CRETACEOUS COALS AND LIGNITES OF THE NORTHWEST.

BITUMINOUS COALS AND LIGNITES OF THE NORTHWEST. b

By R. Pumpelly.

When the Northern Transcontinental Survey was organized in 1881 the question as to the existence of good steam-coal accessible to the Northern Pacific system of roads was of the first importance for the railroads and for the development of the mining and other industries of the Northwestern Territories.

A vast amount of lignite was known and in places worked and used by the locomotives, but it was recognized as of low heating power, and coal was brought from Pittsburgh to mix with it. True bituminous coal was known c to exist at two or three points, viz, the Chesnut mine, near the Bozeman cañon; on the summit of Mullen's pass, near Helena—both in Montana; and on Puget sound, notably at Wilkinson and Carbonado, on the western flank of the Cascade mountains, in Washington territory. Taking these as clues, the survey, represented by Mr. Eldridge and Mr. J. E. Wolff in Montana and Mr. Willis in Washington territory, discovered and explored, under cover, the extensions of these two fields. In the Bozeman district the outcropping of the two or three seams of bituminous coal was traced and opened along a distance of several miles, while in the Puget Sound region a large number of seams were explored under great difficulties, along a distance of 24 miles south of Wilkeson, through the dense forest of the Cascade mountains. In the broad area drained by the upper Columbia river, which was explored for the purpose by Mr. Bayard T. Putnam, no bituminous coal of any value was found, although beds of lignite attest the coal-bearing character of the Cretaceous. The great development of the bituminous coal north of the 45th parallel d is on the western flank of the Cascade, and on the eastern flank of the Rocky mountains. In my personal exploration of the mountains and adjoining plains between the 45th and 49th parallel I was able to define proximately the position of the line of outcrop the coal for several hundred miles from the Teton river south, via the Dearborn and Sun rivers, around the north end of the Big Belt mountains to the Highwood mountains, and through the Judith country. The result of this exploration and subsequent more careful examination at various points by Mr. Eldridge and his assistants went to show that, with all this immense extent of outcrop and correspondingly great area of coal-seams, it was only occasionally that the coal was at the same time of desirable quality and in workable quantities. The great plains are for hundreds of miles away from the mountains underlaid by lignite seams, often attaining a thickness of 7 and 8 feet, and in places much more, of almost clear lignite. As we approach the mountains the lignite disappears as a rule, and, under the action of some cause, apparently, as our results seem to show, by the e pressure of the enormously thickened overlying cretaceous shales, together with the higher temperature to which they were formerly thereby subjected, aided perhaps by the pressure of plication, the fuel has parted largely with its water and oxygen, and become a true bituminous and quite generally a coking coal. But, together with this change in the chemical character of the coal, there comes also a less desirable change in the structure of the beds. The lignite seams, as at Little Missouri, on Sunday creek, near Miles City and on Bull mountain, are, as a rule, nearly clear fuel, with very little bone or slate partings, and have, consequently, a very low ash percentage. On the other hand, the bituminous seams lie near the mountains, where the much coarser character of the sediment and the great thickening of the formation indicate deposition under less favorable conditions, and we consequently find that, with a less thickness of coal-seams, there is very generally combined a high ash percentage, due to the presence of frequent partings of bone and slate or sandstone. f

The differential sampling carried out by the Northern Transcontinental Survey in many hundreds of explorations made well under cover in the unweathered coal represented several hundred miles of outcrop. The samples taken in a uniformly systematic manner were all analyzed, and taken in connection with the measured cross-sections of the seams, they form a very full exhibit of the character of the seams and of their economic value. As will be seen from Mr. Eldridge's report, the seams not infrequently attain a thickness of 6 to 10 feet, but the cross-sections rarely show more than from 18 inches to 2 feet of clean coal without partings. Although a bed may have an aggregate of from 4 to 6 feet of clean fuel, it will generally contain enough bone or slate partings to render the coal quite dirty. In addition to this comes the fact that as a rule the ash percentage of the *clean* coal, which is very low in some of the Wyoming coals, is quite high here, reaching 6 and 8 per cent., which makes it necessary to mine much cleaner than would otherwise be needful, and also renders it much more difficult to clean by washing. Still, where a the distance from better coal is so great, a coal having a considerable ash percentage—12 to 16 per cent.—may be profitably used. But at three points very good coking coal in workable quantity was discovered, with a fairly low ash percentage, which last with care in mining could be reduced still lower. One of these was in the Bozeman field on Sec. 24, T. 2, R. 7 E. The extensive explorations of the Bozeman field are described by Mr. Eldridge. Another will be found described in Mr. Wolff's report on the coal of Rock Creek on the Crow reservation. The third is at a point in the Judith basin. Besides these there were found many points where 2 to 2½ feet of clean coal exists free from partings; and at many other points an aggregate of 3 to 4 feet of clean coking coal can be saved by exceptional care in mining and hand-picking.

In the Wilkeson-Nisqually field of Washington territory there is a vastly greater aggregate thickness of coal than in the Montana column, but it also is apt to be injured by partings of "bone". Still Mr. Willis's exploration b of the country south of Wilkeson discovered workable thicknesses of excellent coking coal, and notwithstanding the cheapness of coal imported to the Pacific coast as ballast, it is probable that exceptional care in mining and in hand-picking will in time lay the basis of an extensive mining industry in this field also.

The extensive explorations of the Northern Transcontinental Survey showed that in the great belt formed by Montana, Washington, and northern Idaho the bituminous coals are practically confined to the eastern flanks and outliers of the Rocky mountains and to the western flanks of the Cascades. The few occurrences of bituminous coal found between the two great ranges are of insignificant character. The deposition of the coal-making matter took place on an immense scale in the Puget Sound region, as is shown by the great number of seams of coal.

The bituminous coal-fields of Montana contain but few seams, and these are apt to vary within short distances c in the quality of their fuel. Whether these bituminous coals extend with the Lower Cretaceous beds eastward under the Laramie of the plains is a question more of scientific than of practical interest. The region in which they exist sufficiently near the surface to admit of mining is in the neighborhood of the Rocky mountains and their outliers. This is also the region where fuel may be most needed for metallurgical purposes and for locomotives on the higher grades of the mountains. The time may come when the great thickness of bituminous shales will be of proportionate economic importance for distillation.

While the area of available bituminous coal is limited, the extent of the lignites is very great, probably coextensive with the Upper Laramie. The larger part of the great plains is apparently underlaid by seams of lignite often presenting a thickness of several feet of fuel very low in ash.

These seams are often exposed in the valleys, and over large areas lie at moderate depth from the surface.

d While these lignites are very inferior for railroad use they will be of the greatest value for domestic purposes and for agricultural steam-power, local manufactories, etc., and when the pressure of population shall require it, the extensive and cheaply-mined seams on the Missouri river may furnish the power to pump water for the irrigation of large areas.

Each of the greater subdivisions of the Cretaceous, viz, the Dakota, Colorado, and Laramie, bears coal or lignite in some part of Montana.

Along the eastern and northern flanks of the Belt range in the Judith basin, on Belt creek and Sand coulée and Deep creek, etc., there is only one known coal-bearing horizon, and this is apparently of Dakota age.

In the sections covering thousands of feet of Cretaceous along the lower cañon of the Yellowstone and at the Bozeman coal-field south of Muir coal occurs at only one horizon—about 3,700 feet above the Jurassic and some e distance above fossils considered by Mr. Whitfield to be of Benton or Niobrara age, and yet so low in the great Cretaceous column as to be apparently below the Laramie. As we recede from the mountains on to the plains we find coal in younger horizons in the Lower Laramie. Where the Upper Laramie has been preserved in high ridges of horizontal strata, as at Bull mountain or farther eastward, where it forms the general substructure of the plains, this horizon bears seams of lignite often of imposing thickness and remarkable purity. We have, as yet, no means of knowing whether the Dakota and Colorado groups are also coal-bearing under the great plains.

But nowhere in this field east of the Cordilleras do we find the Cretaceous marked by the enormous deposition of carbonaceous matter that characterizes it on the western side in the Puget Sound region. Here Mr. Willis' test-pits, sunk for the Northern Transcontinental Survey, exposed more than 700 cross-sections of coal-seams in the Wilkeson coal-field alone, representing over 125 separate seams, in a total known thickness of 3,000 feet, underlying f 10,000 feet of barren strata. Although only 17 of these seams were of workable thickness, 3 to 15 feet thick, a vast aggregate of carbonaceous matter is represented.

The occurrence of these Cretaceous coals and lignites over such extensive areas and under such varied physical conditions should lend a promise of light on the obscure causes that have resulted in the lignitic character of the beds in some regions and their bituminous character in others. Little special attention was given to this question. In Washington territory Mr. Willis' explorations showed that the bituminous coals all occupy flexed areas, while the lignites have been but slightly disturbed. This is an observation which was long ago made with reference to the occurrence of anthracite in the highly-flexed folds of the Appalachians and bituminous coals under less disturbed areas. But in Montana coking coals underly the broad plains north and east of the Belt mountains in a practically horizontal position. Indeed, in so far as any present inference can be drawn from our present

data, it would seem to be that height of superincumbent strata, through the consequent pressure and higher a
temperature, is the most important factor if we exclude possible original differences of the plant matter itself. And this view appears to be held by Mr. Dawson as sufficient to explain the differences in the coals of British Columbia.

Wherever we find the lignites they belong to younger horizons than the bituminous coals. This is the case in the Green River field of Washington territory and on the plains of Dakota and Montana.

The lignites east of the mountains belong mostly in the Upper Laramie. Some beds occur in the Lower Laramie near the top, *i. e.*, in the upper two or three thousand feet—the upper third of the Laramie. The coals north and east of the Belt mountains are of Dakota age, and they have been formerly covered by the vast thickness of the Colorado and Laramie beds that have been since swept away—a thickness of not less than 9,000 feet. The b
Bozeman coking coals, whether they belong to the Colorado or to the Lower Laramie, dip at a high angle under more than 10,000 feet of younger beds.

Mr. Willis' section (Plate LXXXI) shows that the Green River lignites occupy the upper part of the column, the bituminous lignite coming lower down. The 14,000 feet of Coal Measures in the Wilkeson field show no true lignites, though, as stated farther along, more lignitic beds occur near the top; but we know nothing of the thousands of feet of younger strata that may have been removed.

The capacity of lignites, and to a greater or less degree of other coals also, for absorbing moisture from the air was found to influence materially the economic value of analyses, made in the varying climate of the seaboard, of coals mined in the extremely dry plains of Montana.

For this reason, as is stated on page 775, water was determined in each sample, both after 48 hours drying over sulphuric acid and again after a similar exposure to a water-saturated atmosphere. An inspection of the c
tables brings into prominence at once the strongly hygroscopic character of the lignites; but it also appears to show that much of the large percentage of water contained in lignites may, in some instances, be simply absorbed moisture. But after making allowances on this score, it will still be found that the samples, after air-drying over sulphuric acid, contain more or less water according as they are more or less lignitic.

It must be borne in mind that samples from the exposed outcrop of a coal seam contain much more water, accompanying an oxidation of the coal. Thus, the writer took two samples across the whole thickness, 12 feet, of the great seam at Elk Garden, West Virginia: A, from the interior of the mine; B, from the weathered outcrop. The following analyses of these samples, made by Dr. Gooch, show the gain in water as well as in volatile combustible compounds and ash, and the deterioration of the coal by oxidation:

d

	A.	B.
	Per cent.	*Per cent.*
Water	0.19	5.62
Volatile combustible matter	19.98	27.28
Fixed carbon	71.77	54.56
Ash	8.06	12.54
Total	100.00	100.00
Sulphur	1.045	0.800

e

The following table shows the averages of water contained after drying in the manner indicated, in the samples of the different fields. These fields are here arranged in the order of diminishing average percentages of water in the samples. They are also arranged in the order of increasing value of the fuel. (*a*)

f

	Averages.	Water after drying 48 hours over sulphuric acid.	Carbon (by combustion analysis).
		Per cent.	*Per cent.*
Lignites of Dakota and eastern Montana (Miles city)		7.3	71.8
Lignites of Bull mountain, Montana	Average of 56 analyses, ranging from 2.6 to 10.4 water	5.0	73.8–76.0
Lignites of Green river, Washington territory	Average of 6 analyses	4.1	
Newcastle (Seattle) lignite	Average of 4 analyses	2.8	74.5–76.8
Bozeman coal	Average of 73 analyses	1.7	79.7–82.5
Green River coal	Average of 9 analyses	1.6	78.9–83.3
Wilkeson coal	Average of 69 analyses	0.78	80.3–93.4

a The quality of the Green River lignites has not yet been tested as compared with those of Bull mountain.

a I have added also a column showing the range of carbon for the samples subjected to combustion analyses for each field. In this column the carbon increases as the water diminishes, and an examination of the table of combustion analyses on page 790 shows that the range of percentage of oxygen and nitrogen increases with the water.

From our present knowledge we can say that the lignites belong in the younger and the bituminous coals in the older horizons of each field. The topographical and stratigraphical evidence goes to show that the bituminous coals have been covered by a thickness of many thousand feet. Thus in the Bozeman field the coal dips, as already stated, under a thickness of not less than 10,000 thousand feet of existing strata. In the Wilkeson field, on Puget sound, Mr. Willis' columnar section (Plate LXXXI) shows the bituminous coals—those which of all known northwestern Cretaceous coals are lowest in water and highest in carbon—to belong over 10,000 feet down in the column
b yet represented in that field, while the superincumbent covering must have formerly been materially greater. And it is interesting and to the point that the samples from seam CXXIII, represented near the top of the Wilkeson column, contain from 3.98 to 7.04 per cent. of water.

The analyses of the coals under the plains north and east of the Belt mountains show much irregularity in the amount of water. But those samples which were taken from well under cover in the small mines under the plains between the Belt mountains and the Missouri—on Belt creek, Sand coulée, etc.—range below 1 per cent. of water, and it is probable that the higher average of water in the Judith basin samples is due to the oxidation of the outcrops. Thus at Sand coulée the two samples taken from a mine contained 0.56 and 0.47 per cent. of water, while the two from near the surface of the same seam contained 4.02 and 4.84 per cent. The samples from the
c mines show the coal to be comparable, as regards water, with those of the Wilkeson field. As regards the indications of quality as shown by the proximate and combustion analyses, these almost horizontally-bedded coals range more nearly with those from the Bozeman field.

All the evidence is in favor of the influence of pressure, and of the conditions of temperature, etc., accompanying it, as the chief factor in producing broad distinctions between lignite and bituminous coals; and while within the area investigated by the Northern Transcontinental Survey we have found extensive fields that have been subjected to the combined pressure of superincumbent beds and of plication of the strata, and other wide areas where only pressure of overlying beds exists, the action of plication seems to be of secondary importance as regards this distinction.

While the influence of pressure, with the temperature and other conditions due to the corresponding depth,
d appears to determine the amount of water which cannot be removed by an absolutely dry atmosphere, it seems possible that the capacity of certain bituminous coals and anthracites for absorbing large amounts of water is often the result of a profound shattering of their texture, brought about by the shearing movement in folds of short radius, and in the crinkling of trough-ends.

Thus the anthracites of the highly-disturbed and pinched beds of the Rhode Island basin have as strong a capacity for absorbing water from the air as the most hygroscopic lignite from Dakota. A sample of this anthracite from the mine at Portsmouth, Rhode Island, after exposure for sixty-one hours over water, contained 16.91 per cent. of water, while after forty-eight hours exposure over sulphuric acid it contained only 0.53 per cent. A sample of Pennsylvania anthracite similarly treated varied less than 2 per cent., and one of Cumberland coal less than 1 per cent.

e Considering the coals and lignites as fuels, and taking into consideration all the means of forming an opinion, they would rank relatively to each other nearly in the order in which they are grouped in the table, the coals of the Wilkeson field being the best, and the eastern lignites, rich in water and oxygen, being very inferior fuel. As compared with the great standard coals of the world, even the Wilkeson coals are at some disadvantage, owing to their higher contents of ash. But in this respect the real difference is undoubtedly much less than appears from a comparison of the analyses; and this for the reason that while, as a rule, published analyses of coals have been made from picked specimens of the fuel, the analyses given in this volume are of samples taken either entirely across the seam or omitting only such portions as would self-evidently be rejected in mining. But while, with several exceptions, these coals are inferior for steam-making to the Cumberland and Clearfield coals, and to the product of the Pittsburgh seam for coke, they will be of inestimable value to the industries of the northwest.

f The following table showing the general character of the Cretaceous beds, including the Laramie, and the position of the seams of coal and lignite in the Wyoming-Utah belt (compiled from King's *U. S. Geological Exploration of the 40th Parallel*), in Montana (Northern Transcontinental Survey), and in southern British Columbia (compiled from Dr. G. M. Dawson's *Report on the Region of the Bow and Belly rivers*, *Canada Geological Survey*, 1885):

Fortieth Parallel.	Montana.	British Columbia.
LARAMIE.		
Coarse white and reddish sandstones, heavily bedded. Marine and brackish-water fossils. Large development of **coal-seams.** Thickness over 5,000 feet in the Green River Basin.	Upper Laramie.—A rapidly alternating succession of light-gray and grayish-green clays, white argillaceous sandstones, numerous thin **lignite** seams, and 10- to 30-foot benches of yellow massive sandstone containing rounded concretions of brown iron ore; abundant fossil leaves. Thickness, 1,500 feet or more at Bull mountain. Numerous, often large and valuable, seams of **lignite.** Lower Laramie.—A succession of white sandstone and green clay beds near the top, changing below to dark blackish and green clay beds, thin sandstone layers. A few thick sandstones and thin **lignite** seams. Thickness, 7,000 feet.	Porcupine Hills beds.—Sandstones frequently thick-bedded, generally comparatively soft, with intercalated grayish and blackish shales and shaly clays. Fresh water. 2,500 feet. Willow Creek beds.—Soft sandstones, shales, clays, and sandy clays generally with a pronounced reddish or purplish tint. Fresh water. 450 feet. Saint Mary River beds.—Sandstones, shales, and shaly clays in frequent alternations and generally well bedded. Fresh water except near base. Beds of **lignite** or **coal,** especially in lower part. 2,800 feet.
FOX HILLS.		
Coarse white sandstones, heavily bedded. Marine fossils. Thickness, 1,500 feet in the plains; 3,000 to 4,000 feet near the Wasatch mountains. Few **coal** seams; east of the mountains, only 1 seam; farther west, at Cooper creek and Rock creek, several considerable seams of value.	Heavy beds of white and yellow sandstone, forming bold escarpments. Thickness, about 400 feet. No coal observed.	In some parts of the district well-defined massive yellowish sandstone, but inconsstant and apparently often represented by a series of brackish-water transition beds between the Laramie and Pierre. 80 feet.
COLORADO.		
Mostly blue and yellow clays and marls, with thin sandstones, fossiliferous. Thickness, 800 to 1,000 feet east of the mountains; greatest thickness in Uintah and Wasatch, 2,000 feet. **Coal** frequent at all horizons in the Wasatch region, but wanting in the east.	Black, bluish, and lighter colored laminated shales, with arenaceous layers. Near the mountains these characteristics are lost in the prevailing uniformity of coarser textual deposits. Thickness not yet separately determinable near the mountains; on the North Moccasin mountain, 1,800 feet. The Bozeman **coals** possibly belong in the Upper or Fort Pierre beds.	Pierre Shales.—Neutral gray or brownish to nearly black shales include a zone of pale soft sandstone in the northeastern part of Bow and Belly River district, and frequent intercalations of harder sandstone near the mountains. Marine. 4-foot bed of **lignitic coal** or **lignite** (11 per cent. water) at summit of Pierre Bow river. Four or more seams at base of Pierre aggregate 7 to 10 inches coal (one seam 2 to 4½ feet) along Saint Mary and Belly rivers. Apparently the most important **coal** horizon. 750 feet. Belly River series.—Composed of an upper or "pale" and lower or "yellowish" portion, and consisting of alternations of sandstones, sandy clays, shales and clays, **coals.** 910 feet. Lower Dark shales.—Gray to nearly black shales, frequently with arenaceous shales. 800 feet.
DAKOTA.		
Sandstones and characteristic conglomerates. Thickness east of Colorado range, 200 to 300 feet. **Coal** in the Uintah mountains.	Chiefly coarse, at times conglomeratic, sandstones. Thickness, 860 feet on Belt creek. Coal flanking Belt mountains is of this age.	

RELATION OF THE COAL OF MONTANA TO THE OLDER ROCKS.

By W. M. Davis.

The following description of the geology of central Montana is based upon observations made during ten **a**
weeks of the summer of 1883, when employed by Mr. Raphael Pumpelly, director of the Northern Transcontinental Survey, to examine the series of rocks below the Cretaceous coal horizon, with special reference to the sequence and characters of the several formations that might aid in the discovery and determination of the coal-fields. The region examined is included between the lower cañon of the Yellowstone on the south, Fort Benton on the north, and Cadotte's pass over the main range on the west, a triangular area of 120 to 140 miles on a side. Of course, only a small part of the district could be studied. Mr. Waldemar Lindgren, assistant geologist, N. T. S., and Mr. F. S. Bunker, volunteer geologist, aided me in the work.

The rock series.—The rocks observed make a conformable series from the Lower Cambrian to the Upper Cretaceous, with a total maximum thickness of thirty to thirty-five thousand feet.

The Archæan was seen only in the neighborhood of Neihart, about the headwaters of Belt creek in the Little **b**
Belt mountains. It there consists of dark, reddish and gray gneiss, with folia generally at steep angles, cut by granitic eruptions that were not found to extend into the overlying bedded rocks. (*a*)

The Paleozoic series begins with a vast series of Lower Cambrian barren slates, at least ten to fifteen thousand feet thick at many points. In the Main range, at Cadotte's pass, red slates and calcareous layers are common; hard sandstones do not appear. In the Big Belt mountains and southward they are generally of a dull color, drab, bluish, greenish, becoming bright red and purple near the top, with calcareous beds in the middle and lower part, and some quartzite layers about the upper third. In the northern part of the Big Belt range, south of the cañon of Smith's river (Deep creek), heavy quartzite with some conglomerates appear. In the Little Belt range, about Neihart (and in the Lower Yellowstone cañon, according to Hayden, report for 1871, p. 53), this great division of **c**
the Paleozoic is seriously reduced and almost absent. A diabasic eruption is found at several places, with the upper members of these old slates.

The slates are capped by a hard sandstone or quartzite, 100 to 150 feet thick, persistent throughout the area examined, and of much service as a recognizable horizon in connection with the equally persistent, thin-bedded, trilobite limestones, 100 to 300 feet thick, that follow after an interval of shales. These limestones are clearly of Potsdam date.

Another interval of soft shales, seldom well exposed, comes next, and above it the great series of mountain limestones begins. This is often rich in fossils of Lower Carboniferous age, but Silurian and Devonian horizons are not yet established. The strata are mostly heavy bedded, with a small share of shales or shaly limestones, and near the top include two or three hundred feet of massive limestones, sometimes brecciated, but seldom showing **d**
distinct stratification, except in its larger forms, as in lines of bluffs or cliffs. The total thickness of the limestones is about 3,500 feet.

In the lower cañon of the Yellowstone the gate of the mountains is cut in a hard, yellow quartzite, 100 feet thick, that promised to serve well as a mark of the change from Paleozoic to Mesozoic formations, but except in the Bridger range it was not found again.

The great Mesozoic series of sandstones and shales, with very rare calcareous beds, that rises above the mountain limestones with a thickness of 15,000, or more, feet, is very imperfectly divisible, as its fossiliferous horizons are few and far between in the neighborhood of the mountains. The identification of red Triassic beds is

a The numerous outcrops of granitic or metamorphic rocks shown conformably beneath the Carboniferous in all the mountain **e**
centers on the map accompanying the geological report of the exploration of the Yellowstone and Missouri rivers by Dr. Hayden, in 1859–'60 (Washington, 1869), are essentially incorrect. The "Red beds" (Triassic) are also greatly exaggerated. According to the geological map of parts of Montana and Wyoming, issued by Dr. Hayden's survey in 1873, with which our results agree satisfactorily, so far as they cover the same ground, Archæan rocks are seen on the western flank of the Bridger range, in the fine Snowy range, east of the Yellowstone, and about the headwaters of the Gallatin and Madison rivers. On the general geological map accompanying Dr. Hayden's twelfth annual report, for 1878 (1883), all the mountainous area north of the Bridger range is extremely incorrect.

a very doubtful; Jurassic fossils occur 600 feet above the limestones; marine Cretaceous fossils are found at a height of 3,200 feet, and Cretaceous coal at 4,400 feet, as determined near the Yellowstone; while conformable sandstones and shales, with very rare and imperfect plant impressions, extend over 10,000 feet higher. Nothing can now be said as to the share of these indeterminate beds that belongs to the several divisions; nor can an upper limit be assigned to the Cretaceous. All the post-Carboniferous strata about the mountains appear to be Mesozoic, with the exception of the late Pliocene or Quaternary lake deposits in the upper valleys, and of certain strata capping the Crazy and Highwood mountains, at great altitude above the coal horizon, which may be early Tertiary, although there is no direct evidence to prove this.

The eruptive rocks, that occur in great variety in certain districts, have been determined and described by Mr. Lindgren; and the brief mention of them in my report is essentially quoted from Appendix B by him.

b The fossils, of which a list is appended, were determined by Professor R. P. Whitfield.

The entire Paleozoic and Mesozoic series is perfectly conformable throughout, although important members—Silurian, Devonian, Coal Measures, and Triassic—are not yet identified, and probably have no significant thickness. The lower strata rest unconformably on the Archæan gneiss; the relatively modern lake-beds unconformably overlie all the other formations. From this, we infer an Archæan land-surface long eroded; a submergence, with more or less active deposition throughout Paleozoic and Mesozoic time; a relatively active mountain growth about the end of the Cretaceous and the beginning of the Tertiary, accompanied and followed by heavy erosion; a second and minor disturbance about the end of the Tertiary, forming lake-basins in the upper valleys, and probably synchronous with the broad elevation that uplifted the plains. Intrusive and eruptive action seems chiefly to have accompanied the two periods of orogenic disturbance, though some was probably of earlier date.

c *Attitude of the coal.*—The horizon of the workable coals near the Muir tunnel, east of Bozeman, is without question lower than the Laramie formation to which the lignitic coals of the Rocky mountain region have generally been referred; for it underlies many thousand feet of strata that, in certain places, contain Cretaceous fossils, and overlies Jurassic fossils by only 3,700 feet. But in all the region close to the mountains the divisions that have elsewhere been made in the Cretaceous series can hardly be recognized; for the rocks are monotonous, of great thickness, and very poor in fossils, so that much more time than our party had must be given before they can be satisfactorily classified. It is otherwise, however, with the rocks below the coal with which we were especially concerned. The series as already described in brief culminates in the great group of mountain-making limestones, the only one of its kind in the region, and always of strong topographic importance where it rises to the surface; the heavy brecciated masses come near the upper limit of the group, and in the low country outside of the limestone
d ranges, and 4,000 to 5,000 feet (geologically) above them, the first coal horizon may be found. We can, therefore, say at once that the coal belongs north of the Yellowstone lower cañon, and not south of it; at the east foot of the Bridger range, not at the west; that it occupies several basins drained by Sixteen-Mile creek, all inclosed by limestone mountains; that it is quite absent from the Big Belt group, but comes in again in proper order north of the Little Belt. It is a much more difficult matter to determine the attitude of the coal where the Paleozoic rocks are not in sight, as about the Crazy mountains, where only the Cretaceous series or the "coal float" serves as a guide; and this being beyond the work assigned to us, we did not attempt it. After determining where the coal need not be looked for, and where search may be rewarded, there is still much work of closer exploration to be done to discover whether the coal horizon is here coal-bearing or not, and if so, whether the coal is of workable thickness and marketable quality. This was also beyond our province. It is not a little surprising to see that already
e in a territory so recently occupied as Montana, all of the coal horizons that we determined, and many more out of our field, have been discovered and examined by local prospectors or by members of the Northern Transcontinental Survey.

