At the beginning of the earlier period of volcanic activity the western San Juan region was covered by Upper Cretaceous formations, which totaled at least 4,000 feet in thickness. These were unconformably covered by late Cretaceous or early Eocene formations, which contain volcanic debris, and so overlap as to indicate a domal uplift of the region. This uplift was accompanied by the intrusion of monzonite porphyry mainly in the form of stocks and laccoliths. At the close of this igneous activity the first period of ore deposition took place.

During Eocene time erosion carved this great dome into the first generation of the San Juan Mountains, and high altitudes gave rise for a time to glaciation, but continued erosion finally culminated in the formation of the Eocene peneplain. In the central part of the eroded dome, except where the larger and more resistant masses of monzonite porphyry remained as hills surmounting the peneplain and thus protected the underlying formations, the Upper Cretaceous formations were entirely removed, and the older formations were extensively eroded. In the Ouray district nearly all of the Upper Cretaceous formations and locally all of the Morrison formation were destroyed. During this long period of erosion in early Eocene time some of the mineral deposits also must have been totally destroyed, while others, notably those in the sedimentary rocks at Ouray, were partly exposed to weathering.

In later Eocene time the Telluride conglomerate was deposited upon the peneplain. The deposition of the conglomerate was probably accompanied by minor transportation and concentration of gold in some of the stream deposits.

Following the deposition of the Telluride conglomerate there was another period of erosion, which was followed by the great Tertiary volcanic eruptions that formed the San Juan tuff, the Silverton series, and the Potosi series. These eruptions probably occurred during Oligocene or Miocene time, forming a volcanic plateau, and burying the ore deposits of the first epoch to a great depth, possibly greater than their original depth of formation. In late Miocene or post-Miocene time, following the eruption of the Potosi lavas, the second major group of intrusive rocks penetrated the younger volcanic formations. Widespread fissuring and some tilting of the formations occurred, and closely following these disturbances came the second major mineralization of the San Juan region.

With the cessation of the volcanism, erosion and dissection of the volcanic plateau began, and another generation of the San Juan Mountains was formed. According to Atwood[43] these perhaps originally rose 3,000 or 4,000 feet above the present summits. After a considerable period of erosion, warping or doming of the mountain area again occurred and deep valleys were cut by the rejuvenated streams and were later occupied by the early Pleistocene glaciers. Uplifting of the range continued throughout Pleistocene time, and several stages of glaciation and valley cutting have been recognized. The present streams are still actively cutting their valleys. Transportation and deposition of debris during both Pleistocene and Recent time caused further concentration of gold in placers.

ORE DEPOSITS

Metallogenic Epochs of the Western San Juan Mountains

From this historical summary it is clear that the two major epochs of primary ore deposition took place under very different geologic conditions. The conditions that favored laccolithic intrusions during late Cretaceous and early Eocene time also favored the development of "blanket" replacement ore bodies. The Ouray stock, as shown on page 168, gives evidence of having pierced the Mancos shale, to the extent that fissures found in and close by it permitted the escape of gases and vapors to the surface; but in the surrounding area fissures penetrated upward into the yielding shales for only

[43]Op. cit., p. 23.

short distances, and ore-depositing solutions rising along them were forced to spread laterally and seek other channels to places of lower pressure (Figure 1).

Sedimentary beds of comparatively great permeability therefore served as channels for the lateral diversion of the ore-bearing solutions. Those permeable beds that were overlain by impermeable shale horizons were especially favorable for diverting the solutions for great distances in nearly horizontal directions. Ore deposits of the blanket type were therefore formed in a number of these beds. In the Ouray district there were also formed some deposits more typical of fissure veins, and some contact-metamorphic deposits near the Ouray stock where higher temperatures prevailed.

The ores of the first period contain gold, silver, lead, zinc, and minor amounts of copper. The most important deposits, however, near Ouray have been lead-zinc veins and associated replacement deposits containing high grade silver ores. Low grade lead and zinc replacement deposits with much barite are also particularly characteristic of this period. The gold-bearing ores, at least near Ouray, differ from the gold-bearing deposits of later Tertiary age in that they are generally pyritic and contain tellurides associated with native gold. They have been of somewhat less economic importance than the silver ores, and comprise both veins and "blanket" deposits.

As mentioned above, the deposition of the Telluride conglomerate was accompanied by minor transportation and concentration of gold in placers, and the period of formation of the conglomerate may therefore be considered as one of the minor metallogenetic epochs in the history of the San Juan region; but, so far as known, the concentration of gold in the Telluride conglomerate was not sufficient to produce placer deposits of commercial value[44], apparently because of the finely divided state of the gold, and its occurrence partly as tellurides, in the primary deposits of the first period of mineralization.

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[44]Ouray Folio 153, p. 19.

