Ordovician, as they are separated from the underlying Peerless formation and overlying Chaffee formation by unconformities, and no Silurian or Lower Devonian rocks are known in Colorado. As is well known, the Ordovician of central Colorado comprises three formations, the Manitou limestone, Harding sandstone, and Fremont limestone, of Lower, Middle, and Upper Ordovician age, respectively. Of these formations, the Manitou is by far the most widespread, as it is recognized in almost all parts of the Paleozoic basin of central Colorado as well as in the region surrounding the type area near Colorado Springs, on the east side of the mountains. Unlike the Manitou, the Harding and Fremont formations west of the Front Range are largely restricted to the southern parts of the Mosquito and Sawatch Ranges. The Ordovician rocks of the Pando-Minturn area therefore might reasonably be assigned to the Manitou formation, but as they are wholly unlike the Manitou exposed only a few miles away and are very much like the Harding sandstone, they are tentatively referred to the Harding. It is of course possible that the sandstone and quartzite represent a shore facies of the Manitou limestone, but the presence of about 20 feet of typical Manitou limestone near Mayflower Gulch in the Kokomo district,[18] closer to the Front Range highland, makes this seem unlikely.

If the Ordovician rocks of the Pando-Minturn area are Harding, they represent a small outlier considerably removed from the main bodies of Harding quartzite in the southern parts of the Mosquito and Gore Ranges. However, Johnson[19] has shown that unconformities separate the individual Ordovician formations as well as the Ordovician and Devonian in the Sawatch Range region, and the presence of such an outlier would substantiate his conclusion that absence of the Harding sandstone in the northern half of

[18]Koschmann, A. H., and others, op. cit. (Map), and measured section made by the writer.
[19]Johnson, J. H., Paleozoic stratigraphy of the Sawatch Range, Colorado: Geol. Soc. America Bull., vol. 55, pp. 314-324, 1944.

the Sawatch Range is more probably due to pre-Devonian tilting and erosion than to non-deposition.[20]

Similarly, although the relations of the Manitou limestone in the area between Pando and Leadville still remain to be determined, the absence of the Manitou in the Pando-Minturn area probably reflects pre-Harding erosion rather than non-deposition. Manitou limestone of normal character occurs on all sides of the Pando area, including the Kokomo district on the east. Considering that the Manitou of the Leadville district must wedge out somewhere south of Camp Hale, possibly in the Tennessee Pass area, the Kokomo occurrence indicates that the line of wedgeout must trend northeast, forming a re-entrant angle with the edge of the old highland. This suggests that a peninsula-like area extending southwest from the highland to the northern part of the present Sawatch Range was relatively unstable during the Ordovician. During the post-Manitou, pre-Harding period of erosion this peninsula or prong was uplifted so that the Manitou was eroded from it, and during the post-Harding period of erosion it was depressed so that the Harding was preserved on it.

DEVONIAN SYSTEM

Chaffee formation

The Upper Devonian Chaffee formation lies unconformably on the Harding quartzite or the Peerless formation and is unconformably overlain by the Gilman stonestone member of the Leadville dolomite. It comprises two members, the Parting quartzite and the Dyer dolomite. The Dyer constitutes the lower part of the "Blue limestone" of old usage. The contact between the Parting and Dyer members is sharp at most places, but no indication of a stratigraphic break between them has been found, and locally the contact between the two members is gradational.

[20]Johnson, J. H., op. cit., p. 322.

Parting quartzite member.—The Parting quartzite shows a wide range in composition, not only within the Pando area but in the surrounding region as well. At Pando it is predominantly quartzite, but in the canyon north of Pando the lower part is shaly, and farther north, in the Minturn quadrangle, the quartzite locally gives way entirely to greenish shale. The quartzite contains local lenses of conglomerate, and at most places the lowermost bed of true quartzite is conglomeratic, but on the slope of the Sawatch Range west and southwest of Pando the entire section gives way to conglomerate and coarse gritty quartzite. The Parting quartzite contains lenses of dolomite or dolomitic sandstone locally, particularly near the top, and at a few places the quartzitic part of the member gives way entirely to a gritty brown dolomite.

The basal shaly zone in the area north of Pando is everywhere marked at the base by a bed of tough green clay 1 to 4 feet thick. At most places the clay has a curly or kneaded structure and is mottled and streaked dark purple. The clay lies on Harding quartzite at some places and on the Peerless formation at others, and there is typically an angular discordance of a few degrees between the clay and the overlying rocks. The clay is interpreted to be an ancient soil. Soft, friable, greenish and yellowish sandstone, conglomerate, and arkosic grit overlying the clay probably represent some type of terrestrial deposit as they are characteristically "dirty," poorly sorted, and poorly bedded. Sand, grit, and pebble grains in these friable rocks are coated with argillaceous material or locally with white clay, and most of them are iron-stained. Streaks and lenses of the finer-grained material are highly ocherous, and local pockets are essentially a sandy iron ocher. The friable beds are typically overlain by a few feet of yellowish and greenish shale, and this shale is overlain by quartzite. The lower surface of the quartzite is wavy at most places, suggesting a break in deposition, but there is no discordance between the shale and the quartzite.

The quartzite is massive, cross-bedded, and light tan to white. The basal bed is conglomeratic, and many of the overlying beds contain scattered quartz pebbles and local lenses of conglomerate. In contrast to the Sawatch quartzite, the bulk of the Parting quartzite is relatively coarse and uneven in grain; the grains are angular or poorly rounded, and they are predominantly of clear quartz rather than of milky-looking quartz as in the Sawatch.