After this summarized statement of results, the greater part of our report must be taken up with descriptions of the more detailed observations on which they are based.

Measured sections.—Where the structure and outcrops were favorable and our time permitted, the rocks of the older series were measured by telemeter or aneroid barometer, and their fossils were collected with as much care as possible. The results of this work, already presented in summarized form, are now presented in more detail, and illustrated on Fig. 238, under the following headings:

f 1. The Yellowstone section; through the lower cañon and northward. Paleozoic and Mesozoic.
1 A. Section south of Muir. Lower Mesozoic.
2. Across the Bridger range at Flathead pass. Paleozoic and Lower Mesozoic.
3. Wall mountain to Deep creek, southern end of Big Belt range. Paleozoic.
4. Little Belt range, west of Barker. Paleozoic.
5. Little Belt range, north of Barker at head of Otter creek. Paleozoic.
6. Big Belt range, at Benton gulch. Lower Paleozoic.
7. Big Belt range, at Boulder creek. Lower Paleozoic.
8. Cadotte's pass, over the main range. Lower Paleozoic.

These measured sections are supplemented by structural sections of considerably greater length, on Fig. 239.

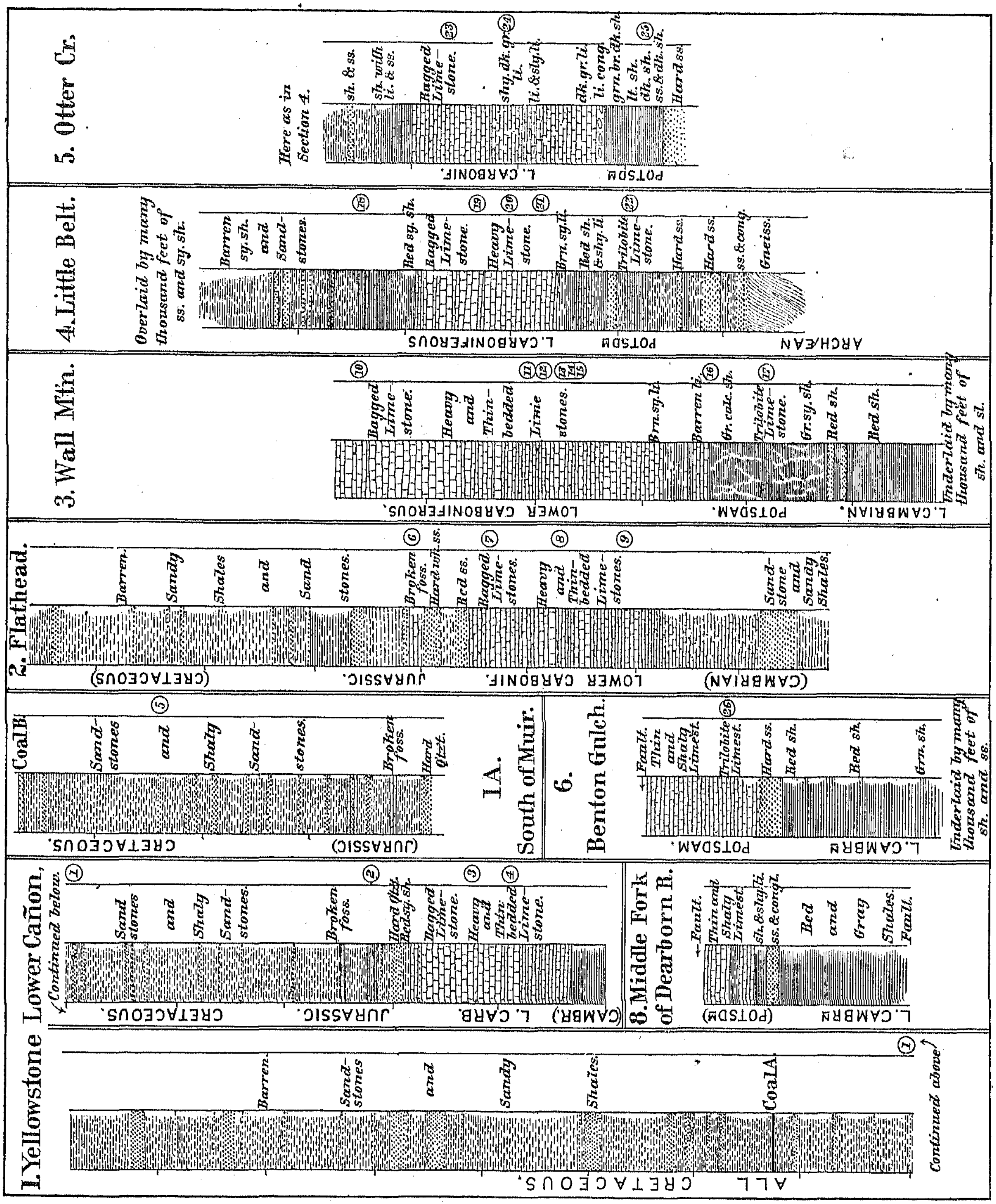

FIG. 238.

Explanatory note.—The descriptions of local sections are numbered to correspond with the structural and columnar sections on Figs. 238 and 239. Localities of fossils are designated by numbers in parentheses in the text and in circles on the plates. The ordinary conventional signs for slates or shales, sandy shales, sandstones, conglomerates and shaly or purer limestones are adopted on the plates, and are sufficiently explained on the columnar sections in abbreviated notes. The abbreviations there used are—brn., brown; calc., calcareous; cong., conglomerate; dk., dark; gr., gray; grn., green; li., limestone; lt., light; qtzt., quartzite; sh., shale; shy., shaly; sl., slate; sly., slaty; ss., sandstone; sy., sandy; vard., variegated; volc., volcanic; wh., white. The scale of the columnar sections is indicated by small marks on the left of the column for every thousand feet; on the structural sections, by small marks on the base-line for every mile; the construction is careful in the former, but in the latter is only approximate. Only the measured sections are given in columnar form; when the outcrops are imperfect the strata are not drawn across to the right of the column. The parts of the structural sections where the measures were made are indicated by a heavy profile line. All formations named on these sections that are not directly proved by our collections of fossils are inclosed in parentheses. No fault-planes were directly observed; they are simply placed where the surface outcrops demand them, and in absence of any evidence of their attitude they are drawn vertical.

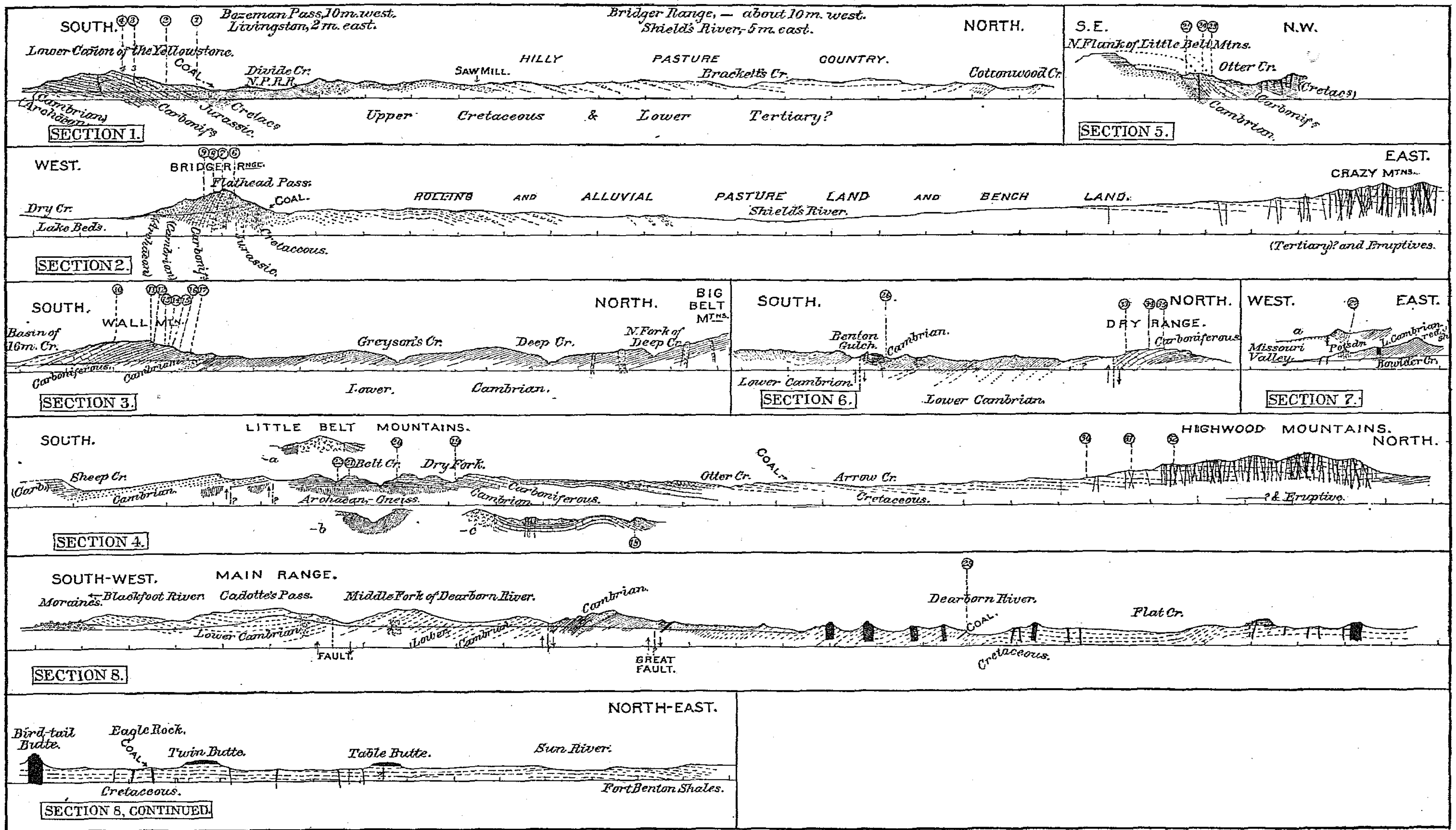
SOUTH.
Bozeman Pass, 10 m. west.
Livingston, 2 m. east.
Bridger Range, — about 10 m. west.
Shield's River, - 5 m. east.
NORTH.
Lower Cañon of the Yellowstone.
COAL.
Divide Cr.
N.P.R.R.
SAW MILL.
HILLY PASTURE COUNTRY.
Bracketts Cr.
Cottonwood Cr.
Cambrian
Archaean
Carbonifs
Jurassic.
Cretacs
Upper Cretaceous & Lower Tertiary?
SECTION 1.
S.E.
N.W.
N. Flank of Little Belt Mtns.
Otter Cr.
Cretacs
Cambrian.
Carbonifs
SECTION 5.
WEST.
BRIDGER RNGE.
Flathead Pass.
EAST.
CRAZY MTNS.
COAL.
ROLLING AND ALLUVIAL PASTURE LAND AND BENCH LAND.
Dry Cr.
Shield's River.
Lake Beds.
Archaean
Cambrian
Carbonif.
Jurassic.
Cretaceous.
(Tertiary)? and Eruptives.
SECTION 2.
SOUTH.
WALL MTN.
Basin of 16 m. Cr.
NORTH.
BIG BELT MTNS.
Greyson's Cr.
Deep Cr.
N. Fork of Deep Cr.
Carboniferous.
Cambrian.
Lower. Cambrian.
SECTION 3.
SOUTH.
NORTH.
DRY RANGE.
Benton Gulch.
Cambrian.
Carboniferous
Lower Cambrian
Lower Cambrian.
SECTION 6.
WEST.
EAST.
Missouri Valley.
Potsdm
L. Cambrian red sh
Bowlder Cr.
SECTION 7.
SOUTH.
LITTLE BELT MOUNTAINS.
HIGHWOOD MOUNTAINS.
NORTH.
Sheep Cr.
Belt Cr.
Dry Fork.
Otter Cr.
COAL.
Arrow Cr.
(Carb)
Cambrian.
Archaean, - Gneiss.
Cambrian
Carboniferous.
Cretaceous.
? & Eruptive.
SECTION 4.
SOUTH-WEST.
MAIN RANGE.
Moraines.
Blackfoot River
Cadotte's Pass.
Middle Fork of Dearborn River.
Cambrian.
Dearborn River.
COAL.
Flat Cr.
Lower Cambrian
Lower Cambrian
FAULT.
GREAT FAULT.
Cretaceous.
SECTION 8.
NORTH-EAST.
Bird-tail Butte.
Eagle Rock.
COAL.
Twin Butte.
Table Butte.
Sun River.
Cretaceous.
Fort Benton Shales.
SECTION 8, CONTINUED.

FIG. 239.

(1) *The Yellowstone section.*—The measures here were made northward across the strike of a great monoclinal, **a**
from the lower part of the heavy limestones, at the upper southern end of the lower cañon, along its western side, across the open country and the coal horizon near Livingston, and beyond the railroad to Fleischman's creek. The base of the limestone series was not found, and the lower measures are inaccurate from local distortion and change of strike; the upper part is more satisfactory. Fossils are rare in nearly all the horizons; enough were found to show the existence of Lower Carboniferous, Jurassic, and Cretaceous horizons, but the barren intervals are so broad that the limits and separate thickness of the several formations can not be given with any approach to accuracy. The 100-foot quartzite that makes the "Gate of the Mountains" may serve as a near indication of the change from the Paleozoic to the Mesozoic. Carboniferous spirifers (see list of fossils 3) occur about 700 feet below it, and heavy limestones are separated from it by only 100 feet of red sandy shales; above it, numerous Jurassic fossils (2) are **b**
found within 200 feet. The base of the limestones was observed by Dr. Hayden in the mountains east of the head of the cañon, where gneiss was found at the base of 1,500 or 2,000 feet of Carboniferous, and 100 or 200 feet of Cambrian sandstones, thus showing the essential absence of the lower slates elsewhere found in enormous thickness.(*a*)

North of the cañon the rocks are often covered; where visible they are sandstones, with a few conglomerates, sandy shales, and shales, often showing cross-bedding. A few imperfect Cretaceous fossils (1) were found 3,200 feet over the limestones. The important coal-bed explored by Mr. Eldridge, N. T. S., is 1,200 feet higher, and above this we measured 6,500 feet of barren sandstones and sandy shales to the southern margin of Fleshman's creek synclinal, and estimated at least 5,000 feet more, all in perfect conformity across the rolling country northward to the synclinal hills beyond Brackett's creek. There is no direct evidence as to the age of these upper **c**
rocks. They yielded only very rare and indeterminate plant remains.

(1 A) *Section south of Muir.*—While getting together my outfit at Mr. Eldridge's camp, 2 miles south of Muir (where the railroad tunnels under Bozeman pass), I employed some spare time in measuring the tilted strata, here well exposed from the coal horizons down to the quartzite that rises on the back of the limestones in the Bozeman mountains. The result is sufficiently shown in the columnar section. Coal B of this section has been determined by Mr. Eldridge to lie 10 to 15 feet under Coal A of section 1. It agrees satisfactorily with the section on the Yellowstone, from which it was distant 12 miles to the west. The fault shown in this district on Dr. Hayden's geological map of parts of Montana and Wyoming should be replaced by an anticlinal fold about an axis plunging steep to the northwest.

(2) *Section across the Bridger range at Flathead pass.*—The heavy Carboniferous limestones, which form the **d**
crest of the Bridger range, are here overthrown so as to dip 60° to 70° to the west; the pass is apparently determined by a small transverse fault, of which the limestones show indication by displacement. Our measures extended through 3,500 feet of sandy Mesozoic strata on the eastern slope, and through 3,000 feet of Paleozoic limestones and sandstones on the west. Imperfect Jurassic fossils (6) were found 500 feet from the heavy brecciated limestones; no Cretaceous fossils were discovered, but, judging from section 1, the coal horizon must run close along the eastern foot of the Bridger range. Heavy timber concealed many outcrops on the western slope, and the narrowness and numerous turns of the ravine leading down from the pass, as well as our limited time, prevented our securing accurate measures or a full series of fossils from the lower rocks. The limestones of the crest-line are the uppermost brecciated members of the series; Lower Carboniferous fossils were found 300, 900, and 1,550 feet below the uppermost limestone. Calcareous beds continue 1,000 feet lower down, and it was probably in some of these that **e**
Dr. Hayden's party found Cambrian fossils in 1872.(*b*) The limestones are succeeded by 1,000 or more feet of sandstones and sandy shales, strongly overturned, and generally buried under *détritus* in the foot-hills. Southward of the pass, on the western flank, Dr. Hayden records the occurrence of Archæan rocks. The valley of Dry creek, which flows south into the East Gallatin, is occupied by an arm of the broad lake-beds of the Bozeman-Gallatin basin.

The part of our structural section east of Shields' river is from notes by Mr. Wolff, N. T. S. The Crazy mountains are thus shown to be homologous with the Highwoods of section 4.(*c*)

(3) *Wall mountain to Deep creek, southern end of Big Belt range.*—The whole Paleozoic series, with the exception of its lowest part, is here exposed in unbroken sequence, giving one of our best sections. It shows a remarkable thickness of bedded rocks, begining with the estimated 12,000 feet of Lower Cambrian slates, extending upward **f**
through 4,500 feet of measured sandstones, shales, and heavy limestones, and culminating in Mesozoic rocks of

a *Geological Survey of Territories*, 1871, p. 53; 1872, p. 30, 30. See also Dr. Peale's account of this cañon, 1872, p. 171, and of the limestones in Rocky cañon, now followed by the railroad west of Muir tunnel, 1872, p. 109.

b See Report for 1872, pp. 74, 75, 84, 171, 172; the range is here called the Gallatin.

c Mr. J. E. Wolff, assistant geologist, N. T. S., spent the past summer (1883) in studying the coal outcrops around the Crazy mountains, and kindly allows me to quote the following general description of that outlying range: "The mountains consist chiefly of barren sandstones, slates, and shales, lying above the coal, and hence considered Upper Cretaceous and Lower Tertiary; they generally dip with small angle into the mountains, but about the northern end are more disturbed. At once, on passing from the surrounding open bench land to the mountain slopes, one meets with eruptive rocks in great profusion; the rocks are literally honeycombed with large and small dikes running in all directions. In places one can see grand displays of dikes in every attitude, cutting a thousand or two feet of horizontal sandstones and slates from bottom to top. The eruptives occur in great variety, and at least three periods of eruption can be recognized by intersections." This shows a close similarity between the Crazy and the Highwood mountains.

a 2,000 or 3,000 feet estimated thickness. The series is well exhibited in numerous and characteristic outcrops, and is perfectly conformable throughout. The oldest slates, cut by broad granitic dikes, form Bald Peak and its neighbors of the Big Belt range east of Townsend; the beds here are chiefly fine gray, bluish, or greenish slates, well indurated. The middle members of the series are gray or bluish, and form high grassy hills with patches of timber south of Deep creek. Near the upper third a number of hard sandstone beds appear. The upper members become shaly, and at last, after about 1,000 feet of dark purplish beds, our telemeter measures began on an equal thickness of red slaty shales, which bring us to the hard sandstone and fine conglomerate ridge encircling the northern flank of Wall mountain. From this point upward there is the normal fossiliferous series, but with unusual thickness. The Potsdam seems to have a greater thickness than determined elsewhere from the fossils (16) found **b** 500 feet above the ordinary trilobite limestone (17), but the former may belong higher in the series. It is to be hoped that a more persistent search would discover fossils in the next succeeding limestones, for 1,300 feet higher our specimens (15) are pronounced by Professor Whitfield to have a decidedly Devonian aspect. The succeeding 2,000 feet of limestones, mostly heavy bedded and brecciated near the top, are proved to be Lower Carboniferous. These limestones outcrop in successive buttresses or walls that encircle the northern end of the mountain, and they are cut through by a small stream, dry when we followed its channel, that leads into Sixteen-Mile creek; thus fine exposures of the rocks are presented. No more interesting field was found during the summer's expedition, and if studied in connection with the ranges running southwest to the upper cañon of the Missouri below Gallatin City, and southeast to the Bridger range, and thence toward Bozeman, it would form a most instructive region for areal **c** and section work.

(4) *Little Belt mountains, west of Barker.*—This section is as valuable as the preceding, with which it presents an interesting contrast. It was measured at several bluff outcrops of nearly horizontal strata in different parts of the series, as shown by the heavy profile line on structural section 4, on a line running nearly north and south, crossing Belt creek about 8 miles below Neihart and the Dry fork about 6 miles below Barker. The series includes the Archæan foundation of gneiss, overlaid by heavy sandstones and sandy shales, with a little white quartz conglomerate at the base, and with the Potsdam trilobites (22) that elsewhere overlie 10,000 or 15,000 of stratified deposits, here occurring at only 1,100 feet from the lowest bedded rock; these are soon succeeded by the even-bedded Lower Carboniferous limestones, rich in fossils (21, 20, 19), by the heavy, ragged limestones, and by shaly beds, with calcareous layers containing Lower Carboniferous fossils (18) at a level that we had before thought to be Mesozoic; these last were found on the northern side of a fine limestone dome that lies outside of the mountain **d** flanks north of Barker (section 4, —c). The higher beds continue in a flattening monoclinal of barren sandstones and shales, with poor outcrops, to the Cretaceous coal of Otter creek, and beyond with great thickness into the Highwood mountains; the fossils (30) found on the southern flanks of the latter are Cretaceous, but higher in the mass they (31, 32) are doubtful, although pointing to the same formation. Interesting eruptive masses of hornblende andesite or dacite, as determined by Mr. Lindgren, break through the Paleozoic strata of the Little Belt mountains (section 4, —a, —c), and basaltic and trachytic dikes in large variety intersect even the topmost beds of the Highwoods in all directions, which are thus shown to be strikingly similar to the Crazy mountains, but we saw nothing of the continuous volcanic area, or of the northward extension of the Carboniferous, shown on the general geological map of the area explored and mapped by Dr. Hayden.

e (5) *Little Belt mountains, Otter creek, 5 miles northeast of Barker.*—This section was measured southward up a small branch of Otter creek, about 2 miles east of the bridle-trail leading out of the mountains from Barker. It was peculiar in yielding a series notably unlike that of section 4, only about 10 miles distant to the west. The ragged limestones are persistent, but the richly fossiliferous limestones of Belt creek and its Dry fork have here almost disappeared, and it was with difficulty that enough fossils (23, 24) were found for the identification of the Lower Carboniferous. Beneath 1,000 feet of these strata there came 850 feet of firm and slaty limestones, in which no identifiable fossils were found, and still lower 500 feet of varied slaty shales, in the lower part of which Potsdam trilobites (25) were found of a genus (*Dikellocephalus*) different from that commonly occurring elsewhere in the Potsdam limestones (*Conocephalites*).

(6) *Northward from Benton gulch, northeast of Big Belt range.*—This section was measured northward from the stage-road between Diamond City and Fort Logan, a mile before it enters the open country of Smith's river (Deep **f** creek), about 5 miles northwest of Fort Logan. We here again found a great development of the Lower Cambrian series below the Potsdam horizon, but unlike that of sections 3 and 8 in holding a number of heavy indurated sandstones with some conglomeratic layers. This would seem to indicate shallows in the old Cambrian sea on approaching the long-existing Archæan island in section 4. The top of the section, cut off by a well-proved fault, consists of limestones and shaly limestones; Potsdam trilobites (26) were found in the lower members of this group. The hard sandstone and the red shales came a little distance below these, as in Wall mountain, section 3, then a monoclinal series at least 10,000 feet in thickness, unless repeated by faults of which we had no sufficient evidence; the lowest layers were cut off by a fault that brought down the ragged Carboniferous limestones, with a throw consequently to be estimated at 14,000 or 15,000 feet. The more even-bedded Lower Carboniferous limestones then rise to form the Dry range, a subordinate, flat, monoclinal ridge, with a good variety of fossils (33, 34, 35); they seemed to be underlaid to the north by rocks of the lower series again, but we had no time to examine them.

(7) *Boulder creek, Big Belt range.*—The old Cambrian slates were measured here below the Potsdam trilobite limestones where Boulder creek flows out on the open lands of the upper Missouri, up the stream to Diamond City. The measures are of but moderate accuracy, as the strata are rather unevenly tilted at several points, besides being intersected by granitic and other dikes near the mountains. The series consists of barren red and purplish shaly slates near the top, changing to gray and bluish lower down, and with some hard sandstones near the bottom, the total thickness measured being about 10,000 feet, and this without entering the heavily-timbered higher points of the mountains. The upper part is drawn in structural section 7, to show the attitude of the limestones that rise in a low ridge north of the creek, and their problematic relation to a ledge of hard quartzite on the same strike, half a mile north. The undisturbed attitude of these two layers over the red shaly slates is shown in section 3. They seem here to be affected by local fractures. Closely-adjoining limestones yielded fossils from two horizons, Potsdam and Lower Carboniferous, and from this, as well as from structural evidence, we have supposed a fault or a torn fold to follow the western foot of the Big Belt range about this locality.

(8) *Section across the main range at Cadotte's pass.*—This section was disappointing in giving no good determinate series of rocks for measurement. A vast thickness of Lower Cambrian slates and shales was exposed in the synclinal axis of the mountains, and repeated by strike faults in the eastern foot-hills, but neither the Archæan base nor the ordinary Potsdam limestones could be found in proper sequence with them. The Archæan rocks do not appear in this part of the range, and although limestones that undoubtedly belong to the Potsdam were found on the Middle fork of the Dearborn river, they yielded us no fossils, and must be regarded as cut off from the main mass of slates by a fault. The most probable sequence of the older slaty rocks that we could put together was obtained on the Upper Blackfoot river, from the moraines (marked on the section) to the summits about the pass; it is as follows, from below upward: Dark slates with a few sandstones, 900 feet; red slates and slaty shales, 1,100; red, gray, and greenish-gray slates and slaty shales, 300; red slates, 300; gray slates, 900; gray slates with some red beds, 300; gray slates with scattered Calcareous beds, 1,200; total, 5,000 feet. The attitude of this mass in the Cambrian series is not determined, but it is very probably in the middle or lower part; its red beds do not seem to correspond with those near the top of the series at Wall mountain, Boulder creek, or Benton gulch. No fossils were found, although many beds were carefully searched over.

