town of Ouray the thickness of the Canyon Creek member is only 300 feet, while above the Uncompahgre formation north of Bear Creek the thickness is 800 to 900 feet. These relations are structurally important since they contribute to the evidence on which the age of the monzonite intrusions has been determined.

As the rock fragments that compose the San Juan tuff are not volcanic bombs or lapilli that have been ejected in molten or semi-molten condition from nearby explosive volcanic vents, it appears that the San Juan tuff was formed by the erosion and transporting from its original site of material of some distant volcanic accumulations. The presence in the conglomerate beds of the Canyon Creek member of the tuff of well rounded boulders of volcanic rocks exhibiting a great variety of types of lava that must have been transported from distant sources gives support to this hypothesis of origin. Furthermore, conglomerate beds in the tuff contain a small proportion of pre-Tertiary boulders and pebbles to at least 400 feet above the base, showing definitely a distant source for part of this material. Some of the angular and more homogeneous breccias give the impression that they may have been extensive mud-flows, in which there was less opportunity for the abrasion and rounding of individual fragments.

The age assigned to the San Juan tuff in the Ouray Folio[22] is Eocene, but more recent investigations in the southwestern part of the San Juan region has shown that the formations of definite Eocene age, such as the Torrejon and Wasatch formations, are entirely free of volcanic material.[23]

Some volcanic material is found in the uppermost Cretaceous formations, but since this material corresponds to a much earlier period of volcanism in the San Juan mountains, as will be mentioned later, it appears that the San Juan tuff is of post-Wasatch age. The Potosi volcanic series, which overlies the Silverton series and the San Juan tuff, has

[22]Idem., p. 8.

[23]Reeside, J. B., Jr., Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin, Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 134, pp. 35-48, 1924.

been shown to be of Miocene age. Although the age of the San Juan tuff may lie anywhere within these age limits, there appears to be no definite means of a closer age determination and hence the formation may be of Oligocene or early Miocene age.

Silverton Volcanic Series

Pending the completion of the mapping and study of the lavas in the Ouray-Telluride-Red Mountain region, no detailed description of the Silverton series will be attempted. The following description is a summary taken largely from the description in the Ouray Folio, but supplemented with some observations of the writer. The Silverton series consists of a succession of flows, tuffs, and breccias, the lavas of which have the composition of andesite, latite, and rhyolite. Between the deposition of the San Juan tuff and the eruption of the Silverton series there intervened a period of extensive erosion that resulted in the formation of a large valley or basin within which most of the rocks of the Silverton series were erupted. In the central part of this basin in the Silverton quadrangle this series attains a maximum thickness of about 3000 feet. It has been divided into five formations, which are named as follows, beginning with the oldest—(1) the Picayune andesite, (2) the Eureka rhyolite, (3) the Burns latite, (4) the pyroxene andesite, and (5) the Henson tuff. The name Picayune andesite has since been changed to Picayune volcanic group, in which are included the other rocks erupted during the same epoch as the andesite.

In the areas about Ouray, Sneffels, and Telluride with which the present report is largely concerned, the pyroxene andesite of the Silverton series appears to be the only formation developed sufficiently to be recognizable. It consists of a series of dark colored porphyritic lavas of dense texture, commonly amygdular or vesicular near the top and interbedded with thin tuffs, agglomerates, and flow-breccias. The exposures of the lavas are characterized by the reddish brown, purplish, or dark color of the massive rocks, and in places by the presence of vesicles filled with opal, quartz, and calcite.

On Whitehouse Mountain the pyroxene andesite appears as a dense flow 60 feet in thickness resting on the San Juan tuff and overlain by tuff of the Potosi series, while in Potosi Peak the series is represented by 300 to 500 feet of flows and tuffs. In the vicinity of Richmond and Imogene basins the Silverton series attains a thickness of 800 to 1000 feet, and some dikes accompanied the eruption of the surface rocks. Here the rocks may include representatives of several of the formations of the series, such as the Eureka rhyolite, the Burns latite, and the pyroxene andesite, but as yet these formations have not been definitely identified.

Based upon the finding of plant remains and fresh-water shells in calcareous tuffs and shales near the top of the Burns latite, the age of the Silverton series is regarded as probably Oligocene or early Miocene.[24]

Potosi Volcanic Series

The uppermost division of the volcanic complex developed in the western San Juan Mountains is known as the Potosi volcanic series. These rocks consist of massive flows with a few thin agglomerate and tuff beds, and the greater number of the rocks are latite or quartz-latite in composition while rhyolites constitute a subordinate part of the series. In Potosi Peak, which is the type locality of the series, there is about 1250 feet of these flows and tuffs. This series of lavas is now found only on the higher peaks and ridges, as erosion has removed the rocks elsewhere and exposed the older underlying formations.