The geologic conditions during the second important metallogenetic epoch are well shown near the Ouray district, where a large part of the Upper Cretaceous sedimentary rocks had been removed by erosion before the building of the Tertiary volcanic plateau. In a few places where the softer shales were protected by laccolithic bodies comparatively thin layers of them were preserved beneath the Tertiary lavas. The late Tertiary intrusions consequently invaded a cover consisting mainly of the more rigid Paleozoic and pre-Cambrian rocks, and great thicknesses of rigid volcanic formations. Under these conditions the fissures which were formed extended from great depths probably to the surface of the volcanic plateau. The conditions which were responsible for the lateral diversion of the metal-bearing solutions in the first epoch had been largely destroyed by erosion, and as a result the tendency for the formation of the blanket type deposit was generally absent during late Tertiary time. Although some ore deposition did take place in the underlying basement of sedimentary and metamorphic rocks, the most important ore deposits of this period have been found within volcanic formations. These conclusions are obviously intended to apply strictly to those areas in the Ouray, Telluride, and Silverton quadrangles, where the geologic conditions outlined above have prevailed. It is conceivable, though not proved, that in areas where greater thicknesses of the Upper Cretaceous formations were preserved from Eocene erosion, ore-forming conditions approaching those of the earlier epoch may have existed during late Tertiary time.

The ores of the late Tertiary period are like those of the first period in containing the metals gold, silver, lead, zinc, and copper, but the deposits are of somewhat different character mineralogically. The principal gold deposits of this period consist of native gold in quartz veins, as contrasted with the pyritic gold deposits of the first epoch. The silver-bearing veins appear to differ somewhat in the details of their mineralogy. The relative proportions of the different metals in the deposits of the two periods is as yet unknown, as the individual deposits of the two periods have not been completely differentiated in other parts of the San Juan region.

The final epoch of gold concentration in the western San Juan mountains was associated with the formation of stream deposits during Pleistocene and Recent time. Some placer deposits of this period have been mined in the San Juan region and have proved of greater importance than those in the Telluride conglomerate.

There is still another epoch of mineralization, represented by deposits in the sedimentary formations along the western slope of the San Juan mountains, which is of considerable importance. These deposits contain concentrations of copper, vanadium, uranium, and radium, but, as they are not associated with those of known igneous origin, their relation to the other events in the metallogenetic history of the San Juan region is not known. They are found in rocks of Jurassic and Lower Cretaceous (?) age.

Descriptions of Deposits

A number of descriptions have been published dealing with the general and detailed character of many of the ore deposits in the Ouray district and it is not possible within the limits of this paper to describe the individual deposits in great detail. It is desired, however, to point out certain differences in the relation of the ore deposits of the two periods to local structure, and to give a few details of the evidence upon which the existence of ore deposits of the two ages has been determined. In addition to the division of the deposits into age groups, certain regional groups may be recognized in areas surrounding Ouray that appear to be distinguished by local conditions of fissuring and by local sources of mineralizing solutions.

LATE CRETACEOUS OR EARLY EOCENE (?) ORE DEPOSITS

General Features

The older deposits comprise all of the productive fissure veins and blanket ore bodies in the Pre-Tertiary sedimentary formations along the Uncompahgre Valley north of Ouray. The area within which these ores have been exposed by the erosion of the Tertiary volcanic rocks is comparatively small and includes a tract extending about 4 miles north of the town, and bounded upon either side of the Uncompahgre Valley by the outcrops of the Telluride conglomerate and the San Juan tuff. Southwest of the town a few silver-bearing veins in the sedimentary rocks near the mouth of Canyon Creek, and the Mineral Farm replacement deposit in the Molas formation and the Ouray limestone are believed to belong to the older group. The forms of ore bodies may be roughly divided into fissure veins and replacement deposits in sedimentary beds, although there is considerable gradation between the two distinct forms, and a single deposit may include both fissure vein and blanket ("bed-vein").

The close association that existed between the intrusion of the monzonite porphyry, the clastic dikes, and the first period of mineralization, is clearly brought out by the conditions found near the stock and along the valley north of the stock and is reviewed in the following paragraphs.

Many ore deposits, the age of which cannot be proved directly, are found entirely within pre-Tertiary formations, and are of the same structural character and mineral composition as those of proved pre-San Juan age. Further evidence of a negative character is that not a single important fissure or dike associated with such deposits or responsible for this mineralization in the pre-Tertiary rocks can be traced into the overlying San Juan tuff. Where late Tertiary disturbances have reopened and extended fissures that were mineralized in Cretaceous or Eocene time, the continuations of these fissures in the overlying Tertiary rocks contain only minor, barren veins of quartz, barite, or calcite, and these veins, where traceable into altered pre-Tertiary rocks, are later in age than the sericite, quartz, and pyrite veins of the first period of mineralization. This relation is well illustrated by veins in and near the "Blowout," especially where the basal beds of the San Juan tuff, entirely free of alteration, rest directly upon intensely altered and fissured rocks of the stock or "Blowout."

A zonal distribution of ore deposits, roughly according to their temperature of formation, is also shown north of the Ouray stock. Within the central part of the stock itself the hydrothermal alteration is very intense, resulting in the feldspathization and silicification of included bodies of rock. This was followed by pyritization, and the development of other hydrothermal minerals, such as sericite, epidote, and hematite. Veins near or within the stock include barren pyrite veins, or pyritic-copper veins containing gold. The copper ores are mostly chalcopyrite and bornite. Nearest to the north flank of the Ouray stock are the contact-metamorphic deposits of the Bright Diamond and other mines (Fig. 1). These deposits contain magnetite, hematite, garnet and other lime silicates, and low grade pyritic ores. Still farther north, and at a higher stratigraphic horizon, are the pyritic gold replacement deposits of the American Nettie mine. These deposits are replacements of the Dakota (?) sandstone and contain in addition to gold-bearing pyrite, some tellurides of gold, and small amounts of sphalerite, galena, and tetrahedrite (gray copper). The typical low grade baritic lead-zinc ores that replaced the sedimentary rocks, together with the silver-bearing lead-zinc veins containing tetrahedrite, are found about a mile north of the stock and extend several miles farther north. There is some overlapping of these zones and gradations between the mineralogical kinds of deposits, as is especially shown by the presence of pyritic veins within the zone of lead-zinc-silver ores and of small bodies of lead ore within the pyritic zones. The positions of these different types of deposits relative to the Ouray stock are shown in figure 1.