The upper part of the series, between these older slates and the great fault of ten or more thousand feet, that brings down the presumably Mesozoic strata of the lower country, is shown on columnar section 8 in sufficient detail without further description.

The Mesozoic rocks farther eastward were very imperfectly exposed, and yielded no fossils to our hasty examination, except close to the coal of Dearborn river, where a few imperfect Cretaceous shells were found (29). The dark shales east of Sun river were supposed to be of the Fort Benton group, from their relation to the outcrops on the Missouri river.

Mullen pass, head of Little Blackfoot river. Many eruptives, strongly-marked alteration of certain beds, and the appearance of concealed faulting prevented our determining satisfactorily the relations of the rocks in this district. The tunnel through the pass is cut through a ridge consisting of members of the Lower Carboniferous limestone, dipping west, broken by intrusive granites. In the valley west of the pass, coal has been found, but its relations to the adjoining rocks could nowhere be discovered. A high ridge a little farther west, through which the Little Blackfoot has cut its way westward, is made of indurated slates and sandstones on the east slope, with the higher parts and western slopes of Lower Carboniferous limestone in typical appearance, overlaid on the west by Mesozoic strata. In the cross valley, Jurassic rocks were found 2 miles above Logan's ranch, but their relations to the Carboniferous were not fully made out.

East of the pass, the limestones are altered for some distance from the granites. Going farther toward Helena, a considerable breadth of barren slates, shales, and sandstones are found; they are probably Cambrian, but we could give no time to their examination.

MOUNTAIN STRUCTURE IN CENTRAL MONTANA.

The reports of Messrs. Haydén and King show that in Colorado and southern Wyoming the Front range of the Rocky mountains rises abruptly from the plains, so that one passes in a breadth of a few miles from the horizontal strata of the endless open country on the east, across the sharply-upturned Mesozoic and Paleozoic strata of the foot-hills to the granitic rocks of the mountains. There is no distinct foreshadowing of this great change at a little distance out from the range, and intrusive rocks are very rarely found in the younger strata. This simplicity is lost in going north, and in Montana we find a much more varied and complicated structure in the several ranges examined between Bozeman and Fort Benton, from latitude 45° 50′ to 47° 50′. In the first place, mesas or heavy dike-ridges of eruptive rocks are not infrequently seen 20 to 40 miles away from the mountains, so that the change from plain to mountainous country is generally gradual, not abrupt; in two cases these outlying eruptives have become centers of short groups, namely, the Highwood and the Crazy mountains, of considerable height, without the aid of Paleozoic or Lower Mesozoic rocks. In the next place, there are upheavals of Paleozoic a rocks branching off of, or altogether separated from, the main range; the Black hills make the southernmost, and perhaps the largest, as well as certainly the best studied example of this type; the Big Horn range (*a*) probably belongs here as well. Farther north, closer to the district we have seen, the Little Belt range branches to the east-southeast or southeast of the more continuous mountain front, and other outliers, presumably of a similar nature, exist farther north.

Finally, the Front range here loses the pre-eminence, the directness and the continuity that characterize it farther south, and hence this name, so appropriate in Colorado, is not used in Montana; it might, however, be applied with more technical meaning to the first long, almost continuous exposure of the Paleozoic rocks found westward from the plains, especially as in northern Montana and in the adjacent British territory it seems to
b regain the simple and dominant form that distinguishes it in Colorado. The term is, however, unsatisfactory, for the mountains that certainly deserve the name of Front range, if the name has any application at all, are sometimes so little elevated that the Mesozoic rocks cross over them, as, for example, at the south end of the Bridger range, (*b*) and are not unfrequently equalled in height by outlying mountains farther to the east.

Throughout this central region of Montana we find scenery that is often fine and pleasing, but, as a rule, of a mildly mountainous type. Sharp and rugged peaks are generally absent, and the views from the valleys, passes and summits nowhere attain the grandeur found farther south or north. (*c*) Permanent snow patches are scarce and small; even the old glaciers had here a small development.

The descriptions of mountain structure that follow will show that the entire conformable series of Paleozoic
c and Mesozoic strata were uplifted during later Cretaceous and earlier Tertiary time. Throughout and after this time of mountain growth vast masses of the older rocks were worn away from the new land-surfaces and deposited elsewhere, chiefly as early and middle Tertiary strata; some of the earlier erosion may have supplied material for later Cretaceous beds before the uplifts had become strongly marked. It is on this account that Eocene and Miocene formations are so generally absent here. But near the end of Tertiary time another movement, or a late phase of the original mountain uplift, disturbed the then established drainage lines by irregular tilting, and so formed a number of orographic lake-basins generally back of the Front range. These were filled to considerable depths with fine argillaceous and marly sediments of presumably Quaternary date, which unconformably overlie the eroded rocks of various earlier formations, thus proving their existence as dry land during the greater part of the Tertiary, as above mentioned. It is these old lake-beds that form the open, dry bench-lands across broad valleys among the various ranges of the Rocky mountains of Montana; and it is noticeable that every one of these areas
d is drained by a stream flowing through a comparatively narrow cañon, the recent work of the lake overflow in cutting down the lowest part of the old barrier. Examples are seen in Paradise valley, above the lower cañon of the Yellowstone; (*d*) the Bozeman-Gallatin-Madison plain, above the upper cañon of the Missouri; the Townsend-Radersburg valley, above the lower cañon of the same river; open valleys, above the lower and middle cañons of the Madison; (*d*) a smaller example on the Little Blackfoot, above Lincoln; and, finally, the valley of Smith's river, above its cañon in the Little Belt mountains, this being the only example of a post-Tertiary lake that we discovered outside of the Front range. Since the filling of the basins and the cutting down of the outlets together succeeded in destroying the lakes, their deposits have been exposed to denudation proportionate to the deepening of the cañons below their upper surface; thus the streams issuing from the mountains have, unfortunately for the ranchmen,
e sunk their channels 30 to 100 or more feet below the bench-land. If these valleys had been settled a few thousand years ago, irrigation of the upper fields would not have been so difficult as it has now become. During the later stages of the lake period, and perhaps continuously down to the present time, a surface-coating or "wash" of coarse material has been spread over the bench-land, from the adjoining mountain slopes, often making it too stony for cultivation, even if irrigating streams could be led upon it. This "wash" is, so far as we could determine, always of local origin, and, in spite of the considerable size and angular form of some of the stones, it seems chiefly of subaerial origin. Ice action was not shown to have had any share in its distribution. Below the lower cañon of the Yellowstone, in the neighborhood of Livingston, where there was no reason to think a recent lake had existed, the coarse wash seems to lie directly on the eroded Mesozoic rocks, smoothing them off to an even slope, without the intervention of lake-beds. Several interesting problems arose in connection with this, and in relation to the old lakes among the mountains, but we had no time to follow them to their solution.

f In spite of their synchronous growth, the mountain ranges within our field of observation show a remarkable variety and irregularity of structure. The Bridger range is a steep or overthrown monoclinal, with the heavy limestones for its crest and a strong fault or torn fold bringing up the oldest rocks along its western base. The Big Belt mountains are composed chiefly of an oval anticlinal of old slates, with steep dips and granitic intrusions.

a Hayden (Report for 1868, p. 70 of reprint of 1873) describes the Big Horn range as containing the same series of granitoid and stratified rocks found in the Black hills, but connected with Wind river section of the main range by a very rugged area of eruptives.

b Hayden, 1872, p. 30.

c The Crazy mountains, an isolated outlying range of Mesozoic strata (see p. 701), seemed to offer finer scenery than the other ranges of central Montana, but we saw them only from a distance.

d Compare Dr. Hayden's Report for 1872, p. 33, and geological map of Montana and Wyoming territories, above headwaters of Madison, Gallatin, and Yellowstone rivers (187–).

The main range, at Cadotte's pass, (*a*) consists of a flat synclinal of old slates, with heavy strike-faults on either **a**
side. The Little Belt mountains, in the Barker district, show a broad, flat anticlinal or plateau structure, with exposures of the Archæan where strongly eroded about Neihart, but with a continuous cover of limestones farther west. The Highwoods and the Crazy range have already been mentioned as consisting of remnants of late Cretaceous strata locally indurated by numerous dikes. Hence, whether we consider the Front range alone or all the ranges together, there is small opportunity to generalize on their structure. They may now be described more in detail.

THE BRIDGER RANGE.

Structure.—This range presents a comparatively simple topographic form, as it consists essentially of a steep **b**
north and south monoclinal of Paleozoic rocks in which the heavy limestones form the crest-line, while the older series even down to the Archæan appear on the west toward the East Gallatin plain, and the newer formations outcrop on the east toward Shield's river. (*b*) The range begins at Bridger pass, near Bozeman, where the older rocks rise from beneath the Mesozoic, (*c*) and extends with remarkable directness 20 miles to the north, when it ends very much as it began. The several lines of elevation farther north, about Sixteen-Mile creek, are of irregular structure and belong between the Big Belt and the Bridger ranges. Dry creek, a branch of the East Gallatin draining the northern half of the range on the western side, follows a broad valley between the Archæan and low Paleozoic rocks of the Bridger on the east and hills of Paleozoic and Mesozoic strata on the west. These latter outcrops are the northerly continuation of the beds exposed in the excellent section along the Gallatin river a little above Gallatin **c**
city, described by Drs. Hayden and Peale. (*d*) Their connection with the Bridger range is obscure. Dr. Hayden says there are several local anticlinals and synclinals in the interval between the Flathead pass and the Missouri, and to these we are inclined to add a heavy fault as well, for it is difficult to explain the valley of Dry creek as an anticlinal alone. There is no western dipping monoclinal that corresponds in height to the eastern or Bridger half of a simple arch; and at the northern end of the range, where the heavy limestones lose their steep dip and roll down to a normal altitude as they descend northward under the Mesozoic formations, the hard, ridge making rocks do not continue westward across the basin of Dry creek, but end abruptly at its eastern margin. Far south the fault may be absent.

At Flathead pass, and probably at other points toward Bozeman, the rocks of the mountain crest are overthrown past the vertical so as to dip 70° or even only 60° to the west, and here the Mesozoic strata of the eastern slope **d**
apparently underlie the Carboniferous of the ridge-line. The eastern foot-hills are separated from the range by a comparatively low valley drained by Bridger creek at the south into the East Gallatin; farther north by Brackett's and Cottonwood creeks that flow eastward into Shield's river; and finally by a branch of Sixteen-Mile creek. This long strike-valley follows beds that cannot be far from the coal horizon, unless unseen folding or faulting complicates the relation between the upper and lower rocks; and further, it marks in general the line between the steeply-inclined old strata of the range and the less tilted newer strata of the foot-hills and lower country. No fossils were found to show the age of these hills, but they are probably of the same horizon as the synclinal of Fleischman's creek, north of the railroad, between Livingston and the Muir tunnel, described in the Yellowstone section. At that point they are all evidently conformable with the known Cretaceous below; but here Dr. Peale, who considers them of Tertiary age, has described them as unconformably overlying the Bridger uplift. (*e*) We could find no **e**
sufficient proof of this. There is very evidently, as our section shows, a marked change of dip between the range and the foot-hills, and of strike as well at many points; but all this change could very well result from the great crushing by which the overturned monoclinal was produced. At the northern end of the range, the Mesozoic strata follow the Carboniferous in simple succesion. We therefore conclude that the Bridger uplift was contemporaneous with that of the other ranges in central Montana, somewhere in the long unrepresented interval after represented epochs of the Cretaceous age.

THE BIG BELT RANGE.

Structure.—The Big Belt range, from Sixteen-Mile creek northward beyond Diamond City, is essentially a long, elliptical anticlinal, measuring 30 by 20 miles, composed of a great mass of low Paleozoic slates, cut by granitic dikes, and reaching elevations of 9,000 feet; thus rising 300 or 400 feet above the timber-line, and retaining some **f**
small patches of snow in a few of its upper ravines through the summer. Its distortions are of a very broad pattern, and folds of small curvature were rarely found within its limits; in the finer layers an incipient cleavage of steep dip is very common. The old slates, dipping irregularly near the middle of the arch, and with steep outward dips on the east and west sides, occupy nearly all the mountain area; the granitic intrusives cover but a small share of the surface, near the center, and the old quartzite and the great limestones are not to be found before reaching the

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a And for a long distance northward, according to observations by Mr. Pumpelly.

b Compare Dr. Hayden's Report for 1871, pp. 45, 46; 1872, pp. 29, 30, 74, 75, 84, 171, 172. The statement concerning the Archæan is taken from Report for 1872, p. 75.

c Id., 1872, p. 30.

d Report for 1872, pp. 72, 172.

e Hayden's Report, 1872.

a margin of the mountains. The eastern flanks were mostly beyond the route of our party, but where visited or when seen from a distance were safely recognized as the old slates dipping away from the central axis to southeast or northeast, and presumably retaining a similar or easterly dip all along this slope. The western flanks, from Boulder creek south to Deep creek, seem to be of similar structure, with opposite dip, but are broadly covered on the lower slopes by a smooth "wash" of recent date; the few ridges that rise through this even surface being outcrops of the hard sandstones that occur in the slates about 4,000 feet below their top; the same hard layers are well shown in the cañon of Deep creek, just above Mr. Carpenter's ranch, about —— miles east of the Missouri.

In going southward from the mountains one may follow the slate anticlinal past the cañons of Deep and Greyson creeks, and well beyond toward Sixteen-Mile creek, where the dip of the anticlinal axis finally carries
b the slates underground. This part of the middle line is not marked by notable elevations, and Deep and Greyson creeks heading to the east of it flow westward across it. The hills of slate are, as a rule, bare of forest growth, and especially in the upper part of the series show their structure, when viewed from a little distance, in grass lines following the belts of more fertile strata, while the ravines give ample outcrops for detailed study. Eastward of this district a synclinal is formed by the slates rising with westerly dip from their eastern plunge, and thus they extend beyond the upper basin of the North fork of Sixteen-Mile creek, in barren, rolling hills that are crossed by a road leading to White Sulphur Springs. This synclinal holds summits that attain a commanding height, and, on following its axis as it descends gently to the south, we are brought to Wall mountain, east of the cañon of a dry fork of Sixteen Mile creek, a wonderfully fine series of curved, rampart-like outcrops of the old quartzite and the
c great limestones; it may be regarded as resembling the prow of a flat-bottomed boat, and is more like Pennsylvanian structure and topography than anything else seen in Montana. Going still farther south, this opens out into the Lower Mesozoic basin of Sixteen-Mile creek, and its eastern rocks are cut by the cañons of this creek and its North fork before they rise into the limestone range that runs to the Missouri, just north of Gallatin City.

Crossing to the western side of the old slate anticlinal, the lower quartzite and some of the lower limestones, with southwestern dip, cap a ridge to the south of Greyson creek; they continue with narrowing area across Greyson creek, near which the quartzite makes a pronounced ridge, and beyond to Deep creek, but thereafter are hidden under the bench-land—if continuing farther north—until they reappear north of Boulder creek, 16 miles farther on. The doubt about their continuity across this interval comes from the absence of intermediate ridges and outcrops through the bench surface, and even of ledges in the stream channels that are here frequently sunk 70 or 80 feet
d below it; and still further from the appearance, at several points along the ridge from Greyson to Deep creek, of an eastern dip implying a change from the anticlinal of the mountains to a synclinal or torn fold having its axis along this line. If this were the case the absence of the old quartzite would be the simple result of erosion to a little lower level than where it was turned up or broken off.

The reappearance of the quartzite and limestone north of Boulder creek repeats many of the conditions of their disappearance south of Deep creek, with the addition of rather more marked irregularity of position, suggesting that the supposed synclinal has here especially been torn into a fault; and, indeed, so it may have been for the greater part of its length. The narrow wedge of old quartzite and trilobite limestones between the high hills of red slates on the east and the open, low bench-land on the west, widens to the north, where the appearance of the ridges in the distance suggested the presence of a large part of the great limestone series. Going up the
e unsymmetrical valley of Boulder creek, we descend obliquely through about a mile's thickness of the slates, which dip to the northwest with moderate regularity before the cañon is reached at the mouth of Confederate gulch. Turning here to the south, nearly as much more slate is passed through before coming to an anticlinal, beyond which the strata dip for some distance rather irregularly or obliquely toward the mountains, instead of away from them, as elsewhere. Dikes become rather common beyond the change of dip. If, instead of ascending the cañon of Boulder creek, one follows the stage road past Diamond City and over the divide to Benton gulch, which leads eastward down toward Fort Logan, the shaly slates are found dipping northward, and when near the low country of Smith's river (Deep creek) they have turned still farther, so as to dip northeast. The occurrence of a well-proved fault of strong throw near the mouth of Benton gulch suggests the probability of others between this valley and the mountain center by which the otherwise vast thickness of the slates here may be reduced at least within the
f not very moderate measure of three miles. The fault alluded to runs nearly along the strike of the rocks, on the northern side of Benton gulch, and brings the trilobite limestones down opposite the calcareous beds of the old slates—a throw of perhaps 8,000 feet. The beds are flexed upward on either side of the fracture, but most distinctly on the south, where a synclinal is produced, 2 or 3 miles wide, near the mouth of the gulch, narrowing westward. On the northern side, the limestones are upturned for only a small distance, but the appearance of a torn synclinal is given by a great mass of the old quartzite, which stands nearly vertical, and which must mark very closely the position of the fault-plane. Farther north there is an apparently unbroken monoclinal, with moderate, constant dips to the south for about 5 miles, the greater part of which consists of the equivalents of the old slates, here much sandier than usual. The series is very well exposed, and unless faulted gives a trustworthy measure of over 10,000 feet of rocks below the old quartzite. On the north it is cut off by a fault of enormous throw at the foot of the Dry range, which brings the heavy, ragged limestones of the Upper Carboniferous down opposite these old shales. This displacement must be in the neighborhood of 15,000 feet. There is a very striking revelation of structure in the

grass-lines already mentioned as characterizing the upper slates on the northern slope of the valley next beyond a
the quartzite; broad and narrow bands of gray and green can be traced along the surface for half a mile at a stretch, and show a surprising number of cross and oblique faults of small throw. In this increasingly persistent easterly strike we have the transition from the structure of the Big Belt to that of the Little Belt mountains; and although the latter is represented on the maps as only on the east of Smith's river, while the former is marked as extending northward to the Missouri, it seems advisable to transfer the description of the Dry range, which comes next beyond the monoclinal of old slates and sandstones, to the next section.

Igneous rocks.—In the central and higher parts of the Big Belt anticlinal of old slates, dikes and irregular masses, chiefly of intrusive granitic rocks, are very common. They seem to have had much influence in hardening the rocks about them, as the fragments of argillaceous, calcareous, siliceous slates on the upper slopes are of firm, b
almost crystalline, texture, and give a sharp, ringing sound when struck. They may also have aided in dislocating the strata, as irregularity of dip increases toward the center of the mountains. Some of the intrusives of the southern part of the range, within the drainage of Deep creek, are distinguished by quartz-crystals in double pyramids, while the large granite boulders brought out from the northern massive, by the old glacier of Boulder creek, commonly contain coarse felspar crystals, often an inch in length. Besides these and some other eruptives on upper Boulder creek, there should be mentioned the diabase, weathering into a characteristic, yellowish-brown, gravelly soil, found in the upper shales, near the old quartzite, and consequently on the margin of the mountains. It occurs in a similar position in several other localities. Here it appears near Greyson and Boulder creeks, just before they flow out on the bench-land. c

Drainage.—The streams flowing from the Big Belt range all seem to be consequent upon its uplift. It is true that Deep creek rises well to the east of the old slate anticlinal axis, but it fails by a still greater distance to cut across the range. The present position of its source may result from a backward cutting of its headwaters.

A former lower elevation of the mountains is indicated by high, level benches, of not uncommon occurrence, in the basins of Deep and Boulder creeks. At several places their surface is remarkably smooth and nearly level, although quite independent of the rock structure below. South of Diamond City there is a strongly-marked bench of gravel with heavy boulders, in which gold-washing has been attempted, and is still continued with moderate success; but the present channel of Boulder creek is cut sharply down through this wash and into the slates, 50 to 70 feet below. The channeling of the open bench-land west of the mountain toward the Missouri has already been mentioned. The unsymmetrical form of the valley of Boulder creek—a long slope toward the mountains, d
and an abrupt slope on the opposite side—is the result of the northward dip of the slates. A similar form is found on the North fork of Deep creek for the same reason.

Glacial action.—After the great blocks of granite on upper Boulder creek had excited our surprise and suggested the possibility of glacial action here, we saw a well-preserved lateral moraine stretching across a small side ravine farther up the valley. It was about 400 feet above the valley bottom, and a small marsh was inclosed behind it. No terminal moraines or scratches on boulders or ledges were found, but the lower limit of probable glacial action was estimated at 6,000 feet. Several small lakes are reported farther in toward the high mountain centers.

THE LITTLE BELT MOUNTAINS.

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Structure.—The Little Belt range begins, according to our maps, on the eastern side of Smith's river (Deep creek) and extends 50 miles to the east-southeast, with an average breadth of 20 miles. Our observations were confined to its western part, about the mining towns of Clendenin and Neihart, in the Barker and Montana mining districts, and here the trend of the range is much more nearly east and west than is usual among the Rocky mountains. For this reason we are disposed to bring the northern part of what is commonly called the Big Belt range within the structural limits of the Little Belt, and thus give it an extension of 10 or 20 miles west of Smith's river toward the upper Missouri. This mountain group seems intermediate, in character as well as in position, between the external and front ranges, and, at our line of crossing, presents several points of resemblance to the Black hills, as may be seen by comparing our structural section 4 with the figure in the report of the lamented Newton. About the upper branches of Belt creek the restored structure would show a broad arch, with the axis f
nearly east and west, flattened on top into plateau form, and having dips of 5° to 15° on either flank. Mesozoic, as well as Paleozoic, strata were probably once continuous across this region, but erosion has now forced back the front of the more yielding Cretaceous layers southward beyond Sheep creek, and northward to the broad valleys of Otter and Arrow creeks, and worn away the great limestone series to Sheep creek on the south, and across Belt creek at the Park below Neihart on the north. (To the east or west of our section the formations have somewhat altered positions.) Between the limestone bluffs the old quarzite is exposed, lying almost flat, and, at places, is cut through to the underlying gneiss. In addition to the plateau structure, there is another equally characteristic, produced by the extrusion of heavy oval igneous masses through the stratified rocks, sometimes even to the top of the Carboniferous series, causing a strong but local uplifting of the beds immediately around the central core, and giving strong topographic forms, as will be described below.

a Section 4 and its relations to the districts east and west may now be described in more detail. The valley of Sheep creek, where followed by the road from White Sulphur Springs to Neihart and for several miles farther up stream, is as drawn in the section on a monoclinal of gentle southward dip. The stream has cut the middle Palæozoic strata down to the old quartzite, which rises slowly to the plateau benches on the north, while the opposite and bolder slope contains part of the great limestones. This limestone range is heavily wooded, and no good outcrops were seen from the valley; but from its sequence above the old quartzite, from its form and altitude, and from the occurrence of Carboniferous fossils in the stream, the above inferences seem safely based. Before going farther north, we may consider the western extension of this monoclinal. The quartzite ridge is its most persistent element; it reaches Smith's river in good strength, but disappears just beyond the southern flank of the Dry range of
b Carboniferous limestones, the two evidently being separated by an oblique fault, with heavy downthrow on the north. (See Big Belt range, p. 706.) On the way here, the quartzite is three times cut through by streams flowing against its dip, but toward the downthrow side of the fault—namely, Sheep creek, Smith's river, and a small stream between the two. The monoclinal valley rises into two high grassy "cols" on the back of the quartzite between the three streams just mentioned. The limestone ridge loses its continuity opposite the quartzite cañon of Sheep creek; south of the second "col" it reappears in normal position for a short distance, but south of the first "col" there is an unexpected and unexplained butte of quartzite. When the monoclinal crosses Smith's river, it must be cut off on the south as well as on the north by a fault, for all the broad area from the Dry range nearly to Benton gulch is occupied by the old slates. We have supposed, although without final evidence, that these two faults converged
c to the west with a narrowing area of Upper Cambrian rocks between them, and meet just beyond Smith's river where the strata of this age are absent.

Returning, now, to the section line and crossing the pass, we follow the quartzite so far that its repetition by faulting becomes very probable, especially as it has only a moderate thickness between the Archæan gneiss and the Potsdam limestones on Belt creek a little farther north. The occurrence of faults, as drawn on section 4, is further confirmed by the reported occurrence of what was called syenite by a local expert, just north of the first quartzite ridge; and a fault here would very probably be continuous with the northern of the two already mentioned, its throw increasing to the west. The quartzite district is not one of easy observation, as it is closely timbered or richly grassed to the concealment of most outcrops, to say nothing of the "terrible torment of flies" which makes summer work in the pine forests of the ridges almost unendurable. Where the nearly horizontal quartzite and
d overlying shaly sandstones lie at a moderate altitude, they often form open, grassy parks, of which the most notable is a beautiful plateau, beginning about 3 miles west of Neihart and extending westward 6 miles with gentle slope, until covered by the limestones about Tillinghast creek. The absence of trees here seems quite independent of fires, and is doubtless inherent in the conditions of soil and surface. Pines of good size are plentiful on the rocky slopes below and above.

On descending from the pass and the glades on its northern side, the road leads down the narrow gorge of O'Brien's creek to Belt creek at Neihart. The quartzite is well exposed at several bench outcrops on the way, and a mile or more from Belt creek includes some 300 feet of soft, gray shales between its upper and lower members. The lower quartzite is two or three hundred feet thick, and lies directly on Archæan gneiss in marked unconformity, but the exact contact was not seen at any point. As the road descends with the stream deeper
e into the gneiss, the quartzite rises gently, and around Neihart it caps several of the mountains 800 or 1,000 feet above the valley bottom, giving a broad example of nearly horizontal strata resting on the highly inclined gneiss. The lower layers here contain some white quartz pebbles, but the greater part is of fine texture. (The moderate thickness of this basal formation from the gneiss to the Potsdam limestones has already been mentioned, and has led us to suppose that we are here in the neighborhood of a Cambrian shore-line, as will be further stated below.) The gneiss is sometimes reddish, with faint foliation and of granitic appearance, and again dark, hornblendic, and well banded. Some blocks found in talus slopes showed the occurrence of intrusive red granite, not seen in place; probably of pre-Cambrian intrusion, as we could learn nothing of the granite rising into the overlying quartzite, although such an occurrence would doubtless have been discovered by some of the numerous prospectors who have searched the region for leads. The leads thus far found are in either gneiss or quartzite,
f and yield lead and silver ores.

