermally altered and weakly mineralized rocks in the intervening area, the U. S. Geological Survey, in cooperation with the Colorado Geological Survey Board, began a study of this area in 1945. As this project is far from completion, a preliminary geologic map of the area near Pando[2] and the present advance report on the stratigraphy have been prepared. The field work on which these reports are based was done chiefly in 1945, with the assistance of R. S. Thoman, and in 1947, with the assistance of W. R. Griffits.

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[1]Emmons, S. F., Geology and mining industry of Leadville, Colorado: U. S. Geol. Survey Mon. 12, 1886.

Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geol. Survey Prof. Paper 148, 1927.

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Crawford, R. D., and Gibson, R., Geology and ore deposits of the Red Cliff district, Colorado: Colorado Geol. Survey Bull. 30, 1925.

Lovering, T. S., and Tweto, O. L., Preliminary report on geology and ore deposits of the Minturn quadrangle, Colorado: U. S. Geol. Survey Open File report, 115 pp. and map, 1944.

[2]Tweto, Ogden, Preliminary map of the Pando area, Eagle County, Colorado. U. S. Geological Survey preliminary map and text, in process of publication.

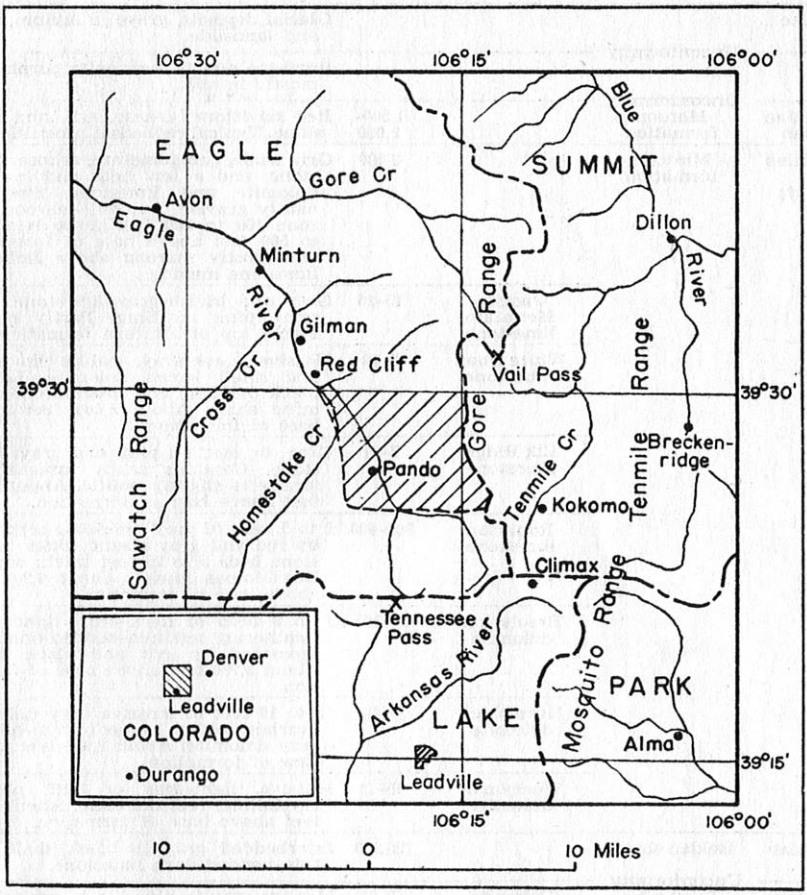

Figure 1. Index map of part of central Colorado, showing location of the Pando area.

The Pando area, in southeastern Eagle county, forms the northern part of the Leadville-Gilman-Kokomo triangle. It is in the northeastern part of the Holy Cross quadrangle and is bounded on the north by the Minturn quadrangle[3] and on the east by the Kokomo district,[4] in the Mt. Lincoln

[3]Lovering, T. S., and Tweto, O. L., op. cit.
[4]Koschmann, A. H., and Wells, F. G., op. cit.