The clastic dikes occupy the same system of east-west fissures in the sedimentary rocks that many porphyry dikes occupy, and none of the clastic dikes has been found in the Tertiary volcanic formations near Ouray. Based upon these geologic relations and upon the fact that many clastic dikes were intruded before the formation of silver-lead veins, their Cretaceous or Eocene age seems definitely established.

Fissure Veins

The older fissure veins may be divided into two mineralogical types, the pyritic veins containing chalcopyrite and gold, and the silver-bearing veins. The gold-bearing veins are most numerous along the walls of the Uncompahgre canyon between the town of Ouray and the vicinity of Dexter and Corbett creeks, and the more productive ones are in the southern part of this area nearer the Ouray stock. They are found in both east-west and north-south fissures. The ore minerals are gold-bearing pyrite and chalcopyrite, and the walls, whether of sedimentary rock or porphyry, are considerably replaced and sericitized. Those veins that follow the walls of porphyry dikes are clearly later than the dikes.

The silver-bearing veins have been the most productive of the older fissure veins, and are represented by such veins as the Bachelor, Calliope, Pony Express, Newsboy, and Black Girl. The mineralogy of the Bachelor and Newsboy veins has been described rather recently by Bastin[45].

Bastin reports that the primary minerals in the Bachelor vein are galena, sphalerite, chalcopyrite, tetrahedrite, pearceite, quartz, barite, and manganiferous calcite. Pyrite is also present in many parts of the veins. The downward enrichment of some of these veins by ground waters has occurred, but except for some bodies of ore relatively close to the surface this process is believed to be unimportant, as some of the veins, such as the Bachelor, do not outcrop conspicuously and are protected by impervious cappings of shale. The minerals known or believed by Bastin to be products of downward enrichment are chalcocite, copper pitch ore, native silver, argentite, pearceite, chalcopyrite (finely crystalline), and calcite. Irving[46] also reports ruby silver ore

[45]Bastin, E. S., Silver enrichment in the San Juan Mountains, Colo.: U. S. Geol. Survey Bull. 735, pp. 70-74, 1923.
[46]Irving, J. D., Ore deposits of the Ouray district, Colo.: U. S. Geol. Survey, Bull. 260, p. 59, 1905.

which was thought to be a product of sulphide enrichment.

The most striking structural features of the Bachelor fissure and vein (also found in a number of other fissures), is a clastic dike, or the "Bachelor dike" as it is locally known, already described on pages 196-198. The relation of these clastic dikes to mineralization is very clear in a number of veins, in which all of the local vein filling followed the injection of the dikes. On the other hand, a number of clastic dikes contain fragments of vein matter and of silicified rocks enclosing small amounts of sulphides. Spurr[47] reports that fragments of barite-silver ore are included in the clastic dike in the Neodesha mine, and upon this evidence interprets the dike as later than the barite-silver ore, but followed by a second stage of sphalerite-galena mineralization lower in silver. Ransome[48], on the other hand, considers the silver ore of the Bachelor and Wedge mines to be definitely later than the Bachelor dike. The conclusions of Irving[49] agree with those of Ransome. The sum of the evidence obtained by the writer from a number of different clastic dikes in other parts of the district, and from an examination of accessible parts of the Bachelor mine, agrees mainly with Ransome's and Irving's interpretation, although there is evidence of minor gas phase and hydrothermal metamorphism, including weak silicification that preceded and accompanied the intrusion of the dikes in parts of some fissures.

Another structural feature of great importance in connection with the fissure veins is the marked influence which the character of the wall rock has had upon the distribution of ore shoots within the veins. The ore is commonly of much better grade between walls of quartzite, limestone, or other harder rocks, whereas the fissures, or veins, contain larger barren areas between walls of shale. It was pointed out by Irving[50] that in some fissures the vein suffers no appreciable diminution in size in the shales, but that the ore minerals were deposited only between the layers of quartzite, whereas

[47] Spurr, J. E., The Ore Magmas, vol. 2, p. 846.
[48] Ransome, F. L., op. cit., Trans. Amer. Inst. Min. Eng., vol. 30, pp. 234-235, 1900.
[49] Ouray Folio, p. 17.
[50] Ouray Folio, p. 16.

in the shales the vein consisted of barren gangue minerals and clay. These particular conditions further suggest the importance of the horizontal movement of the ore-forming solutions as compared to their vertical movement, as suggested on page 198. Had the solutions been travelling directly upward across the alternate layers of sandstone and shale, the alternations of rich and lean layers in the veins would be difficult to explain except by some chemical theory for which we have no basis. If, however, the movements of the solutions were more nearly horizontal, corresponding to the lateral distribution of the more open parts of the fissures in the hard rocks, the absence of ore from the veins in shaly layers could be explained as due to approximate stagnation or lack of complete continuous circulation of the ore-forming solution in the parts of the fissures between shale walls. The occasional finding of rich ore bodies within shale walls would appear to indicate the presence of local channels through the shale zones. The importance of open cross fissures and dikes of the north-south system in facilitating the local upward diversion of the ore solutions is particularly well shown in some of the mines containing "blanket" ore bodies.

