CHAPTER II.

GEOLOGY.

TOPOGRAPHY.

Relief.—The Blue Mountains are situated in the northeastern corner of the State of Oregon. They form an irregular complex of mountain groups which as a whole may appropriately be regarded as a projecting spur from the great central mountain mass of Idaho. On the east, near the Idaho boundary line, which follows Snake River, high plateaus adjoin the mountains and continue into Idaho. The northwesterly limit is well marked by the broad ridge which swells to elevations of 4,000 to 5,000 feet from the lower plateau of the Columbia River and which continues from the southeastern corner of Washington in a southwesterly direction for at least 150 miles toward the John Day River. The westerly limit may be extended to the Deschutes trough, which separates the Blue Mountains from the Cascades, and the southerly boundary is formed by the deserts of Malheur River and Harney Lake. This area includes a great diversity of lesser ranges in confusing complexity, due partly to displacement, partly to extremely heavy lava flows covering the old and probably structurally more simple ranges. A very irregular drainage, caused by the same lava flows, has cut deep valleys into the heterogeneous mass of mountains.

The northeastern part consists of a lava plateau from 4,000 to 5,000 feet high, above which rise the Eagle Creek Mountains, a circular group with a diameter of about 30 miles and elevations exceeding 9,000 feet. Within this plateau lie fertile valleys, at least one of which is a depressed area bounded by fault lines. About 30 miles west of the Eagle Creek Mountains is the Elkhorn Range. This is composed of older rocks, is continuous in a northwesterly direction for about 40 miles, and reaches an elevation of a little over 9,000 feet. Its western slope is not so sharply defined. A spur extends to Bald Mountain (elevation 8,330 feet), and lower ridges connect this high region of old rocks with the Greenhorn Ridge, which, with maximum elevation of 8,100 feet, continues for 30 miles in a general northwesterly direction. The Elkhorn and Greenhorn mountains form the largest area of old, pre-Neocene rocks in the Blue Mountains, which is surrounded practically on all sides by lava masses rising to irregular plateaus with elevations of 5,000 to 6,000 feet. West of the Greenhorn Mountains another pre-Neocene ridge, also surrounded by plateau-like lava masses, extends northwesterly from Dixie Butte (elevation 7,700 feet) toward Long Creek. Lastly, south of Dixie Butte lies the deep John Day Valley, and south of this rises, with an abrupt slope suggestive of a fault line, the imposing Strawberry Range, culminating in Strawberry Peak (elevation 8,600 feet). This range has a marked east-west trend, but it is not of uniform geological build, its eastern part being heavily covered with lava flows, while its western end is composed of pre-Neocene rocks.

To such a degree is the older pre-Neocene structure veiled by the lavas that it is difficult to obtain an idea of its probable configuration. It was by no means a unit, for it was separated into several masses by deep depressions and valleys of erosion; but its general trend was surely southwesterly, although folding movements of different age, faults, and extremely active erosion had greatly diversified its features.

Drainage.—With the exception of the few streams which find their way down to the plains of Harney Lake, the whole region drains either into the Snake or the Columbia River. Snake River pursues its course along the eastern border through the lava plateau, in a canyon which for about 50 miles north of Huntington varies from 2,000 to 3,000 feet in depth. In the high basaltic plateau just west of the Seven Devils this canyon is eroded to a depth of 5,000 feet or even more.[1] Near the mouth of the Grande Ronde the bottom is 3,000 feet below the basalt plateau.[2]

The northeastern plateau and the northern side of the Eagle Creek Mountains are drained by the Grande Ronde and Imnaha rivers, both flowing in sharply cut canyons. The former also cuts far back into the region of the northern Elkhorn Range and heads in the great granodiorite area north of Cable Cove, near Sumpter. The southeastern part of the Blue Mountains is drained by Powder and Burnt rivers. Powder River has a very remarkable course. Heading west of the Elkhorn Range, with a southeasterly direction, it soon turns sharply, in a deep canyon, and takes a northerly direction, which it maintains through Baker Valley. At the northern end of this valley is another, smaller canyon, and a still sharper turn to a southeasterly course, which it keeps until the junction with the Snake. Burnt River also heads in the central region near Sumpter, and then traverses a series of canyons and open valleys until, near Huntington, it joins Snake River.

The whole of the western drainage is through the three forks of John Day River. The North Fork heads near Cable Cove, a few miles north of Sumpter, and flows from there westward through deeply cut canyons. The Middle Fork heads near Austins, opposite Burnt River, and traverses the mountains in a deep but rather broad canyon or

[1] W. Lindgren: Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 88.

[2] I. C. Russell: Water-Supply and Irrigation Papers U. S. Geol. Survey, No. 4, p. 25.

valley with a west-northwesterly direction. The South Fork of John Day River also has its source immediately west of the head of Burnt River and continues for 40 miles due eastward, flowing in the broad, open John Day Valley, bounded on the north by sloping basalt flows, and on the south by the abrupt buttresses of the Strawberry Range.

GENERAL GEOLOGICAL FEATURES.

The part of the Blue Mountains represented on the accompanying map consists of several cores of older rocks partly surrounded by floods of Neocene lavas, rhyolites, andesites, and basalts. If the map were extended somewhat farther north it would be seen that the same lavas entirely surround the northern part of the Elkhorn Range as well as the Eagle Creek Mountains. These cores of older rocks form a salient from the great mass of mountains filling central Idaho. The vast granite area which occupies so much space in central Idaho does not extend into Oregon, but ends some miles east of Snake River, near Huntington, against sedimentary rocks and old lavas which are believed to be of Triassic age. West of these beds, which have a general northeasterly strike, appears a series of argillites, strongly developed about Durkee and the Virtue district and equally strongly represented in the Elkhorn Range. These argillites, which have a general east-west strike, would appear, as far as the present incomplete examinations have been carried, to form a large syncline. In the Elkhorn Range the dips are prevailingly to the south, while in the southeastern part of the area northerly dips predominate. The whole series is moderately compressed, and if the structure were examined in detail many minor folds would probably be found. The rocks consist chiefly of argillites, often very siliceous. Coarse sediments are generally absent. Smaller masses of slates of probably the same age are found in the extreme western part of the area. The age of this series of argillites is believed to be Paleozoic and probably Carboniferous.

In the Eagle Creek Range, surrounded on all sides by high lava plateaus, another series of rocks appears which presents much similarity to the strata near Huntington mentioned above. It consists of shales and limestones with large masses of intercalated lavas. The beds lie nearly flat in the foothills, but are tilted, folded, and strongly metamorphosed in the central part of the mountains. Their age is Triassic, as shown by fossils found in several localities. The same Triassic rocks appear in the northeastern corner of the area exposed below the Neocene lavas of the Snake River Canyon.

In many places all of these sediments, the Carboniferous as well as the Triassic, are disrupted and contain larger or smaller intrusive masses of granite, granodiorite, diorite, gabbro, and serpentine. The granodiorite is most extensively developed in the northern Elkhorn

Range. Diorites, diabases, and serpentines prevail in the eastern part of the mapped area.

Baker Valley, in the center of the district, is the largest Pleistocene area. It is bordered on the east by low hilis, while toward the west the imposing Elkhorn Range rises to elevations of 9,000 feet. At its base is a fault scarp, excellently exposed at the mouth of Salmon Creek in the Nelson placer mines, which indicates that the valley is largely an area of subsidence.