TABLE 1.—*General stratigraphic column of the Pando area, Colorado.*

Age	Formation	Member	Thickness (feet)	Character
Pleistocene				Glacial deposits, gravel, alluvium, talus, and landslide.
	Unconformity			
Tertiary				Intrusive quartz monzonite porphyries, mostly in sills.
	Unconformity			
Pennsylvanian or Permian	Maroon formation		1,500-2,000	Red sandstone, arkose, grit, and mudstone. Typical redbeds. Unfossiliferous.
Pennsylvanian and Permian (?)	Minturn formation		6,000	Grit, shale, conglomerate, arkose, sandstone, and a few beds and reefs of dolomite and limestone. Predominantly grayish, but dull maroon in a zone 100 to 500 feet thick lying 200 to 500 feet above base of formation, and mostly maroon above Robinson limestone member.
		Jacque Mountain limestone	15-25	Gray and bluish-gray limestone, with some pink mottling. Partly oolitic. Marks top of Minturn formation.
		White Quail limestone	8-10	Massive, dark-gray, oolitic limestone and small lenses dolomite. Locally black dolomite and fossiliferous dolomitic shale. About 5,000 feet above base of formation.
		Elk Ridge limestone	7-21	Gray, or mottled pink and gray, limestone. Contains sandy streaks and locally is slightly oolitic. About 4,800 feet above base of formation.
		Robinson limestone	300-400	2 to 5 beds of gray limestone separated by red and gray clastic rocks. Limestone beds 5 to 25 feet thick; contain Des Moines fossils. About 4,200 feet above base of formation.
		Resolution dolomite	30-125	1 to 3 beds of dark-gray, light-gray-weathering, medium-bedded dolomite, separated by grit and black shale. About 3,700 feet above base of formation.
		Hornsilver dolomite	18-28	12 to 16 feet of massive gray dolomite overlain by 8 to 14 feet of thin-bedded gray dolomite. About 2,900 feet above base of formation.
		Wearyman dolomite	15-75	Massive, light-gray or buff, porous, crystalline, reef dolomite. About 2,600 feet above base of formation.
Pennsylvanian	Belden shale		25-200	Interbedded gray to black shale and thin-bedded dark limestone.
	Unconformity			
Mississippian	Leadville dolomite	Dolomite member	67-95	Massive gray to blue-black, crystalline, cherty dolomite.
		Unconformity		
		Gilman sandstone	16-22	Dolomitic sandstone, sandy dolomite, and chert and dolomite breccia in lenticular beds.
	Unconformity			
Devonian	Chaffee formation	Dyer dolomite	73-80	Dark-gray to black, fine-grained, thin-bedded dolomite.
		Parting quartzite	45-57	Tan, pink, and white, coarse-grained quartzite and conglomerate; locally shaly at base, and locally dolomitic at top.
	Unconformity			
Ordovician	Harding quartzite		0-27	Tan, white, and greenish quartzite and some greenish sandstone.
	Unconformity			
Cambrian	Peerless formation		35-99	Thin-bedded, buff, green, purple, and pink sandy dolomite and dolomitic sandstone.
	Sawatch quartzite		140-185	Fine-grained, thick-bedded to massive white quartzite; pink near base and at top.
	Unconformity			
Pre-Cambrian				Schist, gneiss, granite, and diorite; all cut by aplite and pegmatite dikes.

quadrangle. It extends from the flank of the Sawatch Range eastward across the valley of Eagle River to the crest of the Gore Range.