Replacement Deposits In Sedimentary Beds

It has been pointed out in the preceding discussion that the geologic conditions were especially favorable to the formation of replacement deposits in the sedimentary rocks during the late Cretaceous or early Eocene epoch of ore deposition. The condition which especially favored this type of ore deposit was the absence of direct connection of many of the fissures to the surface, because of the thick shale formations in the Upper Cretaceous series. The solutions, unable to move upward in deeper fissures, entered certain permeable sedimentary beds and moved laterally or up the dip of these beds until other fissures and permeable structures were encountered. Only a limited number of beds are known to have been favorable channels for such circulation over areas sufficiently extensive to favor the larger replacement deposits. Favorable horizons that are known have been indicated on the stratigraphic column (Plate II), but not all of these are equally favorable, nor is it certain that those shown represent all of the more favorable beds. These horizons are generally referred to by the miners in the Ouray district as "contacts". The same term is also used in the Rico district for apparently similar horizons, but Ransome[51] has also used the term "blanket" in the same sense. Other conditions than the absolute permeability of the unfractured bed seem to have played a part in the favorability of certain beds. The possibility of the existence of special conditions will be referred to in the following brief discussion of different mineralized beds.

The lowest beds in the Paleozoic sedimentary rocks known to have been replaced by ore minerals lie in the lower part of the Elbert formation of Devonian age. Only one occurrence of low grade ore in the Elbert formation at Ralston gulch, about 2 miles south of Ouray, is known to the writer. This replacement deposit has not been developed and the prospective importance of the Elbert formation as a carrier of ore is unknown. The age of the ore deposition seen is also problematical. It is further possible that the presence of bedding faults in this formation has favored the local formation of ore, a possibility strengthened by the finding of such a fault in this locality. The influence of bedding faults in guiding certain ore channels in the Tintic district of Utah has been suggested by Walker[52]. The stratigraphic position of the Elbert formation between the extremely rigid pre-Cambrian rocks and the overlying massive Ouray limestone has perhaps favored some local brecciation and bedding slips within the latter formation during regional warping or folding of the rocks.

One of the most interesting horizons of replacement deposits lies at the unconformable contact between the Mississippian part of the Ouray limestone and the Molas formation. The only important ore body at this horizon is that

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[51]Rico Folio 130, p. 15, 1905.

[52]Walker, R. T., Deposition of ore in pre-existing limestone caves: Amer. Inst. Min. and Met. Eng., Tech. Pub. No. 154-I, pp. 29-30, Nov., 1928.

of the Mineral Farm mine just southwest of the town of Ouray. The size and geologic relations of the ore shoots developed here may be seen from figure 4. The principal minerals of the ore are quartz, barite, galena, sphalerite, and silver-bearing tetrahedrite. There is some pyrite and chalcopyrite, and possibly other silver minerals, as the deposit is said to have contained small bodies of high grade silver ore. The shape of the ore bodies developed are long and pipe-like and have been explored down the dip of the contact for about 1400 feet at a pitch of 15 to 20 degrees. The largest part of the ore body did not lie within the Ouray limestone, but in one of the basal beds of the Molas formation, similar to bed No. 2 of the Molas section, shown on page 162. This bed near the ore body is 5 to 10 feet in thickness, and where unaltered is a red, sandy, non-calcareous shale containing many angular inclusions of chert derived from the erosion of the chert-bearing beds of the Missisippian limestone The ore shoots are surrounded or partly encased by a zone of completely silicified and bleached shale.

The alteration of the Ouray limestone beneath the ore is singularly weak, however, and has resulted only in slight recrystallization, and some replacement by barite and ore near fractures. The physical conditions at this horizon that have directed the course of the ore channel are not readily apparent. Two sets of fractures can be recognized, however, one striking east-west to northeasterly, and another northwesterly. The northwesterly set appears to be the strongest in the mine, but small fractures of the other set can be detected. Perhaps one of the most significant structural features is the tendency toward blocky fracturing in the Molas shale bed, and this seems to have rendered the bed more permeable than the underlying massive limestones. The route of movement of the ore-forming solutions up the dip of the beds and along the course of the ore shoots and not vertically through the small fissures, is unmistakably clear. The fissures, however, have undoubtedly assisted in providing incipient solution channels and in producing the form of the ore body.