The two sections below show the character of the Parting quartzite in the canyon north of Pando. Elsewhere in the Pando area the Parting consists entirely of quartzite and conglomerate.

Section of Parting quartzite member of the Chaffee formation on cliffs on east side of Eagle Canyon, 2.3 miles north of Pando.

	Feet
Chaffee formation:	
Dyer dolomite member:	
Dark-gray, slightly gritty dolomite.	
Conformable contact.	
Parting quartzite member:	
Quartzite, slightly dolomitic, tan, coarse- and uneven-grained, thick-bedded.	3
Dolomitic quartzite, buff, and interbedded pink vitreous quartzite; dolomitic quartzite contains scattered angular quartz pebbles ½ inch in maximum diameter.	5
Sandy dolomite, with thin lenses of buff vitreous quartzite. Dolomite is gray, medium-bedded to massive, contains angular sand grains ⅛ inch in maximum diameter.	5
Quartzite, with a few lenses of coarse-grained dolomitic sandstone, tan to buff, vitreous, thick-bedded to massive. Top 6 to 12 inches is conglomeratic.	16
Quartzite, white, vitreous, fine-grained, massive.	7
Conglomerate, quartzitic, white, massive. Consists of round to angular pebbles of white quartz and quartzite 2 inches in maximum diameter in a matrix of white quartzite. Slightly wavy contact with bed below.	5
Sandstone, dirty, locally feldspathic, greenish, coarse-grained, friable. No bedding. Quartz grains of uneven size, and scattered iron-stained pebbles up to ½ inch in diameter, are loosely cemented by shaly material that is locally chloritic, micaceous, or iron-rich.	8
Conglomerate, iron-stained, fine-grained. Consists of rounded quartz pebbles ⅛ to ½ inch in diameter loosely cemented by ferruginous and argillaceous material.	4

	Feet
Grit, arkosic, greenish and pinkish, friable; contains scattered ½-inch pebbles.	2
Clay, slightly sandy, greenish and yellowish with local purple mottles, sticky, tough.	2
	57

Angular discordance with Harding quartzite (cuts out 3 feet of Harding in 50 feet).

Harding quartzite:

Buff and greenish quartzite.

Section of Parting quartzite member of Chaffee formation on cliffs on east side of Eagle Canyon, 2.75 miles north of Pando.

	Feet
Chaffee formation:	
Dyer dolomite member:	
Thin-bedded, brownish-gray dolomite.	
Conformable contact.	
Parting quartzite member:	
Quartzite, pinkish white, medium- to coarse-grained, uneven-grained, thick-bedded, cross-bedded. Contains dolomitic streaks and lenses and is dolomitic at top	14.0
Shale and interbedded dolomitic sandstone in ½- to 1-inch beds, green and brown; sandstone weathers rusty.	1.5
Quartzite conglomerate, tan white, massive, vitreous. Consists of ½- to 2-inch angular to rounded pebbles of white quartz and minor white and greenish quartzite scattered unevenly in a matrix of medium-grained quartzite.	7.5
Sandy shale and shaly thin-bedded sandstone, yellowish, soft; consists of rounded quartz grains in a matrix of yellowish ferruginous clay.	6.0
Shaly sandstone, gray, coarse-grained. Consists of rounded quartz grains up to ¼ inch in diameter in shaly matrix.	1.0
Fine conglomerate and coarse-grained sandstone, friable, muddy and ferruginous. Conglomerate consists of ¼- to ¾-inch rounded iron-stained quartz pebbles loosely bonded by ferruginous clay and locally by greenish argillaceous material.	4.5
Conglomeratic grit, dirty, pinkish, friable. Consists of quartz pebbles ¾ inch in maximum diameter in matrix of micaceous and feldspathic, angular-grained, dirty grit.	1.5
Ocherous sandstone, shaly, thin-bedded and fissile.	1.0
Conglomeratic grit, as above.	1.5
Ocherous sandstone; thin lenses slightly dolomitic, a few thin lenses of conglomeratic grit.	2.0
Conglomerate; rounded quartz pebbles 1 inch in maximum diameter in gritty matrix.	0.5

	Feet
Conglomeratic grit and small lenses of yellow arkosic sandstone. Scattered round to angular quartz pebbles ¾ inch in maximum diameter in pinkish grit	2.0
Clay, greenish gray with minor purple mottling, sticky. No bedding except occasional lenses fine sandstone ½ inch thick and a few inches long	4.0
	47.0

Slight angular discordance.

Harding quartzite:

Green thin-bedded quartzite.

The Parting quartzite member is 40 to 50 feet thick at most places along the Eagle River, but it thickens at depressions in the floor of underlying rocks, and it thickens southwestward from Pando on the flank of the Sawatch Range. The local thickening along the river valley amounts to only 10 or 15 feet in most places, but at one place, 1½ miles north of Pando, the Parting apparently extends down to within 35 feet of the Sawatch quartzite in a narrow and steep-sided channel cut into the Peerless formation. Here, for a short distance, the Parting probably reaches a thickness of 100 feet or more, but it is poorly exposed. On the flank of the Sawatch Range south and southwest of Pando the thickness of the Parting increases more or less steadily to about 75 feet, and it may be greater farther southwest in an area yet unmapped.