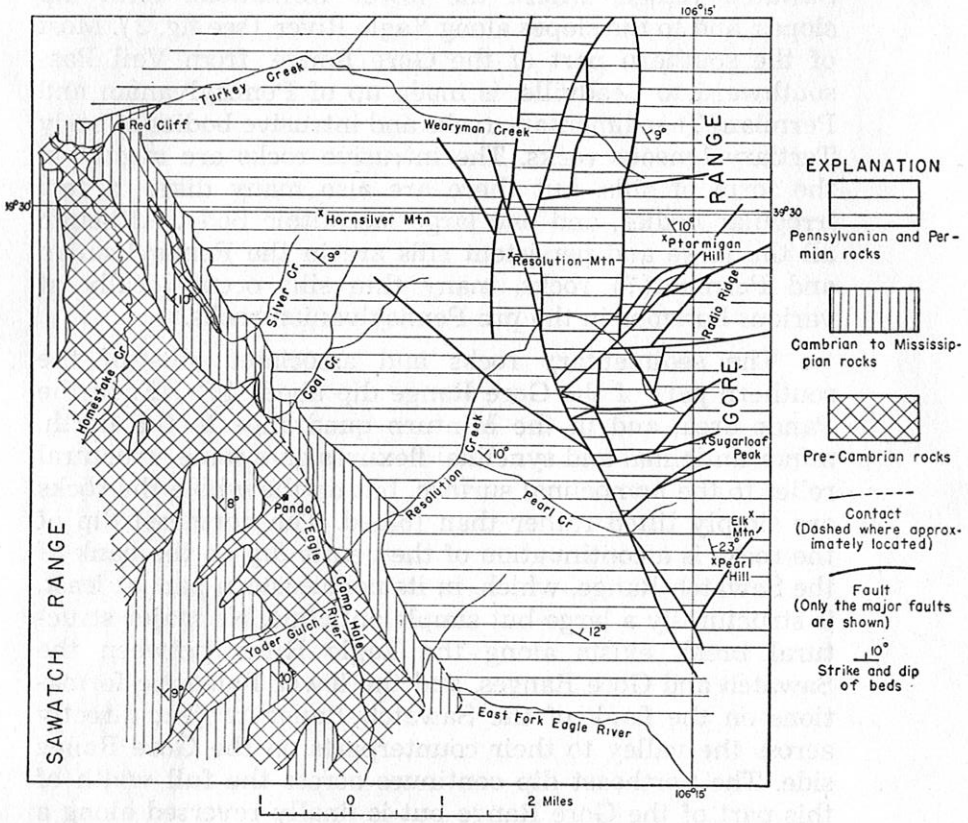

Figure 2. Generalized geologic map of the Pando area, Colorado.

GEOLOGIC SETTING

The rocks of the Pando area comprise pre-Cambrian igneous and metamorphic rocks, Paleozoic sedimentary rocks, early Tertiary intrusive rocks, and Quaternary till, gravel, alluvium, talus, and landslide. The formations and their characteristics are shown in table 1. The pre-

Cambrian rocks are exposed only along the Eagle River and in canyons of the Sawatch Range. Similarly, the pre-Pennsylvanian Paleozoic rocks are confined to the flank of the Sawatch Range, where the lower formations form dip slopes, and to the slopes along Eagle River (see fig. 2). Most of the southern part of the Gore Range, from Vail Pass southward to Leadville, is made up of Pennsylvanian and Permian(?) sedimentary rocks and intrusive bodies of early Tertiary igneous rocks. The intrusive rocks are mostly in the form of sills, but there are also many dikes, a few irregular bodies, and one large laccolithic body. Although all the large and persistent sills are in the Pennsylvanian and Permian(?) rocks, many thin sills occur locally at various horizons in the pre-Pennsylvanian rocks.

The sedimentary rocks and associated sills of the southern part of the Gore Range dip about 10° NE. In the Pando area, and in the Minturn quadrange to the north, minor anticlinal and synclinal flexures give some structural relief to the homoclinal surface, but on the whole the rocks are simply tilted rather than folded. The northeast dip of the rocks is a continuation of the gentle dip on the flank of the Sawatch Range, which, in its northeastern part at least, is structurally a large but simple anticline. No major structural break exists along the Eagle River between the Sawatch and Gore Ranges, and the lower Paleozoic formations on the flank of the Sawatch Range project directly across the valley to their counterparts on the Gore Range side. The northeast dip continues across the full width of this part of the Gore Range but is finally reversed along a synclinal axis near Tenmile Creek, at the west base of the Tenmile Range.

In the Pando area and the region to the south the tilted rocks are shattered by numerous faults, many of which have displacements of hundreds of feet. The faults die out northward, in the southern part of the Minturn quadrangle. The principal fault zone lies about three miles east of the Eagle River at Pando and trends north-northwest. It comprises

several individual faults that have a total displacement of 500 to 1,500 feet, with the east side downthrown. The area west of this fault zone is broken only by scattered faults, most of which have displacements of less than 100 feet. In contrast, the area to the east of the main fault zone is intensely shattered. Faults of many different trends outline polygonal fault blocks in a belt about a mile wide lying immediately east of the main fault zone, and farther east, faults trending northeast to east divide the rocks into a series of large blocks, each of which is cut into smaller blocks by minor faults. This intensely faulted area lies in the obtuse angle opposite the junction of the great Gore and Mosquito faults. The Gore fault, in going southeastward toward a junction with the northward-trending Mosquito fault, appears to weaken and "horsetail," and the reduced displacement on it is evidently compensated by the complex fault system of the eastern part of the Pando area.

PALEOGEOGRAPHIC SETTING

Development of many of the stratigraphic features described below was influenced by the presence, immediately to the east of the Pando area, of the Paleozoic Front Range highland, and possibly by a minor "high" that appears to have existed at the site of the northeastern flank of the Sawatch Range at times during the Paleozoic. North of Vail Pass the west slope of the main ridge of the Gore Range marks the western edge of the Paleozoic highland, as noted by Lovering and Johnson.[5] The Paleozoic formations wedge out in a narrow zone along this slope. The fact that the wedging-out or overlap is unsystematic and is restricted to so narrow a zone led Lovering and Johnson[6] to conclude that the Front Range highland was in existence throughout the Paleozoic, although it oscillated up and down and was doubtless submerged at times. Near Vail Pass

[5]Lovering, T. S., and Johnson, J. H., Meaning of unconformities in stratigraphy of central Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 17, pp. 353-374, 1933.

