SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 6 NUMBER 4

CAMBRIAN GEOLOGY AND PALEONTOLOGY

III

No. 4.—RELATIONS BETWEEN THE CAMBRIAN AND PRE-CAMBRIAN FORMATIONS IN THE VICINITY OF HELENA, MONTANA

(WITH PLATES 39 TO 44)

BY
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(PUBLICATION 2416)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
JUNE 24, 1916

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

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INTRODUCTION

In a recent memoir[1] on the fauna of the Belt formation near Helena, Montana, Dr. August Rothpletz states that he found Lower Cambrian fossils in a shale above a limestone which he identified as the typical Helena limestone of the Belt series,[2] and beneath another limestone regarded by him as also a part of the Helena limestone. He also states that in his four days' work about Helena he failed to find any evidence of an unconformity at the base of the Cambrian and therefore concludes that the Helena limestone and associated formations of the Belt series are of Cambrian age and not pre-Cambrian.

Since my own extended examinations as well as those of other geologists and paleontologists as to the position of the Helena limestone and the age of the fossil fauna of the region lead to conclusions very different from those of Doctor Rothpletz, it has seemed to me

[1] Die Fauna der Beltformation bei Helena in Montana. Munich, 1915, pp. 1-46, with 3 plates.

[2] Bull. Geol. Soc. America, Vol. 10, 1899, Pre-Cambrian Fossiliferous Formations, by Charles D. Walcott, pp. 210-213.

advisable to review in the present paper authentic data on the relations between the Cambrian and pre-Cambrian formations in the vicinity of Helena.

As the conclusions of Rothpletz are based primarily on the finding of Cambrian fossils in a shale interbedded in what he decided to be the "Helena" limestone, the first point to determine is the stratigraphic position of the limestone called "Helena" in his section of the formations on the eastern side of Mount Helena. If the limestone he identified as the "Helena" is not the Helena, then the elaborate deductions and conclusions he has drawn therefrom are without foundation.

In order that we may more clearly understand the distribution of the several formations about the city of Helena, a part of the geological map accompanying Bulletin 527 of the U. S. Geological Survey[1] is reproduced in outline as plate 39 of the present paper. It should be mentioned that at the time Dr. Rothpletz made his study of the rocks in that vicinity he had with him neither a topographic nor geologic map, and apparently before publishing his memoir he had not seen Bulletin 527 of the U. S. Geological Survey[1] containing a fine geological map of the region and a description of the several geological formations. The only geologic map of the area that he refers to is a small scale map published by Weed[2] with all the Cambrian formations grouped under one color. He was therefore dependent on his limited observations for the identification of the pre-Cambrian, Cambrian, and later limestone formations in the Helena section.

Rothpletz speaks of the old and very poor topographic map that he was obliged to refer to when writing his memoir. This is the same map that was used by me when making examinations about Helena in 1898, and it was on this account that the Walcott section was so broadly generalized, and the exact locality of the section and of the figures 3 and 4 so indefinitely stated (see p. 262).

When I made my examinations of the formations near Helena, Mr. L. S. Griswold was engaged in preparing a geologic map under the direction of Mr. Weed, and in studying the Cambrian and later formations more or less in detail. In view of that work, and anticipating the early publication of the results, I did not study and measure the Cambrian and superjacent formations in detail and only collected

[1] Ore Deposits of the Helena Mining Region, Montana. By Adolph Knopf, 1913.

[2] Professional Paper 74, U. S. Geol. Survey, 1912, pl. 1.

a few fragments of fossils from the Meagher limestone and Park shale of the Cambrian, my objective being largely to discover the relations existing between the basal formation of the Cambrian [Flathead quartzite] and the pre-Cambrian formations. The Helena limestone was examined north, west, and east of Mount Helena and its thickness was roughly measured on the line of my diagrammatic section southeast of the suburb of Lenox.

WALCOTT DIAGRAMMATIC SECTION OF 1899[1]

The diagrammatic section showing the relations between the Cambrian and Belt terranes, to which Rothpletz refers a number of times, began on the east with the section of the Belt Mountains in the vicinity of White's Canyon, thence passing over the Lake Beds of the Missouri River Valley to the eastern base of Spokane Hills, north of the boundary line between Lewis and Clark and Jefferson counties. Passing over the Spokane Hills, it next extends across the Lake Beds of the broad Prickly Pear Creek Valley about a mile and a half (2.4 km.) north of the boundary line between Lewis and Clark and Jefferson counties, and a little north of East Helena, where it bends to the west-southwest, near its crossing of the Northern Pacific and Great Northern Railway tracks; this was in order to avoid striking into the fault line (*B-B*) about a mile east of Lenox. Southwest of the railway tracks the section passes over an area underlain by the Empire shale (*Ae*),[2] and reaches the Helena limestone (*Ah*) in the foothills about 1.25 miles (2 km.) southeast of the suburb of Lenox, or about 2 miles (3.2 km.) from the thickly settled suburb in the southeastern portion of the city of Helena. In the diagrammatic section (fig. 10) the Helena limestone is represented as being overlain by formations that include Cambrian, Devonian, and Carboniferous strata. No attempt is made to represent the character of the Cambrian in the sketch other than by a strong black line and lines above it, since the point desired to be brought out in the section and the text was the thinning out of the Helena limestone (*Ah*) and Empire shale (*Ae*) both from the east and west toward the Spokane Hills, and that a great unconformity was indicated by the fact that the Cambrian rested on the Spokane shales in the Spokane Hills with the Helena limestone and Empire shale absent, and that in the Belt Mountains as well as in the vicinity of Helena both of those formations were present between the Spokane shales and the Cambrian.

[1] Bull. Geol. Soc. America, Vol. 10, p. 211.

[2] The lettering used is the same as that on the map (pl. 39).

Reproduction in black and white of portion of geological map of Helena and vicinity published, in colors, as plate 7, Bulletin 527, U. S. Geological Survey. Lettering of geological formations explained in legend on original map.

Fault lines.—There are four (4) principal fault lines. The two most easterly, *A-A*, *B-B*, have displaced a large block of strata that has moved to the northeast. The middle fault, *C-C*, has made little horizontal change in the position of the formations. The westerly fault (O-O), Oro Fino Gulch fault, cuts through the formations on the eastern lower slope of Mount Helena with a relatively small horizontal displacement of the Cambrian and pre-Cambrian formations.

Walcott section. The approximate line of the diagrammatic section (fig. 10, p. 263) is indicated on the map by the broken line *W-W*.

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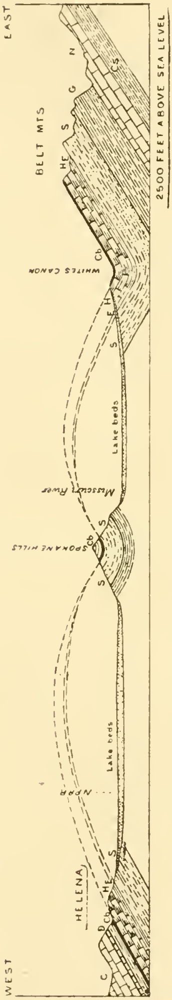

FIG. 10.—Big Belt Mountains—Helena section, indicating unconformity between the Cambrian and pre-Cambrian. Diagrammatic section showing relations between Cambrian and Belt terrane.

Rothpletz states that he could not find the localities of Walcott's diagrammatic figures 3 and 4 showing the unconformity between the Cambrian and pre-Cambrian southeast of Helena. I find on looking up my field notes of September 30, 1898, that I crossed from the west side to the east side of the city of Helena, and followed the outcrop of the Flathead quartzite to the southeast and noted that a half mile east of the thickly settled southern section of the city the Helena limestone is not more than 20 feet below the base of the Flathead quartzite, the interval being filled by arenaceous and argillaceous shales, and that in a prospector's cut about one mile southeast of the suburb of Lenox, the quartzite rests directly on the limestone. At this line of contact there is a slight unconformity between the limestone and quartzite that in a distance of 10 feet shows the upper surface of the limestone eroded so as to cut out 18 inches in thickness of the upper layer. A pen and ink sketch was made in the notes and from it the diagrammatic figure 3 was drawn (see fig. 12, p. 286). This particular locality is about 1.25 miles southeast of the suburb of Lenox, near line of section *W-W*, plate 39.

The field notes state further that at another prospect cut about a mile to the southeast of the one above mentioned a band of argillaceous shale rests on the Helena limestone and the Flathead quartzite rests on the shale. The only evidence of non-conformity here was a small mass of shale left by erosion above the general level of the summit of the shale and rising into the basal bed of the Flathead quartzite. A sketch accompanied this note and from it the diagrammatic figure 4 was drawn (see fig. 13, p. 286). It is quite probable that in the interval between my visit in 1898 and that of Rothpletz in 1913, the sides of the two cuts may have broken down by weathering and thus the contact with the basal bed of the Flathead quartzite have been covered over, or it may be that Rothpletz either did not find the particular localities or that in his confused identification of the pre-Cambrian Helena limestone he did not know which limestone he was on. These localities are southeast of the fault *B-B*, plate 39.

The notes further state that such small unconformities are repeated on a larger scale along the strike by the increase in the thickness of the shales, or by their removal by pre-Cambrian erosion in various places, so that the Flathead quartzite rests in some localities directly on the limestone and in others on the shale.

This latter statement was based on observations made along the line of contact of the Cambrian Flathead quartzite and the pre-Cambrian rocks, from about 1.25 miles (2 km.) southeast of the suburb of Lenox for 2.5 miles (4 km.) to where both formations are cut off by a mass of rhyolite breccia about a mile (1.6 km.) north of the old mining railroad station of Montana City.

We will now consider the Algonkian and Cambrian formations as they were known in the vicinity of Helena, by publication in 1913, also a section of the Cambrian formations 20 miles (32 km.) northeast of Helena and in the Little Belt and Big Snowy Mountains, in order that we may better understand the Mount Helena section and the Rothpletz interpretation of it.

ALGONKIAN AND CAMBRIAN SECTIONS AT HELENA AND VICINITY

In Bulletin 527 of the U. S. Geological Survey,[1] Dr. Adolph Knopf publishes a description of the sedimentary series at Helena, the data for which are taken largely from an unpublished report by Mr. Walter Harvey Weed.[2]

PRE-CAMBRIAN ALGONKIAN FORMATIONS

In speaking of the pre-Cambrian Algonkian formations Knopf says:[3]

> In the Helena district only the four uppermost formations are found, and the top of the Marsh shales has been eroded before the deposition of the Cambrian, so that the upper limit of the formation and its entire thickness are not known.

The four formations mentioned are as follows, from below upward:

Spokane shale.—(*As* on map.) It consists of massive- and thinly-bedded, siliceous shales, usually of a deep-red color, but passing in places into green and gray rocks, containing arenaceous beds merging into sandstone. The rocks form low hills, bordering the Prickly Pear Valley to the northwest of Helena, and a small outcrop occurs between East Helena and Helena between the railway tracks and Prickly Pear Creek.

Empire shale.—(*Ae* on map.) The Empire shale is a shale composed of massive-bedded, greenish-gray, well-banded, siliceous shales, showing color bandings of light and dark material and locally a marked knotty structure.

These shales underlie a considerable area of North Helena and the subdivision known as Kenwood, and extend around to the north

[1] Ore Deposits of the Helena Mining Region, Montana. Knopf, 1913, pp. 86-94.

[2] Idem, p. 86. [3] Idem, p. 87.

and westward of Mount Helena for several miles. Near the railroad about 2 miles (3.2 km.) west of East Helena they consist of pale, greenish-gray slates with characteristic purple spots.

Helena limestone.—(*Ah* on map.) "The Helena limestone is a formation composed predominantly of impure bluish-gray or gray non-crystalline limestone. The limestones occur in beds 1 foot to 6 feet thick and contain thin, interbedded bands of gray siliceous shale, more rarely of green to purple clay shales. The limestones are ordinarily dark blue on fresh fracture, but show a characteristic buff-colored, velvety appearing surface on weathering. The upper beds have a rough surface, with a pale or blue-gray color, and resemble Cambrian rocks. These beds alternate with shale and form the ridges on the northwest foot slopes of Mount Helena.

"The formation has no distinctive physiographic expression within the district, but its relatively massive bedding gives the limestone prominence on the slopes about the city.

"The name was given the formation by Walcott from its typical occurrence about the city of Helena.

"The formation is barren of fossils, though the oolitic character and the local presence of carbonaceous markings has led to the belief that they will ultimately be found. The estimated thickness of 2,400 feet in this vicinity is based on rough measurements, as it is impossible to find a satisfactory exposure of the entire formation for exact measurement. The formation covers a large part of the district, especially about the borders of the Prickly Pear Valley. So far as known the rocks are conformable to the formations above and below, and grade into them by intercalations of shale. The upper and lower limits are therefore not sharply definable. About a mile east of Helena the Marsh shale is wanting and the Cambrian quartzite rests directly on the eroded surface of the Helena limestone. Good outcrops are seen near the high school within the city limits.

"On the north face of Mount Helena the Cambrian quartzite rests on dark-blue and dense limestones, weathering buff, and these rocks in turn rest on pink and buff-colored shales, which appear red in most exposures and are included as part of the Helena limestone. These reddish shales contain numerous massive beds of white cherty limestone, forming reefs running obliquely across the slopes and extending downward within a few yards of the streets of Kenwood. The beds of limestone are 6 to 10 feet thick and in weathering and character resemble those of Paleozoic rocks. The same pink and buff-colored shales, with interbedded limestones, are seen in the gulch east of Lenox, the 4,350-foot knoll [on topographic map] at that locality showing light-gray, fine oolitic limestone with black grains in a white matrix."[1]

Marsh shale.—(*Am* on map.) The Marsh shale consists of red and yellowish-green shales and thin-bedded sandstones.

CAMBRIAN FORMATIONS

These formations were studied by Weed on Mount Helena and they compare quite closely with the same formations as published by Weed in 1900 in his account of the Geology of the Little Belt Mountains of Montana[2] (see p. 273).