In its general aspect the region described is of the geological type so frequently found on the Pacific slope, consisting of closely folded Paleozoic and early Mesozoic strata, shattered by large masses of intrusive granular rocks and covered by Neocene lava flows.

THE ROCKS.

ARCHEAN.

The only area of gneiss in the region described occurs northwest of Bald Mountain, about La Belleview mine. The rock is a coarse-grained biotite-gneiss with prominent schistosity and sometimes a little contorted. The reddish-brown biotite forms large anhedral, often ragged foils. A few plates of muscovite are associated with it. Quartz in elongated grains is very abundant. There is only a very small amount of plagioclase and orthoclase. The composition indicates that the rock is of sedimentary origin, but it is far more altered than the ordinary contact-metamorphic slates. Below La Belleview mine the strike is N. 40° E. and the dip 45° W. The rock is usually sharply separated from the granite.

PALEOZOIC SEDIMENTS.

Rocks referred to the Paleozoic system occupy a large area in the lower Burnt River region, about Pleasant Valley, in the southern Elkhorn Range, and on the headwaters of Burnt River and Granite Creek. Smaller isolated areas of clay slate, inclosed in diorites, diabases, and serpentines, also occur near Susanville, in the Quartzburg district, and near Canyon. There is no clew to the age of these, but they are believed to belong to the same Paleozoic series. The prevailing rocks through the whole of this large sedimentary area are dark and very fine grained, ranging from cherts to siliceous argillites and ordinary clay slates. A large proportion of the sediments show no distinct stratification in ordinary outcrops, but in thin sections the carbonaceous streaks which indicate the planes of deposition are readily recognized. In many places, however, the rocks are normal clay slates of fairly fissile character.

In contrast to the heavy limestones of the Trias, this series contains only isolated lenses, ordinarily of no great length. The only large and persistent belt of limestones known in it is found west of Durkee, as shown on the map.

The cherts are gray to dark gray, and usually consist of extremely fine- and even-grained quartz aggregates. The siliceous argillites are similar, but contain more or less finely divided organic matter, shreds of sericite, and finely divided kaolin. The clay slates are extremely fine-grained rocks with streaks of finely distributed carbon, inclosing lenticular spaces of clearer substance, consisting of microcrystalline to cryptocrystalline aggregates of quartz with kaolin, sericite, chlorite, and calcite, and occasional prisms of tourmaline, rutile, and zoisite. In places the slates are calcareous and contain rounded or lenticular masses of fine-grained calcite. Pyrite and pyrrhotite are generally absent, except in the immediate vicinity of mineral veins. Larger clastic grains are not abundant. Near intrusive granitic rocks the argillites become brownish and somewhat crystalline through a conversion into allotriomorphic aggregates of biotite, quartz, and feldspar. A little magnetite and actinolite are also often present. Such rocks are found all along the main contacts, as, for instance, near the Baisley-Elkhorn vein; they usually extend only a few hundred feet from the contact. In the Present Need tunnel, in the Quartzburg district, a narrow streak of a peculiar dark-gray, almost flinty rock occurs, spotted by irregular black blotches. This consists of an interlocking quartz aggregate filled with sericite and containing bunches and spherulitic aggregates of tourmaline, accompanied by a little calcite. It is inclosed in diabase, and is probably a contact-metamorphic, tuffaceous clay slate.

The strata throughout the region have a well-marked east-west strike. The dip is prevailingly southward and ranges from 40° to 70°. Though the structure has not been definitely worked out, owing to the frequent difficulty of ascertaining strike and dip, it is probably a series of compressed folds. Schistosity is rarely observed, though at a few places in the Elkhorn Range and near Sumpter joint planes and incipient north-south schistosity transverse to the strike may be noted. The strike of the strata is a little north of west near Sumpter and Auburn, while south of Powder River it is from 10° to 20° south of west.

The only place where fossils were found is near the Bonanza mine, at Winterville, where round crinoid stems occur in a small mass of crystalline limestone. The other limestone lenses in the series, though carefully examined, yielded no fossils. Round crinoid stems are most common in Paleozoic rocks; taken in consideration with the fact that the series as a whole has a distinctly older appearance than the Triassic of Eagle Creek, from which it is also petrographically very different, we may with some confidence refer it to the Paleozoic and possibly to the Carboniferous. The series is similar to the Delhi division of the Calaveras formation in the Sierra Nevada,[1] which is believed to belong to the Carboniferous.

Well-defined Carboniferous fossils have been found by Professor Condon in the Crooked River drainage, in the extreme western part of the Blue Mountains.

PALEOZOIC LAVAS.

Compared to the Trias of Eagle Creek, the Paleozoic section is poor in intercalated lavas of the same age as the sedimentary beds. Greatly altered greenstones, of massive and roughly schistose structure, occur in it at Pleasant Valley, and at Unity, which is a railroad station south of that place; also on the road to Clifford from Sumpter, on McCully Fork, a few miles from Sumpter, and in Quartz Gulch, on Olive Creek. These rocks are so much altered that the original character can hardly be ascertained. They are chiefly tuffs, containing much chlorite, epidote, and calcite.

HUNTINGTON SERIES.

These sedimentary beds are exposed near the mouth of Burnt River and along Snake River below that place, at least as far as Mineral, and are described in detail on pp. 752–762. This series consists of limestones, calcareous shales, clay slates, and volcanic tuffs, of red and green color, resting, with flat dips of from 14° to 60°, on a basement of old volcanic rocks. The latter are well exposed in Burnt River Canyon near its mouth, and in the Snake River Canyon below Huntington. The prevailing rocks are greenish or grayish, massive, and fragmentary igneous rocks, showing no bedding nor schistosity. They seem to be largely old rhyolites and accompanying tuffs. The clay slates and limestones at Connor Creek mine and at Mineral belong to the same series, and there is, as far as could be seen, no line which separates it from the Paleozoic series of Weatherby and Durkee. The line indicated on the map is really arbitrary. The only indication of its age obtainable were a few round crinoid stems from the limestone near the gypsum mine at Huntington. I incline to the belief that this series is Triassic, in spite of the lack of distinct separation from the older rocks, and base this belief on the flat dip and on its association with large amounts of volcanic rocks, so characteristic of the Triassic of this region.

TRIASSIC SEDIMENTS.

The Triassic beds found in the United States may be grouped in two widely differing areas. The first include the Red Beds of the eastern part of the Cordilleran system, and consist of a considerable thickness of sandy strata in which fossils are very scarce and which

[1] Geologic Atlas U. S., folio 66, Colfax, California.

probably are not of marine origin. The Triassic beds of the Pacific slope are of very different character, being distinctly marine sediments and generally containing characteristic fossils. The fauna is similar to that of the Alpine province in Europe. The first marine Trias was discovered by Whitney in California, and was examined by Gabb, who identified it with the upper Trias of the Alps. Soon afterward thick Triassic strata were discovered in the Star Peak Range, Nevada, by the geologists of the Fortieth Parallel Survey; and later, Triassic beds with a thickness of several thousand feet were found by Dr. C. A. White[1] in southeastern Idaho. The Triassic beds of California have been described by Professor Hyatt[2] and J. Perrin Smith.[3] The latter, in a recent article, has given an excellent review of our knowledge of the marine Trias of the Pacific coast and its correlation with European and Asiatic occurrences. The Canadian geologists have also discovered beds of similar age and character in British Columbia. Professor Dawson,[4] in 1899, described an extensive Triassic series associated with surface lavas of the same age from the vicinity of Nicola Lake, and named it the Nicola formation. Further discoveries of marine Trias have been made on Peace River and near Glenora, on the Stikine River. McConnell has found Triassic beds on the Liard River, and Dawson again found Triassic beds on Queen Charlotte Island and several other islands in the Straits of Georgia. Still farther north, in the Copper River region of Alaska, the Triassic has recently been identified by Messrs. Schrader and Spencer.