[6]Lovering, T. S., and Johnson, J. H., op. cit., pp. 371-373.

the edge of the former highland crosses the crest of the present Gore Range and extends southeastward toward the northern end of the Kokomo district. It is well exposed at Copper and Tucker Mountains, three miles north of Kokomo, where the Pennsylvanian rocks abruptly overlap the pre-Cambrian,[7] and near Mayflower Gulch,[8] two miles east of Kokomo, where the Manitou limestone rests on the granite, and the Manitou, Chaffee, and Leadville formations have a combined thickness of only 85 feet. The shoreline evidently extended eastward over the present Tenmile Range east of Kokomo, and then extended northward in a small embayment along the east side of this range to the vicinity of Breckenridge and Dillon, from which it extended southeastward into what is now South Park.

Certain features of the Cambrian, Ordovician, and Devonian rocks described in the following pages suggest that a "high" of some kind existed in the Pando area and on the east flank of the Sawatch Range between Pando and Leadville at times during the lower Paleozoic. Such a high may have been a prong of the highland to the east, or it may have been island-like. In going southward and southwestward from Red Cliff, the floor on which the Sawatch quartzite rests becomes increasingly hummocky, the basal conglomerate in the depressions becomes coarser and thicker, and the thickness of the quartzite fluctuates rather widely within short distances. Of the Ordovician rocks, only the Harding quartzite is present in the Pando area, whereas only the Manitou limestone is present a few miles to the south in the Leadville area. The Harding occurs in isolated lenses in the area between Pando and Red Cliff but has not been identified at Pando or southward. The Parting quartzite member of the Devonian Chaffee formation becomes coarser and markedly thicker to the southwest from Pando, on the slope of the Sawatch Range, and in the same area the overlying Dyer dolomite member locally shows evidence of

[7]Koschmann, A. H., and Wells, F. G., op. cit., pp. 86-87.

[8]Koschmann, A. H., and others, Geologic map of the Kokomo district, Colorado: U. S. Geol. Survey Open File map, 1948.

marked erosion before deposition of the Mississippian rocks.

No evidence of this local "high" has been ovserved in the upper Paleozoic rocks. Indeed, no distinguishing effects even of the Front Range highland have been observed in the Mississippian beds, and the Leadville sea probably extended far onto the highland, or even across it. During the Pennsylvanian, however, conditions changed markedly. The Front Range highland stood high shortly after the beginning of Pennsylvanian sedimentation, had a steep western shore, and supplied vast quantities of coarse sediments to the nearby basin. The shore zone is clearly defined by a zone of sharp overlap onto Paleozoic and pre-Cambrian rocks along the western slope of the Gore Range southward to Vail Pass and thence southeastward through the Copper Mountain area to the Tenmile Range east of Kokomo. For a distance of 40 to 50 miles along this line, the average slope of the Pennsylvanian shore zone was at least several hundred feet per mile in a zone 1 to 5 miles wide. Between Pando and Jacque Mountain, five miles to the east in the Kokomo district, for example, about 8,000 feet of Pennsylvanian and Permian(?) rocks are exposed, but at Copper Mountain, two miles farther northeast, Koschmann[9] has found only 25 feet above the pre-Cambrian granite a limestone that on the Pando side lies 4,200 feet above the Leadville. Thus in seven miles approximately 4,200 feet of Pennsylvanian rocks are cut out by overlap against the steep shore of the highland. Similarly, in the southern part of the Mt. Powell quadrangle, 30 miles to the north, red siltstones characteristic of the uppermost part of the Pennsylvanian and Permian(?) section lie on pre-Cambrian rocks east of the Gore fault,[10] but to the west a section comprising thousands of feet of older beds can be seen between the fault and the basin area to the west.

The Pennsylvanian and Permian(?) sediments of the eastern part of the basin adjoining the Front Range high-

[9]Koschmann, A. H., Oral communication.