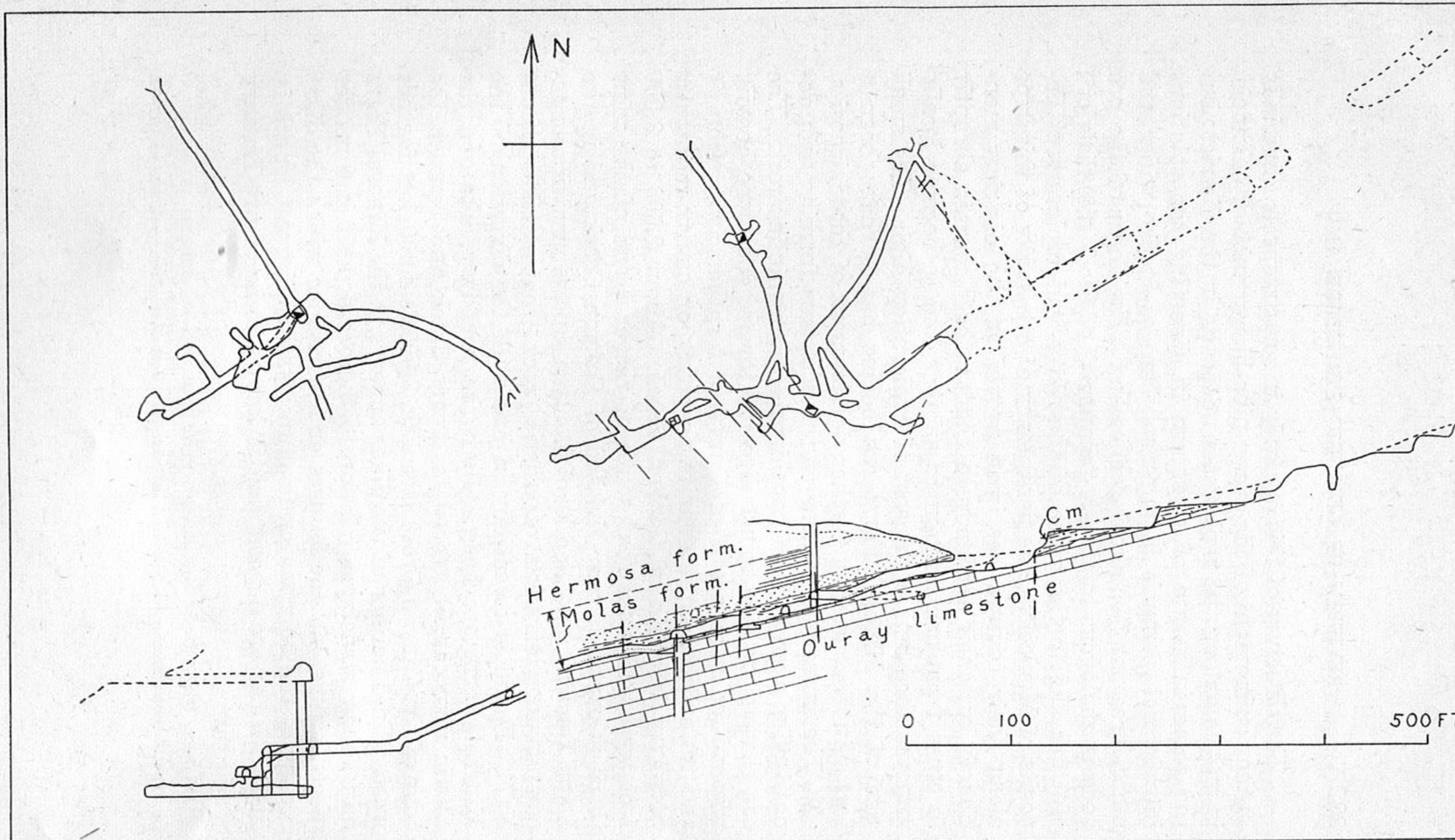

Fig. 4—Plan and section of the Mineral Farm mine and ore body. An example of the pipe-like form of "ore channel."

The structure of this ore body in some respects, especially in the confinement of the ore to pipe-like or tubular channels, is unique among the replacement deposits in the district; but the same influence of structure in diverting the solutions into lateral channels is apparent here as in the wider and more irregular "blanket" ore bodies. The form of the ore body is analogous to the ore "channels" of the Tintic district[53] of Utah and to the pipes of the silver-lead replacement deposits of Mexico[54]. The persistency of ore bodies of this type along their courses has been proved in the districts mentioned, but their tendency to change their courses abruptly to cross from one horizon to another and to become locally impoverished makes the cost of exploration high. The small size of the Mineral Farm ore bodies has perhaps been a factor in discouraging further development of these deposits.

The immediate source of the solutions forming this deposit offer a problem of considerable economic interest. The ore channel or pipe is not directed toward the more heavily mineralized area north of Ouray, but rather away from it and toward the large granite porphyry or quartz monzonite porphyry laccolith of Canyon Creek. About 2,500 to 3,000 feet west and somewhat south of the east end of the mine there is exposed, near the bed of Canyon Creek and in the Legal Tender tunnel, a dike of monzonite porphyry with an accompanying intrusion of clastic rock that strikes about N 71° E and is essentially in line with the direction of the Mineral Farm ore body. Both the porphyry dike and the clastic dike can be traced to Angel Creek and beneath the edge of the Canyon Creek laccolith, 3,000 to 4,000 feet farther west. Since neither of the dikes appears in the Mineral Farm mine, their structural relation to the ore deposit is a matter of conjecture, but the fissures or fissure zone which the dikes occupy is the only major fracture system of great length in line with the ore deposit that is known to be of pre-Tertiary

[53]Lindgren, W., and Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey, Prof. Paper 107, pp. 128-138, 1919.
[54]Prescott, Basil, The underlying principles of the limestone replacement deposits of the Mexican province: Trans. Am. Inst. Min. and Met. Eng., vol. 51, pp. 57-99, 1916.

or early Tertiary age. This dike and fissure have been prospected by the Legal Tender Mining Company with the view that it was the source of the Mineral Farm ore solutions, but their objective to reach the Ouray limestone was not attained. If the mineralizing solutions had entered the sedimentary beds from this fracture at great depths, or even from others in this vicinity that are not exposed, the source and direction of movement of the solutions would appear to have been very different from those solutions which caused the mineralization north of Ouray.