With widespread Triassic areas in California, Idaho, and Nevada, and with similar areas north of the international boundary line, it seemed strange that no rocks of the same age were found in Oregon or in Washington. This gap has been partly bridged by the discovery of very extensive Triassic beds in the Eagle Creek Range, extending from there across Snake River into Idaho, to the vicinity of the Seven Devils. If the sedimentary rocks in the vicinity of Huntington belong to the same age, as is possible, though by no means certain, the area of the Triassic would be still further extended.

A characteristic feature of the Triassic of the Eagle Creek Range is the occurrence of large masses of limestone and some shale, with an abundance of more or less altered lavas poured out during the time when these beds were being deposited.

The Triassic sediments are best exposed on Eagle Creek. All along the foothills of the lower Powder River the Triassic lavas contain smaller bodies of limestone and shale, but on Eagle Creek, below the forks, the sedimentary series prevails and consists of calcareous shales and limestone in horizontal or slightly inclined position. Volcanic

[1] U. S. Geog. and Geol. Surv. of Terr., 1883, Vol. XII, Pt. I, p. 105.

[2] Bull. Geol. Soc. America, Vol. V, p. 395.

[3] Jour. Geol., Vol. VI, 1898, p. 776.

[4] Descriptive Sketch of the Dominion of Canada, by G. M. Dawson: Montreal, Canada, 1879.

breccias are interbedded with the limestone. The total thickness of the series, including the volcanic beds, is probably several thousand feet. Many of the exposed limestone masses are several hundred feet in thickness. Above the junction, as described on page 735, the limestones become converted into marbles and the volcanic breccias into schists, while the whole series acquires a dip of 60° eastward.

Dr. T. W. Stanton examined fossils collected one-third mile below the mouth of East Eagle Creek, and reports them to consist of numerous specimens of *Halobia* and two indeterminable fragments of an ammonite. The *Halobia* is apparently an undescribed species, but the genus itself is characteristic of the Trias. Another lot, collected from the limestone bluff on East Eagle Creek 2½ miles above its mouth, contains *Pentacrinus* columns with spines and fragments of tests of echinoids. From the Miles placers, 1½ miles below the mouth of East Eagle Creek, I obtained, through Mr. F. R. Mellis, of Baker City, a cast of a gigantic gasteropod found in the limestone bed rock during drifting operations on this claim. Dr. Stanton remarks that it has the form of a very large *Turritella* or *Pseudomelania*. Nothing of this character approaching it in size has been described from the west coast, but similar forms described as *Chemnitzia* and *Pseudomelania* are known from the Trias and Jura of Europe. The total length of this cast is 8 inches and its diameter at the thickest end 3 inches.

Along Snake River Canyon, below the mouth of Pine Creek, Triassic lavas and tuffs are again exposed in the bluff below the Neocene basalt flows which cap the hills. These Triassic igneous rocks contain thin beds of black shales and limestone with imprints of a large species of *Daonella* or *Halobia*. A limestone mass 4 miles below Ballard Ferry contained a *Lima* with fragmentary imprints of a *Halobia* (?), and is also probably Triassic. The last two fossils were obtained from Mr. E. Antz, of Ballard Ferry.

From these data and from what is known of the field relations of the strata it is safe to conclude that a Triassic series is developed on a large scale in this region; but from the paleontological evidence at hand it would not be possible to say which one of the numerous subdivisions of the series is present. The Eagle Creek Mountains offer a most attractive field for future study.

TRIASSIC LAVAS.

Extending from North Powder to Eagle Creek along the foothills of the range are large areas of old basalts, andesites, and tuffs, containing in places small masses of limestone and shales. Though greatly altered, they are as a rule not schistose, except in the central part of the Eagle Creek Mountains. Fine-grained uralitic metabasalts were found in the Farley Hills. Near Copper Butte and the claims of the North American Copper Company dark-green or brownish amygdaloid metabasalts and tuffs, often full of calcite nodules and veinlets of zeolites, were collected. Similar altered basalts, andesites, and rhyolites, with their tuffs, were found at many places along Snake River below Pine Creek. Some of these are described in more detail on pp. 731 and 750. At the Sheep Rock mine, on East Eagle Creek, below the Triassic limestone, appears a volcanic breccia of metabasalt and other lavas, which also contains fragments of a granitic rock. A few miles higher up this breccia becomes very schistose. Its original character is not apparent to the naked eye, but the microscope reveals it very plainly. The fragments of lava are pressed flat or lenticular, and secondary hornblende and chlorite suffuses the whole rock.

JURASSIC AND CRETACEOUS SEDIMENTS.

Neither Jurassic nor Cretaceous sediments have been recognized in the area described; but from the Crooked River drainage, west of Blue Mountains, a sandstone with characteristic Jurassic fossils was collected by Prof. Th. Condon, of Eugene, Oreg., and examined by Professor Hyatt.[1] The Chico Cretaceous with its characteristic fossils has been found by Professor Condon at many points in the Crooked River drainage and along the lower John Day River.[2] Lately Dr. Merriam has visited the same region and recognized, besides the Chico Cretaceous, beds possibly belonging to the Knoxville or Lower Cretaceous.

NEOCENE SEDIMENTS.

During the Neocene period most important changes took place in the Blue Mountains. The volcanic flows radically changed the topographic features of the lower slopes; the upper river valleys were dammed and filled with silts and gravels; the upper Snake River Valley became a lake, dammed by the lava barriers extending from the Idaho Mountains to the Cascades, and its surface attained a level corresponding to a present elevation of approximately 4,200 feet. This lake has left abundant traces of its existence throughout the Snake River Valley, particularly between Boise and Weiser and on both sides of the Owyhee Range. The rising waters of the lake followed the river valleys draining toward it far into the mountains, where remains of its deposits may still be found. Surrounding the margin of the lakes are many small, basin-like depressions, which in part are certainly of structural origin—that is, caused by depressions along certain fault lines. These basins are usually filled with lake sediments. As the lake gradually receded, accumulations of gravels followed the retreating waters in the old river valleys, and these now form terraces resting on the lake beds.

[1] Trias and Jura in the Western States: Bull. Geol. Soc. Am., Vol. V, p. 395.

[2] Th. Condon, in Raymond's Statistics of Mines and Mining, Washington, 1870, p. 212. J. S. Diller, Bull. Geol. Soc. America, Vol. IV, p. 214.

the west side there are remains of a well-defined bench at an elevation of 3,100 feet. On the north the beds extend much higher up on the slopes of Lookout Mountain, probably reaching 4,000 feet. They are disturbed, dipping gently westward, and are interstratified with rhyolite tuffs and covered in places by small basalt flows.