From the base upward the following is the order of succession at Mount Helena[3]:

Flathead quartzite.[4]—(*Єf* on map.) "The Flathead quartzite, the lowest formation of the Cambrian system, consists of a hard, fine-grained, massive quartzite varying to grayish-yellow gray sandstone. The lowest stratum in places is pebbly, grading into a conglomerate at the base. The bedding planes range from a few inches to a few feet apart and faint lines of sedimentation are seen. The rock is jointed by sharply cut planes. Higher up in the formation thin bands of gray-brown mottled and green micaceous shale are found locally, increasing in thickness toward the top. The pebbles in the basal bed vary in character from place to place and consist predominantly of the material derived from the immediately underlying beds. As mentioned elsewhere, this quartzite is in most places apparently conformable to the Algonkian, but there is a slight angular unconformity observable east of Helena, and the Marsh shale is in places cut out, so that the quartzite rests directly upon the Helena limestone. The only fossils recognized are scolithus borings. The total thickness of the Flathead quartzite in the Helena district is 300 feet. The formation is easily recognized in the topography of the area, as the resistant nature of the beds causes them to form low foothill ridges, which are prominent on the slopes of Mount Helena, and as the cap reef on the mountain ridge running southward from that peak." (Evidently westward as the Flathead does not extend southward from the peak and the ridge extends west-southwest.)

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[1] Bull. 527, U. S. Geol. Surv., pp. 88-89.

[2] Twentieth Ann. Rep., U. S. Geol. Surv., Pt. 3, pp. 284-287.

[3] Knopf, Bull. 527, U. S. Geol. Surv., 1913, pp. 89-90.

[4] Idem.

Wolsey shale.—The Wolsey shale, Meagher limestone, Park shale, Pilgrim limestone, Dry Creek shale, and Yogo limestone are all included under *Ꞓls* on the map. "The Wolsey shale[1] consists of micaceous and calcareous gray to greenish shales, which contain small oval and flat concretions of limestone, grading in places into thin and very irregular plates of limestone. Trilobite and shell remains of Cambrian types occur abundantly along the contact between these shales and limestones. The rocks are in few places well exposed, owing to their soft and crumbly nature, but their position is recognizable by the ravines cut in them or, on the mountain slopes, by their forming a more gentle angle between the limestone bluffs above and the quartzite ridges below. They have a thickness of about 420 feet" (in the Helena district).

"*Meagher limestone.*[1]—The Meagher limestone is composed of light-gray to bluish limestones, which are shaly near the base, but grade into alternating beds of massive, dark-colored and flaggy, white limestones, and these into thinly-bedded, dark-purple to blue, fossiliferous limestones, forming the top of the series. In other regions the rocks are pebbly, but this character is not conspicuous in the Helena district. The rocks have an estimated thickness of 400 feet. They form the characteristic bluffs on the north face of Mount Helena, extending from the gentle slopes formed by the Wolsey shale upward almost to the very summit of the mountain. The rocks are also seen in the bold cliffs below the east side reservoir. Fossil remains occur, but no collections were made.

"*Park shale.*[2]—The Park shale consists of earthy and micaceous dark-gray to green or purple shales. The rocks are not well indurated and crumble readily, so that very few good exposures are seen. A partial section is exposed in the quarry near the upper part of the city of Helena, and shows the formation to contain lavender or pinkish beds, grading through green shales to a grayish earthy shale carrying an abundance of small fossil shells, identified as *Obolella* [*Obolella* (*Westonia*) *ella*].[3] The upper portion contains limestone lenses in a jaspery shale, which grades downward into a dense cherty rock resembling hornstone. This shale has an estimated thickness of 150 feet. It forms the flat bench on the summit of Mount Helena, between the apex and the northern cliffs, and covers the ridge followed by the trail.

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[1] Bull. 527, U. S. Geol. Surv., p. 90.

[2] Idem, pp. 90-91.

[3] The reference now is to *Obolus* (*Westonia*) *ella*. (Monogr. 51, U. S. Geol. Surv., 1912, p. 455.)

"*Pilgrim limestone.*[1]—The Pilgrim limestone consists of massive beds of bluish to dark-gray limestones. The lowest bed is a dark-colored crystalline rock, mottled with yellow and dark-gray spots; its peculiar coloration and massive character are characteristic of the limestone throughout Montana. This bed of mottled limestone is overlain by light-gray to white, non-crystalline limestone, used for making quicklime in the Grizzly Gulch kilns. No fossils have been found in the mottled limestone, but its position and lithologic character correlate it with the 'Mottled' limestone of the Yellowstone Park folio. This formation occurs on the very summit of Mount Helena, where it forms the uppermost bed of the gentle syncline sweeping down the southeastern side of the mountain. It is also seen in bluffs above the East Side reservoir, and forms a low cliff extending up Oro Fino Gulch for 2 miles above the city, the relief being due to the crumbly nature of the Park shale in which the gulch is being eroded. The mottled beds are 150 feet thick and are overlain by white limestone, which is included in the formation. The total thickness of the formation is 317 feet.

"*Dry Creek shale.*[1]—The Dry Creek shale consists of light-colored brownish-yellow, red, and pink shales and calcareous sandstones. The formation is well exposed in few places, but can be recognized by its topographic relief, as it forms sags in the high ridges and ravines on the mountain flanks. No fossils have been found in the shale. It is correlated on the basis of lithology and stratigraphic position with the Dry Creek shale of the Threeforks and Little Belt regions. The thickness is estimated at 40 feet.

"*Yogo limestone.*[1]—The Yogo limestone consists of light-colored, thin-bedded limestones, with crinkly bands and films of jasper, in many places composed of limestone pebbles held in a glauconitic matrix. The formation corresponds to the so-called 'Pebbly' limestone of the Threeforks folio. It has a thickness of 175 to 450 feet. The jaspery, flaggy limestone forms prominent buttress exposures along the east side of Oro Fino Gulch above the city."

SUMMIT OF THE CAMBRIAN

On the map accompanying Bulletin 527 the line between the Cambrian and Devonian rocks was supposed to be at the upper limit of a well-marked shale deposit. Later work, however, after the map was made, showed that the limestones above this shale also belonged to the Cambrian, and that all of the south and southwest slope of

[1] Bull. 527, U. S. Geol. Surv., p. 91.

Mount Helena was formed of Cambrian rocks; also that the upper boundary of the Cambrian southwest, south, and southeast of Helena would have to be placed at a higher horizon. This, however, does not affect the map for the purpose of the present paper.

CAMBRIAN SECTION 15 TO 20 MILES NORTHEAST OF HELENA, MONTANA, ALONG BEAVER CREEK, ON THE EAST SIDE OF THE MISSOURI RIVER

Beaver Creek rises on the slopes of the north end of the Big Belt Mountains and flows westward to where it empties into the Missouri River. The formations are finely exposed along this canyon. Beneath the Flathead quartzite is a considerable thickness of siliceous, slaty, dark shales of the Grayson formation of the Belt terrane that strike north 42° west (magnetic), and dip 30° southwest 48° west. These shales are overlain by the basal beds of the Flathead quartzite which strike north 58° west (magnetic), dip 30° south 32° west. This dip increases to 40° and gradually to 75° near the top of the ridge on the north, and then returns to 35°. The strike at the top of the ridge is north 50° west (magnetic). The section is given in my field notes as from the bottom up as follows:

ALGONKIAN

Siliceous, slaty, dark shales of the Grayson formation, Belt terrane.

CAMBRIAN

FLATHEAD SANDSTONE

Gray, massive-bedded, quartzitic sandstone, with a few conglomerate layers formed of small quartz pebbles.

At 225 feet from base thinner-bedded quartz sandstones occur and again at 355 feet a band of thinner beds comes in. At 640 feet the massive beds of quartz sandstone give way to shaly sands and shales .... 640 feet.

WOLSEY SHALES

Thin-bedded and sandy shales with irregular, thin-bedded, shaly limestone carrying Middle Cambrian fossils at 180-200 feet. Purple and green argillaceous shales appear at about 600 feet from the base .... 695 feet.

Intrusive layers of eruptive rock occur from above 100 feet at various horizons as interstratified thin sheets that add about 120-150 feet to the total thickness. Fragments of shales are included in the eruptive layers on the north side of Beaver Creek where the eruptive follows the parting of the shale on the lines of bedding for long distances; in places it cuts across the beds and drops a few feet to another parting or disappears altogether.

MEAGHER LIMESTONE

Thin-bedded, bluish-gray limestone with fossils at base. Strike north 50° west. Dip 30° southwest.............................6 feet.

Ptychoparia

Acrotreta

Iphidea

Eruptive ....11 feet.

Limestone. At 165 feet from its base the limestone becomes more massive and gray in color, and is made up of thin layers grouped in massive layers. At 360 feet thicker individual layers appear and continue to the top of the formation. Fragments of trilobites show here and there but very rarely.

Total ....720 feet.

A bed of irregularly-bedded, eruptive rock rests on the limestone beneath the Park shales.

PARK SHALES

Green and purple argillaceous shale.........................290 feet.

PILGRIM LIMESTONE

(*a*) Massive-bedded, gray, oolitic limestone, passing above to bluish-gray, thin-bedded, fossiliferous limestone...............205 feet.

Fragments of Cambrian fossils were seen in a few layers.

(*b*) Light-gray, arenaceous, finely granular or subcrystalline limestone. (Strike north 40° west. Dip 23° southwest.)

In the lower 25 feet small *Hyolithes* occur with bits of trilobites. Above, the strata become more massive and coarser...........135 feet.

A bed of intrusive lava 3 feet thick occurs near the base of (*b*).

The Dry Creek shale and Yogo limestone of Weed were not recognized in this section. The shale is usually only a thin bed that is readily concealed by débris from the limestones above.

SUMMARY:

Pilgrim limestone	340	feet.
Park shale	290	"
Meagher limestone	720	"
Wolsey shale	695	"
Flathead sandstones	640	"
Total Cambrian	2,685	feet.

The next overlying limestone is referred to the Devonian. No line of unconformity was noted in the ridge where the section was measured, although there is undoubtedly an unconformity by non-deposition of the Ordovician and Silurian.

DEVONIAN

1*a*. Massive-bedded, dark steel-gray, arenaceous limestone, weathering to a dirty brownish-gray (oil-stain brown) color.

Obscure fragments of fossils occur at the base. At 65 feet a band 18 inches thick in a massive layer 3 feet thick is almost made up of *Stromatopora*, *Favosites*, etc.

Obscure fragments of gastropods and brachiopods occur 162 feet up and again at 350 feet up in a thin layer of light-gray, fine arenaceous limestone and a dark layer above....................575 feet.

Noted: *Stromatopora, Streptelasma, Heliolites.*

Sections of brachiopods and a gastropod.

1b. Light-gray, arenaceous limestone that forms a strongly marked, even-topped, low cliff, towards the summit. Strike north 60° west (magnetic). Dip 23° southwest......................180 feet.

Numerous small, cherty nodules occur in association with bits of silicified *Stromatopora,* with thinner layers near the top.

This limestone is succeeded by limestones referred to the Carboniferous.

CARBONIFEROUS

1a. Bluish-gray, thin-bedded limestones with cherty nodules and layers of chert in some of the layers. (Layers 1-6 in., 12 in., 24 in., thick.)

This band begins at a saddle west of the slope on the top of *1c,* and is a marked feature on the north side of Beaver Creek beneath the massive, gray, conglomerate limestone cliffs. Total of *1a*..780 feet.

At 375-400 feet noted fossils, and at 740 feet from the base a fauna, in which the following species have been identified by Dr. George H. Girty of the United States Geological Survey:[1]

Chonetes loganensis
Productus ovatus
Productus semireticulatus
Productus gallatinensis
Pustula scabricula
Camarotoechia metallica
Spirifer centronatus
Bellerophon sp.

1b. Light-gray arenaceous to almost pure granular limestone in massive beds. In places carries cherty nodules. Weathers rough, forming jagged cliffs.

At 1,225 feet from the base of *1b* corals occur and at 1,850-1,900 feet up the corals are in great abundance.

Masses of Diphophyllum 2 to 3 feet in diameter.

Syringopora, etc., etc.

Total of *1b*..2,075 feet.

1c. Shaly sands with interbedded bands of gray limestone and sandstone.

At about 600 feet up remains of Bryozoa are abundant. The section is here broken by the canyon of the Missouri River. On the west side of the river high cliffs of sandstone, etc., rise fully 1,000 feet back from and above the river.

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[1] "I would unhesitatingly call this fauna Carboniferous and also unhesitatingly call it Mississippian. It appears to represent the horizon of the Madison limestone. It is not, however, the most typical phase of the Madison fauna, which is of early Mississippian age, and I would not state positively at this time that it might not belong in the middle Mississippian. Even so, it would be within the limits of the Madison limestone as they are at present recognized." (Information in letter from Dr. Girty, of April 5, 1916.)

CAMBRIAN SECTION OF THE LITTLE BELT MOUNTAINS

Dr. Walter H. Weed has published a description of the Cambrian rocks of the Little Belt Mountains section 60 to 70 miles east of Helena and 30 to 40 miles east of the Big Belt Mountains.[1] The several formations were here first named as follows:

7. Yogo limestone	130	feet.
6. Dry Creek shale	40	"
5. Pilgrim limestone	97	"
4. Park shale	800	"
3. Meagher limestone	100+	"
2. Wolsey shale	150	"
1. Flathead sandstone	160	"
Unconformity.		
Belt series: Spokane shale.		

A brief description is given of each formation and a plate (pl. 40) of comparative columnar sections of Middle Cambrian formations in central Montana.

Algonkian formations.—The pre-Cambrian formations exposed on Belt Creek south of Neihart are described and the statement made that the unconformity between the upper formation, the Spokane shale, and the Cambrian Flathead sandstone is well shown on Sawmill Creek.[2]

The Belt formations are named as follows:

5. Spokane shale	210	feet.
4. Grayson shale	955	"
3. Newland limestone	567	"
2. Chamberlin shale	2,078	"
1. Neihart quartzite	702	"
Unconformity.		
Archean.		

STRATIGRAPHIC SECTION OF PALEOZOIC FORMATIONS IN THE BIG SNOWY MOUNTAINS, MONTANA[3]

In an unpublished manuscript report by W. R. Calvert of the U. S. Geological Survey, on the Big Snowy Mountains area 60 miles east of the Little Belt Mountains, based on work done by him and his party during the field seasons of 1907 and 1911, there is a brief account of the Cambrian and pre-Cambrian formations in the vicinity of Half

[1] Twentieth Ann. Rept., U. S. Geol. Surv., Pt. 3, 1900, pp. 284-287.

[2] Idem, p. 283.

[3] Published by permission of the Director of the U. S. Geological Survey.

Moon Pass, which is in the southern central section of the Big Snowy Mountains.