The base of the Potosi series in Potosi Peak and the other mountain ridges near Sneffels is marked by a conglomeratic tuff of light color, and above it is a series of reddish or grayish flow-breccias and gray wavy-banded flows. The basal tuff and flow-breccia comprise about 200 feet of the section, while the banded flows above are two or three in number, the individual flows of which are commonly 100 to 200 feet in thickness. The upper part of the Potosi series

[24]Cross, Whitman, and Howe, Ernest, U. S. Geol. Survey Geol. Atlas, Silverton Folio 120, p. 9, 1905.

on Potosi Peak consists of several hundred feet of thin flows and reddish tuff layers. West of the Creede district, where the Potosi series has been divided into a number of formations, plant remains found in the Huerto formation of the Potosi series indicate that the beds should be correlated with the Florissant lake beds of Miocene age.[25]

The distribution and position of the Potosi series in the Ouray district is of considerable economic interest for the reason that many of the fissures and veins that are prominent and well developed in the lower volcanic formations become broken up and impoverished at higher horizons within the Potosi lavas. This characteristic effect of these rocks has been pointed out in several earlier reports on this part of the San Juan Mountains.

Intrusive Rocks

GENERAL FEATURES

There is a great variety of intrusive rocks within the Ouray-Telluride-Red Mountain region, exhibiting not only a great range in texture and composition, but also in their mode of intrusion. While the work has not progressed to the point where the interrelations of all of these rocks has been determined, a number of important revisions of the previous geologic work in this district have been made. For the reason that these revisions comprise considerable change in the interpretation of the structure of the district, and in the relations of the ore deposits to this structure, the evidence on which these new interpretations are based is given in some detail below.

The most fundamental grouping of the intrusive rocks is based upon age relations, and two major groups of post-Cambrian rocks are recognized on this basis in the Ouray district: (1) The older group includes those rocks which intrude only those sedimentary formations that are now found beneath the Telluride conglomerate and in the San Juan tuff and are separated from the later group by an uncon-

[25] Emmons, W. H., and Larsen, E. S., Geology and ore deposits of the Creede district, Colo.: U. S. Geol. Survey Bull. 718, p. 12, 1923.

formity which represents a long period of erosion free from volcanism. These older rocks are commonly described as monzonite-porphyry and are of late Cretaceous or early Eocene age. (2) The younger group includes those rocks which intrude the highest Tertiary volcanics that are exposed in the district. The composition of these intrusives is more diversified, and they are of Miocene or later age.

Metallization followed or accompanied both of these periods of igneous activity, but under very different geologic conditions, so that the ore deposits of the two periods possess certain inherent characteristics. The characteristic features of these two groups of rocks will be described briefly, together with their age and structural relations.

OLDER INTRUSIVE ROCKS

Quartz Monzonite Porphyry[26]

The term quartz monzonite porphyry may be considered to include the average composition of nearly all the numerous dikes and sills near Ouray, the laccolithic bodies of Dexter Creek, Oak Creek, and Corbett Creek, and the "Blowout" stock just north of Ouray (Pl. I). There is little variation in the composition and texture of the rocks in the different localities near Ouray, although parts of the larger bodies probably approach the composition of granite porphyry.

The typical quartz monzonite porphyry is a medium grained rock of light gray or greenish gray color, which contains fairly abundant phenocrysts of feldspar, mostly plagioclase, and subordinate amounts of the altered dark minerals, hornblende and biotite. At different localities either hornblende or biotite may become the predominant dark mineral, and there is also some variation in the total amounts of these minerals. The crystallinity of the groundmass is especially noticeable in the larger bodies of rock, while the smaller dikes and sills may have a greenish and more dense groundmass. The groundmass is composed of quartz and orthoclase with subordinate amounts of plagioclase and small flakes of biotite.

[26]Cross, W., and Howe, E., Ouray Folio, p .9.

Granite Porphyry

The known occurrence of granite porphyry in the vicinity of Ouray is in the Canyon Creek laccolith, a body of porphyry intruded into the Mesozoic sedimentary rocks above the Dolores formation on the north side of Canyon Creek. This body of rock presumably was originally connected with the porphyry body of Corbett Creek, but the relations are now obscured by the overlying San Juan tuff. It is probable that granitic facies of the porphyries are also present in some of the other intrusive bodies of the district. The following description is given by Cross and Howe[27] of the granite porphyry of the Canyon Creek laccolith:

> "The rock is characterized by its prominent hornblende and plagioclase crystals some of which are nearly 1 centimeter long, lying in a gray microgranular groundmass of orthoclase and quartz and a little magnetite. Quartz seems confined to the groundmass, where it is abundant and developed in distinct dihexahedral crystals only slightly modified by the less regularly formed orthoclase. This groundmass is so largely in excess of the phenocrysts of much altered plagioclase that it seems necessary to call the rock granite porphyry in spite of its strong resemblance to the normal habit of quartz-monzonite-porphyry."