[10]Lovering, T. S., and Tweto, O. L., Preliminary report on geology and ore deposits of the Minturn quadrangle, Colorado: U. S. Geol. Survey Open file report, p. 61, 1944.

land were obviously derived from the highland. They are coarsest near the highland and become finer grained to the west; they are made up of the same rocks as the highland; and they show an increasing proportion of fresh-water sediments, as contrasted to marine, in going toward the highland. The area centering near Pando and extending northward to Gore Creek, near Minturn, and southward almost to Leadville appears to constitute a great delta, or series of coalescing deltas and related fluviatile deposits, built up by streams from the highland to the east during much of the lower Pennsylvanian. The stratigraphic zone from 1,000 to 6,000 feet above the Leadville dolomite in this area contains far more conglomerate and coarse grit than do equivalent zones to the northwest and southeast. The conglomerates and grits are highly lenticular and show cross-bedding and channel structures that suggest deposition by aggrading streams. Locally they form massive lenses, some of them hundreds of feet thick, that show a large-scale, deltaic type of cross bedding that is invariably oriented in such a way as to indicate deposition from an easterly direction. These lenses are probably the rapidly formed deltas of temporary distributary channels.

STRATIGRAPHY

CAMBRIAN SYSTEM

Sawatch quartzite

The Sawatch quartzite forms cliffs along both sides of the valley of Eagle River and forms extensive dip slopes on the flank of the Sawatch Range. The upper part of the formation is well exposed in the cliffs, but because of the pronounced tendency of the quartzite to form talus, the lower beds are exposed only locally, and the basal contact is seldom seen. The quartzite is very poorly exposed on the dip slopes except at the edges of the canyons, and even there its edge is completely buried by talus for long distances.

The lower 40 to 50 feet of the Sawatch quartzite is unevenly bedded, thin-bedded to massive quartzite that has a buff, tan, or yellow aspect, although some beds are white or pink. The lowermost beds include one or two beds of coarse-grained sandstone at most places, but conglomerate is present only locally. Most of the conglomerate consists of rounded quartz granules one-eighth to one-fourth inch in diameter in a sand matrix. It occurs in lenses or thin beds interbedded with sandstone or quartzite in the lower 5 to 8 feet of the formation. A basal bed of coarse conglomerate, with pebbles as much as three inches in diameter, is present locally, particularly in depressions in the floor on which the Sawatch quartzite rests.

The lower yellowish and unevenly bedded unit is overlain at most places by about 10 feet of thin-bedded, yellowish, iron-stained, dolomitic sandstone. The sandstone contains thin beds of brittle, scaly, argillaceous dolomitic sandstone which locally contains abundant brachiopod shells. These shells are all alike and have been identified as the Upper Cambrian genus *Dicellomus* by Dr. W. C. Bell.[11] At two or three places on the cliffs west of Camp Hale, poorly preserved fragments of trilobites have been found in hard gray quartzite at about this same horizon. In the canyon area north of Pando the dolomitic bed was weakly pyritized, and oxidation of the pyrite has left it porous and heavily iron-stained.

The dolomitic sandstone is overlain by 20 to 30 feet of massive gray quartzite, and this quartzite is overlain by about 100 feet of medium-bedded to massive, vitreous white quartzite which contains scattered lenses a few feet long of brown-weathering dolomitic quartzite, particularly in the upper part. At most places the top of the Sawatch quartzite is marked by a distinctive five-foot bed of slightly dolomitic vitreous pink quartzite, which overlies the white quartzite. At a few places, however, the quartzite is white up to the dolomitic sandstone at the base of the overlying

[11]Oral communication.

Peerless formation, and at a few others, lenses of dolomitic sandstone are so abundant in either the white or pink quartzite, or both, that the contact between the Sawatch and Peerless formations is gradational.

The Sawatch quartzite is about 185 feet thick in most parts of the Pando area, but it thins locally to 140 feet or less, as described below.

At most places in central Colorado the Sawatch quartzite rests on a smooth peneplain surface cut over the pre-Cambrian rocks. From the Red Cliff area southward, however, the floor beneath the quartzite becomes increasingly hummocky. Small gently sloping hills or ridges that rise 25 to 30 feet above the old peneplain surface are present between Red Cliff and Pando. Southwest of Pando, hills with slopes of several degrees rise at least 50 feet, and perhaps considerably higher, above the peneplain surface. The only coarse basal conglomerate seen in the Sawatch quartzite in the Pando area is in the depressions between such hills or monadnocks. As the quartzite thins above the hills in the floor, the increasing number and height of the hills along the flank of the Sawatch Range southwest from Pando has the effect of reducing the average thickness of the quartzite in this direction. It is possible that the quartzite wedges out entirely several miles farther south, as Emmons[12] found the Manitou limestone of Lower Ordovician age, lying on pre-Cambrian rocks on a small hill two miles northwest of Leadville.