The "Pony Express contact" or "Pony Express limestone" is one of the more extensively mineralized beds in the Ouray district. The origin of the breccia, which forms the most conspicuous feature of the horizon and accounts for its great porosity, has been discussed on page 173. A few of the mines in which ore bodies have been developed in these beds are the Wanakah mine, Pony Express mine, Newsboy mine, and the Seaberg tunnel exploration. Development work has been done in the "Pony Express beds" in a large number of other mines where the gold-bearing and silver-bearing veins intersect these beds. Perhaps three principal structural types of deposits may be distinguished in connection with these beds, but the distinctions are not always sharply defined. The simplest form of ore body found in them is the large blanket replacement deposit, where the mineralizing solutions have spread and moved laterally through the more permeable parts of the beds. This kind of deposit is represented by the contact-metamorphic deposits and massive sulphide deposits of the Wanakah mine. Although certain master feeding fissures have undoubtedly introduced the solutions into the beds, the massive replacement deposits occur in broad, flat shoots that are sharply conformable to the stratification. The ore shoot in the Wanakah mine is over 300 feet in width at places and has been followed down the dip of the beds for over 1,200 feet. The ores include different mineralogical varieties, ranging from low grade contact-metamorphic ores containing magnetite, garnet, and other lime silicates, to massive pyritic ores, and galena ores. The massive pyritic ores are gold-bearing but, because of their low grade and the difficulties of concentration, the greater part of the deposit has not been mined.

Other structural types of deposits in the "Pony Express beds" are represented by those associated with fissures that are also occupied by productive veins. One of the best examples of this type is the ore deposit of the Pony Express mine. (Figure 5). Replacement of rock and the filling of spaces

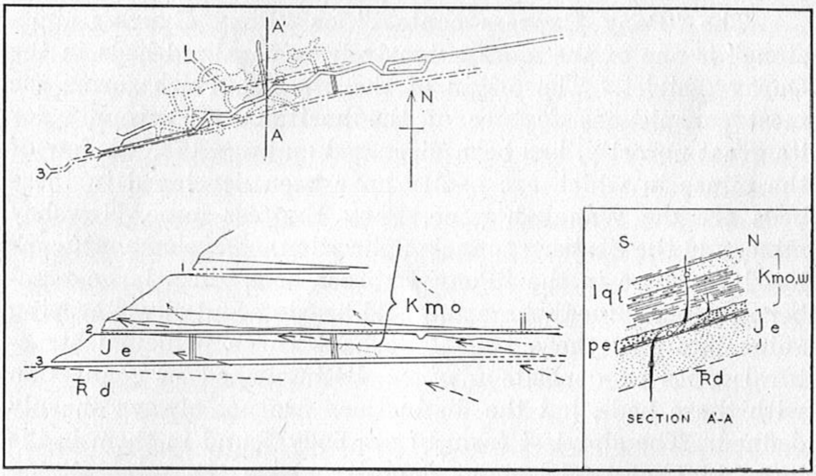

Fig. 5—Plan, longitudinal section, and cross-section of the Pony Express mine, illustrating lateral replacement of beds of ore near fissure veins. The cross-section illustrates a "roll" of the Pony Express fissure. The heavy broken arrows on the longitudinal section suggest the probable course of the main volume of the mineralizing solutions. ꞦRd, Dolores formation; Je, Entrada sandstone; Kmo, Morrison formation; Pe, Pony Express beds; Kmo,w, Wanakah member of the Morrison formation; lq, "Lower Quartzite" of the sandstone member of the Morrison formation.

afforded by fractures and by the original pore spaces of the beds, have both played a part in the formation of these deposits. Some veins break directly through the "Pony Express beds" and the ore shoots extend laterally to either side of the main vein from 5 to 30 feet; other veins are deflected at the bed and the parts above are as much as 40 feet to one side of the parts below. These veins are said to "roll" by the miners, and their flat parts along the bedding are called "rolls". (See Fig. 5.) "Rolls" occur at other horizons in the sedimentary beds, and at least three main rolls in the Bachelor mine have been found in the Morrison formation above the "Pony Express beds." These deflections or offsets are nearly continuous for long distances, some for several thousand feet in the Bachelor mine. It is not certain, however, that they follow exactly the same horizon throughout their length. The bedding fracture is not coextensive with the surrounding sedimentary horizon, but lies only in that part of the beds between the main vertical fissures. Some faulting movement has taken place along some of these nearly horizontal bedding fractures, as is shown by striations upon their surfaces, but the fault movement at right angles to the strike of the main vertical fissures could not have exceeded the width of the main fissure openings. On the other hand, movements parallel to the strike of the main fissures may have been much greater. Essentially the same interpretation of the local character of these bedding fractures in the Pony Express mine has been made by Spurr[55].

The ores of these replacement deposits that are associated with silver-bearing lead-zinc veins are essentially the same mineralogically as the ores in the main fissure veins, but owing to the relatively greater importance of replacement processes in the breccia of the "Pony Express beds", the relative proportion of quartz and barite to sulphide ore is probably greater in these bedding deposits than in the simple fissure veins. The breccia is composed of small fragments of dark shaly limestone that afford an enormously greater surface for chemical reaction than do the walls of a fissure. On this account silicification commonly extends from the main fissure a much greater distance than does the ore. The ores of the Newsboy mine have been described by Bastin[56]. In ore bodies of this kind associated with nearly vertical fissures, the possibility of considerable lateral movement of mineraliz-

[55]Spurr, J. E., The Ore Magmas, vol. 2, pp. 781-785, 1923.
[56]Op. cit., pp. 73-74.

ing solutions as compared to their upward movement should also be considered in developing ore bodies or searching for new ores, the predominance of either of which can perhaps be judged by the local distribution of mineralization and the structural conditions.