These features indicate a period of active erosion probably only shortly preceding Parting sedimentation, and they suggest a possibility that a local "high" on the site of the northeast flank of the Sawatch Range was the source of some of the Parting sediments in this area. Any such highland was probably of island form and relatively small, however, as the Parting is present on all sides of the Sawatch Range. A similar Parting island in the Alma area has been described by Singewald.[21]

Although the Parting quartzite at many places extends higher onto the old Paleozoic Front Range highland than do

[21]Singewald, Q. D., Depositional features of the Parting quartzite near Alma, Colorado: Am. Jour. Sci., 5th Ser., vol. 22, p. 411, 1931.

the other pre-Pennsylvanian formations, particularly along the Gore Range part of the highland, existence of the highland during Parting time can scarcely be doubted. The varied lithologic character, the generally coarse grain, the general angularity of grain, the composition, and the wide range in thickness from the Mosquito Range region[22] northwestward to the Pando area all indicate the presence of a nearby landmass. On the ridge north of the Boston mine in Mayflower Gulch, in the Kokomo district, 20 feet of Parting quartzite overlies the Manitou limestone and is overlain by about 20 feet of typical Dyer dolomite.[23] As the Parting and Dyer intergrade at places, and no stratigraphic break has been found between them in the entire region except at one locality mentioned by Emmons,[24] the thinning of the Parting quartzite from Pando eastward to Mayflower Gulch cannot be attributed to post-Parting, pre-Dyer uplift and erosion, and therefore it probably represents thinning near the highland shore.

Dyer dolomite member.—The Dyer dolomite member lies conformably upon, and locally grades into, the Parting quartzite member. It is overlain disconformably by the Gilman sandstone member of the Leadville dolomite. The Dyer member is 80 feet thick at most places in the area, but shallow channels of pre-Gilman age were cut into it locally, and at some places along the Eagle River it is probably no more than 60 feet thick.

The Dyer member consists principally of thin-bedded, fine-grained, dark dolomite, which is locally cherty. Much of the dolomite is slightly argillaceous, and many beds are separated by shaly partings. The lower half to two-thirds of the member weathers light buff or yellowish gray. The upper part has a blue-gray aspect on weathered surfaces

[22]Singewald, Q. D., op. cit., pp. 404-413.
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, pp. 30-31, 1927.
Johnson, J. H., Paleozoic formation of the Mosquito Range, Colorado: U. S. Geol. Survey Prof. Paper 185-B, pp. 23-24, 1934.

[23]Koschmann, A. H., and others, op. cit. (Map), and section measured by writer.

[24]Emmons, S. F., Geology and mining industry of Leadville, Colorado: U. S. Geol. Survey Mon. 12, p. 61, 1886.

and when viewed closely shows banding in various shades of gray. Near the line between the yellowish-gray and the blue-gray-weathering rocks, about 45 feet above the base of the member, is a persistent thin sandy zone normally 1 to 2 inches thick. This sandy zone is a useful marker bed, particularly as it lies at the base of a prominent dark bed about three feet thick and thus is easily found. At most places it is a sandy dolomite consisting of sparse to abundant, small, rounded, quartz sand grains in a dolomite matrix, but locally it is a white dolomitic quartzite. On the ridge between the highway and the railroad, about a mile north of Pando, small exposures on slopes largely covered with glacial drift suggest that the sandy bed is locally marked by as much as three feet of white quartzite.

The "sand grain marker," as the thin sandy bed was first called by geologists of the Empire Zinc Company at Gilman, is uncommonly widespread for so thin a bed of this type. From the Gilman-Pando area it is persistent to the southeast at least as far as Leadville, and to the northwest at least as far as the White River Plateau, where it has been recognized both at Glenwood Canyon and near Rifle Creek.

The following section shows the character of the Dyer member in the canyon north of Pando. The bedding fault zone shown in the section probably cuts out a few feet of the dolomite.

Section of Dyer dolomite member of the Chaffee formation, cliffs on east side of Eagle Canyon, 2.3 miles north of Pando.

	Feet
Leadville dolomite:	
Gilman sandstone member:	
Sandstone and dolomitic shale.	
Wavy contact.	
Chaffee formation:	
Dyer dolomite member:	
Dolomite, dark gray, weathers buff gray; fine-grained, massive, but shows fine banding on weathered surfaces.	3

	Feet
Dolomite, slightly cherty, with very thin shaly partings, dark gray, fine-grained, thin-bedded but weathers to massive forms. Chert is white.	8
Dolomite in 1-inch beds interbedded with brittle black shale in laminae ⅛ to ½ inch thick. Dolomite black, fine-grained.	1
Dolomite, dark gray, weathers bluish gray, buff gray, and dark gray; fine-grained, thin- to medium-bedded.	10
Dolomite, black, fine-grained, thin-bedded but weathers massive. Sand grain marker at base is 1 to 2 inches of sandy dolomite and local dolomitic quartzite.	9.5
Dolomite, gray to bluish gray, weathers light buff gray, with fine banding; fine-grained, thin-bedded.	6
Interbedded dolomite and fissile shaly dolomite, dark gray, weathers light buff gray; fine-grained, thin-bedded.	4
Dolomite, with a few angular quartz sand grains; black, fine-grained, medium-bedded.	1
Bedding fault zone: Rounded to angular fragments of dark dolomite and sandy dolomite in matrix of sheared shaly dolomite.	1.5
Interbedded dolomite and flaky dolomitic shale in 1 to 6 inch beds; dark gray, weathers brownish, dolomite is fine-grained and slightly sandy.	3
Dolomite, light gray, weathers tan and buff gray; finely crystalline, thick-bedded to massive.	20
Dolomite, gray to dark gray, finely crystalline, thin-bedded; contains a few coarse sand grains in lower foot. Several thin shaly partings.	6
	73.0

Parting quartzite member:

Tan, slightly dolomitic quartzite.