The broad, flat structural-arch of the range rises to the east, and, consequently, the Archæan rocks are exposed over a wider area in that direction; and this increase is further aided by a local upturning between Neihart and Barker. To the west we found the gneiss only in the narrow cañon of Belt creek, where it cuts the quartzite "Park". A few miles farther down-stream the quartzite itself passes below drainage level, and the great limestone series, now north of the arch axis, forms the fine bluffs along this creek and on its Dry fork. It was from these bluffs, opposite the "Park" on Belt creek, and at the point where the stage-road from Fort Benton enters the valley of Dry fork, that we obtained our best measures of thickness and series of fossils; the exposures could hardly be improved. Farther west the base of the series is not revealed; farther east it is largely removed by erosion or broken by eruption. Here it is exhibited in full strength, in simple and unbroken succession, and in numerous and easily accessible outcrops. On the Belt Creek bluffs we measured from the Archæan gneiss up through the Cambrian quartzites and limestones, past the barren, shaly, and sandy limestones, up to layers with lower

Carboniferous fossils, 2,300 feet above the creek. Then crossing about 2 miles to the north, the brown sandy **a** limestone, that was 1,800 feet above Belt creek, was found to have descended to the bed of the Dry fork, while the bluffs above it rose 800 feet to the heavy ragged limestones near the top of the Carboniferous. Finally, near the "summit", where the stage-road passes out to the open country, the ragged limestones run underground, and are overlain by the even-bedded barren limestones and shales and sandstones which lead up to the Mesozoic formations. The structure has all the simplicity and distinctness that one can desire, and there remains only to regret the lack of definite termination of the Paleozoic series. Carboniferous fossils were found 500 feet above the limestones which we had considered the top of the older formations, and beyond these 800 feet of sandy shales and sandstones were measured, and 3,000 to 4,000 feet more estimated, in which no fossils whatever were seen. These latter measures were taken from the northern side of an interesting dome-uplift outside of the mountain's margin, north **b** of Barker. It is surrounded by what we considered Jurassic and Cretaceous rocks, but shows the ragged limestones of the Upper Carboniferous over a circular area 2 or 3 miles in diameter at the center. As in the mountains themselves, the dips are steepest where these limestones run underground, but are moderate, not exceeding 10 or 20 degrees, unless close to the eruptives. A similar dome structure is reported by Mr. Eldridge, N. T. S., for a crater-like elevation farther southeast, near the margin of this range. In a region where orographic displacement is generally in the form of broad, flat arches or long, straight faults, we are disposed to attribute these local disturbances to the effort of incomplete massive eruptions, of which the complete form is described in the next section.

Igneous rocks.—Intrusive granite in the gneiss, probably of pre-Paleozoic date, has already been mentioned; **c** besides this, several other intrusives of equal antiquity were suspected, but opportunity was wanting to examine them. In the stratified rocks the intrusives had two forms—one in the massive outbursts of dacite, the other in dikes in the "Park" quartzite and shales on Belt creek. The latter have a thickness of 10 or 20 feet, and stand about vertical. They stand out in well-exposed walls in the side ravines of the Belt creek cañon; the adjoining rocks are not visibly distorted by them. The dacites form mountains of 1,500 to 2,500 feet altitude (above the surrounding country) and of considerable area. West of Tillinghast creek a mountain of this origin has cross-measures of about 1½ and 3 miles, and is notable for the oval form of its eruptive rock as well as for the small disturbance it produces in the adjoining rocks. It seems to be a vast chimney or "neck", from which the former filling of stratified rocks has been forced out by the thrust of the eruption; and where examined on the south, east, and north, the adjoining Cambrian strata were, with an insignificant exception, found to change abruptly from **d** the nearly horizontal position in the surrounding country to dips of 30° to 70° away from the contact—the breadth of this disturbed belt varied from 100 feet to one-quarter of a mile or more. A similar relation of the igneous and stratified rocks was noticed on the northern slope of the range that extends from the "summit" of the Fort Benton and Barker stage-road to the bridle-trail leading northward from Barker. The Upper Carboniferous limestones stand in steep triangular patches against the slopes between the ravines leading down from the marginal range of the Little Belt mountains; but here we were unable to define the shape of the igneous area. The date of the dacite eruption is certainly post-Carboniferous, and very probably agrees with that of the mountain uplift. There was nowhere any sign of eruptive overflow.

Drainage.—The streams in the mountain region generally flow away from the higher part of its arch, so far as examined, and may therefore be considered consequent; but Sheep creek and Smith's river have already been **e** referred to as flowing across the old quartzite ridge against its dip, and as the latter crosses the entire range and empties into the Missouri on the north, it especially may be of antecedent origin. Another interesting case, but of much smaller size, is seen on the southwestern side of the dome uplift of ragged limestones above mentioned, where a little stream from the higher range runs on the limestones from the south, cuts a cañon 100 to 200 feet deep across them, like the chord of a 60° arc, and flows out and away on the west.

No signs of glacial action were found in this range.

THE HIGHWOOD MOUNTAINS.

Structure and rocks.—The Highwoods present a good example of one type of the external ranges. They stand completely isolated in a surrounding of nearly horizontal late Mesozoic rocks which make a dry, open, somewhat **f** broken country, above which the peaks rise 3,500 feet. The group is about 15 miles long east and west, and 12 miles wide. It consists, where we crossed it at Highwood gap, near the middle, of slates or slaty sandstones, nearly horizontal or irregularly tipped to a moderate dip which seldom exceeds 25°, cut and indurated by numerous dikes of varied composition, running in all directions, standing in all altitudes, and frequently intersecting one another; 5 to 10 feet is a common thickness for the smaller ones; 100 or more feet for the larger. No massive eruption was found on our line of observation, though such may occur among the higher mountains. The dikes often resist weathering less successfully than the adjoining slates that they have baked and hardened, and consequently are not always well exposed; indeed we found it difficult to obtain proof of their relative ages, so generally are the intersections covered. In some cases they stand out like walls, then making serrated ridges if of large size, but more generally their position is marked by faint outcrops, or by lines of greener grass than on the a neighboring slates. Looking from the peaks north of the pass the grass-lines on the foot-hills reveal very clearly the great number and varied attitude of the dikes. About two miles southeast of the pass there is a mass of volcanic conglomerate 200 or 300 feet thick, composed of rather coarse cobbles of dacites, unlike the many eruptives of the range, but allied to the massive eruptions of the Little Belt mountains.

The shales and slates present no notable features; they run through the common varieties of color and composition, the colors being gray, bluish, and brown, and the impurities consisting chiefly of fine sandy material. There are no well-marked layers serving as indices to faults and folds, so that little can be said of their position. They apparently overlie the Cretaceous south of the range and the dark (Benton) shales which soon appear in the *coulées* to the north.

b *Drainage.*—On account of the absence of strata of effective hardness and of master-dikes there seems to be no system or regularity in the form of the mountains or in the arrangement of the valleys. The former culminate in ridges and rounded peaks, from which serrated spurs wander out to the lower country. The upper valleys are all steep-sided, V-shaped, and without benches; evidently the processes of deepening and widening are here going on together, and there is no evidence that these upper streams have ever reached a base-level of erosion. The lower valleys—for example, that of Highwood creek—show on the other hand a distinct flood-plain between well-marked benches or terraces that are quite independent of the rock structure, and thus prove a former relatively lower level of the mass, preserved long enough to allow the streams to cut down their channels close to the then base-level of drainage, and accomplish something of the widening of the valleys by lateral cutting; all this followed by a general
c uplift which restored the deepening action of the streams and enabled them to cut cañon-like clefts in their old flat bases; now succeeded in the outer valleys by a second period of lateral cutting. Where Highwood creek leaves the mountains it has already widened this newer cañon into a flat-bottomed valley broad enough for cultivation. The higher benches also yield good grain-crops wherever water can be carried over it from the upper streams. The elevation indicated by these benches is in the neighborhood of 100 feet.

THE PLAINS AND THE MAIN RANGE.

The journey from Fort Benton, on the Missouri, westward across the plains and over Cadotte's pass, on the main range of the Rocky mountains, gives a beautiful example of the gradual change of structure and topography encountered in going from one of these great geographic types to the other.

d The plains from Fort Benton to Sun river consist of essentially horizontal Cretaceous strata, with gently-rolling surface. Excepting near the rivers and *coulées* the local relief is seldom more than 30 to 50 feet in a mile, and this only in undulations of great breadth. The drainage lines are of older and newer origin. The older are seen in the broadly-open, flat depressions extending with curvature of long radius for miles across the country, followed by insignificant streams, or sometimes sinking into faint basins for very shallow alkaline lakes or sloughs. All these we consider the work of a river system now extinct, a system that, when in activity, cut and carried away an unknown thickness of overlying strata and brought the original surface down near its base level of drainage, thus producing the comparative smoothness of the existing plains. But later, and very probably at the time when the intermontane lakes were formed, the rivers of this old drainage system were turned from their flat courses by a tilting and elevation of the country, and then the second and still-existing system of drainage was instituted.
e The large rivers, such as the Missouri, have cut deep, but comparatively narrow and steep-sided trenches, often in soft rocks, to 400 feet below the old level; but the work thus far accomplished in this new altitude is a very small share of what can be done if the existing elevation above the level of discharge be maintained. On the Missouri there is evidence of a pause in the assumption of the present altitude in the existence of a broad bench—which seems to be a temporary "base-level" held during the change of altitude—250 to 300 feet above the river; but on the Teton, where seen, about 25 miles from Fort Benton, this intermediate bench is not visible. Keeping pace with the deepening of these larger channels, the small lateral streams have cut ramifying ravines in the river banks, making a very rough, almost impassable country, from 1 to 3 miles wide, known as "*the breaks*"; and still smaller streams, probably following new directions since the last tilting of the country, have cut distinct, narrow, but shallow channels on the steeper slopes of the old eroded surfaces. In general the new drainage lines have
f channels proportional to the volume of their wet-weather streams, while the broad old channels are either dry or swampy, or are followed by streams of comparatively small size. Where they hold shallow lakes the basins may plausibly be ascribed to the obstructive action of new streams depositing their alluvial deltas in the old channels. The thickness of strata destroyed in carving out the present general surface of the plains can only be inferred by an extended study of the Cretaceous strata over a broad region; and this we have had no opportunity of making. But the Highwood and Crazy mountains probably give a minimum measure of 3,000 to 5,000 feet of erosion on the country around them, and the plains are therefore to be regarded as plains of denudation, cut down to an old base-level of erosion.

The drift of pebbles and boulders that occurs plentifully over the plains is of peculiar interest. We encountered it first on the plains north of the Highwood range to the Missouri, and again on the way from Fort Benton nearly to Sun river. It may be subdivided into two classes, of which one consists of smaller, well-rolled stones, 6 to 8 inches in diameter, commonly of hard gray, yellow, or purple sandstones, or sometimes of gneiss, **a** generally associated with 5 or 10 feet of fine (yellow), apparently bedded clay, and spreading over the lower bench (250 feet over the Missouri), as well as on the higher level of the plains. The other class of drift includes the angular and subangular and occasionally scratched stones and boulders of all sizes, up to 2, 3, 4, and even 5 feet in diameter, mostly of red or gray granite and gneiss; also of fine, firm sandstones, lying, so far as found, on the surface of the ground. Section exposures were uncommon, and hence we have not full assurance of the constancy of these characters. It is noteworthy that the drift does not extend across the higher, rougher country west of Sun river to the foot of the mountains, and that the source of the large granitic boulders, at least, is not to be looked for in the mountain ranges of central Montana. They come from the north or northeast, not from the west, and should be associated with the numerous heavy boulders of the plains west of the Missouri at Bismarck; with the boulders described by Dr. I. C. White on the Yellowstone; and with the drift along our northern boundary **b** as described by Mr. G. M. Dawson. In view of the thinness of the drift deposits, and the absence of those forms of drift commonly found farther east where we suppose land-ice has acted, we must ascribe this drift of the plains to the action of running water from the west and floating ice-bergs from the east, not to a land ice-sheet. This implies great changes of level since the drift period.

The plains are absolutely treeless; but on the flood-plains of the larger streams there is a plentiful growth of large cottonwoods and small willows, wild cherries, and various bushes. Grass is generally excellent, but there are broad areas where it cannot be pastured on account of the distance to water. Hay is cut by machine for the stage-stations at $12 a ton.

The strata maintain a nearly horizontal position beyond Sun river, and the first clear sign of disturbance is **c** the appearance of eruptive rocks—chiefly basaltic—about 6 miles southwest of Sun river crossing, or Fort Shaw. They occur as sheets and as dikes, and from both a minimum measure of the erosion suffered by the plains here can be obtained. The sheets form typical *mesas*, as in Table and Twin buttes, between Sun river and Bird Tail creek. The hard strata of basalt here are 200 or 300 feet thick (600 to 800 feet above the surrounding country), and seem to lie conformably on their pedestals of horizontal Cretaceous beds, as if of contemporaneous overflow origin, a supposition confirmed by finding a heavy bed of basaltic conglomerate in the Cretaceous series some 15 miles farther west. We may, therefore, believe that Cretaceous times witnessed volcanic activity in the neighborhood of the mountains.

The dikes of basalt are of all sizes, and exert all grades of influence on the topography. Being, as a rule, distinctly harder than the adjoining strata, they stand up in ragged, serrated ridges, most commonly with a **d** northwesterly trend, and a nearly vertical attitude when their dip is determinable. They are very numerous east of the Dearborn river crossing, and have their finest development in the Bird Tail butte and several other similar sharply outlined ridges south of the Fort Benton-Helena stage-road, where their width may be at least 1,000 feet, their height above the adjoining valleys 800 feet, and their visible length about a mile. Four of these buttes are on a straight line, about five miles long, and seem to be points of stronger outbursts on a single fissure of varying width. All the submountainous topography of this region is due to the presence of the eruptive rocks; the sedimentaries still lie essentially horizontal until near the Dearborn river, and the smooth surface of the plains would undoubtedly extend 10 or 20 miles southwestward of its present limits if its erosion here has not been locally retarded by the hard dikes and sheets. When the erosion began the Cretaceous strata must have been at least as high as, and probably higher than, the present summits of the buttes and mesas; so we may infer a subsequent denudation **e** of at least 1,000 feet over all the neighboring plain country. The contemporaneous erosion over many of the adjoining mountain ranges must have been certainly vastly in excess of this measure, the difference in the two amounts being most likely due to their different altitudes above the level of drainage discharge.

The relation of the several features of the plains now described is of importance. Their comparatively smooth surface is not a form of original deposition, but results from the denudation of a broad sheet of strata, as is shown by the attitude of the mesas and dikes. There is every reason to think that this denudation is the work of rain and rivers; but in order that these agents should produce a smooth surface they must perseveringly act until their valleys widen and consume the intervening hills and reduce the surface nearly to the base level of erosion. It thus follows that the present elevated surface of the plains stood for a long period through Tertiary and early Quaternary time close to the level of drainage discharge. The same conclusion is suggested by the broad distribution of ice- **f** rafted boulders of northeastern origin. Subsequent to the general erosion and to the importation of the boulders, the plains gained their present elevation. We are, therefore, led by two independent lines of evidence toward the same series of events in the history of the plains.

After passing the main stream of the Dearborn river, the eruptive rocks decrease in strength, and their topographic force is replaced by the tilting of the bedded rocks. Cross-section 8 shows some moderate dislocation before reaching the river; but on crossing the Dearborn anticlinal, a distinct westerly dip is maintained almost without interruption 15 miles across strike, up the Middle fork to the divide at Cadotte's pass. If there were no repetition by faulting, the beds here seen would measure 40,000 feet. But repetition by faulting must necessarily occur, for the coal horizon is passed at the Dearborn, and Cambrian slates occur in the main ranges; the difficulty in the case lies in determining the lines of fracture. Nearly all the beds are without fossils, and, before reaching

a the mountains, broad areas of flat bench land are covered over with stony "wash" in which outcroppings are very rare. We have, therefore, to offer only a very general explanation of the mountain structure. The Upper Cretaceous, probably repeated by faults, may be considered as reaching up to Gillette's winter ranch, 6 miles beyond the strike of the coal outcrop. Here a projecting spur, southeast of Middle fork (not shown in section 8) is found, capped with hard sandstone, shales, and thin limestones, and flanked with greatly shattered masses of heavy limestone, in which the dip is very indistinct. This we have interpreted as marking a fault of enormous throw, by which the Cambrian quartzite and trilobite limestones are lifted up against the Upper Cretaceous; the uplift must measure 15,000 feet or more. The shattered limestone is probably Upper Carboniferous, caught in the fissure. The line of dislocation marking the separation of newer and older rocks does not, at this point, run with the prevailing strike of the
b district, but bears obliquely to the west, for the quartzite spur does not reach the Middle fork, and a ridge of the same quartzite, repeated a little farther southwest by a strike-fault of moderate throw, is cut off a little northwest of the stream. This quartzite ridge (see section 8) is overlaid by the same shales and thin-bedded limestones as were found on the spur; and although no trilobites were found here, even after much searching, the strata may pretty safely be regarded of Cambrian age. No higher rocks are found, for another strike-fault, again with uplift on the west like all the faults of this side of the mountains, brings up the variegated slates of the Lower Cambrian, which continue with fault-repetitions to the summit of the range.

An easy and well-marked Indian trail leads over Cadotte's pass, a continental divide, at an altitude of about 7,000 feet, and then descends south and southwest to the headwaters of the Little Blackfoot. The surrounding
c mountains reach a height of 9,000 feet or more, and are all composed, from valley bottom to summits, of the Cambrian strata. A mile or two after crossing the pass, the beds lose their southwest dip toward the axis of the range, and become horizontal, and a little further are elevated so as to dip northeast. Going down the Little Blackfoot the exposures soon become very poor, but when seen the northeast dip is still maintained, and the rocks could be better referred to the Cambrian than to any other formation, even beyond Lincoln, twenty miles from the divide. The upper part of the Little Blackfoot cañon, just below Lincoln, our farthest point southwest from the pass, still retained the northeasterly dip, and was still of slates and slaty limestones without fossils. The main range may therefore be regarded as a broad, flat synclinal of the oldest bedded rocks, repeatedly broken by faults generally parallel to its axis, with downthrow on the outer side. This structure is in marked contrast with that of the Big Belt mountains, and indeed is quite opposite to the conventional structure of a mountain range; but according
d to Mr. Pumpelly's observations, it persists for several hundred miles to the north. Within the mountain region eruptives appear but seldom, the Cambrian diabase being noted only in a few places.

Drainage.—The streams are here about square with or parallel to the strike of the rocks, and the cross-streams flow away from the synclinal axis on either side of the range. It may therefore be supposed that a longitudinal elevation was first formed on the mountain-line, determining the water-courses, as well as giving the Cambrian rocks here their considerable elevation; and that, at some later time, lateral uplifting and faulting produced the well-marked synclinal structure, but without sufficient violence to displace the streams. Old base-levels, cut by narrow stream-channels at many points, mark recent massive changes of elevation.

Local glacial action.—On descending the southwestern slope of Cadotte's pass and joining the upper waters of the Blackfoot, we passed the meadow of an extinct lake, now occupied by many beavers, and camped on a moraine
e barrier, about 6 miles from the pass. The moraine had numerous quartzitic stones that we had not seen in place, and many of them were well scratched. Good exposures of unstratified drift were seen in some fresh stream-cuts. It was at first supposed that the glacier which formed this moraine had come from the neighborhood of the pass; but further examination of the distribution of the drift, and its absence from the valleys near the main divide, showed that the ice-fields had been to the northwest instead, where the main range rose higher, and whence the glacier had followed lateral valleys down to the Blackfoot. Other moraines were seen near Lincoln. About Cadotte's pass there was no snow on the surrounding mountains in August; and on the eastern slopes no local glacial action was observed.

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APPENDIX A.—REMARKS ON THE FOSSILS IN THE FOLLOWING LISTS.

BY R. P. WHITFIELD.

There are four principal horizons represented among the following lots of fossils, namely, Potsdam or Primordial, Lower Carboniferous, Jurassic, and Cretaceous. The species of Potsdam fossils represent only one horizon or bed, so far as can be determined from the imperfect material. There are probably not more than three, or at the most four, species present in the whole, and I think most likely not more than two good species, as some of those marked as new (?) may possibly be the young of the larger forms. Still, with more critical study and comparison than is possible by looking over a single lot at a time, as I have had to do, there is much chance for error from recollection.

The Lower Carboniferous may be all of one horizon or bed; but there are evidences of more. In some of the lots there are forms which more properly characterize the Keokuk horizon than others. Of this kind *Spirifera*

striata may be said to be the most marked one. *Spirifera pseudolineata*, Hall, is another, and is present in only a **a**
very few lots. A second horizon is very much better represented in forms which are the same as those which are found in the Spergen Hill beds of Indiana and Illinois. These beds hold a position higher than the Keokuk beds, and as represented here would be equivalent to the Warsaw and Saint Louis horizons of the Mississippi River region. Many of the lots which contain several of the Spergen Hill species also contain forms which are more characteristic of the Chester limestone horizon. These contain the *Productus pileiformis*, McChesney, and *Spirifera setigera*, Hall, though it is possible, and even highly probable, that in this set of localities these forms all exist in a single bed or in a series of beds without zoölogical unconformity. A third set of lots I would call attention to, viz, those in which *Strophomena rhomboidalis* occurs. This series possesses features that would seem to ally its horizon more distinctly with the real Waverly group—Kinderhook group of Illinois Geological Reports. These beds **b**
appear to lie at the base of the Lower Carboniferous series, and it would be interesting to know if at these western localities they hold a similar position, or if the *Strophomena* passes entirely through the Lower Carboniferous formation.

There are a few of the fossils in these Lower Carboniferous layers represented which need particular mention in consequence of their peculiarities. Among these the *Streptorhynchus*, found in so many of the lots as to be nearly universal, is a most puzzling one. Among the individuals represented in the collections there are specimens which might be classed under several names. But as the forms of this genus are so very variable wherever found, I have not considered it of sufficient importance to indicate them by specific names in many, other than the first examined lots, and I think it more than probable that if the lots from each locality were collected together it would be **c**
found that all the forms are present from each of the distinct localities. The forms to which I refer represent *S.*, (*Orthis*) *æquivalvis*, Hall, and *inflatum*, White & Whitf., *S.* (*Orthis*) *Keokuk*, Hall, and *S. kaskaskiense*, McChesney, and *S.* (*Hemipronites*) *crassum*, M. & W. The first two are from the Waverly of the Iowa section, *S. Keokuk* from the Keokuk limestone, *S. kaskaskiense*, McChesney, from the Chester limestones, and *S. crassum*, usually found in the true Coal Measures, though recognized by Meek as common in the Chester beds both in the Mississippi valley and in West Virginia. *Spirifera centronata*, Winchell, is also a form which runs through most of these lots. In the Mississippi Valley region it characterizes the Waverly, and is seldom found above that horizon, but here it seems to be common everywhere, and I have found it to be the same in the Black Hills collections both from Captain Ludlow's expedition collection and from those brought back by the expedition under Henry Newton and W. P. Jenney. **d**

There seems to be a remarkable absence of forms which characterize the Coal Measures of other regions of the Rocky mountains. This is more particularly the case than among any collections which I have ever examined from this range of mountains.

The Jurassic species appear to be all from a single horizon, and might be supposed to have come from a single locality as far as any diversity of character among them is concerned. An absence of the sandstones so abundant among the Black Hills Jura is a remarkable feature.

The Cretaceous fossils are apparently all from a single horizon, and would be classed as No. 2 generally, although they partake somewhat of No. 3, so that I am inclined to think that both horizons are here blended together.

List of fossils from central Montana, determined by R. P. Whitfield. **e**

[The numbers of sections and fossil localities here given agree with those on Mr. Davis' Figs. 238 and 239.]

Section.	Number.	Description.	Formation.
1. Yellowstone Lower cañon	1	Cast of Ostrea or Gryphæa	Cretaceous, 2 or 3.
		Imprint of Inoceramus undabundus	
	2	Camptonectes extenuatus, M.?	Jurassic.
		Camptonectes bellistriata, M. & H.	
		Gervillia Montanensis, Meek	
		Gervillia, sp. nov	
		Perna	
		Pinna, sp. nov	
		Grammatodon inornatus, M. & H	
		Lucina, sp. nov	
		Tancredia? sp. undes	
		Pholadomya Kingi, Meek?	
		Ammonites cordiformis, var. *distans*; and a fragment.	
		Mytilus Whitii, Whitf.?	
		Homomya? sp. nov	
		?——, like Tellina; gen. and sp. nov	
		Ostrea strigilecula, White	
		Pleuromya subcompressa, Meek; M. & H	
		?——, like Perna; gen. and sp. nov	
		Pinna? fragments	
		Volsella subimbricata? M	
		Pecten? fragment of a large costated sp	

List of fossils from central Montana, determined by R. P. Whitfield—Continued.