Belt series.—Of this series Calvert writes as follows: "The oldest strata exposed in the area are correlated with the upper part of the Belt series, of Algonkian age, named from the Little Belt Mountains where studied and first described by Weed.[1] In the Big Snowy Mountains these rocks were actually seen only in Half Moon Pass amphitheatre, but they are believed to be exposed also in connection with several other similar topographic features at the heads of Blake, Careless, and Timber creeks. A thickness of about 300 feet of these strata is exposed near Half Moon Pass, where they consist of dark, limy shale highly indurated and approximating a slate in physical condition. No fossils were found in these rocks, but their similarity to strata in the Little Belt Mountains of definitely determined Algonkian age, together with the marked angular discordance between them and the overlying Cambrian quartzite, seem sufficient to justify their assignment to the Belt series of the Algonkian. At only one locality was the unconformity noted, namely, just to the east of Swimming Woman Creek, in what, if surveyed, would probably be the S. E. ¼ of Sec. 9, T. 11 N., R. 19 E. *At this locality the Algonkian shale dips south at a 19° angle, whereas the overlying quartzite lies practically horizontal, so that an angular unconformity is apparent.*

"It is not known definitely whether the calcareous nature of the shale is due to original content or to later infiltration of descending waters charged with lime from the Paleozoic strata higher in the section. The latter assumption is given weight by the presence of many joint planes and a number of fault zones filled with calcite undoubtedly of secondary origin."

Cambrian formations.—"Lying unconformably on shale of the Belt series is a sandstone 75 feet thick composed mainly of pure quartz. Although indurated, the sandstone is not a quartzite, as stratification is distinct, and cleavage along bedding planes is marked. It is evidently a shore deposit, as cross-bedding is abundant and ripple marks are beautifully developed. The shore phase is also attested by abundant worm trails, the only evidence noted of life existing at the time of deposition of the sandstone. Layers of quartz conglomerate are of frequent occurrence in the sandstone with pebbles

[1] Weed, W. H., The Little Belt Mountains Folio, Geol. Atlas of the U. S., No. 56, 1899.

generally small, but occasionally attaining a diameter of one inch. Because of the lithologic character and stratigraphic relations of the sandstone, it is correlated with the Flathead quartzite of the Little Belt Mountains section.

" Immediately above the Flathead quartzite is a mass of soft strata about 750 feet thick. Continuous exposures of this portion of the stratigraphic section do not occur, but wherever observed the rocks consist mainly of fissile micaceous shale, prevailingly of a greenish hue. There are occasional intercalations of platy, calcareous layers, containing numerous greenish granules, presumably of glauconite. Three collections of fossils were obtained from these rocks in the vicinity of Half Moon Pass. The lowest fossiliferous zone occurs very near the base of the formation and from this zone *Asaphiscus capella* Walcott, *Hyolithes* sp., and *Ptychoparia* sp. were obtained. About 170 feet higher stratigraphically fossils identified as *Obolus matinalis* (Hall) were found in abundance in a calcareous layer. Still higher, fossils determined as *Asaphiscus capella* Walcott were collected. . . . .[1]

" Overlying the Wolsey shale is a formation with very distinct and characteristic lithology. It is composed of layers of firmly cemented, flat, limestone pebbles, with thin parting of gray fissile shale. The thickest layer of conglomerate noted was 4½ feet, and the general average was 2 or 3 feet. Worm trails and ripple marks are plentiful on the upper surfaces of the conglomerate layers, so it would appear that the formation represents a shore phase of marine deposition, a view strengthened by the flat character of the limestone pebbles. From the lithology and the relation to the underlying Wolsey shale this conglomerate is correlated with the Meagher limestone, described by Weed in the Little Belt Mountains folio."

Carboniferous.—" Madison limestone (Mississippian): Overlying the Meagher limestone is a thick mass of calcareous strata that constitutes the great bulk of the Big Snowy Mountains. This mass may be separated into three distinct lithologic units. The lowermost comprises 200 feet of chocolate-colored limestone, cherty throughout and massive in general appearance, though in reality somewhat thinly bedded. A striking characteristic in connection with this limestone is the strongly fetid odor emanating when struck with a hammer, due no doubt to some form of sulphur. It was supposed in the field that this limestone corresponds to one of similar character in the

[1] Names of species are as identified by Walcott.

Little Belt Mountains, assigned by Weed to the Siluro-Devonian. In the Half Moon Pass locality, however, the writer collected fossils from the limestone, near the top, to be sure, but from a zone similar in every respect to the strata between that zone and the Meagher limestone. According to Dr. Girty, who made the identifications, this collection contained *Pinnatopora* sp., *Spirifer centronatus*, and several species of *Fenestella*, referred by him to the Madison limestone of Mississippian age."

Summarized, the Big Snowy section is stated by Calvert as follows:

Age		Formation	Character	Thickness in feet
Unconformity.				
Paleozoic: Carboniferous	Mississippian?	Quadrant	Red and green sh., reddish ss. and usually ls. as top member	1,300
	Mississippian	Madison ls.	Ls., 4 mass members with shaly ls. between	1,400
			Ls. thinly bedded	350
			Ls. chocolate-brown, fetid odor when struck	200
Unconformity?				
Paleozoic: Cambrian		Meagher ls	Ls. conglomeratic, flat pebbles	300
		Wolsey sh	Mainly greenish, micaceous sh	750
		Flathead qtzt	Coarse ss. with qtz. congl. layers	75
Unconformity.				
Algonkian		Belt series	Dark, limy shale.... (exposed)	300

One of the interesting features of the above section is the angular unconformity at the base of the Flathead quartzite. The uplift of the axis of the Big Snowy Mountains in pre-Cambrian time had begun and like similar uplifts of Algonkian strata in the Spokane Hills, west of the Big Belt Mountains, Montana, in the Llano area of Central Texas, and the Grand Canyon area, Arizona, had been cut down by erosion before the deposition of the basal beach sand and gravel by the transgressing Cambrian sea.

ROTHPLETZ SECTION OF MOUNT HELENA

In great contrast with the Mount Helena section of Weed is that of Rothpletz made as a result of a brief examination in 1913.[1] His section on the eastern slope of Mount Helena, from above downward, is as follows:[2]

6. Summit dolomite up to.......... ....250 m. [812 ft.].
5. Gray schists [shales] up to................. 60 " [193 "].
4. Bluish-gray limestones with oolite beds.....500 " [1,625 "].
3. Schists [shales] with limestones in alternating layers.
2. Brownish weathering quartzitic layer.
1. Green and gray argillaceous schists [shales].

Interpreting the above section he says, "When we compare this sequence of rock with Walcott's data, it thus appears that No. 4 corresponds to his *Helena* limestone, which he says outcrops in the upper limits of the city. No. 3 must then correspond to the Empire shales of Walcott, and No. 1 to the Spokane[3] schists [shales], to which No. 2 might be placed as the uppermost section."[4]

He thinks that this interpretation can hardly be correct because the schists of No. 1 have not the red color of the Spokane schists and because the thick, brown quartzitic layer is peculiar neither to the Empire nor the Spokane schists. He says, "A comparison for 2 with the Lower Cambrian Flathead quartzite would be nearer."[5]

In the above statement Rothpletz correlates No. 4 with the *Helena* limestone (*Ah* on map), and it is here that the vital mistake in all of his correlations was made, for his No. 4 limestone is the well-known

[1] Bulletin 527 ("Ore deposits of the Helena Mining Region in Montana") of the United States Geological Survey, with a detailed geological section and map of Helena and vicinity, was available for examination in six libraries in Munich in the fall of 1913, and it must have been accessible to Rothpletz on his return to Munich from the United States in 1913. It was issued in Washington May 1, 1913, and its receipt for the libraries of the Central-Bibliothek des Deutschen und Oesterreichen Alpen-Vereins, Geologisch-Paläontologische Sammlung des Staates, Königl. Bayerische Akademie der Wissenschaften, Königl. Bayerisches Oberbergamt., Petrographisches Institut der Universität, Zeitschrift für Krystallographie und Mineralogie was acknowledged by the America-Institut, August 30, 1913. It was catalogued as received by the Königl. Bayerische Akademie der Wissenschaften, Math.-Physikalische Klasse, 1913, Heft 3, p. 76[5], by which institution the Rothpletz paper was published, June, 1915.

[2] Rothpletz, p. 10.

[3] Rothpletz evidently did not at any time see an outcrop of the Spokane shale as it is exposed northeast of the railroad tracks over three miles (4.8 km.) east of the city. (See *As* on map.)

[4] Rothpletz, pp. 10-11.

[5] Idem, p. 11. This is the Cambrian Flathead quartzite which is described in the section of Mount Helena taken by Weed.

Cambrian Meagher limestone of Weed. The Helena limestone occurs *beneath* No. 1 of the Rothpletz section, and may be found, as stated by Weed, near the high school within the city limits and to the north and west in the Kenwood subdivision. It also extends southeast to and beyond the main business street of the city, ending up against the quartz monzonite (*qm* on map) mass that extends northeast and southwest across the city, cutting off the outcrops of all of the sedimentary formations (see map, pl. 39).

Reference by me to the *Helena* limestone, to which Rothpletz refers, is to its outcrops in the upper limits of the city which are on the lower slopes of Mount Helena, and not to the Cambrian limestone which forms the cliffs and steep slopes well up on the mountain side above the city streets. Outcrops of the Helena limestone are best seen in the city in ditches and cellar excavations for houses.

Rothpletz, after speaking of his reviewing the literature accessible to him, says:[1]

> Prepared with this information, I began at Helena my investigations, which had as their object to find pre-Cambrian fossils, and before going into the discussion of the fossils which I found there, I will next describe the geological conditions as, according to my observations, they appear to me to exist.

The description of his examinations about the city of Helena that follows, clearly indicates that he did not have a clear conception of the pre-Cambian formations exposed in the vicinity of Helena. He confuses the Spokane shales and the Marsh shale with the Empire shale, and the Helena limestone with the Cambrian limestones. On page 9,[2] in speaking of limestones on both sides of the north and south Oro Fino Gulch fault (*O-O* on map), which displaces the formations on the lower eastern slopes of Mount Helena, he says that the Flathead quartzite is not exposed on the northwest side of the fault, but "according to its petrographic character, the limestone itself thus corresponds sufficiently to the Helena limestone, as Walcott has described it, so that there can be no doubt as to the identity of both. The oolitic limestone layers are especially characteristic. . . . ."

On page 10,[3] he states that the northeast slope of Mount Helena above the quarry is constructed exclusively of such Helena limestones, up to the terrace-like shoulder, upon which the real summit mass first rises, and upon the shales which occur at the terrace-like shoulder. He describes the summit limestone [dolomite] as having a thickness of 250 meters (812+ ft.), or more. He considers

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[1] Rothpletz, p. 8, first new paragraph.

[2] Idem, p. 9, line 37, to p. 10.

[3] Idem, p. 10, line 3.

(p. 11[1]) that the shale on the terrace-like shoulder is interbedded in the Helena limestone, according to which the summit dolomite must certainly be identical with the latter (Helena limestone). He considers this view feasible because according to Walcott the Helena limestone has a thickness of 2,400 feet (732 m.). He concludes further that the Flathead quartzites mentioned by Walcott were to be expected in the layer above the summit dolomite. (This would be the position of the Dry Creek shale of Weed, p. 269.)

According to Weed and the U. S. Geological Survey geologists (Barrell, Griswold) who have studied the section, the summit dolomite referred to is the Cambrian, Pilgrim limestone of Weed; the shale beneath it, the Park shale of Weed; and the limestone beneath the shale on the terrace-like shoulder referred to above, the Cambrian Meagher limestone which is underlain by the Wolsey shale, and this by the Flathead quartzite.[2]

Confusion in identification of the pre-Cambrian Helena limestone.—Rothpletz was unfortunate in his location and identification of the Helena limestone.

My note on the section reads as follows:[3]

> Crossing the valley of the Missouri River from Whites Canyon directly westward 10 miles to the Spokane Hills, on the west side of the river, one finds a syncline of Cambrian resting directly on the red Spokane shales. Continuing westward on the same line to the city of Helena, a distance of 14 miles, the Cambrian sandstones are found resting on shales 250 feet above the Helena limestone, or fully 3,000 feet above the contact horizon in the Spokane Hills.

Looking at the map (pl. 39), we find directly east of Mount Helena the outcrop of the Helena limestone (*Ah*) extending across the central portion of the city in a southeasterly direction to where it is cut off by the eruptive quartz monzonite (*qm*). Above the Helena limestone (west of it) an area of the Empire shale (*Ae*) occurs above it and beneath the Cambrian Flathead quartzite (*Cf*). This shale is the 250 feet of shale referred to in the above-quoted paragraph. In order to avoid the quartz monzonite area and to take his diagrammatic section across the strike, I carried the section south of the suburb of Lenox (*W-W* on map) as described by him[4] as follows:

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[1] Rothpletz, p. 11, line 15.

[2] See section, p. 263.

[3] Pre-Cambrian Fossiliferous Formations, Bull. Geol. Soc. of America, Vol. 10, 1899, p. 211.

[4] Idem.

Following the line of contact to the southeast for 1 mile, the Cambrian sandstones may be seen resting directly on the massive beds of the Helena limestone, a slight unconformity occurring at the point of contact, as shown by figure 3. A mile farther to the southeast there are 6 feet of shales above the limestone, a slight unconformity being shown between it and the Cambrian. The section east from Helena extends downward through some 2,000 feet or more of (Helena) limestone and interbedded shales and several hundred feet of siliceous, greenish shales before reaching the red Spokane shales, which underlie the Cambrian in the Spokane Hills.

I there found the section more complete from the Spokane shales (*As*) up to the unconformity at the base of the Cambrian Flathead quartzite (*Cf*), and it was in this part of the section that he obtained his estimate of 2,400 feet[1] (731 m.) or more for the thickness of the Helena limestone (*Ah*). It was unfortunate that I did not make this location clear as it would probably have led Rothpletz to look there for the Helena limestone and not to assume that the higher Cambrian limestones of Mount Helena were typical representatives of the Helena limestone.

Once having identified the Cambrian limestone of the upper portions of Mount Helena as the pre-Cambrian Helena limestone which occurs far below and beneath the Empire shale in the more level slope occupied by the city streets, there was little chance of Rothpletz getting the true relations of the Cambrian formations and the underlying pre-Cambrian Helena limestone in the faulted and displaced area south of the suburb of Lenox.