The presence of coarse, angular sand grains in some beds of the Dyer dolomite, and the similarity of the Dyer dolomite to that in scattered lenses in the Parting quartzite, a patently shallow-water deposit, suggest the presence of a highland nearby during Dyer sedimentation. Other than this inference based on lithology, however, the writer knows of no direct evidence of the position of the Dyer shore on the Paleozoic Front Range highland. The Dyer is absent along the west front of the old highland in the Minturn quadrangle,[25] and as noted above, only 20 feet of it is present in the section of lower Paleozoic rocks near Mayflower Gulch in the Kokomo district, but this more likely

[25]Lovering, T. S., and Tweto, O. L., op. cit., p. 22.

reflects post-Dyer, pre-Gilman erosion than non-deposition. Thus although the highland is believed to have been in existence during Dyer sedimentation, it may have been small, and the Dyer shore may have lain considerably farther east than some of the other Paleozoic strands.

CARBONIFEROUS SYSTEM

Mississippian Series

Leadville dolomite

The Leadville dolomite, of Mississippian age, comprises a basal sandy member about 20 feet thick, unconformably overlain by a dolomite member with an average thickness of about 80 feet. The lower sandy member is here called the Gilman sandstone, and the upper member, or main part of the formation, is referred to as the dolomite member.

Gilman sandstone member.—Sandstone near the base of the Mississippian part of the "Blue" or "Leadville" limestone of old usage (Leadville plus Dyer) was first recognized in the Gilman-Red Cliff district[26] and was also recognized locally at Leadville.[27] In 1929 Behre[28] established the continuity of the sandstone in the Mosquito Range region and recognized it as the basal unit of the Mississippian. The sandstone later proved to be widespread in central and northwestern Colorado, and in 1944 Lovering and Tweto[29] designated it the Gilman sandstone member of the Leadville limestone (or dolomite). As the report in which this was done is not widely available, the term Gilman sandstone member is here re-proposed for the sandstone and associated breccia at the base of the Leadville dolomite.

The Gilman sandstone is named for exposures on the

[26]Crawford, R. D., and Gibson, R., Geology and ore deposits of the Red Cliff district, Colorado: Colo. Geol. Survey Bull. 30, pp. 35-38, 1925.

[27]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, p. 34, 1927.

[28]Behre, C. H., Revision of structure and stratigraphy in the Mosquito Range and the Leadville district, Colorado: Colo. Sci. Soc. Proc., vol. 12, pp. 38-41, 1929.

[29]Lovering, T. S., Tweto, O. L., Preliminary report on geology and ore deposits of the Minturn quadrangle, Colorado: U. S. Geol. Survey Open file report p. 24, 1944.

cliffs of Eagle Canyon at Gilman. It is also exposed extensively in the mine workings at Gilman. At most places it is 10 to 20 feet thick, but a range from 5 to 50 feet has been observed. It consists of lenticular beds of sandstone, dolomitic sandstone, or local quartzite, at the base, overlain by sandy and locally cherty dolomite which at most places is interbedded with and overlain by a breccia of dolomite and chert. The sandstone is yellow, buff, or light gray, medium- to coarse-grained, and slightly arkosic. The sand grains are well rounded and are cemented both by carbonates and by silica. The individual sandstone beds range from 2 to 24 inches in thickness. The sandstone contains lenses of sandy gray dolomite, and it grades upward into sandy dolomite that contains lenses and thin beds of dolomitic sandstone. The sandy dolomite is dense and dark but weathers light. It is typically somewhat brecciated and contains chert in fragments as well as in nodules and lenticles. It contains, or in some places underlies, breccia of chert and dolomite and local fragments of limestone and white quartzite. In the mines at Gilman the Gilman member contains abundant greasy black clay, mostly as the matrix of breccia, but such clay, or black shale from which it may have been derived, is inconspicuous in most exposures at the surface. At most places other than the Gilman area, the breccia, sandy dolomite, or very cherty dolomite comprising the upper part of the Gilman member is in wavy contact with the overlying massive limestone or dolomite, but in the Gilman area the two are separated in most exposures by a few feet of fine-grained, structureless, soft, dark brownish-gray dolomite.

Although the Gilman member shows great differences in detail in sections only short distances apart, the mixture of sandstone, breccia, dolomite, and chert is a characteristic feature, as shown by the following sections near Pando and at Zion Mountain, just north of Leadville.

Section of Gilman sandstone member on cliff on east side of Eagle Canyon, 3.2 miles north of Pando.

	Feet
Leadville dolomite:	
Dolomite member:	
Massive gray dolomite.	
Wavy contact.	
Gilman sandstone member:	
Sandstone, dolomitic sandstone, sandy dolomite, and dolomite, in lenticular masses a few inches to a few feet long. Light gray and buff.	12
Quartzite, white, coarse-grained; persistent bed.	0.5
Shaly dolomite, gray.	0.1
Dolomite and sandstone. Slightly sandy, pinkish-gray, fine-grained dolomite at base, grades upward into sandstone.	1
Dolomite with thin sandy streaks and a few small fragments of gray chert; wavy lamination.	5
	18.6
Wavy contact.	
Chaffee formation:	
Fine-grained, dark-gray dolomite.	

Section of Gilman member on cliff on east side of Eagle Canyon, 2.3 miles north of Pando.