The Sawatch quartzite also thins to the east and northeast from Pando. It is doubtless present beneath the younger rocks throughout the Pando area, but it thins to less than 50 feet in the eastern part of the Kokomo district, as at Copper Mountain, and it is absent locally, as along the north side of Mayflower Gulch.[13] As the Peerless formation is absent in these localities, the thinning could be attributed entirely to erosion that followed deposition of the Sawatch

[12]Emmons, S. F., Geology and mining industry of Leadville, Colorado: U. S. Geol. Survey Mon. 12, pp. 186-187, 1886.

[13]Koschmann, A. H., and others, op. cit. (Map).

and Peerless formations and preceded deposition of the overlying beds. However, in the Minturn quadrangle the Peerless is present above a relatively thin section of Sawatch rocks at places along the edge of the old highland,[14] and as the Sawatch grades into the Peerless at many places, deposition of the Peerless evidently followed that of the Sawatch without interruption. Thus it is unlikely that the Sawatch was thinned by erosion prior to Peerless sedimentation, and hence the eastward thinning of the Sawatch quartzite in the Minturn quadrangle must reflect shoaling against an old shore rather than erosion following some early Paleozoic uplift.

Similarly, the thinning southwest of Pando can be seen to be due in part to irregularities in the floor, and as the Peerless is present in this area and at places is in gradational contact with the Sawatch, and as there is no change in position of the Sawatch-Peerless contact due to change of facies, the thinning near Pando may reflect a shoal or shoreline in the Sawatch sea, rather than later erosion. The absence of both the Sawatch and the Peerless farther south, however, in the locality described by Emmons, could result as well from post-Peerless, pre-Manitou uplift and erosion as from non-deposition at the site of a Cambrian island.

Peerless formation

The Upper Cambrian Peerless formation was known originally as the Peerless shale member of the Sawatch formation,[15] but in recent publications of the Geological Survey it has been designated a formation.[16] With this designation the writer is in accord, as the Peerless is a well-defined mappable unit that is easily distinguished from the Sawatch quartzite in an extensive area northwest of Leadville. Moreover, in this area it is primarily dolomitic and sandy rather than shaly.

[14]Lovering, T. S., and Tweto, O. L., op. cit., p. 17.

[15]Behre, C. H., Weston Pass mining district, Lake and Park Counties, Colorado: Colorado Sci. Soc. Proc., vol. 13, p. 58, 1932.

[16]Singewald, Q. D., Preliminary geologic map and sections of the Upper Blue River area, Summit County, Colorado: U. S. Geol. Survey Prelim. Map, 1947.

The Peerless formation of the Pando area comprises about 100 feet of dolomitic sandstone, sandy dolomite, dolomitic shale, and dolomite, which weather dark brown or brownish maroon and thus contrast markedly with the underlying white Sawatch quartzite. The contact between the Sawatch and Peerless formations is well-defined at most places, but at some the two formations intergrade in a zone 5 to 25 feet thick. North of Pando the Peerless formation is locally overlain by Harding quartzite, which occupies well-defined channels or depressions cut into the upper part of the Peerless. Elsewhere it is overlain by the Parting quartzite member of the Chaffee formation, which locally also occupies steep-sided channels cut into beds of the Peerless formation.

The most distinctive features of the Peerless formation are the dark color on weathered surfaces, the thin and generally irregular bedding, and the wide range in composition from place to place. Most typically the lower part of the formation is dark dolomitic sandstone which is locally thick-bedded or even massive; the middle part is interbedded sandy dolomite, dolomitic sandstone, and dolomite; and the upper part is interbedded dolomite and dolomitic shale. At some places, however, the formation is made up largely of almost pure dolomite; at others it is almost all sandstone; and at still others it contains much shale.

The sandstone, dolomite, and shale each show a wide range in character as well as in porportion from place to place. Most of the sandstone is dolomitic, but some has a siliceous cement; some is glauconitic, and some contains abundant earthy red hematite that is evidently of sedimentary origin. Almost all the sandstone contains fairly abundant flakes of green chlorite.

Most of the shale in the Peerless formation is dolomitic and is pale green or buff, brittle, and platy. Locally, both near Pando and in areas to the southeast and northwest, the Peerless contains considerable soft clay shale and flaky

micaceous shale, but the total shale content is far subordinate to that of dolomite and sandstone.