Latite

A body intruded into the Cutler formation in the vicinity of Lake Lenore and another body intruded into the Morrison formation north of Dexter Creek are grouped under the older intrusive rocks because of their character and structural relations. Both occurrences are associated with dikes or dike-like intrusions. The body at Lake Lenore is connected to a dike that can be traced westward to the road cut on the east side of the Uncompahgre River, while the eastward projection of the fissure aligns with the Bachelor fissure, but the identity of the fissures cannot be definitely established. The Lake Lenore body is of circular outline, only a few hundred feet in diameter, but with very irregular contacts, and tapers both at the east and west sides into dike-like bodies with nearly vertical walls. The body on the north side of Lake Lenore appears to be a sheet-like offshoot of the body west of the lake.

[27] Cross, Whitman, and Howe, Ernest, U. S. Geol. Survey, Geologic Atlas, Silverton Folio 120, p. 11, 1905.

The rock of these intrusive masses is of dense texture and of dark gray or distinctly greenish color, and is particularly characterized at Lake Lenore by the large number of inclusions of sedimentary rocks. A few small phenocrysts of feldspar are present, but no unaltered ferromagnesian minerals remain.

Clastic Dikes

Although the clastic dikes herein described are not igneous rocks, they are manifestly of intrusive origin and are so closely allied in age and associations with the monzonite porphyry intrusions that they may be conveniently described here under the general heading of "earlier intrusive rocks."

These dikes are found within the sedimentary formations of the district that lie below the Telluride conglomerate, and generally occupy the same system of fissures into which the monzonite porphyry dikes were intruded. Altogether eight or nine dikes of this group have been found in the vicinity of Ouray, and it is likely that a number of others have escaped observation. Of the known clastic dikes, two closely follow the walls of porphyry dikes, but in places they split away from the dikes and follow parallel fissures. All of the other known clastic dikes follow fissures of the east-west system in the mineralized area north of Ouray, and several of these fissures contain veins in addition to the clastic dikes. The best known of these dikes, the Bachelor dike of the Bachelor, Wedge, and Neodesha mines, has been described in the geologic literature[28]. Another dike locally well known and similar to the Bachelor dike is the American dike followed by the main incline of the American Nettie Mine.

The dikes are composed of a clastic rock of widely differing appearance and composition, and range in width from a few inches to ten feet. The texture shows all gradations from that of an angular fault breccia to that of a rock closely resembling a conglomerate. The material of the dikes consists of angular and rounded fragments of many different

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[28]Ransome, F. L., A peculiar clastic dike near Ouray; Trans. Amer. Inst. of Min. Eng., vol. 30, pp. 227-236, 1900.
Spurr, J. E., The Ore Magmas, vol. 2, pp. 843-849, New York, 1923.
Irving, J. D., Metalliferous deposits: U. S. Geol. Survey, Ouray Folio 153, p. 17, 1907.

formations cemented together by a variable amount of fine matrix of a greenish or gray color. The fragments exhibit considerable variation in size and shape from one dike to another, and even from place to place within the same dike, but the greater number of larger fragments seen in the dikes are not more than 4 or 5 inches in diameter. In parts of the Bachelor dike the clastic material contains a large number of angular and flat shale fragments, many of which are orientated with their larger dimensions parallel to the walls of the dike. The orientation of the shale fragments in this manner and the intrusion of the dike matter into small fissures and openings near the main fissure, indicate that the formation and injection of the dike was accompanied by great pressure. The smooth and rounded surfaces of many of the harder rock fragments in the dikes give the impression that these have been derived from beds of conglomerate; however, such an explanation cannot be accepted to account for all of the rounded fragments. In part this rounding must be explained by the rubbing together and the consequent abrasion of the angular edges of the fragments during injection.

The problem of the origin of these dikes is not only of scientific, but also of economic interest, because in a number of places the channels occupied by injections of clastic material have later become the loci of ore deposition. Opinions expressed in the literature cited above have also differed as to the mode of origin and sources of these clastic dikes. Ransome's[29] conclusions, based upon study of the Bachelor dike in the upper levels of the Bachelor and Wedge mines, was that

> "a fissure was formed, accompanied by some faulting, and was filled, chiefly from above, by fragments of the soft fissile black shale, which does not occur in the stratigraphically lower beds in the immediate vicinity, and partly by material from the lower light-colored beds forming the present walls."

Spurr's[30] statement regarding the origin of the dike is as follows:

[29]Op. cit., p. 230.
[30]Op. cit., pp. 843-845.