Another confusing condition is the contact on the strike of pre-Cambrian Helena limestone (*Ah*) and the Cambrian limestone (*Cls*). By looking at the map (pl. 39) we find that southeast of the suburb of Lenox and about 1.5 to 2 miles southeast of the thickly built up south section of the city an area of Cambrian and pre-Cambrian strata has been pushed to the northeast one-half mile between the fault lines *A-A* and *B-B*, as shown on the map. This area includes exposures in the section from the base upward of the Empire shale (*Ae*), Helena limestone (*Ah*), and Marsh shales (*Am*) of the Algonkian, and above the latter the Cambrian Flathead quartzite (*Cf*) and the several shales and limestones (*Cls*) of the Cambrian before the overlying Devonian limestones (*Dj*) are met with higher up on the hill slopes. The displacement of this great mass of shales, sandstones and limestones has brought in contact on the strike at *x* (on the eastern fault line (*B-B*)) the pre-Cambrian Helena limestone (*Ah*) and the Cambrian limestones and shales (*Cls*) in such a manner as to cause the outcrop of the Cambrian limestone to be apparently a direct con-

[1] Pre-Cambrian Fossiliferous Formations, Bull. Geol. Soc. of America, Vol. 10, 1899, p. 211.

tinuation of the pre-Cambrian Helena limestone. This contact extends on a north-northeast and south-southwest line for over 1,000 feet (305 m.).

To one who had seen the Cambrian limestones on Mount Helena and mistaken them for the pre-Cambrian Helena limestone, it would be most natural to conclude that not only were the Cambrian limestones the same as the pre-Cambrian Helena limestone, but that the great mass of the Helena limestone southeast of the fault *B-B* was also of the same geological age as the Cambrian limestones.

Rothpletz interpretation of Weed's Cambrian as given in Butte report.—In speaking of the Cambrian section described in Weed's report upon the Butte district,[1] Rothpletz states in substance that, according to Weed, immediately beneath the black Jefferson limestones the shales and limestones of the Cambrian with their basal quartzites rest on the shales and interbedded sandstones of the Belt formation, and further,[2] that " Walcott has, however, separated a part of this thus (above) delimited Cambrian, namely, the Helena limestone and the Marsh shales, and assigned it to the Belt formation. What then still remains over of Weed's Cambrian at Helena is not stated except that the Flathead sandstone [quartzite] forms the base of the Cambrian."

I do not understand this reference of Rothpletz to the Helena limestone and Marsh shale, as Weed has never to my knowledge included the Helena limestone and the Marsh shale in the Cambrian. It serves to further illustrate the confusion in the mind of Rothpletz as to what the Cambrian limestones were, also as to the Helena limestone. In all the publications of Weed and Walcott, the Cambrian limestones are considered to be above the Flathead quartzite and the Helena limestone unconformably beneath it.

Comparison of Rothpletz and Weed Cambrian sections in the Helena district.—Placing in comparison the Rothpletz and Weed sections in the Helena district we have the following result:

Rothpletz	Weed		
6. Limestone (Helena).	Pilgrim limestone	317 ft.	Cambrian.
5. Shales (Capitol Creek).	Park shale	150 "	
4. Limestone (Helena).	Meagher limestone	400 "	
3. Shales (Empire).	Wolsey shale	420 "	
2. Sandstones (Quartzite).	Flathead quartzite	300 "	
1. Shales.	Marsh shale		Algonkian.
	Helena limestone		

[1] Geology and Ore Deposits of Butte District, Montana. Prof. Paper 74, U. S. Geol. Surv., 1912.

[2] Rothpletz, p. 7, line 9.

In view of the data and discussion already presented I do not think it necessary to comment further upon the two sections.

UNCONFORMITY BETWEEN THE CAMBRIAN AND PRE-CAMBRIAN

Having concluded from stratigraphic and paleontologic evidence that there was no unconformity or discordance between the Cambrian and pre-Cambrian at Helena, Rothpletz next proceeds to argue that because the evidence of non-conformity is not readily seen at Helena, Montana, it is quite probable that it does not exist. It was quite natural that he did not discover it about Helena for two reasons. *First,* because it is not very clearly shown. *Second,* he was looking for it within the Cambrian section and not below the Cambrian and above the Helena limestone of the pre-Cambrian (see pp. 279-281).

Grand Canyon section.—If Rothpletz had studied the section at the Grand Canyon of the Colorado River when there in 1913,[1] he might have obtained a very clear conception of the unconformity between the Cambrian and pre-Cambrian. In that section[2] the entire pre-Cambrian sedimentary series of nearly 12,000 feet of sandstones, shales, and limestones were tilted, faulted, more or less broken, and eroded nearly to base level before the transgressing Cambrian sea covered it with beach gravel and sands, arenaceous and calcareous muds in which fragments of an abundant Middle Cambrian fauna were buried. This great unconformity has been illustrated and described several times,[3] but Rothpletz does not refer to it in his memoir, although it is the one great locality where Nature has laid open the history of a great, unmetamorphosed, sedimentary series of pre-Cambrian formations corresponding in stratigraphic position and character with the Belt series of Montana. As giving some conception of the unconformity, a section is inserted here (fig. 11) showing the unconformity between the Cambrian Tapeats sandstone and the pre-Cambrian Grand Canyon series of formations. Four photographs taken in the Grand Canyon are also reproduced in which the unconformity is finely shown (pls. 40-43).

Bow River Valley section.—Rothpletz refers to my description[4] of the Bow River section of Alberta where the Lower Cambrian is

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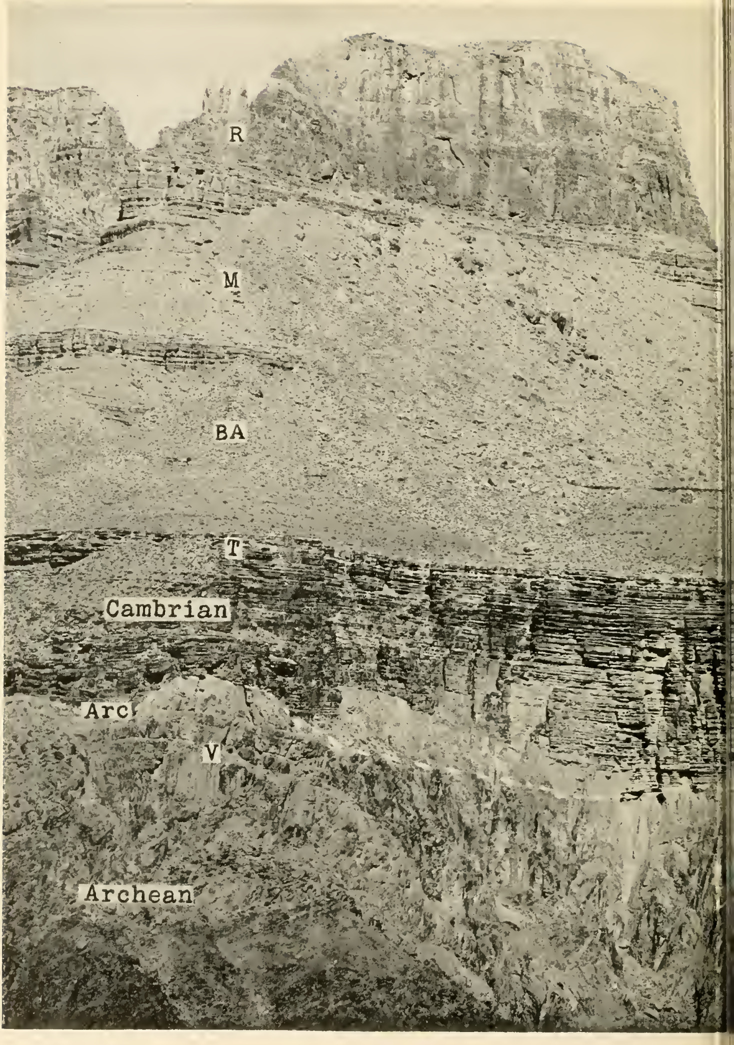
[1] Rothpletz, p. 4.

[2] Walcott, Fourteenth Ann. Rept., U. S. Geol. Surv., 1895, pp. 507-519. Idem, Bull. Geol. Soc. America, Vol. 1, 1889, pp. 51-56, figs. 1-9.

[3] Powell, Exploration Colorado River of the West, 1875, p. 212, fig. 79.
Walcott, 1895, Fourteenth Ann. Rept., U. S. Geol. Surv., pp. 507-517.
Noble, Bull. U. S. Geol. Surv., No. 549, 1914, p. 65, plates 9 and 18.

[4] Smithsonian Misc. Coll., Vol. 53, 1910, p. 426.



Unconformable contact on line (*Arc*) between Archean (*V* = Vishnu series) and Cambrian (*T* = T
forms terraced slope, and in turn is overlain by Cambrian Muav limestone (*M*) and by cliffs of grea
Isis" rests on Carboniferous sandstone.

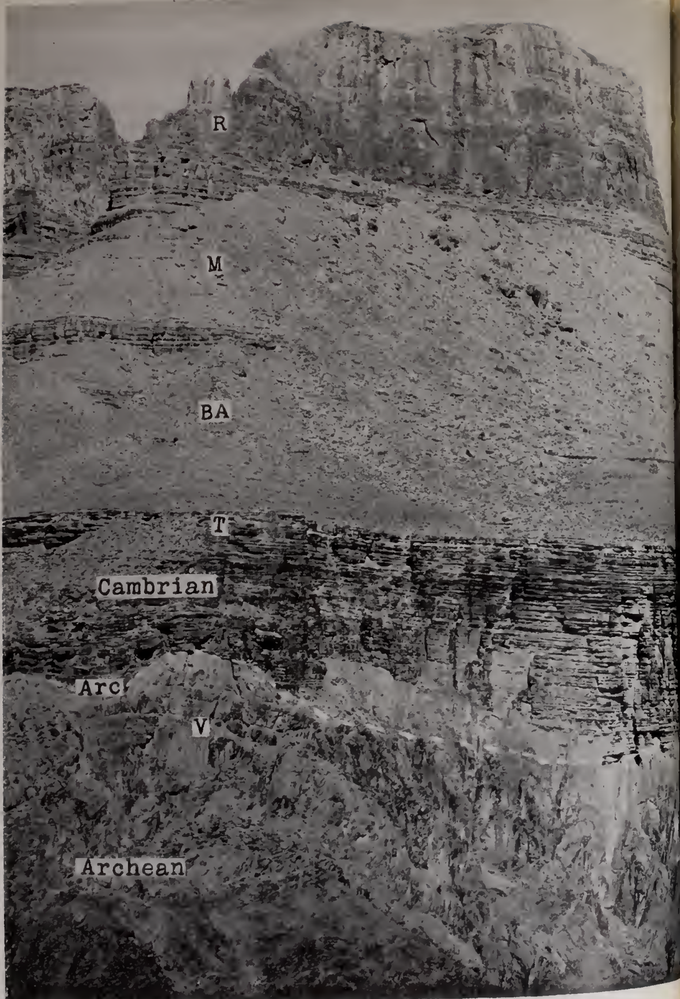
Locality: North side of Grand Canyon of the Colorado River, Arizona, below Bright Angel Canyon.

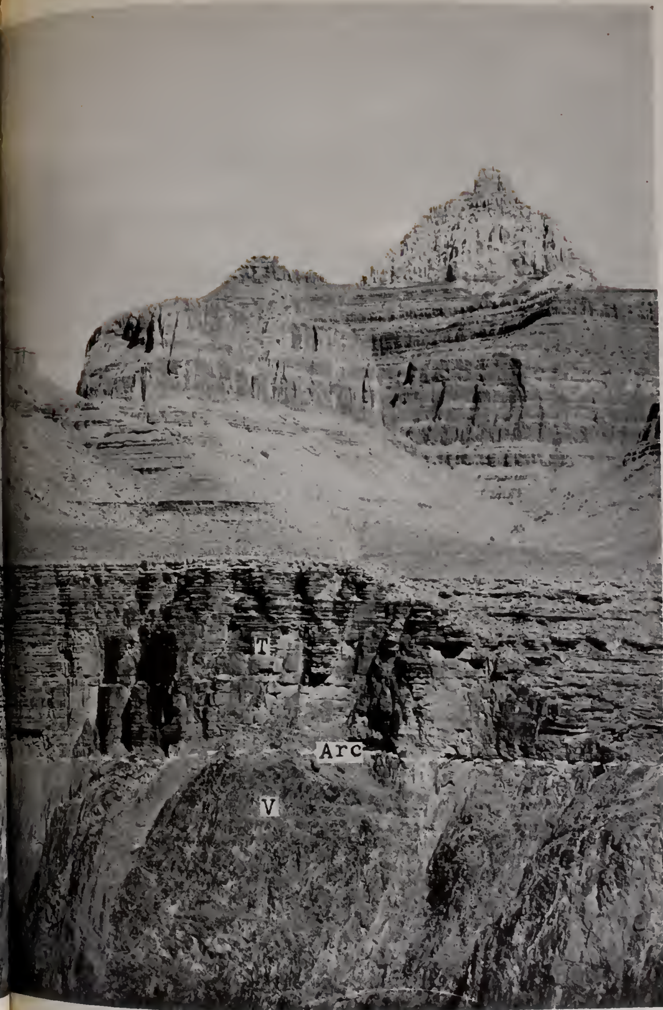
This photograph and also plates 41, 42, and 43 taken by Norman W. Carkhuff, chief photograph

Lettering on plates 40-43. *Carboniferous:* *K* = Kaibab limestone; *C* = Coconino sandstone; *Ssh*
Muav limestone; *BA* = Bright Angel shale; *T* = Tapeats sandstone. *Algonkian:* *Un* = Unkar series.
unconformity between Algonkian and Cambrian.

-tone). Tapeats (*T*) sandstone overlain by Cambrian Bright Angel (*B.A*) formation which (*R*) Carboniferous limestone. High above on right Carboniferous limestone of "Temple of

ogical Survey, under direction of Walcott, in 1901.
upai formation; *Ss*=Sandstone of Supai formation; *R*=Redwall limestone. *Cambrian: M*= =Vishnu series. *Aa*=line of unconformity between Archean and Algonkian. *Ac*=line of





Unconformable contact on line (*Arc*) between Archean (*V* = Vishnu series) and Cambrian (… sandstone). Tapeats (*T*) sandstone overlain by Cambrian Bright Angel (*BA*) formation which forms terraced slope, and in turn is overlain by Cambrian Muav limestone (*M*) and by cliffs of … wall (*R*) Carboniferous limestone. High above on right Carboniferous limestone of "Temple of Isis" rests on Carboniferous sandstone.