	Feet
Leadville dolomite:	
Dolomite member:	
Massive gray dolomite.	
Wavy contact.	
Gilman sandstone member:	
Dolomite, with shaly pockets and, near base, small lenses of light-buff sandstone. Depressions in upper contact filled with round to angular pebbles of quartzite and black chert.	2
Sandstone and dolomite in lenses; sandstone white to buff; dolomite light gray and fine-grained	1.5
Dolomitic sandstone, buff, thick-bedded.	2
Dolomite, slightly sandy, gray, fine-grained.	1.5
Dolomite, gray, fine-grained; contains streaks of sandstone ¼ to 1 inch thick.	2
Interbedded sandstone, dolomite, dolomitic sandstone, and sandy dolomite; all contain fragments of dolomite, sandstone and gray shale up to 1 inch in diameter.	4

Sandstone, arkosic, quartzitic, dark gray, brownish-weathering, thick-bedded.	2
Dolomitic shale and thin lenses of sandstone; banded tan and black, and has streaky, kneaded-looking structure.	1
	16.0

Wavy contact.

Chaffee formation:

Dark-gray dolomite.

Section of Gilman sandstone member on south slope of Mt. Zion, ⅝ mile west-northwest of Canterbury tunnel.

	Feet
Leadville dolomite:	
Dolomite member:	
Massive, fine-grained, black dolomite.	
Wavy contact.	
Gilman sandstone member:	
Dolomite and dolomitic sandstone; dolomite dark gray, very fine-grained, contains abundant black chert fragments and lenticles near top. Sandstone in lenses and thin beds in dolomite.	12.5
Sandstone, quartzitic and dolomitic, buff, medium-grained, thick-bedded. Encloses a few small pods of dense, dark dolomite.	3.5
Breccia: Dolomite and sandstone fragments in matrix of sandy dolomite. A few bright-pink shaly seams at base.	2.0
Interbedded arkosic sandstone, sandy dolomite, and dolomite. Sandstone quartzitic; dolomite dark gray and dense.	2.0
	20.0

Wavy contact.

Chaffee formation:

Thin-bedded, fine-grained, gray dolomite.

The Gilman sandstone member is separated from the underlying Chaffee formation and the overlying dolomite member of the Leadville by unconformities. The Dyer dolomite member of the Chaffee formation is abnormally thin locally, but in such places the Gilman member shows a corresponding increase in thickness, indicating that the Dyer was unevenly eroded before the Gilman sandstone was deposited. Exposures in the mine workings at Gilman show that the Dyer was locally channeled to a depth of at least 25 feet before the Gilman standstone was deposited.[30] On the spur south of Yoder Creek, southwest of Pando, the Dyer shows solution effects and slumping that indicate pre-Mississippian ground-water attack. Although several details in this area still remain to be worked out, it appears that the Dyer thins locally to as little as 30 feet, and the Gilman member seems to thicken correspondingly. Similarly, the upper contact of the Gilman member is a wavy and locally irregular erosion surface. At many places irregularities in this surface and in the erosion surface below the Gilman sandstone have been accentuated by ground-water solution, as shown below.

The Gilman sandstone member is characterized by certain odd structures that seem best explained by solution and collapse. These features and their origin have been described in considerable detail in the report on Gilman,[31] and they will be considered only briefly here. A structure observed at several places is illustrated in figure 4-A. Beds of sandstone and dolomite within the Gilman member change horizon and thickness abruptly, and the contact of the Gilman with the overlying dolomite member of the Leadville is markedly angular. It is unlikely that so angular a contact represents a simple erosion surface over which the dolomite member was deposited. The dolomite beds end abruptly against the sandstone, more as if they were faulted than in sedimentary contact, but there is no sign of deformation in the overlying beds. Features of this type are attributed to the action of ground water. Dolomite at the base of the dolomite member was locally removed by solution, and some dolomite beds sagged into temporary openings. The calcareous cement of the sandstone was leached out, and the free-running sand thus formed filled many of the openings. Later the sand was recemented, but most of sandstone thus formed is friable, in contrast to the hard or even quartzitic sandstone at the base of the Gilman member.

[30] Lovering, T. S., and Tweto, O. L., op. cit., p. 31.
[31] Lovering, T. S., and Tweto, O. L., op. cit., pp. 25-36.

A section along the tunnel at right angles to the section in figure 4-A is shown in figure 4-B.

A somewhat similar type of angular contact and abruptly ending beds is shown in figure 4-C, but here the