The divide between Burnt River and Powder River along the railroad shows most interesting relations. At the summit, which has an elevation of 4,000 feet, is a gap 2 or 3 miles wide, bounded on both sides by low slate hills. The rolling hills are covered with shallow, gently folded lake beds, dipping 12° to 30° E. or W.

The gravel slopes on both sides give positive evidence that an elevation of 4,100 or 4,200 feet marks an old and important base-level. I can see no other explanation possible than this: That the Payette Lake once just covered the summit and the basin of Sutton Creek. Whether the Payette Lake also flooded Baker Valley is doubtful. There seems to have existed a very delicately balanced set of conditions which finally caused Powder River to turn northward and excavate the canyon south of Baker City in the basaltic barrier extending across from the Virtue Hills to the Elkhorn Range. This barrier was originally probably just a little higher than the gap through which the railroad runs.

PLEISTOCENE SEDIMENTS.

Older sediments.—As elsewhere in the Pacific States, there is no distinct line separating the Neocene and the Pleistocene sediments. The two periods insensibly grade one into the other. Assuming that the highest level of the Neocene lake in Idaho marks the middle of that period, equivalent to the Miocene, it follows that the excavation of the great Snake River Canyon comprises the late Neocene (Pliocene) and probably a part of the Pleistocene period. It has been assumed, on the basis of paleontological evidence, that the next lower level of the lake, at an elevation of about 3,100 feet, marks the close of the Pliocene and that the erosion of the Snake River Canyon below that level falls into the Pleistocene.[1] The Glacial epoch then merely becomes a part—and a smaller part—of the Pleistocene period. As a result of this reasoning, the gravel bars along the lower courses of Snake, Powder, and Burnt rivers, up to an elevation of several hundred feet above the present bed, may be assigned to the Pleistocene. But as the tributary streams are ascended, erosion has cut down less deeply into their beds, and Neocene gravels may in places be found at 50 feet, or even less, above the present river level—as, for instance, in the upper Burnt River and Powder River valleys. On the John Day side, as would be expected from the lower level of the Columbia River,

[1] Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 101.

erosion has been more active than on the side facing the upper Snake River Valley. Throughout the whole region the rivers and creeks usually flow over gravel-filled beds, indicating a present slow rate of progress of erosion.

To the Pleistocene period belong also the alluvial deposits in Baker, Pine, and Eagle valleys.

The largest Pleistocene area is that of Baker Valley, an elliptical trough 20 miles long and 10 miles wide. Excepting near the foot of the Elkhorn Range, where large and gently sloping débris fans mark the debouchure of the gulches, it is a remarkably level area. Above and below the valley the river flows in canyons. Interesting evidence has been adduced which proves that a fault line exists along the foot of the Elkhorn Range (p. 652) and that the whole valley is probably a field of depression, similar to so many of the basins in the marginal areas of the great Payette Lake. If the erosion of the lower canyon near North Powder did not keep pace with the sinking along the fault line, Baker Valley must, at some time during the Pleistocene, have been a shallow lake. The only definite evidence of this is the fine-grained kaolinic material capping the gravels in the lower reaches of the creeks at the foot of the Elkhorn Range. At Baker City wells are said to have been drilled through sediments to a depth of 600 feet. Carbonized wood and other vegetable remains are reported to have been brought up from that depth. This shows clearly that the Pleistocene of the valley rests in a closed basin.

Glacial deposits.—It has been shown by Prof. I. C. Russell and myself that during a late part of the Pleistocene period, probably during the Glacial epoch, the canyons of Snake and Salmon rivers were again filled with sediments to a depth of about 300 feet and that the erosion since the close of that epoch has been limited to the removal of these 300 feet of sediments, together with an insignificant deepening of the early Pleistocene rock channel. Between Mineral and Connor creeks, in the upper Snake River Canyon, are indications of a similar filling of the eroded canyon by sand to a similar depth, 300 feet. Aside from this there are few gravel bars higher than 50 feet above the present river bed.

INTRUSIVE ROCKS.

Granite.—True orthoclase granites appear to be absent from the area examined. At least no well-marked occurrences of this rock were found. The granitic area of Sparta consists of a normal soda granite in which the orthoclase is almost entirely wanting, its place being filled by albite. The surface of this granite area is extremely decomposed, and fresh rock can be obtained only from shafts and tunnels. A representative specimen from the Gem mine is a greenish-gray rock, with grains averaging 3 mm. to 5 mm. in diameter. The quartz grains are abundant and large, the feldspars slightly greenish. There are only small amounts of ferromagnesian minerals, mostly chlorite. The thin section shows a very large amount of quartz and a smaller amount of feldspars. Some of these are prismatic crystals, others irregular grains. A number of the feldspars are single crystals; others show a few intercalated lamellæ, the maximum extinction of which in the zone perpendicular to (010) is about 14°, corresponding to albite. No perthite is present. Between the quartz and the feldspar is a little chlorite, probably remains of primary biotite.

A partial analysis of this granite by Dr. W. F. Hillebrand resulted as follows:

Analysis of granite from Sparta.

Constituent.	Per cent.
SiO_2	76.25
CaO	1.70
Na_2O	4.60
K_2O	.59

This indicates a very unusually pure albite-granite containing a large amount of quartz.

In the first foothills west of Sparta and north of Powder River the granite becomes porphyritic by the development of large quartz crystals. This granite-porphyry has a coarsely microcrystalline groundmass of pegmatitic quartz, and much albite and some orthoclase, the latter two in part intergrown in the manner of perthite.

Granodiorite.—The most common granular rock of eastern Oregon is granodiorite. It occupies a large area in the northern part of the Elkhorn Range, including Bald Mountain. It also appears near Cornucopia, in the Eagle Creek Range, and, together with diorite, in the several areas extending from Lookout Mountain to Malheur. The rock is light gray to dark gray in color and its grains are from 2 mm. to 4 mm. in diameter. The quartz grains are gray, the feldspars white; the hornblende, which is usually present, appears in prisms up to 6 mm. long. The biotite, which is always present, forms black scales up to 3 mm. in diameter. Under the microscope the rock has a hypidiomorphic structure. The biotite appears in yellowish-brown, ragged foils, inclosing much magnetite. The most abundant feldspar is a roughly prismatic andesine, embedded in the usual way in anhedral clear quartz and orthoclase. Perthite and microcline are absent. The rock is never schistose and is usually fresh. Only a slight alteration to chlorite and epidote is noticeable in the biotite and hornblende.

A typical rock from near the lake at the northern base of Bald

Mountain, at an elevation of 7,000 feet, was analyzed by Dr. W. F. Hillebrand with the following result:

Analysis of granodiorite from Bald Mountain.

Constituent.	Per cent.
SiO_2	71.23
Al_2O_3	14.61
Fe_2O_3	.93
FeO	1.66
MgO	1.01
CaO	3.29
Na_2O	4.00
K_2O	1.92
H_2O (below 110°)	.17
H_2O (above 110°)	.55
TiO_2	.34
ZrO_2	.02
P_2O_5	.14
MnO	.08
BaO	.08
SrO	.02
Li_2O	Trace.
Total	100.05

The analysis shows that the rock is a normal granodiorite of an acid type, containing a little more quartz than is usual in the granodiorite of the Sierra Nevada.[1] For this reason the other constituents appear with slightly lower percentages than they would have in a rock poorer in quartz. In the small areas and near the contacts of the large areas the rock shows a great tendency to transition into normal diorite. Examples of this may be seen near the Baisley-Elkhorn mine, at the divide between Powder River and Bull Run, on the road from Sumpter to Granite, in the Greenhorn Mountains, and at many other places.