Locality: North side of Grand Canyon of the Colorado River, Arizona, below Bright Angel Cany…

This photograph and also plates 41, 42, and 43 taken by Norman W. Carkhuff, chief photograph… Geological Survey, under direction of Walcott, in 1901.

Lettering on plates 40-43. *Carboniferous:* *K* = Kaibab limestone; *C* = Coconino sandstone; … of Supai formation; *Ss* = Sandstone of Supai formation; *R* = Redwall limestone. *Cambrian:* *M* = Muav limestone; *BA* = Bright Angel shale; *T* = Tapeats sandstone. *Algonkian:* *Un* = Unkar series … *V* = Vishnu series. *Aa* = line of unconformity between Archean and Algonkian. *Ac* = line of unconformity between Algonkian and Cambrian.

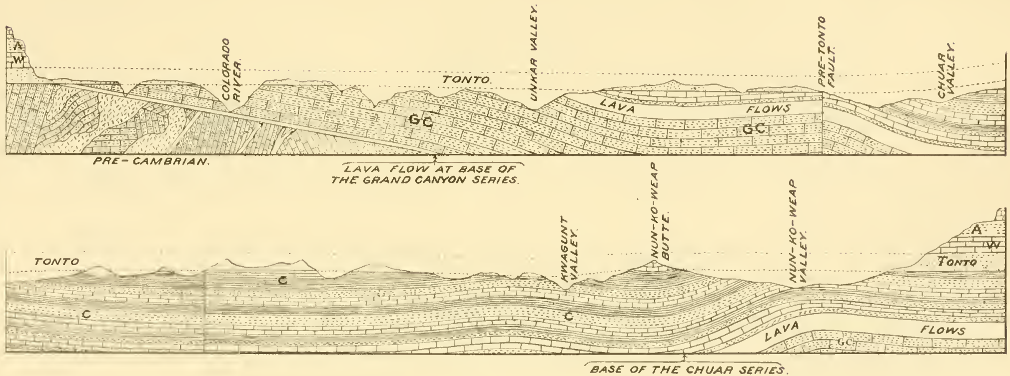


FIG. 11.—Grand Canyon Section. This section crosses the Algonkian strata nearly at right angles to their strike and illustrates the unconformity between the Cambrian and Algonkian rocks. The Cambrian (Tapeats sandstone) has been removed by erosion on the direct line of the section, but it is shown on the sides of the canyon as indicated by the dotted lines. *GC* and *C*, Grand Canyon and Chuar formation, or the strata referred to the Algonkian. *T*, the Tapeats sandstone of the Cambrian. *W*, Redwall limestone of the Lower Carboniferous. *A*, Aubrey sandstone of the Carboniferous.

unconformably resting on the pre-Cambrian Bow River sedimentary series. His criticism of this section is that I did not graphically illustrate the unconformity, and the same comment is made on the diagrammatic section near Helena, Montana.[1]

Of the Bow River Valley unconformity I wrote:[2]

Viewed in a restricted way, much of the pre-Cambrian surface was regular and the Cambrian rocks appear to be conformable to the subjacent pre-Cambrian strata. All about the sides of the valley the strata of the two formations, Fairview of the Cambrian and Hector of the Algonkian, dip away at about the same angle, but, when we apply the test of the varying thickness of the basal Cambrian conglomerate and the difference in the character of the upper beds of the Algonkian in different places, we at once become aware that the pre-Cambrian surface is more or less irregular, and that when the Cambrian sea transgressed over the area now included in the Bow Valley it found a broadly irregular surface with low hills and broad level spaces covered with a deep mantle of disintegrated rock. It washed out the muds and carried them away and deposited the sand and pebbles of its advancing beaches over and around the irregularities of the pre-Cambrian surface.

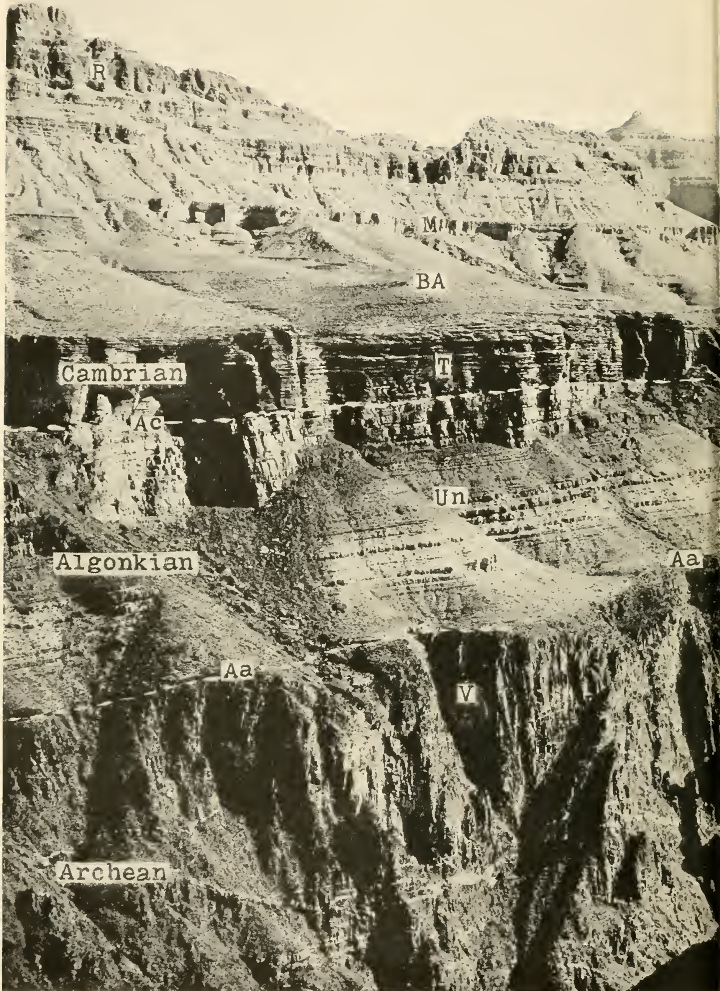
The unconformity is well shown at Fort Mountain, where the basal Cambrian is formed of massive layers 4-10 feet thick, which usually rest directly on the Hector shale (pre-Cambrian). In places, however, slight hollows in the shale are filled with thin layers of a more or less ferruginous sandstone that was deposited by gentle currents prior to the deposition of the massive conglomerate layers. The lower 10-20 feet of this conglomerate contain rounded and angular fragments of the subjacent pre-Cambrian formations (fig. 1, pl. 46). The Cambrian sea was evidently transgressing across the dark, siliceous shales of the pre-Cambrian land and reducing them to rolled pebbles, angular fragments, and mud. The mud gave origin to small lentiles of shale similar in character to the shale below the unconformity, while lentiles of sandstone of greenish tint indicate that fine material was being derived from still older pre-Cambrian formations than the shale. . . . .

Of greater importance is the evidence that the sediments of the two periods were deposited under different physical conditions. The Cambrian sandstones are composed of clean, well-washed grains, and the Cambrian calcareous and argillaceous shales were deposited as muds off shore along with the remains of an abundant marine life. The Hector shales of the pre-Cambrian are siliceous and without traces of life; the sandstones are impure and dirty, with the quartz grains a dead milky white, or glassy and iron stained. The sediments forming them were evidently deposited in relatively quiet muddy waters, and I think in fresh or brackish waters.

It should be noted that in the Bow River Valley section the *Lower* Cambrian rests on the pre-Cambrian, while in central Montana, about the Belt Mountains, it is the *Middle* Cambrian that is at the base of the Paleozoic series.

[1] Rothpletz, p. 22.

[2] Pre-Cambrian Rocks of the Bow River Valley, Alberta, Canada. Smithsonian Misc. Coll., Vol. 53, 1910, pp. 426-427.



Unconformable contact on line (*Aa*) between Archean (*V* = Vishnu series) and Algonkian (*Un* = side of view on line (*Arc*). In center and left side on line *Ac* the Cambrian (*T*) rests unconformabl
Locality: North side of Grand Canyon of Colorado River, Arizona, below Bright Angel Canyon,
One of the finest of the exposures showing the pre-Cambrian surface graded by erosion across the Muav limestone (*M*) form terraces up to base of Carboniferous Red Wall limestone (*R*).

ies); also between Cambrian (T = Tapeats sandstone) and Archean (V = Vishnu series) on right
Algonkian (Un = Unkar series).
from mouth of Bass Canyon.
and Algonkian formations. The two higher formations of Cambrian Bright Angel shales (BA) and

Unconformable contact on line (*Aa*) between Archean (*V*=Vishnu series) and Algonkian (series): also between Cambrian (*T*=Tapeats sandstone) and Archean (*V*= Vishnu series) on right side of view on line (*Arc*). In center and left side on line *Ac* the Cambrian (*T*) rests unconfo[illegible] the Algonkian (*Un*=Unkar series).

Locality: North side of Grand Canyon of Colorado River, Arizona, below Bright Angel Can[illegible]cross from mouth of Bass Canyon.

One of the finest of the exposures showing the pre-Cambrian surface graded by erosion acro[illegible]ean and Algonkian formations. The two higher formations of Cambrian Bright Angel shales (*BA*) and Muav limestone (*M*) form terraces up to base of Carboniferous Red Wall limestone (*R*).

Belt Mountains—Helena section.—By oversight Rothpletz failed to realize that my diagrammatic section to which he refers so frequently was not drawn to illustrate the actual minor unconformities at Helena, but to show the great unconformity indicated by the absence in the Spokane Hills of the Empire shales, Helena limestone, and Marsh shale beneath the Flathead quartzite of the Cambrian.

The Flathead quartzite rests on the Spokane shales in the Spokane Hills and also to the southeast on Deep Creek east of Townsend, Montana. The diagrammatic section is here reproduced as figure 10 (p. 263).

Of the unconformity between the Belt terrane and the Cambrian I wrote in 1899:[1]

Extent and character of recognized contacts.—The contact of the Flathead Cambrian sandstones with the rocks of the Belt terrane may be observed along a great extent of outcrop on the eastern, southern, and western sides of the Little Belt and Big Belt Mountains. Fully 200 miles or more of outcrop may be followed, along which frequent contacts may be observed. On the eastern side, in the vicinity of Neihart, the unconformity between the Cambrian and underlying Belt terrane is clearly evident, though the angular unconformity is generally slight and has been recognized only on Sawmill Creek. Four miles north of Neihart the Cambrian rests on a nearly level surface of (Archean) crystalline schists. West of Neihart it rests on the Neihart (Algonkian) quartzites. On O'Brien Creek, a few miles southwest of the town, it rests on black shales (Chamberlain Algonkian shales), of which there is less than 300 feet in thickness between the Cambrian and the top of the Neihart quartzite. On Chamberlain Creek and upper Belt Creek, 6 miles southeast of Neihart, the Cambrian rests on the (Algonkian) Grayson shales, while along the stage road up Sawmill Creek it is superimposed on the red (Algonkian) Spokane shales. The only exposures on the eastern slope of the Little Belt range, those of the south fork of the Judith, show the Cambrian resting on the drab Grayson shales. These are the only instances known where the red Spokane shales are wanting beneath the Cambrian. Whether the shoreline conditions, which are known to have existed near Neihart during the period when the Belt terrane was formed, caused a wedging out of the beds to the north, so that the Cambrian rests on different horizons at this locality, or whether pre-Cambrian erosion was extensive enough to pare down the exposed edges of the beds, is not certain from the evidence, though the latter view seems improbable. Similar conditions prevailed southward in the Bridger range.

In the north end of the Bridger range, east of Gallatin valley, the Cambrian is seen resting on the Belt terrane, which at this locality does not show its typical development, but consists largely of coarse sandstones and grits composed of Archean débris. In the south end of this range, but a few miles distant from the former exposures, the Belt terrane is entirely wanting, and the Cambrian rests directly on the Archean schists, as it does at Neihart. The

[1] Bull. Geol. Soc. America, Vol. 10, pp. 210-215.

character of the Belt beds indicates, moreover, that the Cambrian overlaps the Belt (Period) shoreline. Forty miles southeast of Neihart, in the Deep Creek and Grayson Creek sections, on the southwestern slope of the Big Belt Mountains, the Flathead rests on the Spokane shales, but at a higher horizon than at the head of Sawmill Canyon. Twenty-two miles north-northeast of Deep Creek in Whites Canyon, the full thickness of the Grayson shale and also about 1,000 feet of the (Algonkian) Helena limestone occur beneath the Cambrian sandstones.

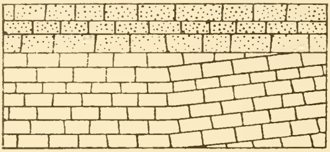


Fig. 12.—Unconformity between Helena Limestone and Cambrian Flathead Sandstone. The locality indicated is 1.25 miles southeast of the suburb of Lenox, and 2 miles southeast of the Capitol building at Helena, Montana.