The predominantly dolomitic rocks which make up a large part of the Peerless formation are buff, tan, green, pink, and maroon, and many of them are mottled in various combinations of these colors. Most of them are sandy and are interbedded with shale or dolomitic shale in thin beds or partings, and they grade into both sandstones and shales. The dolomitic rocks are characterized by wavy banding or lamination and by rock fragments and concretionary structures of several kinds. Some beds contain irregular large flakes of maroon micaceous standstone; some contain slightly rounded thin pebbles of dolomite arranged parallel to the bedding or at an angle, forming edgewise conglomerate; some contain material that resembles cemented breccia; and some contain spherical or ellipsoidal masses that appear to be concretionary or algal. In addition, many of the bedding planes bear prominent fucoidal markings and borings or trails of various kinds. Most of these inclusions and markings are maroon in color, giving a reddish cast to the predominantly buff or tan dolomitic beds, and hence the term "red cast beds" which was applied to these rocks in early reports.

The Peerless formation is about 100 feet thick at most places in the Pando area, but a range from 35 to 112 feet has been observed. This range in thickness reflects erosion prior to deposition of the overlying rocks. At most places the erosion surface at the top of the formation is wavy and has little stratigraphic relief, but it is cut locally by well-defined channels which seem to be of two ages. Most of the channels are filled with Harding quartzite and were evidently formed prior to the Middle Ordovician, but one, on the west side of Eagle Canyon 1.5 miles north of Pando, seems to be filled with Parting quartzite rather than Harding quartzite and thus must be younger than the others. This channel, the deepest observed, extends to a depth of

65 feet, or to within about 35 feet of the top of the Sawatch quartzite.

The sections below show the character of the Peerless formation in the canyon north of Pando and illustrate the general similarity but marked differences in detail in localities only about half a mile apart.

Section of Peerless formation on cliffs on east side of Eagle Canyon, 2.3 miles north of Pando.

	Feet
Harding quartzite:	
Green quartzite and greenish chloritic sandstone.	
Angular discordance, five feet in 50.	
Peerless formation:	
Sandy dolomite, slightly chloritic, pink to maroon, with some "red-cast" mottling; thin- to thick-bedded.	17
Dolomitic sandstone and interbedded dolomitic shale; sandstone pink, with "red-cast" markings and wavy banding; shale maroon, brittle, and flaky.	3
Sandy dolomite, tan and maroon, finely banded.	1
Dolomitic shale, green and maroon, brittle, grades into unit above.	1
Sandy dolomite, mottled tan, pink, and maroon; massive	2
Dolomitic shale and interbedded sandy dolomite; shale green, scaly, brittle; dolomite banded and mottled tan, green, and maroon.	4
Dolomitic shale, slightly micaceous, with thin lenses of sandy dolomite; gray, brownish-weathering, thin-bedded, brittle.	6
Sandy dolomite, streaked and mottled tan and maroon, thick-bedded.	2
Dolomitic shale, slightly micaceous, green and maroon, brittle, platy.	3
Sandy glauconitic dolomite, in 1-foot beds separated by 1- to 4-inch partings of dolomitic shale; dolomite tan; shale maroon to gray.	7
Sandy dolomite and minor dolomitic shale, banded and mottled maroon and tan, thin-bedded. Fucoidal markings on bedding planes.	15
Dolomitic sandstone, tan, thin-bedded.	4
Dolomite, sandy and glauconitic, maroon and tan, weathers dark brownish-maroon; thin-bedded and slabby. Glauconite most abundant at base.	7
	72
Conformable contact with Sawatch quartzite.	
Sawatch quartzite:	
Vitreous white quartzite.	

Section of Peerless formation on cliffs on east side of Eagle Canyon, 2.75 miles north of Pando.