Diorite.—The diorite, which occurs as a facies or local development of granodiorite, is a dark-gray to dark-green granular rock, consisting of andesine or labradorite feldspar, greenish hornblende, and sometimes brown biotite, with magnetite and titanite as accessories. The hornblende is usually roughly idiomorphic, as are, with short prismatic form, the feldspars. Pressed in between the feldspars is frequently a little quartz. Diorites were collected from the Baisley-Elkhorn mine,

[1] Granodiorite and other intermediate rocks, by W. Lindgren; Am. Jour. Sci., 4th series, Vol. IX, p. 277.

from the Coyote Hills near Haines, and from Dixie Creek Canyon above Prairie. Diorites containing some orthoclase were collected from the Powder River Canyon near North Powder.

Gabbro.—The dioritic rocks are sometimes intimately associated with gabbros. It is thus, for instance, in the Robinsonville and in the Virtue districts. The gabbros are greenish-gray granular rocks, composed chiefly of a basic plagioclase and a pyroxene often converted into uralitic hornblende. The gabbros of this region are often irregularly crushed, but rarely schistose. Gabbro areas are found in the Virtue district, in the Elkhorn Range, in the Greenhorn Mountains, and finally near Canyon. In the latter two localities the rock is associated with large areas of serpentine.

A gabbro from the Flagstaff mine, Virtue district, is a mottled, dark greenish-gray rock, much crushed and recemented, but not schistose. The feldspars are saussuritic, of almost flinty appearance. The rock consists of coarse aggregates of light-green amphibole, which also pervades the whole slide in needles and fibers. The originally large grains of plagioclase, which stands between labradorite and anorthite, show extraordinary bends and fractures in their broad twin lamellæ, and are dissolving into new aggregates of basic feldspar. There is no zoisite present. A uralite-gabbro containing much zoisite was collected from the Copper King mine, 7 miles west of North Powder.

One mile below the Little Giant mine, near Alamo, two rocks closely associated with serpentine were collected. One of these is a coarse gabbro crushed almost to a breccia, and containing serpentine and chlorite on the fractures. The other is a fine-grained aggregate of anhedral, light-brownish hornblende, with an andesine or labradorite. At the Virginia mine, Robinsonville, occurs, closely associated with serpentine, a greenish-gray, granular rock of somewhat varying grain, the maximum being 2 mm. The rock originally consisted of colorless augite and basic plagioclase, with typical gabbro structure, but it is extremely crushed, the augites are bent and shattered, and the plagioclase is filled with sericite and traversed by veinlets of calcite and zoisite. At the Great Northern mine, near Canyon, gabbro also appears, associated with diabase and serpentine. The rock is a normal gabbro consisting of broad anhedral grains of augite and basic feldspar; it is greatly altered and filled with chlorite, uralite, and kaolin.

Diabase.—The diabases are granular rocks belonging to the gabbro family and consisting of augite and labradorite feldspar, intergrown with peculiar and characteristic structure. Typical diabases are not very common in this region. Diabases form the prevailing rock of the Quartzburg district and are adjoined on the south, below Comer, by diorites. At the junction of the two forks of Dixie Creek appears a very fresh, dark-green diabase-porphyry, with abundant phenocrysts of uralitized augite and plagioclase in a somewhat finer-grained groundmass of normal uralitized diabase. Near the Present Need mine coarse diabases are found associated with dikes (?) of diorite-porphyry. Similar uralite-diabases are found at Copperopolis, on the east fork of Dixie Creek.

At the Great Northern mine irregular masses of a very altered diabase occur in the gabbro. The rock is filled with calcite and chlorite, only the lath-like feldspar remaining fresh.

Serpentine.—This rock, which is rarely found in Idaho and Montana, begins to appear in force as the Pacific province of intrusive rocks is reached. It forms large areas in the vicinity of Robinsonville and Bonanza, in the eastern part of the Greenhorn Mountains, at Susanville, and in the Strawberry Range south of Prairie and Canyon. At all these places it is closely associated with gabbros and allied rocks. This is so constant that one is forced to believe that the serpentine is an altered form of gabbro, perhaps also of peridotites, and that in its original state it was intruded simultaneously with the gabbros, diorites, and granodiorites into the sedimentary series.

The serpentine is of the ordinary dull-green appearance, and has not suffered greatly from pressure. Thin sections from Canyon show a normal rock with grate structure, containing abundant magnetite, forming a network in the clear serpentine mass. Chromite is found in the serpentine south of Prairie and near the Winterville placer mines.

The older dike rocks.—The sedimentary series and the granular rocks intrusive in them do not contain many dikes. Between Sumpter and the North Pole mine several greatly altered and partly mineralized dikes, which probably originally were diorite-porphyries, cut the argillites. Aplites are sometimes found near the contact of the intrusives, as are minor dikes of diorite and granodiorite. Porphyry dikes of light color, completely altered, bleached, and softened, occur in the Red Boy mine. In the Coyote Hills the diorite contains pegmatitic dikes consisting of orthoclase, microcline, and quartz, together with some idiomorphic andesine and small grains of augites—a very unusual character of pegmatite. In the same locality were found fine-grained dioritic dikes of the kersantite type of lamprophyres, a class of rocks which otherwise seem very rare in this region. In Idaho it has often been observed that gold-quartz veins follow such narrow lamprophyric dikes. The only similar occurrence in the Blue Mountains is at the Connor Creek mine, where a narrow dike of sericiticized and carbonatized porphyry accompanies the vein.

NEOCENE LAVAS.

General statement.—The Neocene period in the Blue Mountain region, as throughout the whole of Oregon, Washington, and California, was characterized by enormous eruptions of lavas of different kinds. So far as known the Neocene lavas of the Blue Mountains belong, almost without exception, to the earlier part of the Neocene period—that is, to the Miocene. Late Neocene (Pliocene) and even Pleistocene eruptions are known to have taken place in different parts of the Northwestern States, but in this region it seems as if the Pliocene epoch had been one of quiescence as far as eruptions were concerned. The Neocene lavas surround the Blue Mountains almost completely. They fill the old valleys of a drainage system occupying a lower level than that of the present streams. The highest parts of the Blue Mountains are, as a rule, not covered with these flows, but on the lower slopes they are piled up in numberless sheets, aggregating as much as 2,000 feet in thickness.