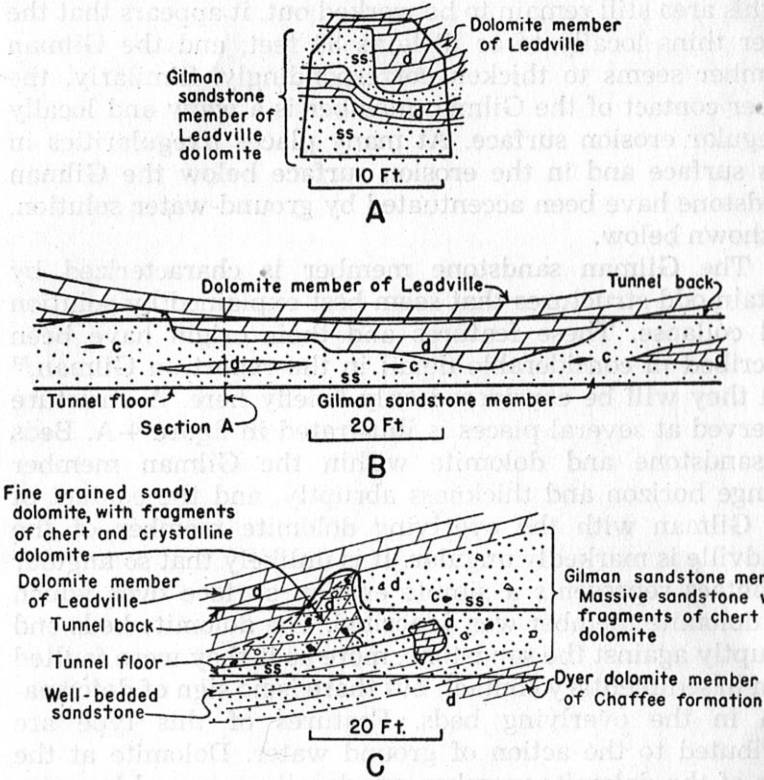

Figure 4. Sections showing features of the Gilman sandstone member in the Leadville Drainage Tunnel. A, face at 35+72; B, section along southwest wall of tunnel, at right angles to section A; C, southwest wall at station 27. ss, sandstone; d, dolomite; c, chert.

materials are more complex and varied. Typical well-bedded Gilman sandstone shown at the lower left in the diagram appears to be truncated by massive or unbedded, friable sandstone that contains fragments of chert and dolomite and, at one place near the contact, a pocket of delicately stratified, loosely cemented dolomite sand. The massive sandstone abuts abruptly against a pocket of soft, sandy, fine-grained dolomite that contains fragments of chert and finely crystalline dolomite. Bedding is obscure in the pocket of sandy dolomite but seems to be much flatter than in the overlying member of the Leadville and in the underlying sandstone. The mixture of materials in this pocket and the massive sandstone is unusual, even for the Gilman member, and it was evidently produced by the reworking of Gilman sandstone and associated cherty and dolomitic beds. The reworking was almost certainly accomplished by ground water rather than by surface agencies. If it were produced by surface agencies, it necessarily would antedate the dolomite member of the Leadville, and its formation would require successive periods of erosion alternating with deposition of material derived from the eroded bed itself, a complex and improbable process. On the other hand, if the Gilman member were reworked by ground water at some later date, deposition of debris derived from the member in open channels within the member and the basal beds of the overlying dolomite might produce exactly these complex relations. The friable quality of the reworked rocks, as contrasted to the hardness or well-indurated character of the overlying dolomite and the bedded sandstone, also suggests that the reworked rocks are younger than both the overlying and underlying beds, as does also the difference in dip between the sandy dolomite and the overlying and underlying rocks.

Most of the breccia in the Gilman member is probably also a product of solution and collapse, as shown in the report cited above. Tongues of the breccia extend downward into the Dyer dolomite member and upward into the dolomite member of the Leadville at places, and slender, unbroken pinnacles of dolomite extend into the breccia; pillar-like masses of sandstone connecting undisturbed beds above and below are surrounded by breccia or by dolomite that shows by such features as cross-bedding and ripple marks that it was deposited as loose sand; some beds are faulted, but the faults are limited to one or two beds, as if a block had parted along a bedding plane and dropped into an opening, and the opening above the faulted block was filled with lithified dolomite sand or with breccia.

The relations described above show that the ground-water attack occured after the dolomite member of the Leadville had been deposited, although it is possible, and even probable, that some solution occurred during the erosion interval that just preceded deposition of the dolomite. The attack probably occurred during the period of erosion between Leadville and Pennsylvanian deposition, when a karst topography formed at the top of the Leadville, and the sandy Gilman member, an ideal aquifer, was buried to a depth of as little as 70 feet.

Dolomite member.—The dolomite member or main part of the Leadville formation lies with wavy or irregular contact on the Gilman sandstone member and is unconformably overlain by the Belden shale. The upper surface of the dolomite is a karst erosion surface marked by many small depressions and a few caves and sinks. Some of the depressions are filled with a few feet of red, yellow, and brown residual clay and chert fragments, similar to the material of the Molas formation of southwestern Colorado.

The dolomite member is 67 to 95 feet thick in the Pando area, or about 60 feet thinner than at Gilman, a few miles to the north. The southward thinning, as well as the range in thickness at Pando, is attributed principally to pre-Belden erosion, but it may be caused in part by local hydrothermal leaching and low-angle faulting.

The dolomite member of the Leadville in the Gilman-Pando-Leadville region is believed to have formed by hydrothermal alteration of original limestone. The dolomite itself has been further altered at many places during later attacks by hydrothermal solutions. Where it is relatively unaltered by later attacks, as at places in the canyon north of Pando, it consists of massive, gray to blue-black, crystalline dolomite. It weathers gray to bluish gray and to massive forms, in contrast to the yellowish tones of the thin-bedded Dyer dolomite. Chert is irregularly distributed in the dolomite and is gray, black, or brownish in color.

Where later alteration occurred, the dolomite is coarsely recrystallized, and some of it shows the alternating bands of coarsely crystalline, vuggy, light and dark dolomite characteristic of the "zebra rock" of the miners. A still later stage of alteration is represented by the so-called "sanded" rocks—dolomite leached and made porous and friable by a peculiarly penetrating process of solvent attack—and finally, much of the dolomite was replaced by dense silica, forming jasperoid.

The character of the dolomite member near Pando is shown by the following detailed section.