" . . . . the vein fissure was split wide open again, and was filled with an upwelling mass of mud, derived from the detritus of the underlying formations. This upwelling mass was probably dammed back, in its ascent along the fissure, by shale beds (the country rock shows an alternation of nearly horizontal sandstones and shales) which afforded no opening sufficient for the passage of a mass of this sort. With accumulating upward pressure, the mass burst through the shale, and the soft shale fragments were borne along, and now are very characteristic of the dike, being arranged in the sandy matrix with their long axes parallel to the walls." He further states, "Elsewhere in this group of mines, breccia injections of the same age occur, but gray instead of black—gray because without the thick mud of black shale fragments characteristic of the Bachelor dike." Spurr's general conclusions are, "These dikes occur between stages of metalliferous veindikes, and are believed to be due to waters and gases residual from the ore magmas."

All but a few of the dikes found in the district can be traced upward from the Paleozoic into the Mesozoic formations, and their content of pre-Mesozoic and pre-Cambrian rock fragments does not change materially within the higher Mesozoic formations. There is no source of the fragments that are foreign to the lower Mesozoic formations, in the overlying Dakota (?) sandstone, Mancos shale, and Mesaverde group, as these formations do not contain boulder beds having the kinds of rock fragments found in the dikes. The fragments furthermore could not have been derived from the Telluride conglomerate in view of the age of the dikes, which are older than this conglomerate. It therefore must be concluded that the principal source of the dike material was beneath the inclosing rocks, especially where the fragments foreign to the walls are in large proportions; but, on the other hand, a varying proportion of the dike material always appears to have been derived from the more immediate wall rocks of the fissures. As an example, the pre-Cambrian rock fragments in the Steele clastic dikes of Abbey Gulch, which outcrop in the Mancos shale just above the Dakota (?) formation, are now hardly less than 1,000 feet above the uppermost beds of the Cutler formation, their nearest possible source. However, in addition to the pre-Cambrian rock fragments, the Steele dikes contain fragments of the Dakota (?) and Mancos formations, which were clearly broken from the more immediate walls of the dikes.

There is also evidence, especially well illustrated in the Bachelor and Calliope mines, that the injected breccias did not move simply in vertical paths, but that the horizontal component of their movement, in some localities, may have been equal to or much greater than the vertical component. This may be illustrated by the accompanying section along the strike of the Bachelor dike (figure 2). In the upper levels of the Bachelor mine the dike contains a large proportion of angular shale fragments that are identical with the over-

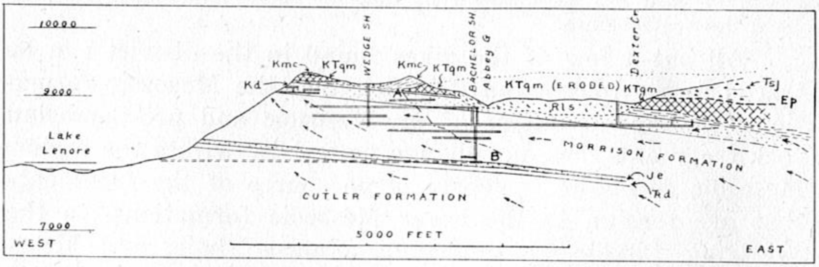

Fig. 2—Longitudinal section along the Bachelor vein and clastic dike. The broken arrows indicate roughly the probable course of the clastic dike injection. Line A-B is the junction of the Bachelor fissure, and the south split or Pony Express fissure. TRd, Dolores formation; Je, Entrada sandstone; Kd, Dakota (?) sandstone; Kmc, Mancos shale; KTqm, late Upper Cretaceous or Eocene quartz monzonite porphyry; Rls, recent landslide debris; Ep, Eocene peneplain. Section based in part upon section of mine supplied by Bachelor Consolidated Mining Co.

lying shales of the Dakota(?) formation, while in the lower part of the mine and in the Neodesha mine, shale fragments are much less common and even the matrix contains less shale. It is unlikely, as has been pointed out by Ransome, that these shale fragments could have been derived from shales lower stratigraphically in the series than the Dakota(?). There are, in fact, no similar shale beds of any appreciable thickness until the lower part of the Paleozoic succession is reached at a depth of nearly 4,000 feet. The position of the dike with shale fragments in the upper levels of the Bachelor mine would suggest that the force of the injection may have been directed from the east toward the west. Thus fragments of the Dakota(?) shales in the dike