Section.	Number.	Description.	Formation.
1. Yellowstone Lower cañon	2	Trigonia Montanensis, M.?; fragment	
		Trigonia, sp. nov	
		?——, Bivalve; gen. and sp. nov	
		Corbula, sp.?	
		?——, two new forms; gen. and sp. nov	
		Goniomya Montanensis, Meek	
		——, allied to *Goniomya*; sp. nov	
		——, allied to *Goniomya*; gen. and sp. nov	
		——, allied to *Astarte Packardi*, White	
		Naticops, sp.?; internal cast	
		Echinoid, new form	
	3	Syringopora	Loose fragments; Lower Carboniferous, with last specimen Jurassic.
		Conophyllum, like *C. Sedaliensis*, White	
		Spirifera Rockymontana?	
		One specimen with Grammatodon inornatus, M?	
	4	Streptorhynchus, fragment very large	Lower Carboniferous.
		Spirifera centronata, Winchell	
1 A. South of Muir	5	Pinna Lakesi, W.?	Cretaceous, 2 or 3.
		Inoceramus umbonatus, M. & H.?	
		Inoceramus problematicus	
		Inoceramus undabundus	
		Inoceramus, fragments	
		Ostrea congesta, Con.?; perhaps a Gryphæa	
		——, resembling *Mactra Siouxensis*, Meek	
		Ostrea strigilecula, White	
		Ostrea or Exogyra, sp.?	
		Natica, sp.?; imperfect casts	
		——, like Turritella, casts	
		Exogyra, sp.?; possibly young of *Ex. costata*	
		Gryphæa, probably like *G. vesicularis*, Lam. (Meek.), but more likely an undescribed species, as it is not vesiculose.	
		Gyrodes depressa, Conr	
		Ostrea congesta, Conr	
		Pteria, sp.?; like *Pt. linguiformis*	
		Pholadomya Berthoudi, White	
		Naticopsis (Gyrodes) depressus, M. & H	
		Glycimeris Berthoudi, White	
		Panopea or Glycimeris, possibly young of *Gl. Berthoudi*.	
		Belemnite, poor specimen; Jurassic?	
2. Flathead pass, Bridger range	6	Ostrea or Gyphæa, small fragments	Jurassic.
		Camptonectes bellistriata, M. & H	
		Bivalves, indeterminate	
	7	Spirifera Rockymontana, Marcou	Horizon of Coal Measures, but in Rocky Mountain region often in top of Lower Carboniferous.
		Athyris subtilita, Hall	
	8	Crinoidal fragments	Lower Carboniferous.
		Syringopora, as in (3)	
		Fenestella, sp.?	
		Stictopora, as in (18), (34), (35)	
		Spirifera centronata, W	
		Spirifera, like *Rockymontana*	
		Athyris, sp. indet	
		Rhynchonella mutata, H	
		Platycrinus, sp. like (19)	
		Bryozoans	
		Chonetes Illinoisensis, M. & W	
		Spiriferina spinosa, fragment	
		Platyceras, sp.?; like *P. acutirostris*, H	
	9	Productus Rogersi, N. & P	Should be Coal Measures.
3. Wall mountain	10	Syringothyris	Lower Carboniferous.
		Zaphrentis centralis, Ed. & H.?	
		Streptorhynchus, as in others	
		Spirifera striata, Sow	
	11	Streptorhynchus, as in others	Base of Lower Carboniferous. Waverly.
		Productus, like *P. hirsutus*, H	
		Productus, like *P. elegans*, N. & P	
		Spirifera centronata, Winch	
		Spirifera setigera, H	
		Spirifera lineata, Mart	
		Orthis Michelina	Lower Carboniferous.

List of fossils from central Montana, determined by R. P. Whitfield—Continued.

Section.	Number.	Description.	Formation.
3. **Wall mountain**		Chonetes, sp. ?	
		Productus, small sp., as in (19), (20), (13)	
		Productus, like *P. Nebrascensis*, Owen, but flat	
	12	Fenestella, as in (34), (35), (23), (19), (18)	
		Stictopora, as in (34), (35), (18)	
		Trematopora, sp. undescr	
	13	Crinoidal remains	
		Productus, sp. nov., as in (19), (20)	
		Productus, like *P. Nebrascensis*, Owen	
		Spirifera centronata, W	
		Spirifera setigera, H	
		Orthis, sp. ? young of O. Michelina ?	
		Streptorhynchus, as in others	
		Chonetes, like *Ch. planumbona*, M. & W	
		Eumetria Verneuiliana, H	
		Rhynchonella mutata ? H	
		Terebratula turgida, H	
	14	Lithostrotion ?	
		Cyathoxonia, sp. undescr	Lower Carboniferous, probably low down, but containing evidence of higher beds as well.
		Productus semireticulatus ?	
		Productus semireticulatus ? Mart, variety	
		Productus, like *P. Indianensis*, H	
		Athyris sublamellosa, H ?	
		Platyceras, like *P. symmetricus*	
		Platyceras acutirostris, H ?	
		Orthis, sp. indet	
		Spirifera centronata, W	
		Sp. pseudolineata, H	
		Spirifera striata, Mart	
		Sp. *setigera*, *H*	
		Eumetria Verneuiliana, H	
		Rhynchonella mutata, H	
		Terebratula turgida, H	
		Crinoidal remains	
		Stictopora, sp. undescr	
		Glauconome, as in other lots	
		Orthis, small, like *O. Michelina*	
		Strophomena rhomboidalis, Wahl	
		Retzia punctulifera, Shum	
		Aviculopecten, sp. ?	
		Allorisma, sp. ?	
		Schizodus, sp. ?	
	15	Zaphrentis, sp. ?	Probably very base of Lower Carboniferous, but has a decidedly Devonian aspect.
		Orthis, imperfect, like *O. Michelina*, D K	
		Streptorhynchus, large, sp. ?	
		Strophomena rhomboidalis, Wahl	
		Productus, like *P. spinulicosta*, H	
		Productus semireticulatus, Mart	
		Spirifera centronata, Winch	
		——, like young of *Atrypa reticularis*, cast	
		Euomphalus, sp. indet	
	16	A single shell, like *Obolella*	Potsdam ?
		Fragments of trilobites	
	17	Conocephalites	
Section 4. Little Belt, west of Barker	18	Lingula, sp. ?	Lower Carboniferous. Some of these are marked like Spergen Hill beds, Indiana, and Warsaw and Saint Louis limestones.
		Productus tenuicostatus, H. ?	
		Fenestella, sp. Nos. 1 and 2	
		Stictopora, like Spergen Hill, sp	
		Rhynchonella mutata, H. ?	
		Productus tenuicostatus, H	
		Athyris trinucleata, H	
		Eumetria Verneuiliana, H	
		Rhynchonella mutata, H. ?	
		Terebratula turgida, H	
		Allorisma, sp. undes. ?; allied to *A. sinuata*, McCh.	
	19	A bold limestone bluff on Dry Fork, Belt creek, 6 miles below Barker, yielding fossils, collected in groups, as follows:	
		About 350 feet above base:	
		Michelina expansa, White	Lower Carboniferous, with a decidedly Waverly aspect in some of the lots, approaching Devonian, while many of the fossils indicate a Keokuk and Warsaw limestone horizon.
		Streptorhynchus, resemb. *S. Chemungensis*, Con	
		Orthis Michelina, L'Eveille	
		Productus, sp. closely resemb. *P. hirsutus*, Hall.	

List of fossils from central Montana, determined by R. P. Whitfield—Continued.

Section.	Number.	Description.	Formation.
Section 4, Little Belt, west of Barker.	19	Productus, sp. ?; small species, probably undescribed.	
		Spirifera centronata, Winchell	
		Crinoid stems and plate, *Platycrinus?*	
		About 220 feet above base:	
		Streptorhynchus, as above	
		Chonetes Illinoisensis, M. & W	
		Spirifera centronata, Winchell	
		Spirifera setigera, Hall	
		Spiriferina spinosa, N. & P	
		About 200 feet above base:	
		Plates of Crinoides, *Platycrinus?*	
		Streptorhynchus, as above	
		Chonetes Illinoisensis, M. & W	
		Spirifera centronata, Winchell	
		Eumetria Verneuiliana, Hall	
		Rhynchonella mutata, Hall?	
		Productus semireticulatus, Mart	
		Productus, small species as in No. 1	
		Bellerophon, sp. ?; internal cast only	
		About 170 feet above base:	
		Streptorhynchus, as above	
		Chonetes Illinoisensis, M. & W	
		Spirifera setigira, Hall	
		Spiriferina spinosa, N. & P	
		Athyris, sp. too poor for determination	
		Terebratula formosa, Hall	
		Zaphrentis, sp.; *Z. centralis*, Ed. & Haime?	
		Crinoid columns	
		Streptorhynchus, somewhat resembles *S. crassum*, M. & W.	
		Productus semireticulatus, Mart	
		Productus pileiformis, McChes	
		Productus, sp. allied to *P. Nebrascensis*, Owen	
		Spirifera centronata, Winchell	
		Spirifera setigera, Hall, res. *Sp. pseudolineata*, Hall.	
		Athyris hirsuta, Hall	
		Eumetria Verneuiliana, Hall	
		Rhynchonella, sp. ?; new form	
		Platyceras, sp. ?	
		Pleurotomaria, sp., new	
		About 130 feet above base:	
		Streptorhynchus, as in first	
		Chonetes Illinoisensis, M. & W	
		Productus semireticulatus, Mart	
		Spirifera setigera, Hall	
		Eumetria Verneuiliana, Hall	
		Fifty to 100 feet:	
		Zaphrentis, sp. resemb. *Z. centralis*, Ed. & H	**This lot always appeared to me to have been mislabeled, as it accords so well in its Bryozoa with lots from a different locality. Otherwise it agrees with these. R. P. W.**
		Platycrinus, sp. new; same as plates in other lots.	
		Polypora, sp. ?	
		Fenestella, sp. ?	
		Glauconome, sp	
		Strophomena rhomboidalis, Whal	
		Productus pileiformis, McChes	
		Productus semireticulatus, Mart	
		Productus, sp. ? resembl. *P. Nebrascensis*, Owen	
		Spiriferina spinosa, N. & P	
		Eumetria Verneuiliana, Hall	
		Athyris hirsuta, Hall ?	
		Terebratula formosa, Hall	
		Euomphalus laxus, White	
		Loxonema, sp. ?	
		Chonetes, sp. ? resembl. *C. planumbona*, M. & W.	
		Streptorhynchus crassum, M. & W. ?	
		Productus Nebrascensis, Owen ?	
		Productus Prattenanus, Norwood ?	
		Spirifera centronata, Winchell	
		Spirifera (Martinia) lineata = ? *S. planoconvexa*, Sh.	

List of fossils from central Montana, determined by R. P. Whitfield—Continued.

Section.	Number.	Description.	Formation.
Section 4, Little Belt, west of Barker..	19	Athyris, sp. like *A. subtilita*, Hall	
		Athyris, sp.? like *A. planosulcata*, Phil........	
		Syringopora, sp.?	
		Chonetes planumbona, M. & W.?	
		Productus, sp.?	
		Spirifera, like *S. striata*, Mart	
		Spirifera Rockymontana, Marcou	
		Rhynchonella, sp.?	
		Terebratula formosa, Hall	
		Platyceras acutirostris, Hall...................	
		Zaphrentis, sp.? like *Z. centralis*, Ed. & H......	
		Cyathophylloid coral, genus undetermined	
		Lithostrotion, sp.?	
		Spirifera, sp.? like *S. Rockymontana*, Marcou...	
		Spirifera? possibly dorsal value of a *Syringothyris*, sp.?	
		Naticopsis or Euomphalus, very imperfect......	
	20	Streptorhynchus, as in other lots..............	Lower Carboniferous.
		Chonetes Illinoisensis	
		Chonetes, like *C. planumbona*, M. & W.........	
		Productus, like *P. Nebrascensis*, id. like (19)....	
		Productus semireticulàtus, Mart	
		Spiriferina spinosa, N. & P....................	
		Zaphrentis centralis, Ed. & H.?	
		Fenestelloids	
		Trematopora, like *Bryozoans*	
		Stictopora, as in other lots....................	
		Terebratula formosa, H. (a little doubtful)......	
		Spiriferina centronata, W.....................	
		Athyris hirsuta, H., very large, approaching *A. sublamellosa*, H.	
	21	Zaphrentis, sp. unknown	Somewhat the aspect of Upper Carboniferous; may be top of Lower Carboniferous, or possibly Coal Measures.
		Fenestella, sp. undet	
		Spirifera, like *S. centronata*	
		Spiriferina, perhaps *S. Kentuckensis*	
		Spiriferina, perhaps *S. spinosa*	
		Athyris, like *A. subtilita*	
		Rhynchonella mutata, H.......................	
		Orthis, like *O. Michelina*	
		Favosites, or Chætetes, small cells, sp.?.......	
		Streptorhynchus	
	22	Conocephalites, two sp........................	Potsdam.
5. Little Belt mountains, Otter creek.	23	Fenestella	Lower Carboniferous.
		Fragt. Zaphrentis.............................	
		Spirifera centronata, Winch	
	24	Syringopora	
		Zaphrentis....................................	
		Streptorhynchus, as in other lots..............	
		Orthis dubia, H...............................	
		Spirifera striata...............................	
		Chonetes, fragments...........................	
		Athyris, fragments	
		Terebratula, = T. turgida?.....................	
		Rhynchonella mutata, H.......................	
		Bellerophon...................................	
	25	Dikellocephalus, sp. nov., like *D. Minnesotensis*.	Potsdam; probably higher than other Potsdam rocks.
		Conocephalites, sp. nov........................	
6. Big Belt mountains, Benton gulch..	26	Conocephalites, sp. nov.......................	Potsdam.
		Conocephalites, like *C. minor*, Shum	
7. Big Belt mountains, Boulder creek.	27	Hyolithes, primordialis, Hall?	Potsdam.
		Hyolithes, like *H. gregarius*...................	
		Crepicephalus, sp. undescr	
		Trilobite fragments............................	
		Orthis Michelina...............................	Lower Carboniferous.
		Chonetes Illinoisensis, M. & W................	
		Chonetes, small, like *C. setigera*, H..........	
		Platycrinus....................................	
		Spirifera centronata, Winch	
		[These are from a disordered region but we supposed them to be all one formation. W.M.D.]	

a *List of fossils from central Montana, determined by R. P. Whitfield*—Continued.

	Section.	Number.	Description.	Formation.
	3. Main range	29	Fragments, apparently of an oyster	Indet. Mesozoic.
	4. Highwood mountains	30	Ostrea, fragments, may be *O. congesta*, Conr	Cretaceous.
			Ostrea congesta	
			Inoceramus, doubtful sp	
			Fish-bones and scales	
			Inoceramus, sp. nov	
		31	Fragment of bivalve shell, like *Unio*	
b			——, possibly Oxytoma mucronata, M. & H.; if so, is Jurassic.	
			Plants	
		32	Cast of Bivalve, like *Sphæriola?*	Cretaceous?
			Ostrea congesta, Conr.?	
			? Imprint of Ammonite?	
	6. Dry range	33	Chætetes or sponge	Lower Carboniferous.
			Fragments of Zaphrentis?	
			Productus pileiformis, McCh	
			Productus semireticulatus, Mart., form like P. bimesialis, H.	
			Spirifera centronata, W	
			Spirifera striata	
			Spirifera, like *S. lineata*, Mart	
c			Rhynchonella mutata, H	
			Rhynchonella, sp.? new to Lower Carb., very closely like Silurian form.	
		34	Zaphrentis, imperfect	Near base of Lower Carboniferous or Waverly.
			Fenestella	
			Glauconome	
			Streptorhynchus, like *S. crassum*, M. & W	
			Productus, like P. bimesialis, H	
			Spirifera centronata, W	
			Spirifera pseudolineata, H., or setigera, H	
			Spirifera planoconvexa, Shum.?	
			Athyris hirsuta, H	
			Rhynchonella, sp. undet	
d			Euomphalus, like *E. laxus*, White	
		35	Fenestella, as in (34); Glauconome, as in (34)	Lower Carboniferous.
			Streptorhynchus, very small sp	
			Strophomena rhomboidalis, Wahl	
			Productus, a form of *P. semireticulatus*, Mart	
			Productus, like *P. Shumardi*, H	
			Spirifera setigera, H	
			Spirifera, sp.? like *S. scobinata*, Meek	
			Spirifera centronata, W. (young)	
			Athyris or Nucleospira	
			Rhynchonella mutata, H	
			Rhynchonella, sp. nov., remarkable form	
e			Terebratula sp.? large form, like *T. inornata*, McCh., but truncated in front; not T. turgida, H.	
			Terebratula formosa, H	
			Platyceras, like *P. ammon*, W. & W	
	—— Mullen pass	......	On pass, Spirifera centronata, W	
			On limestone range, 3 miles west, Spirifera striata.	
	In valley of Little Blackfoot river, 2 miles above Logan's ranch.	......	Ostrea strigilecula, White	
			Camptonectes, indistinct, like *C. extenuatus*, Whitf.	Jurassic.
			Pectenoid shell, like *Entolium*, but probably new genus, possibly a Syncyclonema.	
			P. meleagrinella curta, M. & H., sp	
f			Tancredia?	
			Pentacrinites asteriscus, M. & H	

APPENDIX B.—ERUPTIVE ROCKS.

By Waldemar Lindgren.

Engaged as assistant geologist to the Northern Transcontinental Survey early in the summer of 1883, I was assigned to the party of Mr. W. M. Davis, sent out to study the lower strata of Paleozoic and Mesozoic age and their relation to the coal-bearing series on the eastern slope of the Rocky mountains in Montana. The eruptive rocks in the districts traversed being of great interest and importance, I found time and opportunity to give some attention to them. The field-notes relating to them, accompanied by the results of the microscopal and chemical examinations, are added here as an appendix to Mr. Davis's report on the general stratigraphy and paleontology. To Mr. Davis I am greatly indebted for many valuable field-notes. The short time at my disposal and the great diversity of rocks may perhaps be an excuse for the often incomplete and cursory character of the examinations.

At first a few remarks on the general topography and geology:

Topography.—The Rocky mountains occupy the western part of Montana, with a general trend to the northwest, or somewhat more to the north; the eastern slope runs between longitude 109° W. (Clark's Fork mountains) and 114° W., where the chain crosses the frontier of British Columbia. In their southern and middle parts, however, they do not form a continuous range or straight line of uplift, but are broken up in many detached mountain groups, separated by the numerous rivers which have their headwaters in this region. Thus, the main divide between the Pacific and gulf of Mexico does not run parallel to the eastern slope of the mountains; it crosses the Idaho boundary line at 114° W. again, but runs very irregularly in the southern part of its course.

In the south, toward the Wyoming boundary-line, the Snow mountains and Clark's Fork mountains rise to from 10,000 to 11,000 feet of altitude. Pryor and Big Horn mountains stretch far out eastward and branch off into Wyoming. The lower ranges of the Snow mountains cross the Yellowstone river at its sharp bend southward from the pass of Spring or Rocky cañon, through which the Northern Pacific railroad runs, and now trend northward as the well-defined Bridger range, the divide between the Yellowstone and Gallatin rivers. In front of the Bridger range, and separated from it by the broad Shields River valley, stands the rugged group of Crazy mountains, with their peaks 10,000 feet high, and which continue northward in the lower Elk mountains. Westward lies the fertile and extensive Gallatin valley, with the three forks of the Missouri and the lower ranges across the river; southward, a long and glittering sky-line of snowy peaks toward the Idaho line.

The Bridger range is continued northward in the mountains of Sixteen Mile creek, and these in their turn by the Big Belt range (maximum altitude about 10,000 feet), which at last flattens and disappears above the easterly bend of the Missouri. East of the Big Belt, and not very distinctly separated from it, we have the Little Belt range, stretching out for 50 miles, sloping down northward toward the great plains south of the Missouri and connecting in the south with the Elk mountains. In front of the Little Belt range there are the isolated masses of the Big Snowy, Judith, and Moccasin mountains; north of the Missouri, again, the lonely group of the Bear-paw mountains.

From the bend of the Missouri, from a northerly to an easterly course, however, the character changes; the outlying sentinel mountain groups disappear, and instead we have one continuous chain, at the same time forming the main divide, rising boldly and abruptly from the great plains. This main range runs far north into British Columbia, with a general trend of north-northwest; its peaks and summits toward the British frontier are covered by snow- and ice-fields.

General geology.—It is difficult to sketch, in brief outlines, the complicated and diverse geology of Montana, especially as our knowledge of it still is in a very imperfect and rudimentary state. What we know about it, up to the present time, is chiefly due to the explorations of Messrs. Hayden and Peale, and this knowledge is mainly confined to the southern and eastern portion of the mountains. Of the northern and western parts only a few dominant and general features are yet discovered. The geological maps of Montana, published in the reports of the survey of the territories, only indicate the structure in a very general manner, and parts of them are exceedingly incorrect. The time to construct an approximately accurate map has certainly not yet arrived.

As everywhere on the eastern slope of the Rocky mountains, we find in Montana a perfectly conformable series, extending from the Cambrian, resting upon unconformable Laurentian gneiss, up to the Cretaceous, including the much-disputed upper member of that group, the Laramie. Near, and in, the mountains, presumably close to the old shoreline, the Cretaceous and Laramie attain an enormous development.

It must be remembered that Mr. Hayden's Eocene is equivalent to the Laramie or coal-bearing formation.

From the plains in front of the mountains where, in a few places, the Laramie is exposed, with a thickness of 8,000 to 9,000 feet, it can be directly traced up toward the mountains. The sediments there growing coarser and thicker, and very poor in fossils, it naturally becomes difficult to recognize and trace the subdivisions in the Cretaceous group elsewhere established.

Far out in the plains we notice the first slight disturbances in the Cretaceous. As we come nearer to the mountains they grow larger and more pronounced, till they finally appear as those enormous synclinals and anticlinals, now deeply eroded and cut, which constitute the predominant feature of the mountains. Often the larger folds are suddenly cut off and faulted, showing the lower strata in direct contact with the younger Cretaceous.

a The Carboniferous limestone is laid bare by erosion on a large scale, and the task of the geologist to trace this great limestone sheet, with its complicated wrinkles and folds, is not always an easy one.

The Big Horn, Pryor, and Clark's Forks mountains are all more or less clearly anticlinal uplifts. The latter group, as far as our knowledge of it goes, is considerably faulted toward the northern edge, and the center occupied by older slates, Azoic rocks, and granite.

The sheet of Carboniferous limestone, with Jurassic and Cretaceous strata above, forms a portion of the foothills of the Snowy mountains, crosses the Yellowstone above Livingstone, and runs northward, forming the well-pronounced Bridger range, here having changed to a nearly vertical position. The valleys on both sides are occupied by Laramie layers. Northward again the limestone flattens, forming the great synclinal of Sixteen-Mile creek, with the Cretaceous in the middle of the basin, swelling up westward to the remarkable anticlinal of the
b Three Forks of the Missouri, rising also northward and mantling the southern end of the gigantic, compressed anticlinal of Big Belt mountains, composed of Cambrian slates. North of Diamond City this anticlinal submerges again under the now slightly-inclined limestones of the lower Missouri and Smith's River cañon.

Somewhat north of the great bend of the Missouri the limestones sink in their turn under the Cretaceous strata of the great plains. The broad valley of the Missouri, between the two cañons, is now filled with the deposits of a quaternary lake.

Topographically and geologically closely connected with the Big Belt is the Little Belt range. Generally speaking it is an anticlinal uplift. Northward, around the Barker mining district, the sheet of Carboniferous appears soon to sink as usual with gentle dip under the Mesozoic strata of the plains. The interior seems much faulted, and to great extent made up of Silurian sandstones; even the Laurentian gneisses are exposed at one place.
c Andesitic eruptions play an important part on the northern slope, and probably, also, on the southern; the far extending eastern slope is little known, but presumably also has the Carboniferous and Jurassic strata exposed along the border.

The free-standing groups of the Judith, Moccasin, Bear-paw, and Big Snowy mountains are all anticlinals, generally dome-shaped elevations. The latter, opposite the Little Belt, is broken on its southern edge by a fault-line, bringing the Laramie in contact with the Carboniferous.

The isolated groups of the Highwood and the Crazy mountains are of partially volcanic origin.

From the point, though, where the Missouri leaves its limestone cañon and changes its northerly course to northeast, making a bend of about 100°, we notice a most marked change in the geological structure. In traveling toward the now sharply-defined main range, the Cretaceous strata are seen steadily dipping to the west, and cut
d by numerous dikes of younger eruptive rocks. At the base of the mountains we find a large fault, bringing up, Cambrian slates, and sometimes a zone of Carboniferous limestone on a level with the late Cretaceous deposits. This remarkable and long fault-line has been found by Mr. Dawson in British Columbia, by Mr. Pumpelly at Marias pass, and by our party at Cadotte's pass.

ERUPTIVE ROCKS FROM LITTLE BELT MOUNTAINS.

(Hornblende dacites and mica-augite-trachytes.)

The interior part of Little Belt around the sources of Belt creek is extensively covered by Silurian sandstone
e equivalent to the Potsdam sandstone. This at Neihart is seen unconformably covering the Laurentian gneisses; the gneiss is traversed by a number of granite dikes, with coarse structure and flesh-colored feldspar. I have nowhere seen these dikes extend up into the overlying Silurian sandstone, and their age must consequently be fixed as pre-Silurian. Small fissure veins with silver ores traverse the gneiss and the sandstone.

Following Belt creek down some miles northward we come to a beautiful plateau or park, formed by this same sandstone, in which the creek has cut a cañon 500 feet deep with steep sides. The west side of the park is bordered by Tillinghast creek, flowing into Belt creek some miles farther down.

The Paleozoic limestone appears here again on a grand scale. It forms the mountains west, north, and east of the park, covering the country as a 3,000-foot, heavy, slightly inclined sheet, in which the creeks have cut down deep cañons with abrupt, fortress-like walls.

f This region is characterized by numerous and large eruptions of a quartziferous hornblende-andesite or hornblende-dacite. The dacite breaks through Carboniferous limestone, and appears, not as dikes, but as large, compact bodies, pushing up and disturbing the immediately surrounding strata. Dikes of dacite probably appear besides these massive eruptions, although I did not succeed in finding any.

The first great massive is the mountain closely west of Tillinghast creek. Seen from the Park it looks like a long, broad elevation, rising about 100 feet above the creek. The mass is 2 miles long, and perhaps 1 mile broad. The contacts are well exposed, and show very clearly how the eruption affected the surrounding Carboniferous and lower limestone; the whole can be compared with nothing but an enormous "plug" driven up through the sediments. It does not disturb the sedimentary rocks to a great extent; its only action has generally been to turn up, perhaps even reverse, the edges of the surrounding, generally nearly horizontal, strata for a distance of one thousand or two thousand feet.

Close to one contact on the eastern side a black, somewhat metamorphosed Silurian (?) slate was seen dipping 15° *toward* the eruptive; actual contact not seen.

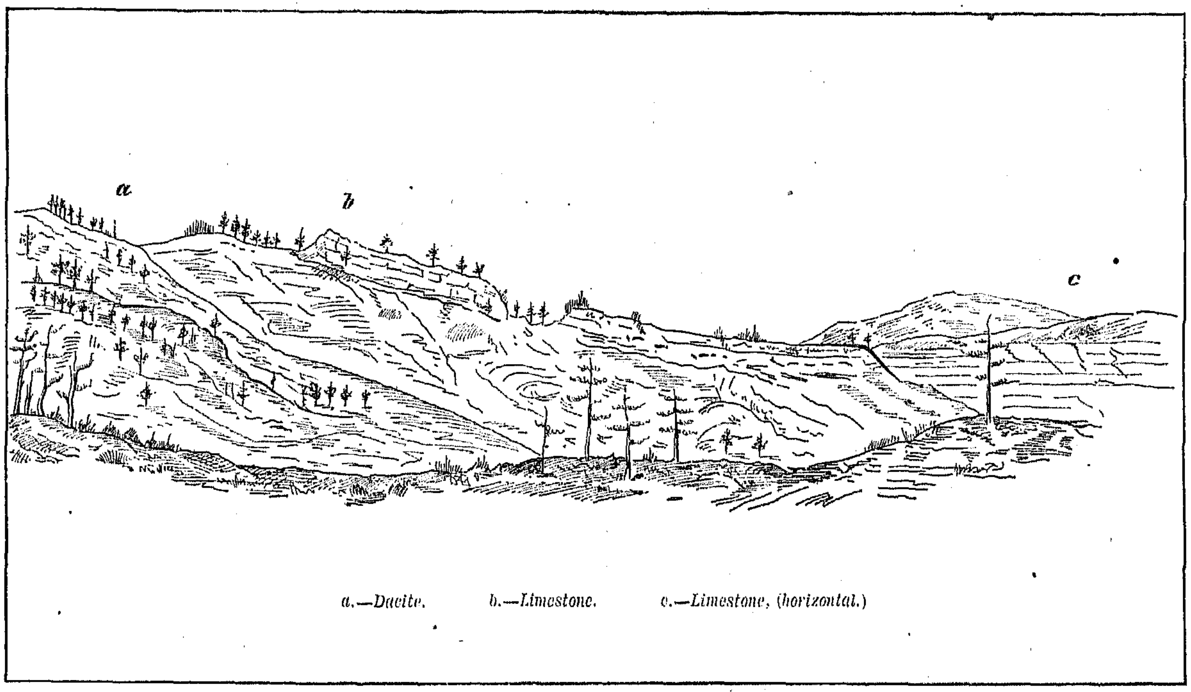


FIG. 240.—CONTACT OF HORNBLENDE-DACITE AND CARBONIFEROUS LIMESTONES. TILLINGHAST CREEK, LITTLE BELT MOUNTAINS, MONTANA.