Section of dolomite member of the Leadville at south end of high cliffs on east side of Eagle Canyon, 2.3 miles north of Pando

	Feet
Belden shale:	
Gray to black shale, and gray to white quartzite.	
Irregular contact.	
Leadville dolomite:	
Dolomite member:	
Dolomite, cherty, dark gray, weathers light gray; finely crystalline but partly recrystallized and coarse-grained.	1
Dolomite, dark gray, finely crystalline, massive.	7
Dolomite, cherty, dark gray, finely crystalline, medium- to thick-bedded; has fine banding in places. Chert is dark but weathers light; occurs in stringers ½ to 1 inch thick.	9
Dolomite, dark gray, finely crystalline; thin- to medium-bedded;weathers buff gray. Contains small lenses of brownish chert and irregular masses of siliceous dolomite.	8
Dolomite, dark gray, fine-grained, massive; mostly recrystallized to light-gray, coarsly crystalline "zebra rock."	10
Dolomite, slightly cherty, dark gray, fine-grained and medium- to thick-bedded; has hackly fracture. Chert is black.	12
Dolomite, recrystallized to light-gray "zebra rock." Massive; contains a few nodules of dark chert.	5
Dolomite, black, fine-grained, hackly, thin-bedded.	2
Dolomite, light gray, fine-grained, massive. Contains a few small nodules of black chert.	6

Dolomite, gray, massive; mostly recrystallized, with zebra structure.	3
Dolomite, gray, medium-bedded, fine-grained to lithographic.	4
	67

Irregular contact.

Gilman sandstone member.

Both the dolomite and the Gilman members thin to the east and northeast from the Eagle River. The entire Leadville dolomite is absent along the Gore fault in the Minturn quadrangle, where Pennsylvanian rocks lie on the Parting quartzite.[32] Only about two feet of the Gilman member and about 25 feet of the dolomite are present in the Mayflower Gulch section in the Kokomo district.[33] This eastward thinning to a vanishing edge no doubt reflects pre-Pennsylvanian erosion rather than non-deposition, for evidence of an erosional unconformity between the Mississippian and Pennsylvanian deposits is widespread. No evidence that the Paleozoic Front Range highland existed during Leadville time is seen in the character of the Leadville sediments or their stratigraphic relationships along the west side of the Gore and Tenmile Ranges, and if the highland did exist at this time, the shore must have lain considerably farther north or east than the shores of either the earlier or the later Paleozoic seas.

Nomenclature of the Pennsylvanian and Permian(?) Rocks

Several names have been applied in various senses to the Pennsylvanian and Permian(?) rocks of west-central Colorado, as shown in table 2. Names were first applied to these rocks in the Leadville region by Emmons,[34] who called the lower shales, 150 to 300 feet thick, the Weber shale, and 2,500 feet of the grits overlying this shale, the Weber grit. These terms were based on an assumed correla-

[32]Lovering, T. S., and Tweto, O. L., op. cit., pp. 22, 25.

[33]Koschmann, A. H., and others, op. cit. (Map), and detailed section measured by writer.

[34]Emmons, S. F., Geology and mining industry of Leadville, Lake County, Colorado: U. S. Geol. Survey 2nd Ann. Rept., pp. 219-220, 1882; U. S. Geol. Survey Mon. 12, pp. 67-70, 1886.

Table 2.- History of terminology for Pennsylanian & Permian(?) rocks of west-central Colorado

(Not intended to show exact horizontal correlation of lithologic units or time intervals)

Leadville District Emmons 1882-1886	Crested Butte Eldridge, 1894	Tenmile District Emmons, 1898	Colorado River Valley: Roth, 1930; Donner, 1936; & Basset, 1939	West Elk Mtns. Vanderwilt, 1937	Gore Area Brill, 1942	West Central & Northwestern Colorado Brill, 1944	Minturn Quad. Lovering & Tweto, 1944	Mosquito Range Singewald, 1942 Koschmann & Wells, 1946	This Report	Southwestern Colorado (Generalized)
Upper Coal Measures	Maroon formation	Wyoming formation	Maroon formation: State Bridge Siltstone member	Maroon formation	State Bridge formation	State Bridge formation	Maroon formation	Pennsylvanian and Permian (?) rocks: Upper unit	Maroon formation	Cutler formation
Weber grit	Weber limestone	Maroon formation	Maroon formation: Rock Creek conglomerate member	Hermosa(?) formation	Battle Mountain formation	Maroon formation		Pennsylvanian and Permian (?) rocks: Middle unit	Minturn formation	Rico formation
Weber shale		Weber grit	McCoy formation		Belden shale member	Belden shale		Pennsylvanian and Permian (?) rocks: Lower unit	Belden shale	Hermosa formation
		Weber shale								Molas formation

tion with the Pennsylvanian rocks of Weber Canyon, Utah. In 1894 Eldridge[35] distinguished 100 to 500 feet of Weber limestone (Weber shale) in the Crested Butte quadrangle, and called the 4,500 feet of grit, shale, and conglomerate lying between the Weber limestone and the Jurassic the Maroon formation. No Triassic rocks were recognized. Emmons later used the term Maroon in the Tenmile district,[36] but restricted it to beds about 1,500 feet thick lying above the Weber grit, rather than including the Weber grit in it as Eldridge had done. He placed the lower boundary of the Maroon formation at a limestone bed known as the Robinson and the upper boundary at a limestone bed known as the Jacque Mountain. He assigned 1,500 feet of red beds above the Maroon to the Wyoming formation, a term that is no longer in use.

Validity of the correlation of the Weber, as used by Emmons in the Mosquito Range, with the Weber of Utah later was questioned, and the U. S.Geological Survey began to refer to the Weber as the Weber(?) formation.[37] This usage was continued for several years in the Mosquito Range region.