In the Morrison formation above the "Pony Express beds" there are several other horizons at which mineralization of sedimentary rocks has occurred, and two horizons developed in the Wanakah mine have been indicated on the stratigraphic column. These are not so persistently mineralized, however, as the "Pony Express beds." The "lower quartzite", or the basal sandstone bed of the sandstone member of the Morrison formation, shows a persistent but usually weak mineralization in many parts of the district. It has generally been most favorable to the pyritic type of replacement carrying gold, where the bed is intersected by the gold-bearing fissure veins. Pyritization of the bed extends great distances from any noticeable feeding fissures, and its permeability is probably due to the ability of the sandstone to support small open fractures and to the natural porosity of the unaltered sandstone. Solutions causing silicification and pyritization of the bed have probably moved considerable distances within the sandstone from the places where they were originally introduced.

The most important replacement ore deposits in quartzite are those of the American Nettie mine, which are found in several horizons in the Dakota(?) sandstone. The Valley View mine on Cascade Mountain, south of the Ouray stock, and the Stenographer mine on Oak Creek about 2 miles southwest of the stock are other examples of deposits in this formation. Mineralization in the Dakota(?) sandstone is quite widely distributed, but only a few of the mines have been commercially productive. The general character of the ore bodies in the American Nettie mine have been described by Irving[57]. Because of the complexity of the ore bodies and the variable and somewhat complex character of

[57] Irving, J. D., Ouray Folio 153, p. 18; also U. S. Geol. Survey Bull. 260, pp. 65-71, 1905.

the ores, complete and detailed description of this deposit cannot be attempted at this time. The primary ores according to Irving consisted of pyrite, chalcopyrite, galena, sphalerite, tellurides of gold and silver, argentiferous tetrahedrite, and molybdenite. Massive or crystalline pyrite is by far the commonest sulphide, while barite and quartz are common gangue minerals closely associated with the sulphides. The ores are found in irregular deposits within the Dakota(?) sandstone, which is altered to hard quartzite throughout the mineralized region. Certain horizons in the quartzite have been especially favorable to the circulation of the mineralizing solutions. Attention has been called to these horizons under the description of the Dakota(?) section measured at the Schofield tunnel. The Dakota(?) quartzite in the mine is seamed by a great number of irregular fissures, and is further traversed by a number of major fissures, monzonite porphyry dikes, and by one prominent clastic dike. It is generally conceded by those familiar with the mine that the fissures, even many of the relatively minor ones, were of great importance as indicators of ore channels during mining operations. Most published descriptions of the mine have therefore emphasized these fissures as feeders of the mineralizing solutions, and have pictured the solutions as rising nearly vertically through these fissures and along the walls of dikes, and finally spreading laterally beneath impervious shale layers. Undoubtedly certain major fissures, and a few dikes, perhaps especially the Jonathan dike, a prominent north-south dike through the mine, have provided channels for the upward movement of mineralizing solutions. Nevertheless the writer believes that sufficient emphasis has not been placed upon the movement of mineralizing solutions nearly parallel to the bedding of the quartzite, aided or guided by minor fractures and the permeability of the beds. The complete conversion of the Dakota(?) sandstone to quartzite, a process clearly connected with the period of mineralization, demonstrates the original permeability of this formation. The general east-west trend of the mineralized body of quartzite suggests that the solutions within the beds were moving from the east toward the west and somewhat diagonally up the regional dip of the Dakota(?) sandstone. Sufficient detailed data on the depth of the ore bodies within the hill is not at hand to show conclusively where the major part of the solutions gained access to the sandstone, but perhaps the Jonathan dike was of importance, although some mineralization east of the dike shows conclusively that the mineralizing solutions came in part from much deeper within the hills and farther to the east. The apparent movement of mineralizing solutions in this mine from east to west would agree with the somewhat more definite indications of east to west movement found in the Pony Express and Bachelor veins several thousand feet farther north of these deposits. It would appear that along the east side of the Uncompahgre Valley north of the Ouray stock, to at least as far as Dexter Creek, there had existed a regional tendency for the mineralizing solutions to move from the east toward the west, indicating a high pressure area beneath the laccolithic bodies. exposed northeast of the Ouray stock and along Dexter Creek. In some places the mode of injection of the clastic dikes further supports this possibility.

LATE TERTIARY ORE DEPOSITS

In the immediate vicinity of Ouray the late Tertiary ore deposits are mostly fissure veins, but it is not until areas considerably south of Ouray, or the region midway between Ouray and Telluride, are reached that important productive veins of this age are found. There are, however, several groups of late Tertiary veins of prospective interest nearer Ouray. These include in part the veins of The (Portland) Amphitheatre, that cut the San Juan tuff and underlying sedimentary rocks, and those along the canyon of the Uncompahgre River in the Algonkian quartzites and slates. Some strike north to somewhat northwesterly, and others more nearly east. The north-trending system appears to be the northward termination of the fissured and mineralized area of Bear Creek and the lower part of Poughkeepsie Gulch, where the San Juan tuff is cut by a strong nearly parallel system of north-south fissures.