	Feet
Harding quartzite:	
Green quartzite.	
Wavy contact.	
Peerless formation:	
Sandy dolomite, buff, tan, and brown, brown-weathering; "curly" sand-rich streaks weather in relief; "red-cast" markings in a few beds; thick-bedded at base, medium- to thin-bedded in upper 20 feet.	35
Dolomitic sandstone, dark maroon with small pink mottles, and a few pink lenses and beds; some beds strongly micaceous; alternate thick and thin beds; thick beds finely laminated. Fucoidal markings and trails and borings on bedding planes. Some thin laminae are glauconitic.	8
Dolomite, slightly sandy, mottled gray and maroon, massive; fine, irregular, wavy, siliceous streaks 1 to 2 inches apart weather in relief.	3.5
Sandy dolomite, in 6- to 10-inch beds, and interbedded fissile dolomitic shale; maroon, with some green mottling in shale. Irregular lamination and "red-cast" mottling in dolomite. Worm borings(?) as much as 1 inch in diameter and 8 inches long on some bedding planes.	4.5
Sandy dolomite and interbedded micaceous and sandy dolomitic shale, green; dolomite thin-bedded and finely laminated; shale fissile. Shale becomes more abundant upward.	16
Sandy dolomite, tan, brown-weathering, finely laminated; in 12- to 18-inch beds with 1- to 4-inch partings of green-gray, micaceous, platy dolomitic shale. Lower dolomite beds strongly glauconitic.	6
Sandy dolomite, maroon, weathers red-brown to dark maroon; thick-bedded in lower half, thin-bedded, with some interbedded dolomitic shale, in upper half. Abundant "red-cast" markings.	26
Sandstone, dolomitic and glauconitic; dark maroon, weathers reddish to brownish black; massive, cross-bedded. Contains irregular small knots and streaks of light maroon, sandy dolomite.	13
	112.0
Conformable contact with Sawatch quartzite.	
Sawatch quartzite:	
Light-tan dolomitic quartzite, with lenses of brown dolomitic sandstone.	

ORDOVICIAN SYSTEM

Harding quartzite

White and green quartzite that unconformably overlies the Peerless formation and unconformably underlies the Parting quartzite member of the Chaffee formation is

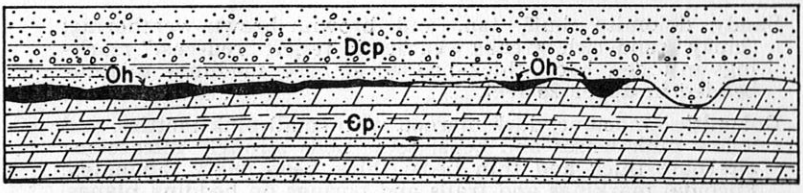

Figure 3. Diagrammatic cross-section showing relation of the Peerless, Harding and Chaffee formations in Eagle Canyon between Pando and Red Cliff.

assigned to the Middle Ordovician Harding quartzite. The quartzite is present locally, in relatively small lenses, from Pando northward to the south edge of the Minturn quadrangle, about a mile south of Red Cliff, and farther north it is continuous but thin as exposed along the Eagle River.[17] It reaches a maximum observed thickness of about 50 feet at the north end of the Sawatch Range, four miles west of Minturn. It is absent south of Pando.

In the canyon area north of Pando the Harding occurs chiefly in lenses (as seen in cross-section) filling well-defined, steep-sided channels or depressions cut into the Peerless formation as shown in figure 3. Minor remants of it occur in scattered and very thin lenses, some of them only a foot or two thick, in shallow depressions in the top of the Peerless formation. The deeper channels are filled with light-tan to white, massive, cross-bedded, vitreous quartzite. One such channel, near an old tramway on the east side of Eagle Canyon 2¾ miles north of Pando, is 100 to 200 feet wide and 20 feet deep. A northeastward trending mass of Harding quartzite about 250 feet wide on the ridge west of

[17]Lovering, T. S., and Tweto, O. L., op. cit., (Map).

the river may be a continuation of this same body. If so, the quartzite definitely fills a narrow, northeastward trending channel rather than some circular or irregular depression in the top of the Peerless.

The massive cross-bedded quartzite of the channels is overlain by relatively thin-bedded greenish sandstone and quartzite. Most of the sandstone is argillaceous, and some of it contains nodules of greenish and reddish dolomite coated with green clay. The following section shows the character of the greenish beds:

Section of Harding quartzite near old tramway on east side of Eagle Canyon, 2.75 miles north of Pando.

	Feet
Parting quartzite member of Chaffee formation:	
Tough green and purple clay (old soil?).	
Harding quartzite:	
Quartzite, green, vitreous, cross-bedded	2
Argillaceous sandstone and fissile clay shale, green soft	1
Sandstone with small lenses of quartzite, yellowish-green, thin-bedded	1.5
Clay shale, green	2
Argillaceous sandstone, greenish	0.5
	7.0
Peerless formation:	
Buff sandy dolomite.	

The greenish sandstone and quartzite of the section given above grade laterally into the upper part of a lens of massive, tan to white quartzite in a channel 100 feet to the south.

The Harding rocks of most exposures show a slight angular discordance with respect to the Peerless; the maximum observed discordance is 6°.

The rocks here referred to the Harding quartzite have been searched for the fish scales characteristic of the Harding in most localities, as well as for other fossils, but none have been found. They might, accordingly, be of any age between Upper Cambrian and Upper Devonian, the age of the Chaffee formation. However, they are almost certainly