Crossing the valley of the Missouri River from Whites Canyon directly westward 10 miles to the Spokane Hills, on the west side of the river, one finds a syncline of Cambrian resting directly on the red Spokane shales. Continuing westward on the same line to the city of Helena, a distance of 14 miles, the Cambrian sandstones are found resting on shales 250 feet above

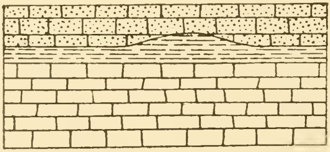
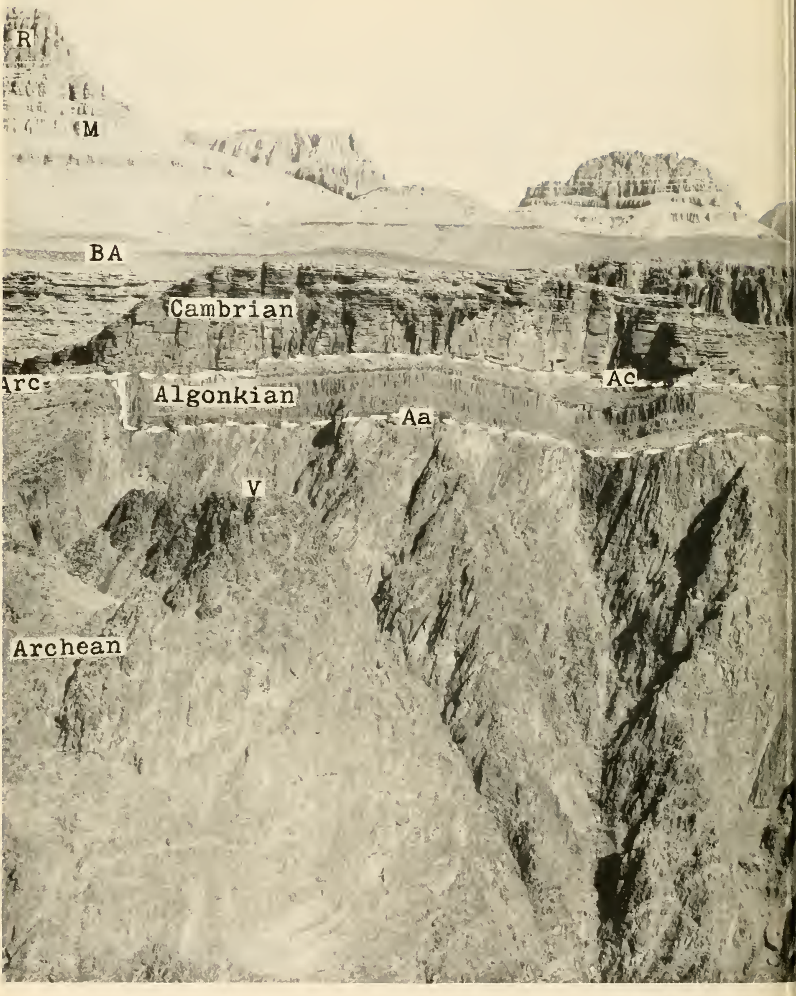


Fig. 13.—Unconformity between Marsh Shale and Cambrian Flathead Sandstone. The locality indicated is about 1 mile southeast of the locality of fig. 12, or 3 miles southeast of the Capitol building.

the Helena limestone, or fully 3,000 feet above the contact horizon in the Spokane Hills. Following the line of (the Flathead-quartzite-Spokane shale) contact to the southeast for 1 mile, the Cambrian sandstones may be seen resting directly on the massive beds of the Helena limestone, a slight unconformity occurring at the point of contact, as shown by figure 12. A mile farther southeast there are 6 feet of shale above the limestone, a slight unconformity being shown between it and the Cambrian (fig. 13). The section east from Helena extends downward through some 2,000 feet or more of limestone and interbedded shales and several hundred feet of siliceous, greenish shales



Unconformable contact on line (*Aa*) between Archean (*V* = Vishnu series) and Algonkian (*Un* = Unkar serie
removed latter to left over Archean before deposition of the Cambrian (*T* = Tapeats sandstone). The unconform
the Algonkian (*Un* = Unkar) series elsewhere on plate; more fully shown in plate 43.

Locality: North side of Grand Canyon of Colorado River, Arizona, opposite Grand View trail. This is wh
Archean at *A*. (American Jour. Sci., 3d ser., Vol. 26, 1883, p. 438, third paragraph.)

've bed of basalt rests on the Archean. Erosion cut across the entire Algonkian (*Un*=Unkar) series and of Cambrian is between Archean (*V*=Vishnu) series on the left side of plate on line (*Arc*), and between

nade by Walcott during winter of 1881-1882 came down over Tonto terrace and Algonkian cliffs to the

Unconformable contact on line (*Aa*) between Archean (*V* = Vishnu series) and Algonkian (*Un* = Unkar · massive bed of basalt rests on the Archean. Erosion cut across the entire Algonkian (*Un* = Unkar) series and removed latter to left over Archean before deposition of the Cambrian (*T* = Tapeats sandstone). The uncon base of Cambrian is between Archean (*V* = Vishnu) series on the left side of plate on line (*Arc*), and between the Algonkian (*Un* = Unkar) series elsewhere on plate; more fully shown in plate 43.

Locality: North side of Grand Canyon of Colorado River, Arizona, opposite Grand View trail. This is …ion made by Walcott during winter of 1881-1882 came down over Tonto terrace and Algonkian cliffs to the Archean at *A*. (American Jour. Sci., 3d ser., Vol. 26, 1883, p. 438, third paragraph.)

before reaching (north of railway tracks) the red Spokane shales, which underlie the Cambrian in the Spokane Hills.

The relations of the Cambrian and the subjacent Belt terrane on the line of the section from Helena eastward across the Spokane Hills to the Big Belt Mountains are indicated in the diagrammatic section, figure 10, (p. 263).

Northwest of Helena the contact between the Cambrian and the Belt terrane is followed to the crossing of Little Prickly Pear Creek, 6 miles west of Marysville. The Helena limestone outcrops all along the hills and gulches, and at Marysville the subjacent Empire shales occur beneath the limestone. West of the Marysville Canyon area the siliceous beds dip from 10 to 15 degrees to the northwest and pass above into the Helena limestone series, on which rest the Marsh shales. Crossing east-northeast, to the Gates of the Mountain, on the Missouri, 18 miles north of Helena, one finds the Cambrian sandstones resting on the red Spokane shales. This contact is again well shown on the eastern side of the Missouri River, on the road to Beaver Creek. On Beaver Creek the Cambrian rests directly on the Spokane shales, which, with the Grayson shales, constitute a thickness of several thousand feet between the Newland limestone and the base of the Cambrian. The contact at the crossing of Soap and Trout Creeks, to the northeast, is essentially the same as at Beaver Creek and the Spokane Hills, although there is a variation in the beds of the Grayson, which come in contact with the Cambrian.

At most of the outcrops where the lower beds of the Flathead (Cambrian) sandstones come in contact with the Belt rocks the dip and strike of the two are usually conformable, so far as can be determined by measurement. This holds good all around the great Big Belt Mountain uplift. It is only when the contacts are examined in detail, as near Helena, that the minor unconformities are discovered (figures 12 and 13), and only when comparisons are made between sections at some distance from each other that the extent of the unconformity becomes apparent.

Explanation of apparent conformity.—The reason for the apparent conformity in strike and dip between the two groups appears to be as follows: In pre-Cambrian time the Belt rocks were elevated a little above the sea, and at the same time were slightly folded, so as to form low ridges. One of these ridges is now the base of the Spokane Hills, where the Helena limestone (and Empire shales) and the upper portion of the Spokane shales were removed by erosion in pre-Cambrian or early Cambrian time. Usually there is very little, if any, trace of this pre-Cambrian erosion contained in the basal sandstones of the Cambrian. On Indian Creek, however, west of Townsend, which is on the strike of the Spokane Hills uplift, the basal bed of the Cambrian is made up almost entirely of fragments of the subjacent Spokane shales. Fragments of these shales were also observed in the sandstones of the Cambrian in the Little Belt Mountains near Wolsey postoffice. These illustrations are exceptional, the base of the Cambrian sandstone being formed usually of a clean sand, such as might be deposited where the sea was transgressing on the land.

The gentle quaquaversal uplift of the Belt rocks (of the Big Belt Mountains) gave them a slight outward dip toward the advancing Cambrian sea, so that the sediments laid down on the Belt rocks were almost concentrically conformable to them. Subsequent orographic movements have elevated the Belt rocks into mountain ridges and have tipped back and in many instances folded the superjacent Cambrian rocks, but the original concentric conformity between the beds of the two series remains wherever the lines of outcrop are at right angles to the plane of erosion of the Cambrian sea which cut across the Belt rocks toward the center of uplift.

Extent of unconformity—The extent of the unconformity between the Belt and the Cambrian may never be ascertained, as there is no section known where the sedimentation is unbroken from the Belt to the Cambrian. The greatest example of erosion is in the Spokane Hills, where the Helena limestone, with its superjacent Marsh and subjacent Empire shales, has been removed (fig. 11, p. 263). In other localities the red Spokane shales have been largely removed, but some of these are so far from the Spokane Hills section that it may be urged that they were not originally deposited in any greater thickness than is shown in the sections. The unconformity now known proves that in late Algonkian time an orographic movement raised the indurated sediments of the Belt terrane above sea-level, that folding of the Belt rocks formed ridges of considerable elevation, and that areal erosion and the Cambrian sea cut away in places from 3,000 to 4,000 feet of the upper formations of the Belt terrane before the sands that now form the middle Cambrian sandstones were deposited.

I think that an unconformity to the extent indicated is sufficient to explain the absence of lower Cambrian rocks and fossils and to warrant our placing the Belt terrane in the pre-Cambrian Algonkian system of formations.

Epeirogenetic unconformities.—Rothpletz seeks to explain the unconformity at the base of the Flathead quartzite by considering it as only the result of the filling up of a basin by sediment and the subsequent depression of the basin so that sedimentation was resumed, as has been the case many times in the history of sedimentary deposition on the North American Continent. In advancing this view, however, he fails to consider the great unconformity in the Grand Canyon area where profound faulting and displacement followed by prolonged erosion took place prior to the Cambrian transgression and sedimentation; the equally great disturbance and erosion in the Llano area of central Texas;[1] and the Spokane Hills uplift east of Helena, where a ridge of the Belt series rocks was eroded so as to remove 3,000 feet or more before the Spokane shales were buried beneath the sands of the transgressing Cambrian sea and the Big Snowy Mountains unconformity (p. 274).

In a recent publication I spoke of the post-Algonkian, pre-Cambrian unconformity as follows:[2]

CAMBRIAN BASAL UNCONFORMITY

From the Robson Peak region of British Columbia and Alberta to Arizona and southern California, a distance of over 1,000 miles (1,600 km.), clear evidence of a transgressing Cambrian sea has been found in many localities, proving conclusively that a general unconformity occurs here between the

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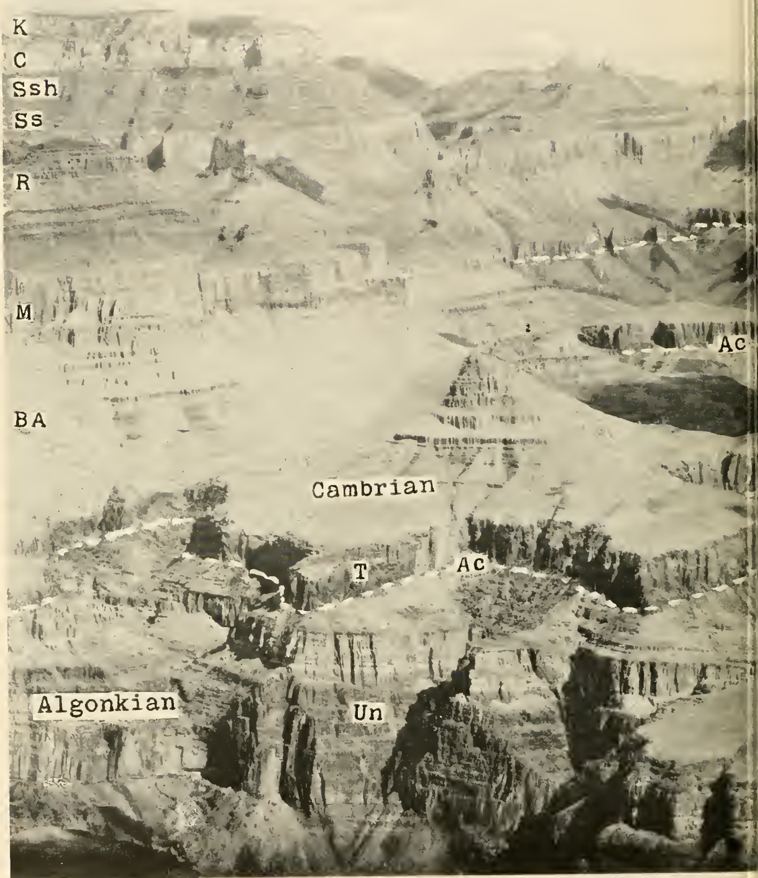
[1] Walcott, American Jour. Sci., 3d Ser., Vol. 28, 1884, p. 432.

[2] Problems of Geology, Chap. 4, Yale Univ. Press, 1914, pp. 170-171.



Unconformable contact between the Cambrian (T = Tapeats sandstone) and the finest exposure of A
exposed between the Archean as seen in plate 42 and the highest beds of the Algonkian shown on the ri
beneath the cliffs of Cambrian (T = Tapeats) sandstone as the outcrop of the latter winds in and out arou
the Chuar series (Ch) are beautifully exposed on the west side of the Grand Canyon in the Canyon Valley
gressing Middle Cambrian seas covered them with its beach sands.

The line of unconformity (Ac) at the base of the Cambrian (T = Tapeats sandstone) cuts across thou
The locality is on the north and west sides of the Grand Canyon of the Colorado River, Arizona, opp

etamorphosed strata in the world. Fully 6,000 feet of the Unkar and Chuar series of formations are
ate 43, beneath the Cambrian. The red sandstones of the Unkar series (*Un*) stand out in strong relief
anyons and projecting headlands between them. To the north the sandstones, shales and limestones of
nd Nunkoweap. Everywhere erosion planed these formations down nearly to a level before the trans-

in thickness of the Algonkian (*Un* = Unkar) series on which it rests.
'iew, and where the Colorado River flowing from the north bends to the westward.

Unconformable contact between the Cambrian (T = Tapeats sandstone) and the finest exposure [illegible] [illegible]tamorphosed strata in the world. Fully 6,000 feet of the Unkar and Chuar series of formations are exposed between the Archean as seen in plate 42 and the highest beds of the Algonkian shown on [illegible] plate 43, beneath the Cambrian. The red sandstones of the Unkar series (Un) stand out in strong relief beneath the cliffs of Cambrian (T = Tapeats) sandstone as the outcrop of the latter winds in and out [illegible] the canyons and projecting headlands between them. To the north the sandstones, shales and limestones of the Chuar series (Ch) are beautifully exposed on the west side of the Grand Canyon in the Canyon [illegible]ar and Nunkoweap. Everywhere erosion planed these formations down nearly to a level before the transgressing Middle Cambrian seas covered them with its beach sands.

The line of unconformity (Ac) at the base of the Cambrian (T = Tapeats sandstone) cuts across [illegible] feet in thickness of the Algonkian (Un = Unkar) series on which it rests.

The locality is on the north and west sides of the Grand Canyon of the Colorado River, Arizona, [illegible] and View, and where the Colorado River flowing from the north bends to the westward.