The rocks of this series are separated into three groups—the basalts, the rhyolites, and the andesites. The basalts are the most widely distributed of the rocks, but the rhyolites and the andesites also occupy large areas.[1]

Regarding the succession of these lavas, the evidence is not altogether satisfactory. South of Baker City and near Durkee the basalts cover rhyolitic tuffs. On the divide between Powder River and Burnt River, south of Baker City, the basalts also seem to rest against older masses of rhyolite. On the other hand, near Canyon basalt flows appear to be overlain by rhyolite tuffs, and on the flanks of Strawberry Butte a dike of rhyolite apparently cuts the basalt flows.[2] Near Austin basaltic flows seem to cover the andesite. It will be seen that the evidence is somewhat contradictory, but, on the whole, it seems probable that the eruptions were begun by rhyolites, followed by andesites, and closed by the basaltic outbursts. Near Boise, in the adjoining region of Idaho, the rhyolites were the earliest of the Neocene eruptives, and were succeeded by a basalt. In the Silver City district, in southwestern Idaho, on the other hand, the rhyolite is later than the basalt, as is clearly seen in the section of the Trade Dollar mine.[3]

Rhyolite.—The rhyolites are generally absent from the eastern and western parts of the area described. The largest rhyolitic eruption is found south of Baker City, where it builds up the divide between Powder River and Burnt River from a point some miles west of Hereford down to thé mouth of Clarks Creek. The hills north of Burnt River consist almost entirely of rhyolite. The same rock continues up

[1] A valuable contribution to the literature of the lake beds and eruptive rocks of the lower John Day River has recently been published by Dr. J. C. Merriam. (University of California, Bull. Dept. Geol., Vol. 2, No. 9, pp. 269-314.) He finds in the John Day River Basin, below Canyon, the following formations: (1) Eocene lake beds, with flows of rhyolite and andesite (Clarno formation); (2) John Day series (Miocene) of tuffs, with several flows of rhyolites; (3) Columbia River lava (Miocene basalts); thickness over 1,000 feet; (4) Mascall formation (probably Miocene) of tuffs and ashes; (5) Rattlesnake formation (probably Pliocene), consisting of gravels, tuffs, and rhyolite, the latter overlying Columbia River basalt; (6) Terraces (Pleistocene) up to 100 feet above the rivers.

[2] These rhyolites of Canyon are evidently identical with those in the Rattlesnake formation of Dr. Merriam, which he regards as of Pliocene age. See footnote 1, above.

[3] Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 140.

to the divide, 2,500 feet above the river, and down the northern slope toward Powder River until at an elevation of 5,000 feet (1,000 feet below the summit) the covering basalt flows are met with. Toward the east this rhyolite gradually thins out, and near Pleasant Valley only a few small areas are found covering the slates. Rhyolite tuffs occur, as stated, near Baker City, on Griffin Gulch and Sutton Creek, also near North Powder, on Wolf Creek, and finally at Canyon.

The rhyolite is of the normal reddish or brownish lithoidal variety, with small crystals of feldspar and quartz contained in a streaky microcrystalline to cryptocrystalline groundmass. The rhyolite tuffs are light-colored, grayish rocks, which usually are easily dressed, and therefore make good building stone. They consist of a mass of rhyolitic fragments, often pumice-like in character, and cemented by a finer mass of the same material.

Dacite.—A few miles north of Hereford, on Big Creek, occurs a flow of light-brownish rock closely associated with the rhyolite. It contains abundant porphyritic crystals of quartz, glassy feldspar, and brown biotite in a hypocrystalline groundmass of trachytic structure. The feldspars are a plagioclase approximating to labradorite in composition, and the rock should therefore be classed as a dacite.

Andesite.—Andesites are practically absent from the whole eastern and northern part of the area described. At Granite and in Bull Run, for a few miles above the town, however, bluffs of hornblende-andesite appear on both sides of the stream, apparently covered by basalt. The thickness attained is only from 50 to 100 feet. The rock is light gray and porphyritic, containing small phenocrysts of feldspar and hornblende in a fine-grained groundmass consisting of plagioclase and hornblende. The structure of the groundmass is trachytic. The feldspar phenocrysts are apparently labradorite. In their largest development the andesites are found on the headwaters of Burnt River and on the divide between that river and the Middle Fork of John Day. They even extend as far west as Prairie, near which place they are apparently covered by later basaltic flows. The andesitic eruptions in the vicinity of Clifford have a thickness of probably not less than 1,000 feet, and form a greatly dissected plateau, the summit of which attains an elevation of from 5,000 to 6,000 feet. To a very large extent the andesites are of fragmental character—that is to say, they consist of tuffs and breccias. On the road from Sumpter to Hereford the divide between Powder River and Burnt River is covered by 300 feet of andesitic tuffs and breccias well stratified, coarser layers alternating with more fine-grained material, almost like sandstones. These tuffs dip 20° N., and at the summit of the ridge have an elevation of 5,500 feet. On the south side of the ridge andesitic breccias prevail down to an elevation of 4,500 feet, when the underlying rhyolites appear, covered by dacite. West of Burnt River the heavy flow which extends down toward Susanville and Prairie consists very largely of coarse breccias, containing angular fragments of andesites of varying appearance. Some are dark gray; others brownish or black. Many fragments are vesicular. This breccia is cemented by a finer mass of the same material, and the whole forms a well-consolidated mass. The resemblance to the andesitic breccias overlying the auriferous gravels in California is very striking.

The rocks are chiefly normal hypersthene-andesites, containing phenocrysts of labradorite, augite, and hypersthene inclosed in a brownish, glassy groundmass containing small needles and prisms of feldspar. Sometimes fragments of lighter color are present which contain, besides augite and pyroxene, some needles of hornblende.

Basalt.—As is well known, basalt is the predominating rock among the eruptive masses surrounding the Blue Mountains. Basalt flows cover vast areas in the eastern part of the region described, adjoining Snake River, where they form the extensive plateau which almost completely surrounds the Eagle Creek Mountains. Throughout the larger part of this area the basaltic formation consists of a great number of superimposed flows which are well exposed along many sharply incised canyons. The flows are from 50 to 150 feet thick, and slight differences in weathering render them very conspicuous in favorable exposures. East of Cornucopia the basaltic flows reach a total thickness of over 2,000 feet; only rarely are they accompanied by or interbedded with tuffs. This formation, with its characteristic exposures of thin, superimposed beds of dark-brown color, extends over thousands of square miles north, east, and west of the Eagle Creek Mountains. It is the same formation which Prof. I. C. Russell has named the Columbia River lava, and it must be acknowledged that the persistent extent of these beds over such a vast territory deserves to be specially pointed out by a local name. If this name is to be preserved as a distinct formation name, I would suggest that it be restricted to the basaltic lavas of Miocene age. It seems to be the intention of Professor Russell to give it a somewhat wider significance, including under it different kinds of lava of Miocene or Pliocene age. This seems scarcely advisable if the name is to be preserved in the significance given to it above. The Columbia River lava crosses Powder River just south of Baker City and appears on the low hills separating the upper from the lower river. The flows are here very thin, rest on clays, sands, and fine gravels, and slope gently eastward.

Little Lookout Mountain is covered by a succession of basalt flows evidently belonging to the same formation. Similar rocks are exposed in Burnt River Valley, between Weatherby and Durkee, and on the spur between Rock Creek and Snake River. On the Idaho side the characteristic flows descend to river level, showing that the canyon must have been excavated before the period of basaltic flows.

The Elkhorn Range from Auburn north is free from basalts and other Neocene eruptions, but at its southern end, in the first sharp bend of Powder River, south of Baker City, basaltic flows are piled up to an elevation of 4,700 feet, or a total thickness of about 1,000 feet. Heavy masses of basalt form bluffs on both sides of Granite Creek, below the town of Granite, and extend from here nearly up to the summits of the Greenhorn Range.