Contact at southern end 590 feet above the creek (Fig. 241): At the contact very steep-dipping limestone, decomposed where it touches the also decomposed eruptive; in a few hundred feet distance the dip has flattened out again.

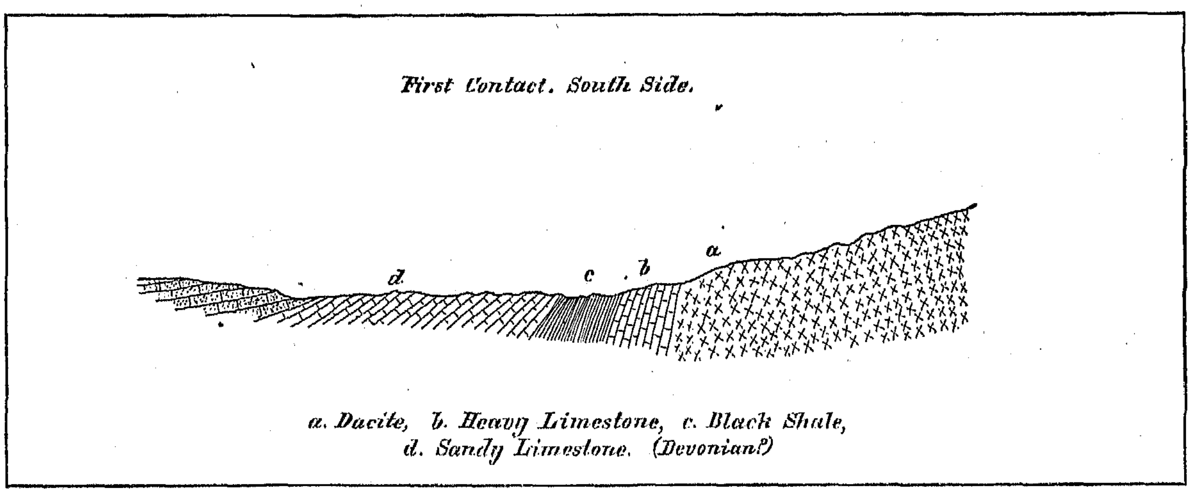
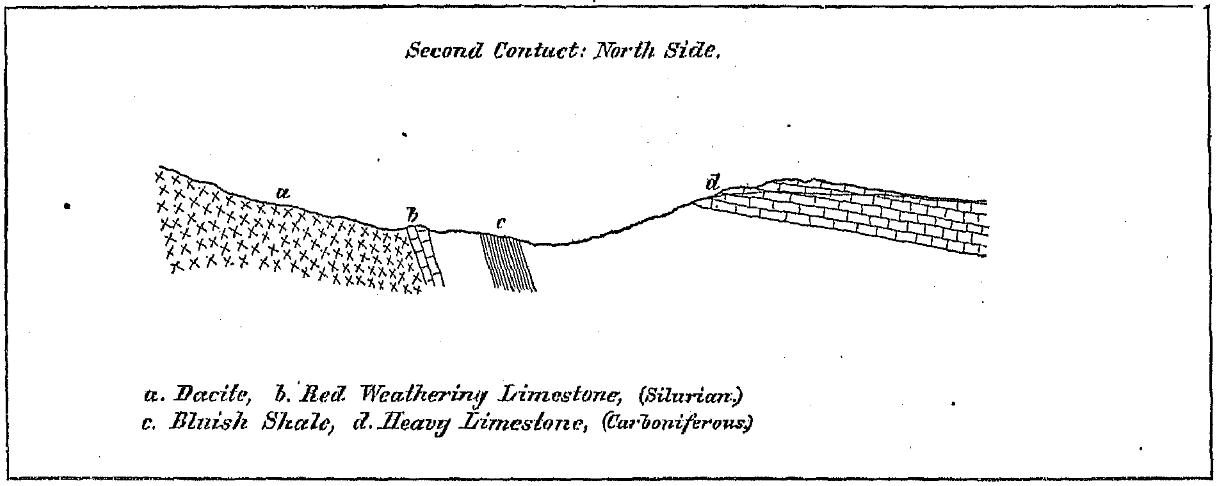


FIG. 241.

Contact at northern end (Fig. 242): Actual contact not seen; near it, however, a steep-dipping, red-weathered Silurian (?) limestone and conglomerate; a few hundred feet from this place only a slight dip northward shown by the heavy Carboniferous limestone. Fig. 240 is a view at the north end showing the beautiful curved form of a heavy limestone bench near the eruptive. Nowhere are there signs of intrusive sheets or overflows. The whole is doubtlessly very much eroded, and we have here only the nucleus—the lower interior part of a perhaps originally far more extensive eruption. As to its age, the strata here only give evidence of its being post-Carboniferous; there is, however, abundant proof—beside the microscopic diagnosis—for pronouncing the eruptive of a Laramie or later age. (See beyond under Highwood mountains and Dearborn district.)

a Farther west, beyond this eruptive, there seems to be others of the same character, but the time did not allow our exploring of that region. At Belt creek, on the other side of the Park, a similar rock, but quartz free, consequently hornblende-andesite, was found loose; the dike or massive from which the pieces have come could not be found.

b



c

FIG. 242.

A dike of apparently typical mica-augite minette crosses Belt creek about 6 miles below the mining town of Barker, and protrudes like a sheet in the ravine leading down to the creek.

Hornblende-dacite.—(1) Tillinghast eruptive. Yellowish-gray color; porphyritic habitus. Crystals of a glassy feldspar, and a smaller variety of a yellow color. Throughout the mass, evenly but not copiously distributed, brown mica and hornblende needles 1 to 2^{mm} long and 0.2^{mm} thick; a few small quartz crystals; all embedded in a d grayish groundmass. The quantity of hornblende and mica varies somewhat, and occasionally, in some parts of the eruptive, goes so high as to impart a greenish color to the specimen. Sometimes the glassy feldspar is absent.

Thin section: In a grey groundmass are embedded sanidine; few, but larger, fresh crystals, mostly rounded, showing the cracked surface and zonar extinction of the sanidine; these are the glassy feldspars. In order to prove them conclusively as sanidines a small portion was isolated, powdered, and the angles of extinction in the faces of O P and $\infty P \breve{\infty}$, measured on the thus-formed microscopic cleavage. They were found to be 0° or 5° to 6°, consequently corresponding to sanidine.

Plagioclase is the predominating feldspar; general form, short rectangular or prismatic; striation, very narrow; often two systems crossing each other; colors of polarization, dull grayish. Angle of extinction between two adjacent, hemitropic bands in zone perpendicular to $\infty P \breve{\infty}$, measured up to 34°, or $17^{\circ}+17^{\circ}$. This feldspar is e consequently most probably *oligoclase.*

In some sections besides this there also occurs a small number of another kind of plagioclase, presumably more approaching the labradorite. Long rectangular form, always very decomposed, and always, at usual thickness of section, shows the colors of polarization—light brown, deep blue. Polysynthetic twin structure often missing; when occurring, very fine.

Quartz in irregular, rounded grain, clear as usual, and carrying a great number of fluid inclusions with moving bubbles, and also gas-pores. Glass inclusions rare. As to the quartz and its relation to the groundmass, see farther down. The mica is brownish-green, very fresh, with strong absorption. Hornblende often very decomposed into viridite and filled with opacite; when fresh with splendid cleavage and not very strong absortion: $c > b > a$; c, grayish brown; b, yellowish brown; a, yellowish green. In some sections hornblende, in others mica, is prevailing. f Augite occurs in two sections sparingly, in small, light green, fresh prisms. Apatite, with its usual characteristics, is also sometimes present.

All these minerals are imbedded in a micro- to crypto-crystalline groundmass of quartz and feldspar; sometimes it is almost impossible, even with high power, to resolve it; sometimes it appears already under No. 4 Hartnack as a clear micro-crystalline aggregate. Between the single grains some very small remains of glass may occasionally be observed. This variety of dacite is to be referred to Doelters "porphyritic dacites" in his classification of the Hungarian rocks. In all of the specimens quartz is largely represented, and always has a tendency to granophyric structure.

I do not know that this structure has been noticed before in dacites. In some sections the quartz-grains appear, so to speak, crushed, all the fragments being perfectly parallel in their optical orientation. The intervening space is filled by feldspar. From this we notice transition down to a complete granophyric structure of the groundmass. The groundmass contains a network of quartz, with included feldspar, and is divided into irregular a portions, in which the quartz crystals extinguish simultaneously. In one section all of the larger quartz crystals have the same structure.

A determination of SiO_2 in one variety, rather rich in hornblende, gave $SiO_2 = 64$ per cent.

The age of this dacite is sufficiently proved by the occurrence of precisely the same rock in Laramie conglomerate of Highwood mountains, and as dikes in Laramie strata near the main range.

In Little Belt, this type is furthermore represented by a large massive eruption, 3 miles north of Dry fork of Belt creek, near the Summit stage-station, on the road from Barker to Fort Benton. It here cuts through the edge of the Carboniferous limestone just before it disappears under the flat, Mesozoic strata of the plains and shows, only not quite so clearly, disturbances at the contact analogous to what we already have described from the b Tillinghast eruptive.

Another type is the above-mentioned rock found loose on the slope of the hills near Belt creek. Macroscopically a greenish gray, fine granular substance, showing thin hornblende crystals in a white feldspar groundmass.

Thin section.—Long crystals of the common, green hornblende, few biotites and rare quartz grains in a perfectly crystalline mass of plagioclase, sometimes with prismatic outlines. Sometimes, however, glass remains are pressed in between the crystals. This variety would seem to approach, in Mr. Doelter's classification, the granitophyric dacites.

Mica-augite-trachyte dike on Belt creek (appearance of a mica-minette).—Dull, brownish-gray colored rock, weathering brown, an apparently homogeneous groundmass with numerous, imbedded biotites and occasionally a c reddish, imperfectly-defined feldspar crystal. Rather porous; the cavities occupied by small amygdaloid nodules or secondary quartz. Upon closer inspection it appears that the uniform gray groundmass gives a slight reflection as if from large cleavage faces.

Thin section: A perfectly crystalline rock of irregular, large feldspar individuals; no groundmass or perceptible glass between the crystals; these are generally cracked and show absolutely no polysynthetic twin structure, the general characteristics pointing decidedly toward orthoclase. As no good optical measurements could be obtained, some powder of the crystals was submitted to microscopical test. The thin laminæ parallel to $\infty P \grave{\infty}$ always show an extinction of 5° to 6°, counting from the edge $0 P, \infty P \grave{\infty}$. The feldspar is consequently orthoclase (sanidine). A cloud of microlites of the substances mentioned below fills parts of the feldspars, making them appear opaque; other parts are clear; little or no decomposition. d

Quartz in small quantity, probably secondary, sometimes fills a space between feldspar crystals.

Next to the orthoclase, the biotite is the most important mineral; it occurs in larger sheets, down to the smallest microlites, always as an inclusion in the feldspar.

The isolated hornblende is very doubtful, being much decomposed, and filled with apatite.

Much more common is a clear, light-green augite, also embedded in the feldspar in irregular granules or small prisms. There is about as much augite as mica, and it also goes down to the smallest dimensions.

No titanite; some apatite and magnetite throughout the mass. Thus, products of first consolidation, augite, brown mica, apatite, magnetite; second consolidation, orthoclase.

We have here a rock, consisting principally of orthoclase, mica, and augite, which, judging from macro- and microscopical diagnosis, most undoubtedly is to be referred to Mr. Rosenbusch's family of the mica-syenites or e minettes (*Mikr. Physiogr.*, p. 121), the large amount of augite making it approach the augite-syenites. From its geological position we can infer nothing more than a post-Carboniferous or rather post-Silurian age. Thus far there is nothing remarkable, but its relation to subsequently-described eruptives makes it more than probable that this typical minette of a decidedly old appearance in reality is a very young Tertiary rock, and younger than the large dacite eruption in the neighborhood.

The first evidence toward this conclusion comes from the study of a large dike near Otter creek, north end of Little Belt, 6 miles north of Barker. We are here east of the formerly-mentioned large limestone sheet, in a region of more marked disturbances. The strata swell up and form several anticlinals. On the western flank of such an anticlinal, in layers considerably above the Carboniferous, and doubtlessly of Jurassic age, the dike in question appears, forming a high ridge on the west side of the creek. In a snow-white mass of small feldspar granules or f crystals are imbedded a great number of biotite foils, perhaps 4^{mm} in maximum diameter. They do not lie parallel, but intersect the feldspar in all directions, thereby often obtaining an icicular appearance.

Thin section: An essentially crystalline mass of long rectangular, but also irregular, large feldspars. A few individuals are plagioclase, but the predominating number show all the characteristics of orthoclase; rather milky, filled with interpositions, but not decomposed; many Carlsbad twins. On account of the irregular form and absence of cleavage no reliable stauroscopic observations could be made, and it was found necessary to establish the species of feldspar conclusively by means of an alkali determination; and such was made in the laboratory of the survey by Mr. Whitfield and gave: $K_2O = 5.5$ per cent.; $Na_2O = 4.1$ per cent.

The alkali, contained in the biotite and the glass (see below), might influence these numbers, but considering that these constituents only make about 10 to 15 per cent. of the mass, it becomes evident that they would not change the result very notably. Making due allowance for the small quantity of plagioclase, we come to the conclusion that the feldspar in question is an orthoclase or sanidine, rich in Na_2O.

a Biotite, embedded in the feldspar as irregular sheets or bacillæ; very fresh, and showing strong absorption.

Augite, light grass-green, perfectly clear, no dichroism; mostly in form of irregular granules between the feldspar crystals, but not dispersed through them as microlithes.

Apatite, in long needles, traversing the feldspar. Small quantity of magnetite.

Thus, products of first consolidation, biotite, augite, apatite, and magnetite; of the second, sanidine (and plagioclase).

The generally triangular interstices between the feldspar crystals are filled by a clear, almost colorless glass without any interpositions, but occupying only a small part of the section. Sometimes it is seen filling the interior part of a prismatic feldspar crystal, making the impression of a corrosion of the sanidine in the yet liquid magma.
b In a few places, with crossed nicols, faint bluish spots appear in the glass; this seems to be due to polarization by pressure.

Here again we have a biotite, augite, orthoclase rock, in which, however, the feldspar does not fill the space completely, but contains remains of glass. It bears decidedly the character of a younger rock, and must be referred to the mica-augite-trachytes, the younger equivalents of the mica augite-syenites. In discussing Highwood eruptives we shall find the augite-trachytes on a large scale again, and there they can be proved being of a post-Cretaceous age.

Their analogy, microscopically, with the pseudo-minette of Belt creek is so great that I have no hesitation in pronouncing both varieties to belong to one period of volcanic activity. Furthermore, the time between the Silurian
c and Cretaceous periods was in the west of America comparatively quiet, and only disturbed by a few granitic eruptions in some places. Thus we have here an instance of a younger rock appearing to perfection like the corresponding "old" form.

This illustrates how unsatisfactory the prevalent division of eruptive rocks in pre- and post-Cretaceous really is.

HIGHWOOD MOUNTAINS.

The Highwood mountains form a completely isolated group, about 15 miles south of Fort Benton, occupying 14 miles from east to west and 12 miles from north to south. From their highest peaks the great plains of the upper Missouri may be seen extending, arid and brown, in all directions; southward the hills of the Little Belt mountains break the monotony of the horizon, and in clear weather the snowy peaks of the Main range are
d visible toward the west.

The slightly inclined Carboniferous limestone of the northern Belt mountains dip, as one proceeds northward, under Triassic and Jurassic strata, which in their turn are covered by flat Cretaceous strata, here forming the surface of the great plains and gently sloping down toward the Missouri. Standing on a plateau of an average altitude of 4,000 feet, the mountains attain a maximum height of 7,600 feet. Their base is covered by a scant vegetation, above which the higher ridges, sometimes wonderfully serrated, stand out brown and barren.

The Highwood mountains are mentioned in Dr. Hayden's *Final Report on the Exploration of the Upper Missouri and Yellowstone*, 1872. Dr. Hayden remarks having seen from the road from Fort Benton to Judith basin some sharp peaks, indicating volcanic origin to the south or southwest. He undoubtedly refers to the Highwood
e mountains. On the map accompanying Hayden's report they are marked as an anticlinal with Carboniferous and older strata, none of which could be found at the time of our visit.

The strata extending close up to the first hills are almost horizontal, and can be identified as the Fort Benton black slate (Cretaceous No. 2), which also appears, according to Hayden, on the north and west side of the mountains. Approaching the slopes isolated volcanic dikes are encountered; they increase in number as one advances, and finally form a complete network; the sedimentary rocks included between them are highly metamorphosed and hardened, often more or less disturbed, but, perhaps, as frequently retaining their horizontal position; the highest parts of the mountains are often formed of these horizontal and hardened strata. Nowhere were any evidences found of the upheaval of any rocks older than the Cretaceous.

To explain the genesis of this remarkable group, it must be borne in mind that nowhere in the surrounding
f country are any strata higher than Cretaceous No. 2 found. The question naturally arises, why the rest of the marine Cretaceous (about 1,000 feet) and the enormous Laramie deposits (8,000 feet on the plains and over 20,000 feet near the mountains in Montana) are not represented—and the answer is, that they once did cover the plains and that the 4,000 feet of the Highwoods are the only remaining remnant of the heavy sheet.

Since the end of the Tertiary era the untiring erosion has cut away thousands of feet of sediments, but the dikes and the metamorphosed strata of a Tertiary volcanic district resisted the destructive power far more than the softer sandstones and shales, and thus the Highwoods have been chiseled out and left standing alone as a monument of volcanic force. We have laid bare to our eyes the nucleus, the inbound structure of a Tertiary volcano or group of volcanoes.

Thus far only dikes, but no intrusions or laccolites, have been found. That such eruptive forms may exist, however, is quite probable.

The Highwoods do not stand alone in America as a type for this peculiar form of mountains resulting a from the combined effect of volcanic and erosive agencies; the Spanish peaks in Colorado, for instance, evidently belong to the same class—nor do they stand alone in Montana. The beautiful group of the Crazy mountains north of the Northern Pacific railroad are, according to Mr. J. E. Wolff, essentially similar; also, the Birdtail mountains west of the Highwoods, near the main range, on the road from Helena to Fort Benton.

The dike eruptives of the Highwoods subdivide into two clearly distinguished but intimately connected groups, *trachytes* and *basalts;* the former are nearly all angite-trachytes, the latter andesite (noseane) basalts. They consequently belong to a class of volcanic rocks, which, in America, has generally been regarded as late Tertiary, and there is indeed in their occurrence nothing to contradict such a supposition. They certainly traverse strata, much higher than the Cretaceous, and on the other side they manifestly date before or shortly after the beginning b of the erosion. Of the two groups the basaltic seems the older; only one intersection, however, was noted, a trachytic, highly feldspathic dike cutting a dark basaltic one.

Before entering on the discussion of the dike eruptives a brief mention may be made of a remarkable volcanic conglomerate, apparently forming a part of the strata surrounding the dikes and occurring about 1 mile east of the road across Highwood gap, about 5 miles south of the divide. It is interesting because the pebbles are composed only of dacite and hornblende andesite, probably derived from once existing now obliterated massives, similar to those of Little Belt mountains. The position of this conglomerate can not be more than 1,000 feet above cretaceous No. 2, exposed at the foot of the mountains; that is, it must be placed in the Lower Laramie. That the andesitic eruptions in Montana began in the later Cretaceous period or in earliest Laramie, is an inference to be drawn from this occurrence and confirmed by other facts to be mentioned later. c

The pebbles are rather large, up to 10^{cm} in diameter, and are composed of hard grayish or brownish porphyritic rocks; in a brown or light-gray groundmass are imbedded small hornblende prisms and a great number of white feldspar crystals, generally less than 2^{mm} long. A few larger feldspars resemble orthoclase.

Thin section.—The feldspar appears predominatingly as plagioclase, while some supposed to be orthoclase could not be distinctly proved as such. The same two varieties of the plagioclase mentioned in the discription of the Little Belt dacites, we meet here again: (1st) Short, prismatic crystals, with polysynthetic striation, dull colors of polarization and symmetrical extinctions indicating oligoclase. (2d) Longer, prismatic crystals with no or few polysynthetic bands and dark blue—light-brown colors of polarization.

Quartz does not occur as larger porphyritic crystals, but is common in the groundmass of some slides.

Green hornblende crystals and a few foils of brown mica are to be observed. d

The groundmass is in some varieties clearly micro-crystalline, composed of feldspar and quartz; in others, crypto-crystalline; in others again, glassy, with sometimes micro-fluidally arranged plagioclase microlites, and without quartz.

There is a great similarity between these rocks and the dacites of Little Belt and Dearborn districts, and I feel but little hesitation in classifying them as hornblende dacites and hornblende andesites, and belonging to the same time of eruption.

Trachytes.—The trachytic rocks are quite abundantly represented, and of a great variety of appearance. Only one instance of a pure sanidine rock, or sanidinite, has been found. Augite, or sometimes biotite, but as far as observed, hornblende never enters. From varieties poor in these constituents, but rich in feldspar (orthoclase and oligoclase), the series runs down to dark, heavy rocks, composed of equal quantities of augite and sanidine, or with predominating augite. The biotite never holds such a prominent place, but in most cases accompanies the e augite. Sometimes, but seldom, the olivine appears.

The occurrence of such a variety of undoubted trachytes in the United States is in itself quite remarkable. Very few, I believe, of the supposed trachytes of the Fortieth Parallel have borne the test of renewed examination, and it appeared as if this group of Tertiary eruptives were compartively rare in America. Future examinations will, I think, discover quite large trachytic districts in Montana.

The occurrence, on the other hand, of such large quantities of augite entering in the composition of these rocks is quite unusual; so much so, in fact, that Rosenbusch (*Mass. Gest.*, p. 179), after giving the definition of trachyte, makes the following important restriction: "The quantity of the micaceous, augitic, or hornblendic constituents is always limited, and not even microscopically prominent (auffallend)." On page 200, while discussing f the difficulty of classifying the trachytes, Rosenbusch refers to the probability that eventually trachytes richer in mica or bisilicates may be found, which would allow the establishment of subdivisions running parallel with those of the syenites.

It seems, indeed, as if here such a subdivision had been found, *i. e.*, that corresponding to the augite syenites.

The rocks may conveniently be described in the following order: (1) Sanidinite; (2) augite (biotite) trachytes. Equivalents: Augite syenite. (*a*) coarse granular; (*b*) porphyritic, groundmass mainly feldspathic; (*c*) porphyritic, groundmass augitic, glassy.

(1) *Sanidinite.*—A dike of about 50 feet thick of this rock was found in the southern foot-hills, near the road to Fort Benton. A yellowish-gray, somewhat porous and rough rock, with large (1 to 2^{cm}) yellowish, cracked sanidine crystals. An alkali determination of the rock, made by Dr. Gooch, gave, Ka_2O : 11.82 per cent.; Na_2O : 2.5 per

a cent.; consequently an almost pure sanidine rock. *Thin section:* Large sanidine crystals, of thick, lamellar habitus, in a groundmass of smaller sanidines; much limonite in the groundmass; no plagioclase observed; trace of isotropic glass; biotite isolated.

(2) *Augite-trachytes* (often with biotite).—(1) *Crystalline:* On both slopes of the Highwood mountains we find a light-colored, predominantly-feldspathic rock closely related to the one just described. Light gray or yellow, coarsely crystalline; cleavage planes of the feldspar up to 8^{mm} long; no porphyritic or well-developed crystals. Augite in small grains, sparingly; very few biotites.

Thin section: Small, irregular green, augite grains, as before, imbedded in a perfectly crystalline mass of feldspar individuals, irregular or prismatic with broken ends.

There are probably three feldspar varieties: (1) Orthoclase (sanidine) irregular granules with bluish-gray
b colors of polarization. (2) The large prismatic individuals which seldom, if ever, show polysynthetic structure; only exceptionally a few very thin bands were noticed. Colors of polarization grayish brown, deep blue. It is undoubtedly plagioclase, but of what variety I am unable to say. (3) Small quantities of another plagioclase (oligoclase) with exceedingly fine striation, often grown into and curiously interlaced with the sanidine.

Decisive optical measurements being impossible, an alkali determination was kindly made by Dr. Gooch, and gave $Na_2O=7.88$ per cent., $K_2O=5.66$ per cent. An oligoclase with such a quantity of potash can hardly be assumed, while on the other hand the sanidine may contain a considerable quantity of soda; this in connection with the optical observations will render the assumption probable that here are present about equal quantities of sanidine and plagioclase.

The perfectly crystalline development and the total absence of any basis or groundmass is remarkable.

c (*b*) *Porphyritic feldspathic groundmass.*—On the northern side, a few miles from the divide, a heavy trachyte dike intersects the road to Fort Benton. Here the augite begins to appear in more prominent quantities.

Greenish-gray fine-grained rock, porphyritic by a large quantity of parallel, thin lamellar, white sanidine crystals (maximum, $5.10^{mm} \times 1^{mm}$). In the groundmass numerous small feldspar grains; dark green, often perfectly developed augite crystals up to 3^{mm} long, and numerous small biotites. The sanidine crystals were determined as such by the method of Boricky, and also by an alkali determination by Dr. Gooch, which gave $K_2O=11.36$ per cent., $Na_2O=2.14$ per cent.

Thin section: The groundmass is fine-grained, and composed of sanidine, augite, and biotite with traces of glass; further opacite and a few small, clear apatites, proved as such by micro-chemical tests.