In 1930 Roth[38] applied the term McCoy formation to the Pennsylvanian rocks in the northern part of the Paleozoic basin of west-central Colorado, and in 1935 Vanderwilt[39] restricted the Maroon of original usage in the western part of the basin and introduced the term Hermosa (later changed to Hermosa(?)[40]) from southwestern Colorado for

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[35]Eldridge, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (no. 9), p. 6, 1894.

[36]Emmons, S. F., U. S. Geol. Survey Geol. Atlas, Tenmile district special folio (no. 48), pp. 1-2, 1898.

[37]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, p. 38, 1927.

[38]Roth, R., Regional extent of Marmaton and Cherokee mid-continent Pennsylvanian formations: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 1265-67, 1930.

[39]Vanderwilt, J. W., Stratigraphy of Pennsylvanian Hermosa formation in Elk Mountains, Gunnison County, Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 19, pp. 1668-1677, 1935.

[40]Vanderwilt, J. W., Geology and mineral deposits of the Snowmass Mountain area, Gunnison County, Colorado: U. S. Geol. Survey Bull. 884, pp. 21-29, 32, 1937.

beds in the lower part of the series approximately equivalent to the Weber(?).

In 1942 Brill[41] introduced the terms Belden, Battle Mountain, and State Bridge, the latter taken from an unpublished report by Donner,[42] for the Pennsylvanian and Permian(?) rocks of the Gore area, including the Tenmile, Pando, and Gilman districts. He included in the Battle Mountain formation a maximum of 6,300 feet of beds lying between the Leadville limestone and the siltstone of the State Bridge formation, including in it all the Weber, Maroon, and Wyoming of old usage in this area, and distinguished the beds formerly called Weber shale as the Belden shale member of the Battle Mountain formation. He applied the name State Bridge formation to siltstone and fine-grained redbeds 225 to 1,100 feet thick lying above the Battle Mountain and below the Triassic Shinarump conglomerate in the region northwest of Minturn. In a later paper Brill[43] raised the Belden shale to formation rank and proposed use of the old term Maroon for all the beds lying between the Belden and State Bridge formations. He assigned the Maroon formation to the Pennsylvanian and correlated the State Bridge formation with the Permian Phosphoria formation.[44]

In 1944 Lovering and Tweto[45] applied the term Maroon to all the beds between the Mississippian Leadville limestone and the Triassic Shinarump conglomerate in the Minturn quadrangle, but in other recent reports of the Geological Survey, the uncertainties of nomenclature and

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[41] Brill, K. G., Late Paleozoic stratigraphy of the Gore area, Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 26, pp. 1375-1397, 1942.

[42] Donner, H. F., Geology of the McCoy area, Eagle and Routt Counties, Colorado. Univ. Michigan dissertation, 1936.

[43] Brill, K. G., Late Paleozoic stratigraphy, west-central and northwestern Colorado: Geol. Soc. America Bull., vol. 55, pp. 621-656, 1944.

[44] Since the present paper was written, the report by Donner cited above has been published. (Donner, H. F., Geology of the McCoy area, Eagle and Routt Counties, Colorado: Geol. Soc. Am. Bull., vol. 60, pp. 1215-1248, 1949.) In this report Donner abandons the terms Weber, Maroon, and Rock Creek, used in the original report, and divides the Pennsylvania-Permian(?) section of the McCoy area into the McCoy formation, 3567 feet thick, and the State Bridge siltstone, 525 feet thick.

[45] 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. 39, 1944.

correlation have been expressed by recognition only of "lower," "middle," and "upper" units of the Pennsylvanian and Permian(?).[46]

In order to establish a working nomenclature for projects and reports now in progress, several members of the Geological Survey directly interested in upper Paleozoic rocks of west-central Colorado held a field conference in central and southwestern Colorado in September 1948. As a result of this conference it was concluded that: (1) From the practical point of view, as in mapping, it is desirable to subdivide the Pennsylvanian and Permian(?) rocks; (2) the natural subdivisions differ in stratigraphic position from place to place; (3) one of the boundaries between major subdivisions in all areas, except the McCoy-State Bridge area, lies within the Maroon formation as used by Brill[47] rather than at the top of this formation; and (4) considering the different stratigraphic limits of the mappable units from place to place, the absence of marker beds persistent over more than local areas, and the wide range in character of the major units, as of gypsum contrasted to grits, it is inadvisable to attempt to define identical units in all parts of the Pennsylvanian basin of central Colorado until detailed work is done in the areas intervening between those recently worked.

In accord with these principles, it is now proposed by those working in the eastern part of this area to recognize three formations in the Pennsylvanian and Permian(?) section of the Gore and Mosquito Ranges. The lowest of these is the Belden shale as used by Brill.[48] The middle fromation is here given a new name, Minturn formation. To the upper formation, the old and widely used name, Maroon formation, is applied in a restricted sense.

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[46]Singewald, Q. D., Stratigraphy, structure, and mineralization in the Beaver-Tarryall area, Park County, Colorado: U. S. Geol. Survey Bull. 928-A, pp. 5-15, 1942.

Koschmann, A. H., and Wells, F. G., Preliminary report on the Kokomo mining district, Colorado: Colorado Sci. Soc. Proc., vol. 15, pp. 59-70, 1946.

[47]Brill, K. G., op. cit. (1944), pp. 627-638.

[48]Brill, K. G., op. cit. (1944), pp. 624-627.