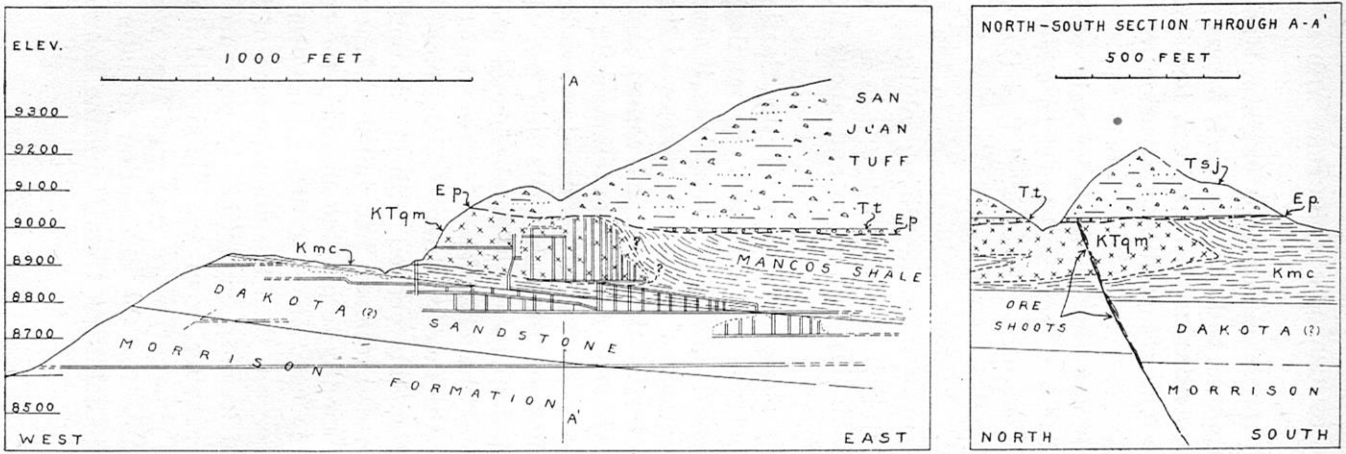

Fig. 3—Longitudinal and transverse sections along part of the Calliope vein to illustrate the unconformity at the base of the Tertiary volcanic rocks, and its relation to the late Cretaceous veins. The geologic conditions at the east end of the ore shoot within the monzonite porphyry are considerably generalized owing to lack of accurate data (indicated by question marks). Kmc, Mancos shale; Ktqm, late Upper Cretaceous or early Eocene quartz monzonite porphyry; Tt, Telluride conglomerate; Tsj, San Juan tuff; Ep, early Eocene peneplain. Section of mine based upon map supplied by Calliope Mining Co.

at the west end of the mine could be explained as having been derived from shale beds to the east, where the regional eastward dip continually brings them to a lower elevation beneath the thick laccolithic intrusion of Dexter Creek.

Mineralogical changes in the Bachelor vein whereby it becomes higher in zinc and iron, and lower in silver content at depth and toward the east, also suggest that the mineralizing solutions followed a course similar in part to that of the clastic injection. Further evidence as to the regional directions of movement of the mineralizing solutions is given by the flat eastward pitch of the ore shoots in the Calliope vein (Figure 3) which lies parallel to and about 1200 feet north of the Bachelor vein.

Based upon this close association of the clastic intrusions with hydrothermal activity and, by analogy with known surface phenomena of volcanic eruptions, it seems very probable that the injection of the clastic dikes was the result of a violent escape of volcanic gases and vapors and accompanying solutions, which had become temporarily trapped beneath an impervious blanket of sedimentary rocks. The occasional relation betwen dike channels and ore channels is accountable on this hypothesis. The absence of ore and of much alteration along the channels of other dikes usually can be explained by the field relations, which show that the fissure had been completely choked with clastic debris, and that further volcanic disturbances had failed to fracture the walls of the dike sufficiently to provide channels for the later stages of mineralizing solutions. If this explanation of the dikes is essentially correct, then the dikes become of importance as indicators of local accumulations of pressure due to vapors and gases escaping from the vicinity of intrusive bodies. Where dike channels were reopened they would become equally favorable for the circulation of later hydrothermal, vein-forming solutions from the same source.

Age and Correlation of the Older Intrusive Rocks

The age of the intrusions of monzonite porphyry is quite definitely limited to latest Cretaceous or early Eocene time. The bodies of porphyry intrude the Mancos shale, the youngest Cretaceous formation exposed in the district, but are overlain unconformably by the Telluride conglomerate, of Eocene age. Large boulders and angular blocks of the partly altered and weathered porphyries are included in the Telluride conglomerate, both near the Canyon Creek laccolith and the Dexter Creek intrusive body, and weathered blocks are also included in the San Juan tuff wherever it rests directly upon the monzonite porphyries. The evidence indicates that a long period of erosion and weathering of the porphyries preceded the deposition of the Telluride conglomerate. The Ridgway till, near Ridgway, which is older than the Telluride conglomerate, also contains large boulders of weathered porphyry that in all probability were derived from erosion and glaciation of these same rocks.