The feldspar microlites are undoubtedly of the same nature as the larger crystals, and in fact a gradual transi-
d tion from the porphyritic down to the smallest individuals can be noted; the sanidine is generally lamellar and elongated in the direction of the clino axis; somewhat opaque so that no accurate measurements can be made.

Biotite appears frequently as small fresh-brown laminæ from 1^{mm} down to microlitic dimensions. The occurrence of mica as constituting part of a trachytic groundmass is to be noted as something very unusual.

The augite is the same variety, which we find in *all* Highwood dike eruptives, trachytes, or basalts, and which seems also to be largely represented in other Tertiary eruptive districts of Montana. In this rock it appears both as perfect crystals and as irregular grains. The crystal form is generally long prismatic of the combination ∞P. $\infty P \breve{\infty}$. $\infty P \bar{\infty}$. P. OP, the first three forms often equally developed. Color dark green, in thin section, clear grass-green; pleochroism very seldom appreciable, generally very fresh, showing great resistance to decomposition. Good prismatic cleavage. Twins, not observed macroscopically, are frequent in thin section, the twin plane,
e generally with some interposed hemitropic bands, cutting the direction of cleavage in prismatic crystals with an angle of about 19°. Beautiful zonar structure by inclusions of groundmass or by alternating darker and lighter zones is common. Extinction, maximum 40° to 45°. This important variety should be examined chemically.

The augite increases in the trachytes, now to be described, and the sanidine gradually disappears.

A specimen from the southern slope has the same structure as the one just mentioned, but the sanidines are much smaller (maximum, 3^{mm}) and thinner; as much augite as sanidine is present, appearing as porphyritic crystals and as grains in the groundmass. The main part of this is formed of short, milky feldspar microlites, doubtlessly also sanidine; isolated, somewhat doubtful plagioclase microlites. Small quantities of biotite, opacite, and apatite.

Another very similar specimen shows some glass in the groundmass; no plagioclase; all the short feldspar microlites appear with extinctions from 0° to 5°.

f Finally, in a series of specimens the porphyritic sanidine disappears and the augite takes its place in long, dark green, well-developed crystals; the groundmass is also dark-greenish or gray, and consists of larger augite grains in a maze of small, short microlites; a few polysynthetic plagioclases may be noticed. Generally, however, the extinction, when measurable, ranges from 0° to 5°. From this and from the shape of the microlites we must class them as sanidines.

It is not to be denied that a separation of the feldspars here would be very desirable in order to ascertain the percentage of plagioclase contained in the rock. The transition from larger sanidines to the microlites, however, can be so clearly noticed that but little doubt as to the nature of the latter can be entertained.

Specimen No. 42 is a dark-green rock, in which with the naked eye only the larger porphyritic augite crystals can be distinguished.

Thin section: Larger and smaller augites in a sanidine groundmass with doubtful glass remains; rather much opacite and hematite. It appears as if these opacites resulted from originally-formed but later destroyed hornblende crystals. Few biotites. **a**

Specimen No. 41 is similar, and shows augite crystals up to 4 to 5^{mm} long. Groundmass composed of short, clear sanidines, slightly reddish from fine hematite dust; larger augites and small quantities of biotite and opacite.

In two specimens of this highly augitic trachyte has olivine been noticed. One, from Highwood mountains, is perfectly similar to the varieties just described; carries large augite with beautiful zonar structure, besides biotite, magnetite, and small olivine crystals with a yellow fringe. Sanidine groundmass, with some glass as usual. The other, closely related to the Highwood rocks, is found by Professor Pumpelly near the head of the Musselshell river, 80 to 100 miles south of the Highwood. Macroscopically, a grayish-green rock with porphyritic long (maximum, 10^{mm}) and slender augite prisms, in a groundmass of augite, biotite, and a white mineral. **b**

Thin section: The common Highwood augite in larger and smaller crystals, here more decomposed than usual to chloritic products; in the Highwood rocks the augite is almost always perfectly fresh. Few fresh olivines, rather much biotite, some opacite, and an exceptionally large quantity of apatite, proved as such by microchemical tests.

The groundmass is composed of a network of larger and shorter feldspar-microlites, with some glass. Undoubtedly much sanidine (extinction, 0° to 5°), but also considerable quantities of plagioclase. It seems rather doubtful where this rock should be referred. In spite of its basaltic constitution it certainly belongs to the natural group of the Highwood trachytes. Pure, unquestionable *plagioclase basalts*, belonging to the same eruptive epoch and with the same augite variety, do exist in Montana, in the Birdtail mountains, west of Highwood mountains.

It now only remains to describe the last subdivision (c), that of porphyritic augite-trachytes with augitic, glassy groundmass. **c**

Specimen No. 10, found on the southwest slope, appears as a dense dark green or greenish gray groundmass in which are embedded lamellar, thin, and perfect sanidine crystals, clear or slightly reddish; no parallel distribution of the porphyritic crystals is noted; maximum size, 3^{mm} long and broad by $\frac{1}{2}^{mm}$ thick.

In thin section the large feldspars are perfectly fresh and clear, beautifully contrasting with the green groundmass. Generally appearing as Carlsbad twins and showing all the characteristics of sanidine. Longer individuals are crossed by irregular cracks; zonar extinction is common; thin sections about perpendicular to $\infty P \grave{\infty}$ extinguish parallel to the edges; on broad crystals, cut approximately parallel to $\infty P \grave{\infty}$ the angle $0P . \infty P \grave{\infty}$ was measured to 116°. One axis of elasticity makes an angle of 5° with the clinoaxis. Farther embedded in the groundmass, and sometimes in the sanidine, are smaller, irregular, slightly dichroitic *augite* grains (grass-green to olive-green), and a small number rounded or hexagonal isotrop sections clear or slightly brownish. Taking into consideration the results obtained from the basalts, they must be regarded as *nosean* or *analcite*. **d**

Under immersion objectives the homogeneous groundmass is resolved, and shows a colorless glass in which are embedded numberless, thin augite needles, often with beautiful microfluidal structure. There is a series of specimens very similar to these trachytes, but generally more or less decomposed. The larger augite grains occur sparingly and show a peculiar bacillar structure. The microlites of the groundmass extinguish here with an angle of 10° to 20° and appear to have been changed to hornblende; the glass basis shows irregular faintly polarizing spots.

That this group of trachytes is not limited to the Highwood mountains is proved by a specimen collected by Mr. G. H. Eldridge in the Judith mountains about 80 miles southeast from the former. It shows large and perfect (up to 3^{cm} long) reddish sanidines prismatically elongated parallel to the clinoaxis embedded in a green, dense groundmass, which, hastily examined, appears very decomposed and consisting of much *viridite*, small feldspar microlites, and some glass. **e**

Analcite (nosean) basalts.—The second, and perhaps the larger, group of the Highwood dike eruptives, is composed of these remarkable rocks. Their constituents now are augite, olivine (biotite, magnetite, apatite in subordinate quantities), and analcite—absolutely no plagioclase, leucite, or nepheline can be found. It is probable that the analcite has resulted from the decomposition or the molecular change of a primary nosean. It cannot be denied, however, that there is much in the microscopical appearance which only with difficulty can be explained by this supposition, and often the appearance would lead the observer to regard the analcite as a primary mineral. The presence of pure nosean has, indeed, not been proved, but a small quantity of sulphuric acid, always present in these rocks, together with other facts, renders it very probable that this mineral was in reality the primary. **f**

The basalts appear as dark-green to greenish-gray rocks, with porphyritic augite-crystals up to 10^{mm} long, generally presenting the combination $\infty P . \infty P \grave{\infty} . \infty P \acute{\infty} . 0P . P$. The mass containing the augites is generally fine grained and consisting of augite-grains, brown olivines up to 0.5^{mm}, and round or hexagonal white crystals of analcite (nosean) up to 1^{mm}. Mica is not generally seen macroscopically. The fresh rock is often exceedingly hard and compact. Specific gravity 2.4 to 2.6. When decomposed, the basalts become soft and brown, cavities are formed and filled mainly with stilbite.

In thin section the general aspect of the rocks is that of larger augite- and olvine-crystals and clusters of augite, biotite, and opacite microlites, embedded in a white mineral which sometimes simply appears as a groundmass, but more generally also is distinctly crystallized as a number of rounded, hexagonal, seldom octagonal, a sections, ranging from 1^{mm} to 0.1^{mm}, with sharp outlines, or dissolving into the general groundmass. In short, the mineral in question behaves as does the leucite in the leucite-basalts. Very fine grain, however, such as is seen in many of these has not been observed here. Generally objectives 2–4 are fully sufficient. This white groundmass and these crystals now consist mainly or exclusively of analcite.

The first variety examined is apparently perfectly fresh fine-grained rock in which the small white crystals can be clearly seen with the naked eye. In thin section the white mineral forms numerous rounded or hexagonal individuals and a small amount of groundmass. It is clear and nearly colorless, only slightly brownish as from finely-divided dust—no inclusions of zonally or otherwise arranged microlites in the crystals; no cleavage; only in a few places is the mineral slightly milky and opaque. Between crossed nicols, perfectly isotropic only with an occasional bluish b spot often coinciding with the milky portions. In very few places decomposing to an aggregate of desmine needles—the other constituents, and especially the *olivine*, are perfectly fresh and intact.

The mineral was separated by means of the solution of Thoulet and analyzed. Specific gravity, 2.2. Dissolves easily in HCl, SiO_2, separated as slimy powder.

c

	Highwood.	Analcite from Kaiserstuhl (Weltzien). (*a*)
	Per cent.	*Per cent.*
SiO_2	54.90	54.02
Al_2O_3	23.30	22.54
Fe_2O_3	Trace.	1.35
CaO	1.90	2.91
MgO	0.70	0.57
Na_2O	10.40	10.14
K_2O	1.60	0.71
H_2O	7.50	8.93
	100.80	101.17

a See Dana's Mineralogy.

A small quantity of sulphuric acid is present, but was not determined; also trace of chlorine. The mineral d has unquestionably the composition of analcite.

The second basaltic variety is macroscopically quite similar to the first; the constituents of the groundmass are perhaps not quite so easily recognizable with the naked eye. In thin section, with reflected light, it again appears structurally quite similar to the first; in transmitted and polarized light the groundmass and the rounded crystals are observed to behave differently. They are generally white and milky as if decomposed, not uniformly so, however; irregular patches and spots are of ideal clearness and purity. No cleavage or interpositions can be noted in the crystals. Between crossed nicols peculiar phenomena of polarization are noticed, the clear parts often, not always, remain isotropic; the largely predominant milky parts are double refracting, and show dull, bluish-gray colors; neither the groundmass nor the crystals have an aggregate structure; every one of the latter is to be regarded as one individual. Most of them show irregular larger spots, alternately dark and light, when the stage is revolved, e but in a number, apparently where the section has a certain crystallographical orientation, a peculiar division of each crystal into triangular areas with their apex in the middle and alternately dark and light is seen. The most common is a division in 4 sectors, but in some I have observed 6 or 8. I know of no other of the here possible minerals but the analcite which presents such phenomena. Dr. A. Ben-Saude, while examining the optical properties of the analcite (*Neues Jahrbuch*, 1882), came to conclusions closely corresponding with the here observed facts. Some analcite varieties are quite isotropic; others, when cut in an arbitrary direction, present irregular alternatingly dark and light spots; cut parallel to a crystallographical surface he noted a division in triangular sectors, 4 when parallel with $\infty O \infty$, 8 when parallel with mO, and so on.

Here, too, a separation was effected, and the analcite (very impure from want of material) subjected to analysis. It contained—

f

	Per cent.
SiO_2	24.16
Al_2O_3	15.50
Fe_2O_3	2.10
CaO	2.12
MgO	2.42
Na_2O / K_2O	6.79
H_2O	4.50
Residue	41.00
Total	98.59

Small quantity of sulphuric acid noted but not determined; very little K; the separation of SiO_2 and insoluble a residue was made with KOH, and is consequently not to be regarded as very accurate.

Assuming that the Fe_2O_3 is present as hematite or magnetite, further subtracting a quantity of SiO_2 necessary to form Mg_2SiO_4 (dissolved olivine), we obtained, by recalculation—

	Per cent.
SiO_2	43.59
Al_2O_3	30.24
CaO	4.13
Na_2, K_2	13.26
H_2O	8.78
Total	100.00

b

This is a result such as may be expected from a decomposed nosean; the SiO_2 is too low for analcite (nosean has SiO_2 38 per cent.) and the Al_2O_3 is too high. That on the other hand pure analcite exists in the rock can be but little doubtful from the results of the optical examination; we may perhaps regard the white mineral as a mixture of some primary nosean and predominating secondary analcite.

The olivine and augite here, as in the first variety, are entirely fresh and clear.

The third variety is a dark-green rock of very fine grain, and with but few porphyritic augites. In thin section c fresh augite crystals and sharp-edged intact olivines are imbedded in a perfectly clear—only exceptionally milky—mass, showing no tendency to crystallize in separated sections; the mineral here apparently plays the same part as does the nepheline in certain rocks. Between crossed nicols parts remain dark; other irregular patches light up with faint bluish-gray colors; even here a division of the mass in triangular sections can occasionally be noted. This variety has not been analyzed.

Let us now rapidly review the results obtained:

The mineral which, with augite and olivine, mainly constitutes the rocks has sometimes exactly, sometimes only approximately, the composition of analcite, and should perhaps properly be regarded as a pseudomorph or analcite after nosean; the hexagonal form of the sections is also a proof in favor of nosean as the primary mineral; sodalite and leucite cannot with any degree of probability be regarded to have ever entered into the constitution d of these rocks.

It remains a very remarkable thing, indeed, that such a radical change could take place without effecting the augite or the olivine in the least, and so as to give the analcite in many cases absolutely the appearance of a primary mineral.

No instance is known to the writer where the analcite plays a part such as in the rocks here described; it either, as in Kaiserstuhl, fills former leucite crystals as an aggregate, or as in the plagioclase basalt (the "analcimite") of the Cyclopean islands fills cavities in the otherwise also very decomposed rock.

As helping toward an explanation of the Highwood occurrence, the not very constant composition and the great tendency to decomposition of the nosean should be taken into consideration.

The first stage in the decomposition of a nosean with 36.1 per cent. SiO_2 + 24.9 per cent. Na_2O, and 8 per cent. e SO_3 + 31 per cent. Al_2O_3 would be the removal of sulphates of sodium and aluminum, with addition of water and some silica. No change in the accompanying minerals.

The second stage is in contrast to the first characterized by aggregate decomposition of both the analcite and the accompanying minerals.

In fine fissures or in the middle of an analcite crystal brilliantly polarizing isolated zeolithic needles and small aggregates appear; they extinguish parallel to their larger axis, and have, parallel to it, a splendid cleavage in one direction; it is without doubt stilbite; macroscopically the stilbite occurs in larger quantities, filling cavities in decomposed rocks. The aggregates grow rapidly, and at last the analcite crystals are totally replaced by a maze of desmine needles in an opaque brown mass. The olivine is decomposed, the very resistant augites attacked, and chloritic products formed. From a chemical point of view the remaining alkali is dissolved, the percentage of f Al_2O_3 lowered, and the quantity of water doubled. A certain quantity of Ca present in the nosean and analcite is not extracted during these changes, but appears rather concentrated in the last stage.

Average composition of stilbit

	Per cent.
SiO_2	57.4
Al_2O_3	16.5
CaO	8.9
H_2O	17.2
Total	100.00

Such, if correctly interpreted, would be the history of the chemical changes in these rocks.

a In the described varieties the other constituting minerals retain the same appearance, and can be described together.

Augite.—Only one variety, the same occurring in all Highwood rocks, has been observed, and for the description the reader is referred to the trachytes (p. 725). The larger are often perfectly developed crystals up to 10^{mm} long; the smallest are imbedded as clusters of long microlites or small grains in the analcite mass. Sometimes a peculiar grouping of the small analcite crystals around a large and somewhat corroded augite crystal is seen.

Olivine.—Clear, sharp-edged crystals traversed by irregular cracks, generally ranging in size from 0.5^{mm} to 0.1^{mm}. Probably very rich in Fe, which may account for the energetic resistance to decomposing agents. Often surrounded by a thin fringe of brown biotite. Small inclusions in form of brown crystals (spinel) were
b noted. The decomposition, beginning along the cracks at the same time as the formation of stilbite, proceeds rapidly and results in a brown, ferruginous mass.

Biotite.—Almost always microscopical, embedded as fine foils in the groundmass; color, brown; clear and fresh; especially clustering around the olivine.

Magnetite.—Irregularly distributed in the mass in form of small grains. At beginning of decomposition the hematite appears.

Apatite.—Small, sometimes rather short, slightly dusty, but clear prisms and sections, often as inclusions in augite. Proved to be apatite by microchemical tests.

It is certain that these Highwood rocks deserve a close and attentive study, much more extended than that
c which my time and material allowed me to undertake; especially are chemical investigations necessary.

The collection was comparatively small, and does by no means include all parts of the mountains; future examinations will doubtlessly reveal rich harvests for the petrographer in the Highwoods and in the mountains of the Upper Musselshell river.

ROCKS FROM LINE OF ERUPTION IN FRONT OF MAIN RANGE, NORTHERN MONTANA, SOUTHWEST OF FORT BENTON.

[Feldspar basalts, Leucitoide basalt, Liparite, Dacite, Hornblende andesite, Diabase.]

Sun river, Birdtail, and Dearborn districts.—For 50 miles southwest of Fort Benton the great plains stretch out their monotonous, slightly undulating surface with nearly horizontal layers of Cretaceous shales and sandstones in
d or above Hayden's No. 2. The first slight disturbances we notice near Sun river with its fertile and well-cultivated valley, doubly beautiful after the dreary, brown alkali plains. A few miles after crossing the Sun river we see the first eruptive rocks. To the right a long ridge appears, evidently a dike, and to the left a large, square butte (Table butte), rises to several hundred feet high, with steep sides, and a diameter of about a mile. This is clearly an overflow or intrusion, covering the softer Cretaceous sandstones. The ground is covered with detritus from the mountain; it is a dark, nearly black, dense rock with a few larger, prismatic augite crystals of the same characteristic appearance as those in Highwood eruptives.

In thin section.—Few large, clear, green augites, same variety as the Highwood augite. Olivine in small, decomposed grains; occasionally a small, single feldspar crystal, resembling sanidine. Groundmass composed of augite and magnetite microlites, imbedded in a colorless base. The microlites are often arranged so as to divide up
e the colorless mass more or less clearly in round sections, always very small; these are isotropic or very faintly polarizing. The whole recalls decidedly a leucite basalt, but it may be difficult to prove whether the colorless base is glass, leucite, or analcite; a specific gravity separation and analysis should have been made, but unfortunately the time at my disposal did not allow it. A strong instance in favor of its being a leucitic basalt is that the powder dissolves easily in HCl, leaving the augite, of course, and the silica as a *powder*. The optical characteristics of leucite—the striation—one can hardly expect to see when the questionable crystals attain so small dimensions as the case is here.

Following Mr. Rosenbusch's nomenclature, I refer the rock to the leucitoid basalts, used when the leucite could not be conclusively proven as such.

A mile or two farther on a dike of a similar rock crosses the road, standing 20 to 50 feet high as an
f irregular, rough wall, and running out in a southeasterly direction; and now a whole mountain group with serrated and sharp outlines appears near the horizon. They are the Birdtail mountains. To the south some regular, low, truncated cones, probably overflows or intrusions; southeasterly in front of us five large, steep cones or cupolas with a number of smaller peaks before and behind. The country around us begins to show undulating hills, the rocky wall of a dike traversing the sandstones occasionally.

The sandstone becomes coarser, more friable, and soon assumes a southwesterly dip of 10° to 15°. After a 17 miles'—from Sun river—ride we arrive to the stage station, Eagle Rock. Following a 20-foot broad dike, with soft, very decomposed mass up to a higher hill near the station, a good view is soon obtained of this wonderful landscape. Closely northward two square buttes again, called Twin mountains, an overflow or intrusion, showing columnar structure and resting on the sandstone layers. Southward dikes run everywhere, rising one behind the other with outlines never smoothed into curves by erosion, but sharp, torn, and irregular. Behind them rise the cupolas of the Birdtail mountains, at a distance rather resembling the basaltic cones of Bohemia and Auvergne. The laminated sandstones surrounding us are cut and worn by erosion into peculiar forms, resembling chairs, pillars, pulpits, and so on.

This landscape, surprising in itself, grows still more so by the uniform, dreary, brownish-gray color and the misty haze suffusing it. It is a volcanic landscape *par excellence.*

A few miles from Eagle rock the road runs close to one of the largest cones, the Birdtail mountain, so called from the peculiar curve its outlines present when viewed from the northeastern side. The name has been extended to the whole group. The height seems to be about 800 feet or 1,000 feet. Passing by it, however, it changes form, and now, seen from the west or northwest, appears narrower and sharper, showing in fact that we here have to do, not with a regular basaltic cone, but with a part of a large dike uncovered by erosion.

The sandstones, being of so much looser texture than the eruptive, are very easily eroded, thus leaving the dikes carved out like monuments. Without a doubt, all the other cones of the Birdtail district are of similar structure.

The main difference between this eruptive center and that of Highwood seems to be that here the erosion has progressed more rapidly, no such marked metamorphisms as in Highwood having hardened the surrounding rocks.

In most cases the disturbances of the sandstones caused by the eruptives are very unimportant, and sometimes not to be perceived.

A few miles from the Birdtail mountain we cross a small divide and come to the Flat Creek valley; at this divide a thick sheet of a dark, basaltic rock covers a volcanic conglomerate of the same substance. It does not seem as if the conglomerate were contemporaneous with the Cretaceous sandstones; those have, in the neighborhood, a steeper dip, while the eruptive sheet and the coarse conglomerate only are slightly inclined; it has the appearance of being formed after the beginning of the disturbances and erosion. From this center dikes composed of the same material radiate, one cutting the road a few hundred feet below the divide.

From here to Dearborn river, about 9 miles, we notice few indications of eruption along the road. Southward several dikes are seen. Between Dearborn river and Flat creek the Cretaceous, now coarse sandstones, form a flat anticlinal. This eruptive region, along the Missouri, from Table butte to Flat creek, has an extension of about 18 miles, its center being in the dikes of the Birdtail mountains. It is a late eruption, most probably approximately of the same age as the Highwood group, and, as far as my knowledge goes, only composed of basic augitic rocks, mainly feldspar-basalts. No complete collection was secured, only specimens from more prominent points.

Birdtail mountain (53 *et al.*).—A dark-brown, dense rock with slight resinous luster. Porphyritic augite crystals of the common Highwood type.

Thin section: Large, light-green augites with inclusions of glass and magnetite; olivine throughout, but not abundantly, all more or less decomposed into a brown, opaque mass. Much magnetite, few apatite prisms. Plagioclase in large, irregularly bordered, prismatic crystals; all with polysynthetic twin structure, very decomposed. Groundmass consisting of few augite, predominating magnetite and feldspar microlites, probably exclusively plagioclase, mostly showing twin structure. The rock is rather decomposed, and oxide of iron is abundant.

Conglomerate, dikes and overflow, from Flat creek (54).—A dark gray groundmass with the usual augite crystals. *Thin section:* Fresh, light-green augite; very few olivines, decomposed; larger, tolerably fresh plagioclase; groundmass very glassy, with augite grains, irregular pieces of viridite and plagioclase crystals. Some magnetite and hematite distributed through the mass.

These eruptives must consequently be classified as plagioclase basalts. In many points, for instance, in the green, fresh augite, characterized by long prismatic form and about equally developed pinacoids and prisms, these rocks resemble those of the Highwood group. There, however, the sanidine prevailed, and probably no plagioclase as microlite, certainly none as larger crystals, could be found in the examined basaltic rocks.

DEARBORN DISTRICT.

Altogether different from the Birdtail is the Dearborn eruptive region. The Dearborn river has its sources in the Main range, the Middle fork in Cadotte's pass, and flows into the Missouri after a course about 30 miles long. A good idea is obtained of the geological structure of the main range (briefly mentioned in the introduction), and of the eruptives in front of the same, by traveling up to the mountains along the river.

The large fault of the main range here throws up the Cambrian slates and a part of the Carboniferous and Silurian rocks in contact with the (Laramie) coarse sandstones, dipping constantly toward the mountains. The dikes do not rise with irregular serrated forms as the basic eruptions of Highwood and Birdtail, but form lower ridges with softer outlines, or are not visible in the configuration of the ground. They further are confined to the Cretaceous strata, and do not seem to continue in the Paleozoic layers. They finally, with few exceptions, run approximately parallel to the general strike and the fault of the rocks; that is, have a northwesterly or somewhat more westerly trend, and this would, perhaps, suggest the idea of the dikes being really overflows, contemporaneous with the deposition of the Laramie sandstones. So much seems certain, that the dikes are older than the fault, and date from a time when the Laramie was in its original position, or at least only in an incipient stage of disturbance. We find, indeed, no younger basaltic rocks among the eruptives, but only hornblende-dacites, andesites, and liparites, the former eruptions, as proved elsewhere, having at least commenced already in Laramie formation. As to the liparites, a the granular or porphyric varieties are intimately connected with the dacites. The glassy variety, also found at the Dearborn, we again find as overflow or intrusion at Sixteen-Mile creek; the date of eruption is not certain, but would seem to be rather to refer to the age of dacites and andecites than to the basalts and trachytes.

Liparite: Dike near the town of Dearborn (59); a light yellowish-gray rock, with rough fracture, many small quartz grains, and reflecting, white feldspar crystals. Brown mica very scarce.

Thin section: Quartz granules in great number, mostly rounded or irregular; only glass and groundmass inclusions, no fluid inclusions. Feldspar of two kinds: (1) By far predominating, presenting all the characteristics of sanidine; extinction measured on some smaller prismatic crystals; maximum, 5° along the crystals; few sharply defined individuals. (2) Smaller, scarcer crystals of rather decomposed and milky triclinic feldspar; variety,
b impossible to determine; groundmass, microcrystalline; composed entirely of sanidine and quartz granules. This is consequently a typical liparite of granular porphyritic development.

(64) From a 300 foot broad dike near the fault line of the main range on the Dearborn; has the appearance of a brown porphyry with glistening faces of small feldspar crystals.

Thin section: Porphyritic plagioclase, most likely oligoclase, in perfectly fresh crystals, carrying few inclusions. Most of them have a rounded or corroded form. By far the greatest number show twin striation, but not regularly, so that sometimes one-half of the crystal is simple, while the other shows very fine striation. Zonal and undulating extinction is common, even among the polysynthetic individuals. The few simple crystals doubtlessly also belong to the same variety as the striated. In most cases the rounded form and absence of cleavage permitted no rigorous
c optical examination, but in some instances an extinction of 2° to 3° along the larger simple crystals was measured. Extinction of hemitropic bands of the plagioclase was remarkably small, 10°+10°, and never higher, being repeatedly measured. The simple microlites extinguish about parallel to their length extension. Most of the feldspar is consequently oligoclase. No larger quartz granules. A few decomposed brown mica crystals.