Basaltic flows are again noted near Austin and on the lower slopes of the John Day Valley from Prairie to Canyon. They are beautifully exposed on Strawberry Butte, south of Prairie, and it is probable that the headwaters of this river are entirely surrounded by these igneous masses. On Strawberry Butte the total thickness of the flows probably amounts to several thousand feet. As in the southern portion of the area, individual flows are well exposed, appearing as dark-brown strata on the abrupt slopes of the mountain.

In petrographic character the basalts show little variation. They are entirely normal rocks of their kind, with or without olivine, and ordinarily contain a moderate amount of glassy groundmass. Occasionally, however, this glassy base almost disappears, and the rock then is usually somewhat coarser, having the appearance of a diabasic rock. Vesicular and massive flows alternate; the former are usually the more glassy varieties. From near the mouth of Canyon Creek, at the town of John Day, was collected a black, fine-grained basalt of unusual freshness. It contains nearly lath-shaped crystals of labradorite, abundant fresh, small olivine grains, and a brownish augite. These constituents are cemented by a small amount of dark-brown glass containing very beautiful arborescent forms of magnetite. A short distance north of Medical Springs (20 miles north-northeast of Baker City) the rocks are very unusually glassy basalts. Thin sections show them to consist chiefly of glass filled with minute crystals of pyroxene and a few larger phenocrysts of plagioclase. The rocks also contain a few larger prisms of hypersthene.

The question of the manner of eruption of these enormous masses of basalt has always been an interesting one. It is generally believed that the magma was not ejected from volcanoes, but that it poured out in a comparatively quiet manner from large fissures in the crust. This view has been substantiated by the discovery of a large number of basalt dikes at Cornucopia and other places high up on the flanks of the mountain, and in such a position relative to the flows that it is not to be doubted that the foci of the eruption were located at these places. A description of this interesting occurrence will be found under the head of Cornucopia mining district. The rocks collected from dikes prove in all cases to be normal basalts containing a varying but generally small proportion of glass. Basalt dikes were also found at Mineral, Idaho, at Sparta, and on the road from Rye Valley to Mormon Basin; but in no place are they exposed on such a magnificent scale as in the Bonanza Basin, near Cornucopia.

GEOLOGICAL HISTORY.

The oldest rocks of the Blue Mountains are represented by the relatively small area of gneiss embedded in the granodiorite north of Bald Mountain. Undoubted Archean gneiss is not often met with in the Pacific States. Mr. H. W. Turner[1] has described areas of probable Archean gneiss from the Big Trees quadrangle, Calaveras County, Cal. This area is embedded in granitic rocks of much later date. In Idaho, along the Nez Percé trail, north of Salmon River, two large areas of gneiss were found[2]—one near Shoup, the other at Elk City. Both have the appearance of true Archean gneisses and both are shattered by later granites. These isolated occurrences are of much interest, as they indicate the character of the basement upon which the Paleozoic rocks were deposited. The composition of the Oregon gneiss probably indicates a sedimentary origin, but it is completely recrystallized over a large area, which precludes the supposition of contact-metamorphic origin. Unfortunately, no contacts between the gneiss and the sedimentary rocks were observed; but it is likely that the latter were deposited unconformably upon the gneisses.

During the Paleozoic age the sea extended over what is now the Blue Mountains and probably connected with the Carboniferous sea of eastern Nevada and California. The deposits of this sea consisted of argillaceous and siliceous mud, which during long subsequent ages consolidated to argillites, more or less rich in silica. These were the prevailing sediments, but a few interbedded strata of limestone were also formed, the largest appearing now in the hills west of Durkee. The sediments contain interbedded volcanic rocks (tuffs and greenstones) in a few places, but they are not prominent. The only clue to the age is furnished by the round crinoid stems in the limestone of Winterville. This argillite series is undoubtedly older than the Trias of the Eagle Creek Mountains, and may without much uncertainty be referred to the Paleozoic, possibly to the Carboniferous, which is so extensively developed in California. The whole argillite series, from Weatherby to the Greenhorn Mountains, is composed of fine-grained sediments, indicating deposition in deep waters. Sandstones, quartzites, and conglomerates are entirely absent, according to present information.

This probably Paleozoic series is adjoined, toward Huntington, by another series of clay slates, shales, and limestones, with some gypsum. At Huntington these sediments rest with flat dip on heavy masses of old lavas and tuffs, which now are considerably altered, though nowhere schistose. The general character of this series shows much similarity to the Trias of the Eagle Creek Range; on the other hand, toward the northwest these rocks soon change into the steeply dipping argillites

[1] Geologic Atlas U. S., folio 51, Big Trees, California.
[2] Unpublished notes, W. L.

of the Burnt River Canyon above Durkee, which have been considered as Paleozoic. No contact line or unconformity could be observed, and the whole series dips northward. The line drawn on the map is wholly arbitrary and may have to be revised. Indeterminable fossils, some of which seemed to be round crinoid stems, were found in the Huntington series near the gypsum quarry.

The structural features show considerable regularity. The argillites of the Elkhorn Range trend a few degrees north of west and dip about 60° S. South of Burnt River Canyon and as far down as Huntington the strike is southwesterly or south-southwesterly, the dip generally being at steep angles toward the north. Thus it would seem that the sediments are folded, roughly speaking, into one great geosyncline. Strongly marked slaty cleavage is generally absent, though in a few places in the Elkhorn Range are indications of joints and cleavage planes perpendicular to the stratification. In many places the argillites are massive and fail to show the direction of the stratification. The thickness of the argillite series can not be safely estimated at present; it doubtless amounts to several thousand feet.

During the Triassic period the ocean again covered this region, though the abundance of surface lavas and tuffs indicates that the waters were shallow and land masses not far distant.

The Triassic of the Eagle Creek Mountains and Snake River consists of shales and limestones interstratified with a vast amount of more or less altered tuffs and lavas, and is exposed all along the lower Powder River and the upper course of Eagle Creek. There is reason to believe that these Triassic lavas extend as far northwest as the Farley Hills and the greenstone areas west of the North Powder, and they certainly again emerge from below the basalt flows in the canyon of the Snake River, below the Seven Devils. In this canyon they contain smaller strata of shale and limestone with Triassic fossils. Tuffs and old lavas with intercalated sediments and limestones again appear in the mining district of the Seven Devils, on the Idaho side. Along Eagle Creek the little-altered limestones and shales contain *Daonella* and *Halobia*, as well as pentagonal crinoid stems and fragments of ammonites and echinoids. In the foothills the strata sometimes lie nearly horizontal, but in the Eagle Creek Range they quickly acquire an easterly dip and become greatly altered by dynamometamorphism. The limestones change to marbles, the volcanic tuffs to amphibolitic schists. The central parts of the Eagle Creek Mountains are built up of these altered Triassic rocks. Outside of this area the strata and the Triassic lavas show no evidence of compression or traces of schistosity, although the volcanic rocks may have been considerably altered by ordinary hydrometamorphism, producing epidote, chlorite, and zeolites. The thickness of the Triassic beds and accompanying volcanic rocks is considerable, but has not been directly measured. Without doubt the total amounts to several thousand feet.