Further evidence as to the age of this igneous activity is obtained from the Cretaceous and Eocene sedimentary rocks that lie to the north and south of the western San Juan Mountains. Acknowledgment is due to Dr. E. S. Larsen of Harvard University for suggestions regarding this evidence, and for the permission to make use of parts of his unpublished manuscript on the San Juan volcanic region. The McDermott formation, described by Reeside[31], on the southern flanks of the mountains is the earliest of the Cretaceous formations to contain volcanic material; the proportion of volcanic material in it decreases southward. Overlying the McDermott formation unconformably is the Animas formation as re-defined by Reeside[32], of questionable Eocene and possibly Cretaceous age. This formation also contains much volcanic material. The overlying formations of unquestionable Eocene age, the Torrejon and Wasatch formations, do not carry volcanic material. Based upon the evidence furnished by these

[31]Reeside, J. B., Jr., Upper Cretaceous and Tertiary formations of the western part of the San Juan basin, Colo. and N. Mex.: U. S. Geol. Survey Prof. Paper 134, pp. 24-28, 1924.

[32]Op. cit., pp. 32-35.

formations, Larsen[33] summarizes the beginning of volcanism in the San Juan Mountains as follows:

"The abundant andesitic fragments in the McDermott formation, the last of the sediments placed in the Cretaceous by Reeside, and their entire absence in the older sediments shows that volcanism began in the San Juan Mountains before the end of the Cretaceous. Volcanism must have been again active during the deposition of the earliest Eocene sediments in Animas time. The later sediments of the San Juan Basin and the Telluride conglomerate indicate that volcanism was practically lacking in the nearby area during later Eocene time. It finally broke out again in Miocene time, with the accumulation of the great volcanic complex that makes up the present mountains."

Reeside[34] now believes that it is more consistent to begin the Tertiary with the Puerco formation and place the dinosaur-bearing Animas and Ojo Alamo formations in the Cretaceous, and if this be the correct interpretation of the age of these beds, then the early volcanism indicated by the sediments would be of late Cretaceous age. There can be little doubt that this volcanism was associated with the same epoch of igneous activity as produced the earlier intrusive bodies at Ouray, although the age relations of the monzonite-porphyry intrusions to the surface eruptions has not been determined.

Crawford[35] has recently shown that "the porphyries found at intervals from Gunnison County to Breckenridge belong to a single petrographic province." Estimates of the age of these porphyries in Central Colorado have placed their intrusion in the Cretaceous or in the Tertiary, but the upper age limit of their intrusion has been difficult to estimate because of the absence of Tertiary rocks near their contacts. Based upon the similarity in their texture and mineral composition and approximate correspondence in age between the older porphyries of Ouray and those of central Colorado, it seems likely that the porphyries of the Ouray district represent a southwestward continuation of the intrusive province of central Colorado. However such a correlation can only be tentative until a more complete study has been made of the petrographic character and distribution of the older intrusive rocks in southwestern Colorado.

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[33]Unpublished manuscript.
[34]Personal communication.
[35]Crawford, R. D., A contribution to the igneous geology of Central Colorado: Amer. Jour. Sci. vol. 7, p. 375, May, 1924.

Structure of the Older Intrusive Rocks

Both the form of the older intrusive bodies and the character of the mineralization associated with them, were determined to a great extent by the character and local structure of the sedimentary formations. Near the end of Cretaceous time a series of nearly horizontal Mesozoic formations overlay the tilted and folded Paleozoic rocks. These comprised from the base of the Upper Cretaceous upward: the non-marine Dakota(?) sandstone, 150 to 250 feet; the Mancos shale (marine), 1200 to 2000 feet; the Mesaverde group (marine), 300 to 1000 feet; Pictured Cliffs sandstone (marine), 125 to 240 feet; Fruitland formation (brackish or fresh water), 340 to 530 feet; and the Kirtland shale (fluviatile), 800 to 1000 feet[36]. The total thickness of these formations may be estimated to have been at least 4000 feet in the vicinity of the western San Juan Mountains.

Resting upon the Kirtland shale with local unconformity there is a series of andesitic tuffs, and tuffaceous sandstones and shales, comprising the McDermott formation, which mark the beginning of a long period of volcanic activity in Upper Cretaceous time, as heretofore mentioned on page 201. The Animas formation, which overlies the McDermott formation and also contains much volcanic debris, locally overlaps the McDermott formation, the Kirtland shale, and part of the Fruitland formation[37]. The Animas formation indicates by these overlapping relations that important crustal disturbances were occurring in connection with the volcanism. South of the present San Juan Mountains these volcanic formations comprise a total thickness ranging from a few hundred feet to about 3000 feet. Atwood[38] has pointed out in summarizing the geographic history of the San Juan area that a great dome was formed near the close of the Cretaceous time, and that during this period of mountain growth there was some vol-

[36]Reeside, J. B., Jr., Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin, Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 134, pp. 3-24, 1924.