In the San Juan tuff northeast of the Ouray this particular system is no longer recognizable, or at least has become so weak as to be of little economic interest. In the area of San Juan tuff immediately east and north of the stock, there is a conjugate system of northeasterly and northwesterly fissures, some of which contain veins. Many of these veins, however, are barren quartz with a little barite, but some contain small amounts of base metal sulphides and are said to have been prospected because of their gold content. In this same area a few fissures and faults, of east and north trend, appear to represent the reopening of pre-Tertiary or Eocene fissures in late Tertiary time. Most of these fissures contain barren quartz and barite, and some only barren carbonates.

In the San Juan tuff on the slopes of Hayden Mountain southeast of Ouray two pronounced fissure systems are found, one striking north to north 15° west, and another north 50°-70° east. Farther southwest along Canyon Creek the northerly system has a strike of about north 35° west, and approaches parallelism with the important northwesterly fissures of the strongly mineralized area to the west. The late Tertiary fissure systems of the northeastern part of Hayden Mountain show a stronger mineralization than the late Tertiary fissures northeast of Ouray, but the few veins developed have not as yet been proved to be of economic value. The late Tertiary veins have thus far been given only a preliminary study so that the distribution of the more strongly mineralized areas cannot be considerd in this paper.

The restudy of the mineralogy of these veins has not been completed, but some of them have been studied by modern methods and described by Bastin[58]. Certain mineralogical changes that may take place in veins that are explored in depth, either toward the base of the San Juan tuff in the area southwest of Ouray, or beneath their present outcrops in

[58]Bastin, E. S., op. cit., pp. 74-109, 1923.

other rocks near Ouray may, however, be mentioned. By driving of the lower Camp Bird tunnel and connecting this with the upper workings, the Camp Bird vein is now exposed throughout a vertical range of 2300 to 3000 feet below its outcrop. The change in character and texture of the vein in this vertical range is striking. On the upper levels the vein is a compound vein with an early stage of deposition characterized by sulphides of the base metals, and later stages characterized by gold-bearing quartz and barren quartz. In the intermediate and lower levels the gold-bearing quartz and base metal sulphides are closely associated with primary (hypogene) specularite. This appearance of specularite with depth is probably significant and indicates a tendency toward downward impoverishment of the commercial sulphides by vein deposition at higher temperatures[59]. Microscopic examination of ore and altered rock from the lowest Camp Bird tunnel level shows the specularite to be an early vein mineral and to have been veined and replaced by the later base metal sulphides. The association of the native gold with quartz containing specularite in the gold shoot at the east end of the mine, and the replacement of the early specularite as mentioned above, show that the minerals first formed at lower temperatures nearer the surface had later formed at greater depths within an earlier high temperature zone. The highest levels at which specularite appears in the vein are 1,000 to 1,200 feet above the lowest tunnel level, so that a considerable overlapping or telescoping of the temperature zones is apparent in this vein. Therefore there appears to be no reason to expect a sudden change from base metal sulphides to barren specularite at moderately greater depths below the lowest level. Also judging by the appreciable production of gold made by the Camp Bird from the deeper shoot, the first appearance of specularite in the Tertiary fissure veins in general is not a matter of immediate concern. Nevertheless, because of the absence of important gold shoots in

[59]Butler, B. S., and Burbank, W. S., Relation of the electrode potentials of some elements to the formation of hypogene mineral deposits: Am. Inst. Min. and Met. Eng. Tech. Pub. 166, Feb., 1929.

the specularite zone on the lowest Camp Bird level, such a change in mineralogy when found in Tertiary veins suggests the need for considerable caution in deeper explorations, especially with regard to expectations of gold and silver content. Apparently not only a sporadic distribution of gold and silver is to be expected within this zone, but also a more gradual impoverishment of base metal sulphides.

It was pointed out in previous paragraphs that, owing to the removal of the Upper Cretaceous formations by erosion before the deposition of the Telluride conglomerate and the San Juan tuff, geologic conditions during Tertiary time did not favor the formation of the different types of replacement deposits found among the late Cretaceous or early Eocene ore deposits. The mineralizing solutions rising in the late Tertiary fissures were not subjected to influences that would cause them to leave the fissures and move through the surrounding sedimentary rocks. Accordingly wide fissures that have been productive only in upper parts of the San Juan tuff would not be expected to produce extensive lateral replacement deposits in sedimentary formations beneath the volcanic rocks. Some lateral enrichment might, however, be expected in extremely porous beds, such as the "Pony Express beds," or some replacement of the wall rocks might have occurred in formations such as the Ouray limestone, if these rocks were not so deeply buried at the time of ore deposition as to be in a zone of too high temperature. The Portland vein, a late Tertiary vein at the head of The Amphitheatre, shows lateral enrichments in the beds of the Telluride conglomerate and in the Ouray limestone, but these do not extend any great distance from the vein. Probably intricately fissured zones near Tertiary intrusive bodies that have penetrated through the sedimentary rocks and into the overlying volcanic formations would provide geologic conditions more favorable to the formation of replacement bodies similar to those of the older period of mineralization.

Another type of Tertiary ore body that would favor extensive replacement of the surrounding deeper sedimentary rocks is the "chimney" or "stock" ore body, of the kind well represented in the Red Mountain district.