Cambrian and pre-Cambrian. This marked unconformity is the record of the advancing, overlapping Lower Cambrian sea of southwestern Nevada, the Middle Cambrian sea of Utah and Idaho, and finally the Upper Cambrian sea of Colorado and the interior continental area.

The Cambrian rocks may be abruptly conformable upon the Algonkian or Archaean,[1] or apparently conformable, as in areas where there has been very little disturbance of the subjacent Algonkian beds.[2] Over the interior of the continent the Upper Cambrian strata unconformably overlap the Algonkian and Archaean,[3] and there is here no record of any part of the Lower Cambrian period. I do not know of a case of proven conformity with transition deposition between Cambrian and pre-Cambrian Algonkian rocks on the North American continent. In all localities where the contact is sufficiently extensive, or where fossils have been found in the basal Cambrian beds or above the basal conglomerate and coarser sandstone, an unmistakable hiatus has been found to exist. Stated in another way, the pre-Cambrian land surface was formed of sedimentary, eruptive, and crystalline rocks, the deposition of which did not in any known instance immediately precede the Cambrian sediments. Everywhere there is a marked stratigraphic and time break between the known pre-Cambrian rocks and the Cambrian strata of the North American continent.[4]

The Lower Cambrian is characterized in southwestern Nevada by the presence of the Lower Cambrian[5] (Waucobian)[6] fauna, which there ranges through some 4,000 feet (1,220 m.) of strata that have no known line of demarcation at the base to separate the Cambrian from some pre-Cambrian Paleozoic formation. This leads to the hope that still older beds and faunas will be discovered in this region which will establish a base to the Cambrian not entirely founded on unconformable superposition of the Cambrian on pre-Cambrian formations.

In mentioning the pre-Cambrian surface I said:[7]

From the evidence afforded by the stratified rocks and their contained fossils, the first known sediments were deposited in a shallow marine basin that occupied an area now included in southwestern California and adjacent portions of Nevada. The incoming Cambrian sea encountered a land surface deeply disintegrated and more or less eroded nearly to base-level. Compared with the earlier epochs of Algonkian time it was a featureless surface, the elevations caused by folding and uplift in the geosynclines and the adjoining geanticlines of the Cordilleran, Lake Superior, and Appalachian areas of Algonkian time having been largely degraded. The rising waters met with only slight elevations in the Cordilleran trough, as evidenced by the almost entire absence of coarse conglomerates and the presence, above the coarse

[1] Tenth Ann. Rept., U. S. Geol. Surv., 1891, p. 551, fig. 48.

[2] Bull. Geol. Soc. America, Vol. 10, 1899, pp. 210-213.

[3] Tenth Ann. Rept., U. S. Geol. Surv., 1891, pl. 44, pp. 561-562.

[4] Twelfth Ann. Rept., U. S. Geol. Surv., 1892, pp. 546-557.

[5] Tenth Ann. Rept., U. S. Geol. Surv., 1891, pp. 515, 549.

[6] Smithsonian Misc. Coll., Vol. 57, 1912, p. 305.

[7] Problems of Geology, Yale Univ. Press, 1914, Chap. 4: The Cambrian and its Problems in the Cordilleran Region, p. 167.

basal sandstones and fine conglomerates, of deposits of very fine-grained sandstones and mud rocks.[1]

Absence of marine life in the Algonkian sedimentary rocks.—The almost total absence of a definite marine life in the unmetamorphosed limestones, shales, and sandstones of the Belt formations and all Algonkian formations does not apparently appeal to Rothpletz. With every physical condition favorable to the presence and flourishing existence of an abundant marine fauna there has not been in 30 years examination of these formations by many keen-eyed geologists and paleontologists an authentic reported find of a fauna unmistakably marine and allied to the Cambrian faunas. I reported a transient modified marine fauna from the Grayson shales[2] and traces of life in the Grand Canyon series.[3] Later, I recorded algal remains[4] and bacteria[5] from the Newland limestone of the Belt formations, but all of these seem to indicate fresh or brackish water life or a fragment of a marine fauna adjusted to fresh-water conditions. This taken in conjunction with the character of the Algonkian sedimentation seems to point to a non-marine epicontinental origin for the known Algonkian formations.[6]

Further, when speaking of "Pre-Cambrian Continental Conditions," I said:[7]

> The North American continent was larger at the beginning of known Cambrian time than at any subsequent period other than possibly at the end of the Paleozoic and the end of the Cretaceous, when the land was equally extensive. Indeed, it is highly probable that its area was greater then than even now, for no marine deposits containing pre-Cambrian life, as they were laid down in Lipalian[8] time immediately preceding the Cambrian period, have been discovered on the North American continent or elsewhere so far as known.

[1] Darton has described coarse conglomerates at the base of the Cambrian of the Black Hills, South Dakota, but this is in an early Upper Cambrian formation and far east from the Cordilleran region. It seems to be a local deposit. (Prof. Paper, U. S. Geol. Surv., No. 65, 1909, pp. 12, 13.)

[2] Bull. Geol. Soc. America, Vol. 10, 1899, pp. 235-238.

[3] Idem, p. 232.

[4] Smithsonian Misc. Coll., Vol. 64, No. 2, 1914.

[5] Proc. Nat. Acad. Sci., Vol. 1, p. 256, 1915.

[6] Problems of American Geology, Yale Univ. Press, 1914, Chap. 4: The Cambrian and its Problems, pp. 164-167.

[7] Problems of American Geology, Yale Univ. Press, 1914, Chap. 4: The Cambrian and its Problems, pp. 166-167.

[8] Smithsonian Misc. Coll., Vol. 57, 1910, p. 14 (footnote).

Lipalian (λειπα+αλs) was proposed for the era of unknown marine sedimentation between the adjustment of pelagic life to littoral conditions and the appearance of the Lower Cambrian fauna. It represents the period between the formation (beginning) of the Algonkian continents and the earliest encroachment of the Lower Cambrian sea.

PALEONTOLOGICAL EVIDENCE

The paleontological evidence given by Rothpletz in favor of the Lower Cambrian age of the "Capitol Creek shale" (= Park shale of Weed) is interesting. He tabulates it as follows:[1]

	Lower.	Middle.	Upper Cambrian.
1. *Protospongia* cf. *fenestrata*	×	×	
2. *Rustella edsoni* var. *pentagonalis*	×		
3. *Lingulella helena*		×	
4. *Obolella crassa*	×		
5. *Obolella atlantica*	×		
6. *Acrotreta* cf. *sagittalis*	×	×	×
7. *Kutorgina* cf. *perrugata*	×		
8. *Hyolithes* cf. *billingsi*	×	×	

By the above identification and interpretation of the fossils from the shale a strong case is made out for the Lower Cambrian age of the Park shale of Weed, or as Rothpletz states it: "We conclude that the fauna of the Capitol Creek shale is doubtless Lower Cambrian, but that it very possibly and indeed very probably belongs to an upper horizon of the Lower Cambrian."[2]

I wish I could agree with Rothpletz as to the Lower Cambrian age of the fossils he lists and illustrates, as it would be a great pleasure to me to know that the Lower Cambrian was unconformably superjacent to the Belt series of formations in this section of Montana as it is on the north side of the Bow River Valley in Alberta, Canada.[3] Such a condition would not alter in any way the position of the Helena limestone, which is far below in the pre-Cambrian Belt series.

Stratigraphically (ante p. 281) we have seen by the section of Weed at Mount Helena that the Park shale (= Capitol Creek shale of Rothpletz) is 1,100 feet (335 m.) or more above the base of the Middle Cambrian and 2,455 feet (755 m.) above the base of the Middle Cambrian on Beaver Creek, 20 miles (32 km.) northeast of Mount Helena. This makes it difficult to consider the fauna of the Park ("Capitol Creek") shale in the Lower Cambrian even though the fossils should appear to favor it. The Wolsey shale is 400 feet (123 m.) below the Park shale in the Mount Helena section, the interval being occupied by the Middle Cambrian Meagher limestone which Rothpletz by error identified as the lower portion of the pre-Cambrian Helena limestone. The fauna of the Wolsey shale zone

[1] Rothpletz, p. 41.

[2] Idem, p. 41.

[3] Smithsonian Misc. Coll., Vol. 53, 1910, pp. 426-427.

includes at a locality near Wolsey 11 miles (17.7 km.) south of Neihart in the Little Belt Mountains:

Micromitra pealei (Walcott)
Obolus (*Westonia*) *ella* (Hall and Whitfield)
Lingulella desiderata (Walcott)
Scenella sp. undt.
Dorypyge ? quadriceps (Hall and Whitfield)
Alokistocare ? labrosum Walcott
Asaphiscus calenus Walcott

Six miles (9.6 km.) northwest of Neihart I found at the same horizon:

Micromitra pealei (Walcott)
Obolus tetonensis Walcott
Scenella sp. undt.

Below Sixteen Post Office, in Sixteen Mile Canyon, Meagher County, Montana (Locality 159f):

Alokistocare pomona Walcott
Dolichometopus bessus Walcott

Five miles (8 km.) east-northeast of Logan, and 1 mile (1.6 km.) north of junction of East and West Gallatin Rivers, Gallatin County, Montana:

Obolus (*Westonia*) *ella* (Hall and Whitfield)
Acrocephalites ? majus Walcott
Asaphiscus camma Walcott

The above Wolsey shale fauna is far below the Capitol Creek (Park) shale and above the Flathead quartzite.

When making my examinations about Helena in 1898, the results of which were published in 1899,[1] I found abundant fossil remains in a hard, dark, finely arenaceous or siliceous shale (= Park shale of Weed) on the southeastern slope of Mount Helena about 200 feet (60 m.) above the road in the canyon of Grizzly Gulch which extends down into the southwestern suburb of the city. I followed these shales to the southeast and found similar fossils 2 miles (3.2 km.) southeast of the city (about one-half mile southeast of the suburb of Lenox) at a locality near one to which my attention had been called by Mr. Griswold. The fossils include at both localities:

Obolus (*Westonia*) *ella* (Hall and Whitfield)
Lingulella helena (Walcott)
Hyolithes
Ptychoparia

[1] Geol. Soc. of America, Vol. 10, Pre-Cambrian Fossiliferous Formations.

All of the specimens in the shale are more or less flattened by compression and usually more or less distorted. Frequently the distortion of the brachiopods takes the forms shown by Rothpletz, plate 2, figures 4 to 12; plate 3, figures 3 and 5. When the dorsal valves of *Lingulella helena* are shortened by pressure they are apt to arch up and curve down rapidly on the posterior side; the usually rounded postero-lateral margins also assume a more angular outline.

DETERMINATION OF GENERA AND SPECIES BY ROTHPLETZ, AND NOTES BY WALCOTT

1. Prostospongia cf. *fenestrata* Salter (pl. 2, figs. 2-7, of Rothpletz.)

This form of sponge spicule is met with in both the Lower and Middle Cambrian formations. It is particularly abundant in the shales of the Middle Cambrian. Specific and even generic determination is very difficult.

2. Rustella edsoni var. *pentagonalis* Rothpletz (pl. 1, fig. 10, of Rothpletz).

This is evidently a dorsal valve of *Obolus* (*Westonia*) *ella,* which preserves the concentric striation so characteristic of that species when the outer surface has been removed by clinging to the matrix. *Rustella edsoni,* with which it is identified, has been found only in association with *Olenellus* on Lake Champlain, Vermont, and near York, Pennsylvania, on the eastern side of the continent. *Obolus* (*Westonia*) *ella* is a common form in the Park shale on Mount Helena, and I am surprised that Rothpletz did not find it there and also more abundantly where he collected the fauna southeast of Helena.

For comparison I am illustrating (pl. 44, figs. 6, 7, 8, and 9) dorsal valves of *O.* (*W.*) *ella* from the Park shale on the southeast slope of Mount Helena, also ventral valves which have been shortened and broadened a little by compression. *Obolus* (*Westonia*) *ella* occurs in passage beds between the Lower and Middle Cambrian.[1] It is most abundant in the Middle Cambrian, and rarely if not doubtfully present in the Upper Cambrian.

3. Lingulella helena (Walcott) (pl. 2, figs. 1 and 2, of Rothpletz).

This is very abundant in the Park shale on the southeast slope of Mount Helena, also in the same band of shales where outcrops occur

[1] The stratigraphic position of the beds containing this fauna in northern Montana is open to discussion. I have long considered them as doubtfully Lower Cambrian or Middle Cambrian. They may be claimed for either until more detailed studies are made at the typical localities where they occur.

southeast of the city of Helena. In the vicinity of the faults that cut the shale the specimens are apt to be more distorted than from the shales on Mount Helena. Rothpletz gives an excellent petrographic description of the shale. In speaking of the subsequent alteration of the shales he says, " Simultaneously with the origin of the compression-bedding there occurred an inner movement in the entire rock mass, which led in places to distortion, elsewhere to compression. On this account the nearly circular fossil shells frequently retain a lengthened form, and this is one of the difficult conditions in the determination of the fossils." [1]

The ventral valves of *L. helena* illustrated by Rothpletz (pl. 2, figs. 1, 2) are normal in form and size, but he does not name and illustrate the dorsal valve except under other names. To me all of his figures 4 to 12, plate 2, and figures 3 and 5, plate 3, are in size and in such characters as are preserved, representatives of the dorsal valves of *L. helena* (see pl. 44, figs. 1-5 of this paper).

4. Obolella crassa (Hall) (pl. 2, figs. 4, 5, 7-12, of Rothpletz).

This is one of the greatest surprises of the Rothpletz determinations. The shells illustrated are small, the largest according to Rothpletz 5 to 7 mm. in diameter, and the shell is preserved as phosphate of lime. *Obolella crassa* is a species with the valves from two to three times the size of the shells figured by Rothpletz [2] and the valves are thick and built up of layers of carbonate of lime, although originally they may have been calcareo-corneous. All known specimens of *Obolella crassa* have been found in connection with the Lower Cambrian *Olenellus* fauna at localities on the eastern side of the North American continent.

To one acquainted with *Obolella crassa* as the species occurs in the limestones of the Straits of Belle Isle, Labrador, and the St. Lawrence River province, it seems impossible to consider the distorted Park shale specimens as even superficially related to *Obolella crassa* or even to the genus *Obolella*.

The Rothpletz figures referred to *Obolella* appear to illustrate more or less distorted dorsal valves of *L. helena*.