Groundmass, glassy, characteristically liparitic. In a brown, microfelsitic mass, perfectly isotropic, are imbedded a great number light or colorless streaks and stripes, bent, twisted, and folded in the characteristic way. The white stripes have a micro-crystalline structure and are composed of feldspar and quartz.

Were it not for the large amount of plagioclase, I would, without hesitation, place this rock among the liparites. Strictly speaking, it should be classified as an acid, glassy porphyrite.

Hornblende-andesite: (62) and (63) are both specimens from dikes very near the great fault, and of a type which seems to be largely represented. (63) is a dark gray, very fine, granular rock; with naked eye small crystals of
d hordblende, mica, and felspar visible.

Thin section: Large, but scarce, biotites; few larger plagioclase crystals. Groundmass a maze of feldspar microlites of long prismatic form, some showing striation; single crystals extinguish from 0° to 3°; the feldspar is consequently oligoclase; besides hornblende very decomposed and with faint absorption. The microlites are embedded in a clear glass; (62) is similar, but more altered.

This andesite seems to be more related to the variety of dacite found on Belt creek, Little Belt mountains, than to the typical hornblende-andesite.

Hornblende-dacites: Also largely represented, and of a striking similarity with the Little Belt dacites. (60) are beautiful specimens from two large dikes at a small alkali lake, about 2 miles from Mr. Gillette's ranch. The rock presents a somewhat porphyritic habitus, with snow-white felspar crystals up to 3^{mm}, occasionally rounded quartz
e grains up to 2^{mm}; smaller hornblende needles and some dark mica in a yellowish-gray groundmass, with granular fracture.

Thin section: Large, rounded quartz grains, curiously enough without fluid inclusions. Grass-green, long hornblende crystals, with no very strong absorption; cleavage very well pronounced; maximum extinction about 18°. Biotites few and decomposed.

Feldspar mainly if not exclusively plagioclase, of those two varieties already described at the examination of Little Belt eruptives and Highwood conglomerate. (1) Short rectangular or square sections, often zonar structure, very fine striation, gray colors between crossed nicols. Maximum extinction of hemitropic bands here again measured to 10°+10°; doubtlessly oligoclase. (2) Larger prismatic crystals, with scarce and oft-missing striation; colors between crossed nicols light brown, deep Labrador blue. No sanidine noted. Groundmass, very fine micro-
f crystalline of granular feldspar and quartz.

(65) from a dike several miles farther up, shows macroscopically large yellow sanidine crystals in a groundmass of smaller feldspar grains, decomposed mica, and quartz.

Thin section: Smaller and larger rounded quartz grains, with numerous fluid inclusions with moving bubble; also glass inclusion. Small decomposed crystals of hornblende and black mica. The feldspar crystals of medium size are all a somewhat decomposed plagioclase (oligoclase). When a part of the larger sanidines is cut by the section it appears with the usual characteristics of that mineral. Groundmass micro-crystalline, not resolved by low powers, composed of quartz and irregular simple feldspar granules (plagioclase or sanidine?); no hornblende in the groundmass. The quartz, especially in the groundmass, is characterized by a pronounced granophyric structure, recalling again the Little Belt dacites. Every quartz grain of the groundmass appears as if scattered around a certain space in smaller grains, optically with parallel orientation.

The sanidines, known also with smaller development from Little Belt connect this dacite with the liparites; a the line of demarcation between the two species becomes difficult to draw distinctly.

Still more largely the sanidine seems to be developed in a dike of similar material on the North fork of Dearborn. Professor Pumpelly has collected from that locality a quantity of larger perfect orthoclase crystals up to 3^{cm}, extended along the clino-diagonal and generally presenting the combination $O\text{–}P . \infty P \grave{\infty} . \infty P$. They do not appear as sanidine, but resemble typical orthoclase. The rock carrying these crystals I have not seen.

A few dikes of a typical diabase, in the Cambrian slates near the divide, will be mentioned farther on, in connection with similar rocks from the Big Belt mountains.

MULLEN PASS AND JEFFERSON COUNTY ERUPTIVES. b

Hornblende-granitite, Liparites—The geology west of the Missouri is but little known. The first range on the west side of the broad Missouri valley, between the two cañons, is reported as composed of limestone and other sedimentary rocks. Soon, however, going west, we come into an extensive field of an eruptive granite.

One interesting point is the contact at the pass height of the Northern Pacific, Mullen tunnel; from there the line of contact runs southeast, passing close to Helena and Jefferson City. The granite contains mineral lodes in great number and indeed some of the most valuable mines of Montana. The study of the age and qualities of this eruptive, to which I shall refer in the following as the *Jefferson granite field*, is of great interest. I shall first describe it as it appears at Mullen. c

The west slope of the main range, opposite Cadotte's pass, seems to be largely composed of Cambrian or Silurian quartzites and slates. They also appear 10 to 20 miles north of Helena as green and red slates. Coming down from the hills into the valley of Little Blackfoot, 8 miles from Mullen pass, broad dikes of a dark, porphyritic eruptive appear, cutting a series of sedimentary rocks. It appears on examination that the dikes intersect Jurassic strata, identified by fossils, underlaid by some Carboniferous limestone; and that farther on the rocks are considerably disturbed, and consist of large masses of a hard, gray hornstone or quartzite, unknown to such an extent in the general series. This quartzite seems to follow below the comparatively small quantity of limestone. In this quartzite, a few miles from Mullen, is a dike of a granite identical with the one of the large eruptive; a mile west of divide is a large dike of a black, dense eruptive.

In the valley between this ridge and the divide there is a formerly-worked coal-seam; strike north 10° east, dip, 20° west. About a quarter of a mile southward, at the tunnel, we are already in the typical granite. At the d divide, west side, there is a dike of a light-colored, porphyritic eruptive, probably a liparite. On the other side, we suddenly come to a series of sedimentary rocks striking northeast and dipping southeast, the lower part of which consists of quartzites and the upper part of Carboniferous limestone (*Spirifera centronata and Encrinites* at the road); the highest part at the contact with the granite shows alternating bands of black and white limestone, the latter crystalline, saccharoidal, and very metamorphosed, without fossils. The granite at the contact is coarse granular. For several miles going east the creek runs exactly on the contact line between the granite and the always crystalline white limestone. To the right the eruptive field extends, a rough and broken country, with high, rounded cliffs, showing the characteristic "woolsack" structure of the granite.

A few miles below the divide, always following the railroad, we leave the granite and pass over a 4-mile long monoclinal dipping east, similar to the one of Little Blackfoot, with gray Carboniferous limestone, a series of hard e flinty quartzites, and finally a succession of gray and brown slates cut by dikes of a light-colored eruptive similar to the one from Mullen; no fossils. Approaching Helena, the ground is more covered and the structure not so easily ascertained. Near Helena, Jefferson City, and Clancy the line is continually marked by a zone of metamorphosed limestones or dolomites; portions of the limestone seem sometimes to be included in the granite.

From all these stratigraphical facts we may draw a few conclusions: (1), that the granite is eruptive, and that it cuts strata at least as high as the Carboniferous limestone, and that in the series intersected we find Jurassic rocks (Logan's ranch, Little Blackfoot); (2), that the phenomena of metamorphosis at the contact very closely resemble those which elsewhere have been found to mark the boundary line of eruptive granites; (3), that, probably in Cretaceous or Tertiary time, eruptions of liparitic and andesitic rocks have again intersected the district.

A very puzzling question, however, is the occurrence of a coal-seam of probably Laramie age at Mullen f tunnel; possibly the great eruption is of Jurassic age, and the Cretaceous strata deposited in an insulated basin unconformably on the older rocks, disturbed by the granitic outburst, have since in their turn participated in the general great post-Cretaceous movements. The problem is very much in need of further investigation.

In many points the petrographical examination confirms these conclusions.

I had at my disposal specimens of the granitite from Mullen tunnel, and from Gregory mine, 16 miles southeasterly in the same eruptive. The same description can be used for both occurrences.

Macroscopically, it is a fresh, coarse, granular rock, in which can be distinguished quartz, biotite, much green hornblende, and a white feldspar, and can consequently at once be classified as a hornblende-granitite.

Thin section: Numerous irregular quartz granules with many fluid inclusions; only the smaller with moving bubble; a greenish-yellow biotite, not very largely represented; green hornblende in irregular crystals with strong absorption, sometimes decomposed to viridite, and often associated with grains of magnetite.

a *Feldspar.*—Orthoclase scarce, plagioclase by far predominating, with splendid striation and generally vivid colors. Maximum extinction of hemitropic bands, $22^{\circ} + 22^{\circ}$. It is consequently a feldspar approaching Labrador. Few inclusions. Apatite in long thin, needles, and some titanite.

The above-mentioned granite dike near Mullen pass is exactly similar, but rather decomposed.

The similarity to Zirkel's "Jurassic granite" from Nevada is immediately and clearly perceived, and thus the microscopical investigation confirms the results obtained from observations in the field.

A specimen from the large, dark dike one quarter mile west of the pass was also examined. It is a black, hard, and perfectly dense rock.

Thin section: Very decomposed, and apparently containing much calcite. Irregular pieces of a green,
b somewhat dichroitic chlorite, presumbably decomposed hornblende, imbedded in a crystalline mass of irregular feldspar crystals, mostly plagioclase as far as can be seen on account of decomposition. The dike is therefore composed of an aphanitic diorite, and probably contemporaneous with the great granite eruption.

Near this dike Mr. Davis found some crystalized garnet, a mineral very often appearing at the contact of dioritic and granitic rocks with sedimentary, calcareous layers.

In the interior of the field the pure granular structure of the granite does not seem to be continuous; it changes suddenly or more gradually to a denser dark-gray or dark-green porphyritic facies, with less quartz and much decomposed hornblende. In some of these varieties I have also found a light-green augite, very decomposed and with imperfect cleavage.

c The above-mentioned white or light-yellow, hard, porphyritic rock, occupies considerable room in the interior parts, for instance at the Gregory mine, where it covers an area of 1 or 2 square miles; it has all the characters of an overflow in connection with dikes; in fact the upper levels of the Gregory mine are in this eruptive, while lower down the granite and peculiar facies of the granite suddenly appear again.

A complete examination of this younger eruptive has not been made; from the few sections prepared it appears that part of it is a mica-andesite containing porphyritic plagioclase with zonar structure, brown mica scarce, and a ground mass of micro-crystalline structure, with small, often polysynthetic feldspar microlites. Predominatingly, however, a light-yellow liparite occurs, with a great amount of sometimes large granules of quartz, and a generally porphyritic, micro-crystalline structure.

The ore-veins cut through both liparite and granite, and are in their turn cut by several minor faults or "breaks".
d We must, consequently, attribute to them a Tertiary age.

One facies of the granite found in a cross-cut in Gregory mine is of peculiar interest as compared with the eruptive dikes of Big Belt mountains; macroscopically dark gray, dense.

Thin section: Small but sharp and perfect quartz crystals (double pyramid), few augites decomposed to a pale-green substance, often preserving the short prismatic crystals of the pyroxene. Numerous small, irregularly rectangular, somewhat opaque and decomposed plagioclase crystals with broad polysynthetic bands—all imbedded in a very fine, crypto-crystalline gray groundmass. This peculiar mode of development may be designated as a quartz-augite porphyrite.

DISTRICT OF BIG BELT MOUNTAINS.

[Quartz-augite porphyrite, Diabase, Quartz-diabase, Hornblende-andesite and Dacite, Augite-andesite, Liparite.]

e It is interesting to note the recurrence of those older, acid eruptions in the Big Belt on the opposite side of the Missouri, about 30 miles east of the Jefferson field.

The large anticlinal of Cambrian, more or less metaphorized, slates, constituting the main chain of Big Belt, is cut on its eastern flank by several minor dikes, and also contains a massive eruption or very large dike. The old celebrated diggings of Confederate gulch contain numerous boulders of a hornblende granitite, very similar to the one already described; going upward, we find that all these boulders come down the narrow cañon of Boulder creek, branching off southeasterly into the wooded and not easily accessible mountains; although following the cañon for several miles we did not succeed in finding the source of the granitic boulders. They doubtlessly come from a smaller eruptive near the headwaters of Boulder creek.

A marked increase in the metamorphism of the dark slates was noted, going up Boulder creek; soft and
f laminated at Confederate gulch, they, higher up, become hard and glistening.

Fifteen miles southward we visited the interior part of Big Belt again, going up Deep creek toward Bald mountain, the highest peak in the range (about 10,000 feet). We still are in the large slate anticlinal. High up, on the slope of Bald mountain, or rather of the peak next to it, we noticed several dikes of a porphyritic rock.

The first dike—lowest down—a very weathered, white rock, with large, perfect quartz crystals—the double pyramids, so characteristic of the porphyries.

Thin section: Large, very decomposed plagioclase crystals; some irregular feldspar crystals without striation—may be orthoclase. Quartz in angular sections, with numerous fluid inclusions. Few prismatic, light green, and fibrous crystals; decomposed augite; very few clear unaltered granules of pyroxene, markedly dichroitic—grass-green to faint yellowish-green. No good extinctions could be measured. Some thin stripes of a brown substance and opacite, possibly altogether decomposed hornblende; groundmass predominating, light colored; crypto- to micro-crystalline, very decomposed. The rock must be classified as a *quartz-porphyrite.* Farther up again, at an a altitude of about 8,000 feet, there is another dike with a similar, but differently developed rock, with beautiful porphyritic structure. In a gray or greenish-gray dense groundmass are imbedded round quartz grains up to 1^{mm} in diameter, and equally large gray or light red plagioclase in rectangular or square sections. Sometimes a feldspar crystal is exposed by weathering and then shows the form of albite, ∞ P and O P being about equally developed.

Thin section: Very decomposed, feldspar and groundmass being filled with kaoline. The large feldspar shows polysynthetic structure, with generally vivid colors; maximum extinction of hemitropic bands, $20° + 20°$. Large rounded quartz grains, sometimes fissured and the cracks filled with groundmass; numerous fluid inclusions. A few irregular grains of pyroxene; here also dichroitic. All imbedded in a decomposed, gray, micro-crystalline groundmass of feldspar and quartz. It is consequently a quartz-porphyrite. This rock, although coarser b porphyritic is exactly similar to the one described from the granite field near Gregory mine; and thus the age of these dikes is established as pre-Cretaceous and post-Carboniferous, probably Jurassic, and contemporaneous with the hornblende-granitite. Still farther up, near the summit, the greenish slate contains another dike with a dark gray, dense rock, without any crystals visible.

Thin section: This also appears very decomposed, but similar to the already-described dark eruptive from Mullen. Irregular pieces of decomposed hornblende, beside some long, fresh crystals; opacite throughout. Some larger, decomposed plagioclase crystals; groundmass very micro-crystalline; constituents hardly discernible, but probably feldspar and quartz. As the presence of the quartz is not proven, we must call it a hornblende porphyrite.

Thus we see that, although the Jurassic eruption of acid magma mainly took place west of the Missouri, it was c also extended eastward to the Big Belt range, in form of dikes and smaller massives. The magma is quite differently developed, for instance—(*a*) as hornblende granitite (plagioclase predominating; (*b*) as quartz porphyrite (large quartz crystals, some augite); (*c*) hornblende porphyrite (with quartz presumably in groundmass).

We notice that the pyroxene is never developed in the coarser, crystalline varieties; only—and sparingly—in the porphyritic and aphanitic varieties. These rocks can hardly be mistaken for younger, liparitic or dacitic eruptives. The feldspar, for instance, is very different, showing broader striation with vivid colors, and doubtlessly approaches labradorite.

Besides these dikes of an older, acid magma, there are others of younger age. A large dike of typical hornblende-andesite can be traced for several miles from the place where it cuts Boulder cañon. It is dark green, with small white feldspar crystals. d

Thin section: Green, fresh hornblende, in prismatic crystals; square and rectangular plagioclase crystals with zonar structure. Little opacite; groundmass mostly feldspathic, micro-crystalline.

At the mouth of Confederate gulch, 5 miles lower down in the foothills of Big Belt, composed of steep, dipping Silurian quartzite and limestone, girding the Cambrian anticlinal, there is an andesitic, double dike, running about parallel to the strike, about N. 70° W. It is about 200 feet wide, and consists of a dark green and a brown rock between which there is a breccia, showing the green eruptive to be the older, pieces of it being included in the brown.

The former is a (hornblende) dacite of a very different appearance, however, from the dacite of Little Belt and Dearborn. Composed of numerous small clear, quartz crystals, somewhat decomposed plagioclase in rectangular crystals, and a green viridite (probably decomposed hornblende) filling the greater part of the room e between. Some crypto-crystalline groundmass.

The latter is a pure andesite, with clear, sharp plagioclase crystals with zonar structure; extinction maximum between hemitropic bands, $23° + 23°$. Small amount of decomposed hornblende. Some small, violet-brown doubly-refracting crystals. All included in a glassy and micro-feldsitic groundmass, with some feldspar microlites.

Here I will also mention a diabase appearing as dikes most constantly in the red, Cambrian, or Silurian slates. It is purely crystalline, heavy, and dark. Macroscopically, white feldspar faces and granules of a dark mineral are seen. I have seen it at Cadottes pass, at the mouth of Confederate gulch, near Deep creek; also in the foothills of Big Belt; finally, 20 miles southeast of Deep creek, near the North fork of Sixteen-Mile creek, always in the red slate, never in high strata. The dikes are about 50 to 100 feet wide, and always easily discernible on the surface by the deep-brown rusty color it imparts to the ground. f

A specimen from Cadotte's pass is composed of fresh triclinic feldspar, irregular granules of a violet-brown augite, and much magnetite mostly surrounding the augite.

The dike from Deep creek, although macroscopically similar to this, presents on microscopic examination a most peculiar and interesting feature. It is a quartz diabase and a quartz diabase with granophyric structure of a rarely-seen beauty.

Feldspar.—Irregular granules and long crystals; generally gray colors and very fine striation; a few without striation, but from general appearance they must also be plagioclase. A few crossed striations. Not striated, rectangular sections extinguish obliquely. Few inclusions; rather fresh appearance.

Augite.—Irregular granules, nearly colorless or very pale-brown or green; now very decomposed, often only showing a remaining nucleus of fresh substance. Decomposes first into hornblende; then the hornblende gradually changes to chlorite, and the chlorite to brown or dark ferruginous products. Sometimes the augite changes a directly to yellow and brown products. The hornblende often appears as the direct continuation of an augite crystal, the cleavage extending from the latter to the former. The whole process is exactly similar to the general decomposition of diabasic augite as stated by Rosenbusch. Apatite in long needles. Magnetite abundant.

Quartz in large quantity, showing the most beautiful granophyric structure; the fragments of one individual—often regularly triangular in shape—are dispersed through the feldspar; very often also forming the threads of a perfect network; the large quartz granules are on the whole poor in inclusions, but carry some fluid pores with moving bubble.

Quartz diabases are of very rare occurrence, but a quartz diabase with granophyric structure I can safely claim as new to science.

The country south of Big Belt mountains, including the Bridger mountains, Sixteen-Mile Creek mountains, b and the Bozeman district is on the whole not very rich in eruptive rocks, the limestone-sheet and the Laramie sandstone covering most of the region.

On the headwaters of Gallatin and Madison rivers the eruptives must occur again on a large scale. Not having visited these districts, I can unfortunately say nothing of their character. At Bozeman and in the Gallatin valley pebbles and small boulders of a very porous and vesicular black lava occurs, indicating large eruptions, probably recent overflows.

The Cretaceous basin of Sixteen-Mile creek, above the limestone cañon, presents some interesting points.

Along the river there is a good exposure of Cretaceous rocks. Near the crossing of the road from Dry creek of Bridger mountains to White Sulphur Springs I noted the following section: 25 feet light-gray coarse (Laramie) sandstone; 60 feet dark greenish-gray sandstone, resembling a tufa, with obscure plant remains; 12 feet coarse c volcanic conglomerate of dark, often glassy eruptives. A few miles down the creek the same section, practically, is observed, but here a sheet, probably 20 feet thick, of a brown or yellow porphyry—a liparite—covers the conglomerate. The sandstone belongs most undoubtedly to the same Laramie formation, so enormously developed on the eastern slope of the mountains. The conglomerate and tufa occurring in it are of interest as indicating the age of the eruptives. Now, thin sections of the boulders in the conglomerate prove them to be prevailingly pure augite andesites; therefore the age of these coincides with that of the Laramie deposits. The andesite appears as a dark-green rock, with somewhat glassy luster and small glistening feldspar crystals.

Thin section: Feldspar very fresh, of rectangular form; all plagioclase, with fine striation and gray colors of polarization. Presumably oligoclase. Very few, but clear and fresh light-green augites (not rhombic pyroxene), in irregular granules. Groundmass prevailingly glassy, with few feldspar and augite-microlites. The glass is filled d with opacite or hematite dust, sometimes micro-fluidally arranged in strings.

The exact position of these conglomerates in the general series of the Laramie I am unable to fix.

The second eruption in time is that of the red liparite. I can not venture to decide whether we here have an overflow contemporaneous with the sediments or an intrusion. If the former, the time of the liparitic eruptions would be placed much farther back than has been generally assumed. It is a salmon-colored, or yellow, dense rock, without any porphyritic crystals.

Thin section: Light-colored, irregular, round spots, bent and twisted stripes of a microcrystalline mass of sometimes clearly discernable quartz and feldspar; thin fissures, running irregularly and filled with chalcedony, the light-colored stripes are imbedded in a brown microfelsitic groundmass; hematite granules microfluidally arranged, often surrounding the lighter parts. It is a typical, liparitic groundmass.

e That not all augite andesite is necessarily of Laramie age is shown by a dike, as far as I could ascertain, *cutting* the sandstones near Shields' river, east of the Bridger range, about 12 miles from Livingston. It is a typical, somewhat decomposed augite-andesite.

Another Laramie conglomerate, of which, however, I am able to fix the position more accurately, occurs near Bozeman coal-fields. Mr. J. E. Wolff, of the Northern Transcontinental Survey, kindly furnished me material for a rapid examination.

The total thickness of Laramie series at the coal-fields, as measured by our party near Livingston, exceeds 30,000 feet; at a certain point above the Jurassic strata fossils are found, identified by Prof. R. P. Whitfield as belonging to Hayden's Cretaceous No. 2; 2,000 feet above these the Bozeman coal-beds appear; 200 feet above these we find the conglomerate, consisting of hornblende-andesites, which, consequently, must be of Lower Laramie f age.

Macroscopically, the pebbles appear as a dark-green or gray rock, with white feldspar crystals.

Thin section: Only triclinic feldspar, with large extinction; mostly regularly rectangular crystals, with zonar structure by inclusions. Hornblende readily to be recognized, but very decomposed to opacite; groundmass brown, microcrystalline, with some glass. Another specimen has the hornblende decomposed to viridite.

There is a great similarity between these andesites and those described from Big Belt mountains at Boulder creek.

From all this it may be seen that we must not attempt to limit the periods of the eruptions too much from inclination to systematic division. Probably the andesitic eruptions began early in the Laramie period and lasted with different intensity till or after the end of the same.

CRAZY MOUNTAINS.

Every traveler on the Northern Pacific must have noticed the rugged and majestic group of the Crazy mountains north of Livingston. Their perfect similarity to the Highwoods—only on a larger scale—is a fact which I could not but observe when seeing them from a distance. I believe Mr. Hayden mentions them in his before-mentioned report on the Yellowstone and Missouri as the "Crazy Woman's mountains", and suggests their being "an anticlinal uplift". Mr. J. E. Wolff, of the Northern Transcontinental Survey, who has visited them, gives an account which altogether proves their perfect analogy with the Highwoods. They are formed of a very shallow synclinal of Cretaceous sandstones, nearly horizontal even at the highest points; the layers are highly metamorphosed, and cut in all directions by a maze of eruptive dikes. Mr. Wolff collected some specimens from these dikes, but as yet no examination of them has been made(*a*); a large field, promising rich returns, is here open.

RÉSUMÉ.

I shall now attempt to condense, in a few words, the more important conclusions derived from the study of some of the eruptive rocks in Montana.

The oldest eruptive is without doubt the granite with red orthoclase, found as dikes in the gneiss at the headwaters of Belt creek, Little Belt mountains. The second eruption of Cambrian or early Silurian age is a diabase, sometimes appearing as a quartz-diabase, in which the quartz has a granophyric structure (quartz pegmatoide, Levy). During the rest of the Paleozoic era complete calm appears to have reigned here as well as in other parts of the Rocky mountains.

In the Jurassic period, presumably, a large and extensive eruption of acid magma took place, developed in massives or dikes as dioritic granite and quartz porphyrites, the latter dividing into augitic and hornblendic porphyrites.

The most remarkable and varied part of the history of eruptions is that comprising the Laramie and Tertiary series. The order of succession is not always easy to prove, especially as no sedimentary rocks younger than Laramie are found in the districts in question. One definite conclusion is that the andesitic eruptions commenced late in the Cretaceous period or in the Laramie.

While Mr. Clarence King pronounced the hornblende-andesites as pre-Miocene, we can here more definitely say that at least a part of them are of Laramie or even pre-Laramie (marine Cretaceous) age.

According to the elsewhere established sequence, the next younger eruptive would be the hornblende-dacites (sometimes approaching liparites) appearing as massives in Little Belt mountains, and as dikes in Laramie in front of the main range. I have no direct evidence of their age compared with that of the andesites. In the Highwood mountains we find them together with andesites in a Laramie conglomerate.

No augitic dacites, and only few augite-andesites were found.

Liparites are found in front of the main range as dikes in Laramie strata.

No liparitic or basaltic overflows or lava-fields were met with; they doubtless exist, though, in southern Montana toward the Idaho boundary line.

The most recent of the eruptives appear to be the trachytes and basalts. They occur generally intimately associated, and doubtless belong to one and the same period of eruption. They are post-Laramie, presumably of Pliocene age. The trachytes are nearly all developed as augite-trachytes, and some are amazingly rich in augite. The basalts are in part plagioclastic; another part consists of the new group of the analcite (nosean) basalts, originally composed of nosean, augite, and olivine, but with the nosean extensively changed and metamorphosed into analcite. These eruptives generally occur as dikes, sometimes crowded together in great number; the trachytes appear to be younger than the basalts.

a Mr. J. E. Wolff has described the Crazy mountains and their rocks in the *Neues Jahrb.*, 1885, I, p. 69, and in a more extended paper printed for the Northern Transcontinental Survey—*Notes on the Petrography of the Crazy mountains*, etc., Heidelberg, 1885. Andesites (propylites), tephrites, diorite, and some metamorphic sedimentary rocks are found there.—R. PUMPELLY.