[37]Idem., p. 33.

[38]Atwood, Wallace W., Eocene glacial deposits in southwestern Colorado: U. S. Geol. Survey Prof. Paper 95, pp. 22-24, 1916.

canism, and that there were porphyritic intrusions in addition to the deposition of volcanic tuffs, the evidence for which is found in the Ridgway till, an Eocene glacial deposit underlying the Telluride conglomerate. The boulders of porphyry found in the Ridgway till were found by the writer to be essentially identical in composition with the porphyry intrusions in the Paleozoic and Mesozoic formations near Ouray. It therefore seems that the contemporaneous volcanism indicated by the McDermott and Animas formations was accompanied or followed by comparatively shallow intrusions of porphyry within the San Juan dome. Although the actual age relations of the monzonite-porphyry intrusions to the surface eruptions has not been determined, we may conclude that an older group of laccolithic and volcanic mountains existed in what is now the site of the western San Juan Mountains, and that the porphyry intrusions at Ouray represent one of the centers of igneous activity around which these mountains were built.

The Upper Cretaceous formations consisted for the most part of easily deformed shales and sandstones, and contained, near the base of the section, from 1200 to 2000 feet of soft clay shales and sandy shales comprising the Mancos shale. In the older, more rigid Paleozoic formations the intruding monzonite porphyries assumed the form of dikes and thin sills, which are very numerous and well exposed in the vicinity of the Ouray stock. However, upon penetrating into the softer Mesozoic rocks, which were more susceptible of deformation, the porphyries spread into large laccolithic bodies and the sediments were arched above them. Although the flexibility of the Mesozoic rocks and the spreading of the laccoliths had a tendency to prevent the magmas from reaching the surface, a number of stocks appear to have penetrated even the youngest Mesozoic rocks. Conditions most favorable to the spread of the monzonitic magmas existed near the base of the Mancos shale, as is illustrated by the laccolithic bodies of Dexter Creek, Corbett Creek, Cascade Mountain, and Cow Creek. Less commonly laccoliths developed with their bases in the Morrison formation as illustrated by the Canyon Creek laccolith. The original size and shape of the laccoliths near Ouray are unknown because these bodies were partly removed during Eocene time, but, by analogy with similar intrusive bodies in regions southwest of Ouray, we may reconstruct the general geologic conditions after the intrusion of the porphyries. Such a reconstruction aids in understanding the nature and distribution of the ore deposits that formed about some of these older intrusions.

In *figure 1* a somewhat generalized restoration is given of the Ouray stock, or "Blowout" as it is locally known. This section extends from Cascade Mountain on the south to Dexter Creek on the north. The present erosion surface is indicated by a solid line and the surface of the Eocene peneplain by a heavy broken line. The Tertiary volcanic rocks have not been indicated on the section, but remnants of them now occupy the part of the section lying below the recent erosion surface and above the surface of the Eocene peneplain. The restoration of the eroded Cretaceous rocks is based upon sections of these formations measured in southwestern Colorado,[39] and shows the approximate thickness of Cretaceous rocks between the Mancos shale and the base of the McDermott formation.

The Ouray stock shows evidence of having penetrated the Mancos shale, and possibly may have penetrated some of the overlying formations. It would appear that fissures were formed reaching to the surface as indicated by the intense hydrothermal alteration in the vicinity of the intrusion. In the central part of the stock the sedimentary rocks have been displaced bodily upward, but are upturned slightly on the northern edge. At the base of the Mancos shale large laccolithic bodies spread laterally from near this stock. Parts of them are still preserved both to north and south of the stock on the east of the Uncompahgre valley and near Twin Peaks on the west side of the valley. It appears likely however that

[39]Reeside, J. B., Jr., Op. cit., pp. 3-8.

a considerable part of the Ouray stock and part of the laccolithic bodies are concealed beneath the San Juan tuff northeast or east of the "Blowout."

The sharp upturning of the Paleozoic formations on the north flank of the stock is not related to the intrusion of this body, as is suggested by a view from the valley, although it has been locally accentuated by the intrusion of dikes and sills and by drag near the edge of the stock. It is mainly caused by a monoclinal fold of pre-Dolores (pre-Triassic) age, and it may be seen from figure 1 that the overlying Mesozoic beds truncate the upturned edges of the Paleozoic formations. This sharp monoclinal fold is well exposed about a mile west of the "Blowout" on the opposite side of the Uncompahgre valley.