5. Obolella atlantica Walcott (pl. 2, figs. 3 and 6, of Rothpletz).

Figure 3 appears to represent a fragment of ventral valve of *Lingulella helena,* and figure 6 a distorted dorsal valve.

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[1] Rothpletz, p. 27, middle of last paragraph, going over to p. 28.

[2] Monogr. U. S. Geol. Surv., Vol. 51, 1912, pl. 54.

6. *Acrotreta* cf. *sagittalis* (Salter) (pl. 3, fig. 10, of Rothpletz).

This is a Middle Cambrian and Upper Cambrian species of Europe and a Middle Cambrian species in the Atlantic Coast provinces of North America. The specimen figured by Rothpletz is a compressed ventral valve and is much more likely to be *Acrotreta depressa* (Walcott) [1] of the Middle Cambrian of the Rocky Mountains.

7. *Kutorgina* cf. *perrugata* Walcott (pl. 3, fig. 1, of Rothpletz).

This is a figure of an undeterminable fragment of a large brachiopod.

8. *Hyolithes* cf. *billingsi* Walcott (pl. 3, figs. 2 and 4, of Rothpletz).

This is a very common form of *Hyolithes* and is abundant in the Park and Wolsey shales at Helena and elsewhere.

The fragments of trilobites figured by Rothpletz on plate 3 have no special significance except that they are of Cambrian age.

COMMENT ON PALEONTOLOGICAL EVIDENCE

Rothpletz does not seem to have established a strong case for the Lower Cambrian age of the Park shale fauna. There does not appear to be the slightest foundation for assuming that because there are some superficial resemblances in form between the distorted shells in the shale and the various species with which he has identified them, the fauna is, therefore, of Lower Cambrian age. The fossils are unlike the Lower Cambrian species with which they have been identified, and such a known association of species does not occur at any one locality and zone anywhere in the world.

The impression made upon me is that Rothpletz once having been misled by his interpretation of the stratigraphy was unconsciously influenced to determine his fossils as of Lower Cambrian age. The purpose for which he went to Helena, that is, to discover pre-Cambrian fossils in the Belt formations,[2] would have been served by Middle Cambrian fossils quite as well, provided they came from what had previously been identified as a pre-Cambrian formation. The discovery of fossils in a Middle Cambrian shale at Helena in which they had previously been found is evidently not what Rothpletz thought he was doing either in the field or in the laboratory.

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[1] Monogr. U. S. Geol. Surv., Vol. 51, 1912, pl. 66, figs. 8, 8*a-c*.

[2] Rothpletz, p. 8.

CONCLUSIONS

The conclusions of Rothpletz's reconnaissance in the vicinity of Helena, Montana, are essentially as stated below, followed by my own conclusions on the results announced by him, the numbering being the same for each set of conclusions.

1. (*Rothpletz*) That the upper limestone No. 6 of his section (p. 281) of Mount Helena is a part of the pre-Cambrian "Helena" limestone of Walcott.

1. (*Walcott*) The Rothpletz limestone No. 6 is the Middle Cambrian, Pilgrim limestone of Weed (p. 281).

2. (*Rothpletz*) That No. 5 of his section, the Capitol Creek shale (p. 281), is a bed of shale interbedded in the "Helena" limestone of Walcott.

2. (*Walcott*) The Rothpletz shale No. 5 is the Middle Cambrian, Park shale of Weed (p. 281) that carries a typical Middle Cambrian fauna at Helena and vicinity.

3. (*Rothpletz*) That No. 4 of his section (p. 281), the limestone beneath the Capitol Creek shale, is the lower portion of the Helena limestone of Walcott.

3. (*Walcott*) The Rothpletz limestone No. 4 is the Middle Cambrian, Meagher limestone of Weed (p. 281) which has been recognized around the Big Belt and Little Belt Mountains.

4. (*Rothpletz*) That No. 3 of his section (p. 281), the shales beneath the lower limestone, is the pre-Cambrian Empire shale of Walcott.

4. (*Walcott*) The Rothpletz shale No. 3 is the Middle Cambrian, Wolsey shale of Weed (p. 281) which carries a typical Middle Cambrian fauna.

5. (*Rothpletz*) That No. 2 of his section (p. 281), the brownish weathering quartzite beneath the Empire shale of Conclusion *4*, may be the upper part of No. 1 (=pre-Cambrian Spokane shale of Walcott). He qualifies this by saying, "A comparison for No. 2 with the Lower Cambrian Flathead quartzite would be nearer."

5. (*Walcott*) The Rothpletz quartzite No. 2 is the Middle Cambrian basal Flathead quartzite of Weed (p. 281) that is superjacent to the Belt formations about Helena, the Spokane Hills, and around the Big Belt, Little Belt and in the Big Snowy Mountains.

6. (*Rothpletz*) That No. 1 of his section (p. 281), the green and gray argillaceous shale, occupies the position of the Spokane shale of Walcott.

6. (*Walcott*) The Rothpletz shales No. 1 are the shales above the pre-Cambrian, Helena limestone and beneath the Cambrian Flathead quartzite, and occupy the position of the Marsh shale as it occurs elsewhere.

7. (*Rothpletz*) That the fauna of the Capitol Creek shale No. 5 of his section is of Lower Cambrian age (p. 291).

7. (*Walcott*) The Rothpletz "*Lower*" Cambrian fauna of his shale No. 5 (= Middle Cambrian Park shale of Weed) is the usual Middle Cambrian fauna characteristic of the Park shale on Mount Helena and southeast of the city of Helena (pp. 268, 292).

8. (*Rothpletz*) That having found a "*Lower*" Cambrian fauna in the shale of No. 5 and concluded that this shale was interbedded between 4 and 6 in the pre-Cambrian, Helena limestone of Walcott, it followed that the Helena limestone was of Cambrian age and along with it the conformably subjacent Empire and Spokane shales and presumably all of the Belt formations of Walcott.

8. (*Walcott*) The Rothpletz identification of the Middle Cambrian Pilgrim and Meagher limestones on Mount Helena and southeast of the city of Helena as the pre-Cambrian Helena limestone of Walcott is incorrect, and further it was the main source of the Rothpletz series of errors in connection with the stratigraphic position and age of the Cambrian and pre-Cambrian formations about the city of Helena.

9. (*Rothpletz*) That not having observed an unconformity at Helena beneath the Cambrian as stated by Walcott, such an unconformity probably did not exist.

9. (*Walcott*) The Rothpletz failure to find any evidence of an unconformity at the base of the Cambrian is most natural as he unknowingly identified the Cambrian limestones as the pre-Cambrian Helena limestone and hence did not recognize and probably did not see at all the Helena limestone which is beneath the unconformity.

10. (*Rothpletz*) That in the absence of an unconformity at the base of the Cambrian (at Helena) and the absence of a distinctive pre-Cambrian fauna all of the so-called North American pre-Cambrian sedimentary formations of the Belt series were probably of Cambrian age.

10. (*Walcott*) The evidence both direct and by deduction sustains the view of a long pre-Cambrian interval of erosion resulting in a marked unconformity. The Algonkian in America consists of a great series of epicontinental formations between the Archean and Cambrian. The Rothpletz view of considering all of the pre-Cambrian sedimentary formations of North America corresponding to the Belt series as of probable Cambrian age is without evidence to support it.

Some general conclusions.—(*Walcott*) It is unfortunate that my respected colleague in preparing his memoir should have failed to fully examine literature on the subject available in the libraries of Munich or to secure fuller information and maps from official sources in this country. A request on his part for information as to what had been published on the Helena district, sent either to the Director of the U. S. Geological Survey or to me in the winter of 1913-1914, or while he was at my camp on Burgess Pass, British Columbia, would have informed him of the geologic map of the Helena District and descriptions contained in Bulletin 527 of the Survey.

In final conclusion let me add that there is a great amount of work yet to be done on the pre-Cambrian sedimentary rocks of the North American continent. Those of the Lake Superior region are largely well mapped and described, as are portions of those of the Appalachian region, central Texas, southwestern Colorado, and northern Arizona, but large areas in Montana and northward in Alberta and British Columbia remain to be studied, mapped, and described. New discoveries will be made and older views changed, but in the light of our present information I think we are forced to accept the evidence that the Algonkian formations of North America are of pre-Cambian age; of continental origin, and formed of terrigenous deposits that accumulated on river flood-plains and other favorable areas, or deposited in epicontinental, brackish-water seas or fresh-water lakes that filled depressions within the area of the Cordilleran and Appalachian geosynclines [1] and the Lake Superior region.

[1] Problems of Geology, Yale Univ. Press, 1914, Chap. 4: The Cambrian and its Problems, p. 165.

DESCRIPTION OF PLATE 44

PAGE

Lingulella helena (Walcott) ....

FIG. 1. (× 5.) Exterior of a slightly distorted ventral valve from locality **302s**, Middle Cambrian: Park (siliceous) shale, 1.5 miles southwest of Helena, Lewis and Clark County, Montana. U. S. National Museum, Catalogue No. 27320a.

2. (× 5.) Cast of the interior of a dorsal valve showing area, from the locality represented by fig. 1. U. S. National Museum, Catalogue No. 27320d.

Figs. 1 and 2 are the originals of figs. 3 and 3c of Plate 24, Monogr. 51, U. S. Geol. Survey, 1912.

3 and 4. (× 5.) Somewhat distorted dorsal valves associated with typical ventral and dorsal valves such as those represented by figs. 1 and 2. U. S. National Museum, Catalogue Nos. 62545 and 62546.

The specimens represented by figs. 3 and 4 are from the same shale and locality as those represented by figs. 1 and 2.

5. (× 6.) A small distorted dorsal valve. U. S. National Museum, Catalogue No. 62547.

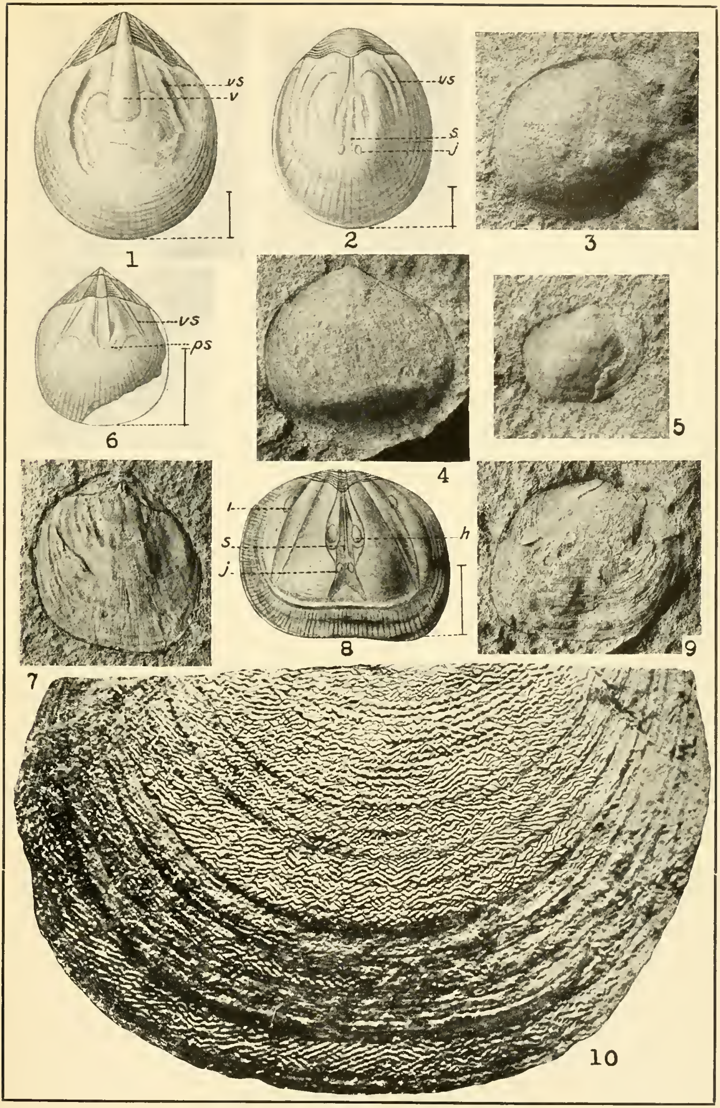
The specimen represented by fig. 5 is from locality **4u**, Middle Cambrian: Park shale, on the northwest side of Grizzly Gulch about one-half mile southwest of the city of Helena, Montana.

Obolus (*Westonia*) *ella* (Hall and Whitfield) ....

FIG. 6. (× 2.) Impression of the interior of a ventral valve from locality **302s**, Middle Cambrian Park shale in Grizzly Gulch, southwest of Helena, Montana. U. S. National Museum, Catalogue No. 51686a. Specimen figured by Walcott, fig. 1*g*, Plate 47, Monogr. 51, U. S. Geol. Survey, 1912.

7. (× 2.) Slightly compressed and distorted ventral valve. U. S. National Museum, Catalogue No. 62548.

8. (× 2.) Impression of the interior of a slightly distorted dorsal valve from the same locality as specimen represented by fig. 6, showing the characteristic muscular impressions. U. S. National Museum, Catalogue No. 51686b. Specimen figured by Walcott, fig. 1*k*, Plate 47, Monogr. 51, U. S. Geol. Survey, 1912.



BRACHIOPODA FROM PARK SHALE OF MIDDLE CAMBRIAN

Obolus (*Westonia*) *ella* (Hall and Whitfield)—Continued. PAGE

FIG. 9. (× 2.) A distorted dorsal valve associated with the specimen represented by fig. 7, U. S. National Museum, Catalogue No. 62549.

Figs. 7, 8 and 9 are from the Middle Cambrian: (**302s**) Park shale, on northwest side of Grizzly Gulch, about 1.5 miles southwest of the city of Helena.

10. (× 10.) Enlargement by photography of the surface of a specimen preserved in a shale where the exterior surface does not adhere to the matrix. Where the surface clings to the matrix, the specimens have the appearance of those illustrated by figs. 7 and 9.

Fig. 10 is of a specimen from locality **4g**, Middle Cambrian: about 325 feet (99.1 m.) above the base of the Cambrian, in the Flathead shales of Peale, 1 mile (1.6 km.) north of the junction of East and West Gallatin Rivers, Gallatin County, Montana.

U. S. National Museum, Catalogue No. 51685c. Specimen figured by Walcott, fig. 1 *o*, Plate 47, Monogr. 51, U. S. Geol. Surv., 1912.