Though the strata of known Triassic age were at no place observed in contact with the Paleozoic series, it is probable, from the general relations, that there is an unconformity between the two series of strata. This implies that there were pre-Triassic uplift and folding, and that the Triassic beds were laid down on the upturned edges of the Paleozoic strata. It is not unlikely that during this uplift the intrusions of the diorites and gabbros of the Virtue district and the southern Elkhorn Range occurred. Among the volcanic tuffs and breccias of the Trias fragments of quartz-diorites are found.

After the deposition of the Trias followed another and more extensive uplift, probably the same which affected the whole of the Pacific slope. Both the Triassic and the Paleozoic series were folded, though the former in places still lies nearly horizontal. The Trias was violently compressed in the area now occupied by the Eagle Creek Mountains. The uplift was accompanied by very extensive intrusions of granular rocks, and as these now appear in the highest parts of the mountains and as great erosion has since taken place, it follows that the Blue Mountains in Jurassic and early Cretaceous times must have been a range of imposing height. The intrusions consisted of granodiorites, diorites, gabbros, and peridotites, the latter now partly converted into serpentines. They extend over the whole area from the Eagle Creek Mountains to the Elkhorn and the Greenhorn ranges. The time of this great uplift is difficult to fix with exactness from the data at hand. It was certainly post-Triassic and pre-Neocene. Jurassic strata have been found on Crooked River, west of the Blue Mountains, and also near Burns, south of Crooked River,[1] but their relation to the older strata is not known. Sandstones of Chico age, underlain by Knoxville beds, have been found at several places on the lower John Day River,[2] under such circumstances as suggest that they may connect below the lavas of the Cascade Range with the Cretaceous of western Oregon. It seems probable then that, at least as far back as the Chico Cretaceous, the western foot of the Blue Mountains was skirted by the sea, and that the uplift and intrusion of the granular rocks are of pre-Chico age. In the Sierra Nevada the time of similar upheavals has been determined as post-Jurassic and pre-Chico, and thus it becomes probable that the disturbance in the two provinces took place about the same time. Regarding the form of the mountain range after the great uplift, we know little except that it had a general east-west direction. A very active erosion had worked on it for a long time, but had failed to reduce it to anything like gentle topographic outlines. That the pre-Neocene rivers had excavated their channels to a greater depth than the present streams is certain, for the lavas descend to the level of Snake River below Huntington, and that mighty stream flows for many miles on a basaltic

[1] Trias and Jura in the Western States, by A. Hyatt: Bull. Geol. Soc. America, Vol. V, p. 401.

[2] J. S. Diller: Bull. Geol. Soc. America, Vol. IV, p. 214. Oral communication by Dr. J. C. Merriam.

bed. Take away the lava flows which cover the flanks of the Blue Mountains, and you would see rising to imposing heights, almost from sea level, and separated by a lower gap, two great, roughly circular mountain groups—the Eagle Creek Mountains and the Blue Mountains proper. They formed a projecting spur from the great crust-block of central Idaho, but did not connect directly with the Sierra Nevada.

Then, as now, the Blue Mountains were seamed by gold and silver veins, and gold-bearing gravels accumulated in its valleys. The formation of the veins followed the great intrusions of granitic rocks, and may be placed in the Jurassic or early Cretaceous.

Such were the conditions when the great Neocene lava flows began to pour out from numberless fissures on the flank of the mountains. At first came rhyolites and andesites, then basalts in increasing volume. Lava streams covered each other in endless succession. The lower water courses became filled with basalts, damming the headwaters and creating lakes. The sharp slopes became sloping plateaus, and finally the Blue Mountains stood like islands in a basaltic sea, a salient of the Idaho mass, separated from it by the black surface of slowly cooling flows. The rivers had to adjust themselves to these new conditions and lay out their lower courses anew. Hence all these strangely changed river courses and sediment-filled upper basins which form such difficult problems in the geology of the Blue Mountains. The bar of lavas thrown across from the Idaho Mountains to the Cascades resulted in the formation of a great lake in the central Snake River Valley, the waters of which reached elevations of about 4,200 feet. Establishing an outlet through the present course of Snake River, the lake was gradually drained. The Pliocene and the early part of the Pleistocene period were times of active canyon erosion, with many temporary checks, resulting in the formation of benches and bars of gravel high above the present drainage level. One of the most difficult problems is the explanation of the present course of Snake River below Huntington. Certain parts of the canyon must have been excavated before the Neocene period, even if it was largely filled again by local basalt flows. Below the mouth of Powder River the Snake for a long distance flows over basalt, and it seems probable that the old canyon turned somewhat westward and found its way toward the Columbia closer to the Eagle Creek Range. The question is, What caused the post-basaltic river to lay out its course across the high plateau of lava and across the projecting shoulder of the Seven Devils, which attains at least 6,500 feet in elevation, and where the canyon now is correspondingly deep? It would seem as if a much more natural outlet could have been established across the Deschutes gap at the foot of the Cascades, or through the present Baker Valley and down the direction of the Grande Ronde River. Much more detailed examinations are necessary to explain these problems.

After the close of the Neocene, or even during the middle of that period, followed other orogenic movements of a less violent character. The lake beds of Durkee Valley, of the Sutton Creek Plateau, and of Rye Valley were thrown into gentle folds and also faulted. At Rye Valley undisturbed Pliocene river gravels cover lake beds of Miocene age which form a monocline dipping gently westward. Besides this, there is no doubt that slow epeirogenic movements of the crust took place in eastern Oregon in Neocene and post-Neocene times, but their exact nature and amount are doubtful. The pre-Neocene drainage was cut deeper than that of the present day, and hence it would seem likely that this region has suffered depression of considerable amount. It seems, indeed, impossible that the extrusion of such enormous masses of lavas over such a vast area should not be accompanied by slow continental movements of some kind. To such movements is probably also due the course of Snake River Canyon below Huntington, referred to above.

After the Pliocene and early Pleistocene epochs of erosion, the Sierran period of Le Conte,[1] during which the conditions of the present day were gradually established, followed the Glacial epoch, when the climate became much colder and glaciers covered the higher region of the Eagle Creek, the Elkhorn, and the Greenhorn ranges. But this was of relatively short duration as compared to the period of erosion. The glaciers have disappeared only very recently, not many thousand years ago. Compared to the glaciers of the Sierra Nevada and the Cascade Range, they were of small extent.

There is reason to believe that there is an old fault line located at the eastern foot of the Elkhorn Range and that Baker Valley is essentially an area of subsidence. At some time in the Pleistocene period renewed faulting occurred along this line, as is shown most convincingly by the exposures at the Nelson gravel mine, near the mouth of Salmon Creek (p. 653). What the total amount of this faulting is remains doubtful. A dislocation of at least 200 feet is shown by the exposures.

PHYSIOGRAPHIC PROBLEMS.

The Blue Mountains abound in physiographic problems caused by many changes in river courses due to the lava floods. A few of these have been briefly touched upon in the detailed part of this report and in the paragraph on Neocene sediments; but many of them, and the most important ones, among which is the origin of the Snake River Canyon, are still unsolved, and a rich field here remains for future work. This report, being principally limited to problems of economic geology, is very incomplete in respect to the physiographic branch of geology.

[1] The Ozarkian and its significance in theoretical geology: Jour. Geol., Vol. VII, 1899, pp. 525-544.