YOUNGER INTRUSIVE ROCKS

General Features

In the immediate vicinity of Ouray the younger intrusive rocks are represented by only a few dikes cutting the San Juan tuff. Representatives of these dikes are the "Germania" dike of The Amphitheatre east of Ouray, the Bridalveil Creek dike, and the Calliope dike just north of Dexter Creek. All of these dikes radiate from a late Tertiary volcanic center near the head of Cow Creek, 4 or 5 miles east of the Ouray district. Between Ouray and Telluride another group is represented by the Mt. Sneffels-Stony Mountain stock, and by numerous dikes occupying fissures in the Tertiary lavas in the vicinity of, and southwest of, this large stock. South of Ouray in the west central part of the Silverton quadrangle the late Tertiary intrusions are represented by the porphyry stocks and dikes of the Red Mountain district.

As yet there has been no further detailed study of the rocks of the late Tertiary intrusive groups, and the following brief discussion is based upon the descriptions in the Ouray, Telluride, and Silverton folios, and upon recent preliminary examination of some of the intrusions.

Varieties of Intrusive Rocks

The late Tertiary intrusive rocks in this particular area of the San Juan Mountains present a much greater variation in their composition and texture than do the late Cretaceous intrusive rocks. The rock of the large stock intrusion outcropping in Mt. Sneffels and Stony Mountain has been called gabbro-diorite by Cross, who describes the intrusion as follows[40]:

"The compound name indicates primarily that much of the rock is intermediate between gabbro and diorite, and also that there is a transition from gabbro to diorite.

"The principal rock of Stony Mountain, as seen at its summit and down the eastern slope, is a dark, coarse or medium-grained gabbro, composed chiefly of plagioclase rich in lime, with abundant hypersthene and diallage-augite. Even in this rock there is some orthoclase and quartz, while in some phases of the rocks here included there is a considerable amount of these two minerals, and a transition develops toward the rock called monzonite."

In the fissured volcanic rocks surrounding Stony Mountain there are a large number of dark colored dike rocks which appear to have been intruded at some stage during the invasion of the magma that formed the stock. Altered dike rocks of this series are found along the walls of some of the veins in the Sneffels region, and many of them at least are older than the veins.

The intrusive masses and dikes outcropping near Red Mountain and at the head of Full Moon Gulch are of more alkaline composition and have been grouped under the name of quartz syenite porphyry by Cross and Howe, who describe the rocks as follows[41]:

"Scattered through the quadrangle are several occurrences of allied prophyries, most of them plainly intrusive masses, which are characterized by their large orthoclase or anorthoclase crystals. . . . Nearly all of the rocks here referred to are quartz-syenite-porphyries, that is, they consist principally of alkali feldspar, but contain enough quartz to require recognition of that constituent in the name. They also carry some plagioclase rich in soda and usually both augite and biotite, sometimes abundantly, in distinct phenocrysts.

"The rocks possess a dark aphanitic groundmass, which predominates over the phenocrysts in most cases. . . ."

These intrusive rocks of the Red Mountain region were

[40]Cross, W., U. S. Geol. Survey, Geologic Atlas, Telluride Folio 57, p. 7, 1899.

[41]Silverton Folio 120, p. 11, 1905.

also intruded before the late Tertiary mineralization, and their alteration has been very intense in the vicinity of the Red Mountain ore deposits.

The few dikes found in the San Juan tuff near Ouray belong to several series of andesites and hornblende latites[42]. Their intrusion appears to have preceded the period of Tertiary mineralization, but deposits of economic importance have not been found in the fissures in which the dikes occur.

Age and Structure

As all of the intrusive rocks of the Tertiary group intrude the San Juan tuff, and those of Stony Mountain and Mt. Sneffels intrude the Silverton and Potosi lavas, it is presumed that the majority of the intrusions are of post-Potosi, hence of Miocene or later age. In the area between Ouray, Telluride, and Red Mountain the Tertiary intrusions have assumed the form of stocks and dikes, and so far as known have not been found as sills and laccoliths in the Paleozoic and Mesozoic formations. There are, however, no exposures of the underlying sedimentary rocks near the stocks mentioned, so the form which these larger Tertiary intrusions assume in the underlying formations is not known. The number of dikes which occupy the northwest fissures in the area between the Stony Mountain stock and the Camp Bird mine suggests the possibility of some relation between the intrusion of this stock and the fissure system of this area. There are, however, a great many more fissures and veins than dikes. The close association shown between the Ouray stock and the Cretaceous mineralization either is lacking, or is less evident, between the late Tertiary stocks and the Tertiary veins.

History of the Western San Juan Mountains

Before proceeding to the discussion of the two epochs of mineral deposition, a brief review of the geologic history of the western San Juan Mountains from late Cretaceous time to the present will be helpful.

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[42]Ouray Folio, pp. 11-12.