THE MARYSVILLE GRANODIORITE STOCK, MONTANA

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ABSTRACT

The Marysville granodiorite stock of Montana is six miles north of the northern end of the Boulder bathylith. Around the stock cluster the rich gold-bearing veins that made the Marysville mining district famous in the early history of Montana. The Marysville stock is only one of many stocks that occur in the zone surrounding the large Boulder bathylith. The matter of determining whether these bodies are genetically linked to the bathylith is an elusive problem often met in areal geology. Three hypotheses have been advanced to account for the relationship between the Boulder bathylith, the Marysville stock, and the gold veins geographically associated with the stock: (1) the stock is an outlier of the bathylith and the veins are genetically related to the stock; (2) the stock, though an outlier of the bathylith, did not bring the ore but by its position determined the location of the veins by structural control; (3) the stock is much younger than the bathylith, is Oligocene in fact, instead of late Cretaceous or late Paleocene and was the gold-bringer. The second interpretation appears to be greatly strengthened by new evidence obtained during recent detailed investigation of the region by the writer, and the conclusion is reached that the Marysville stock is an outlier, probably a cupola of the Boulder bathylith, as is indicated or proved by the numerous scheelite-bearing pyrometasomatic deposits formed by the stock in its contact aureole as well as by the bathylith in its aureole, and that the gold veins were formed much later, in connection with the dacite extrusions just south of Marysville which are auriferous, or with the still later rhyolite eruptions, which also are auriferous.

The Marysville stock is surrounded by late Precambrian rocks of the Belt series—in ascending order, the Empire formation, the Helena limestone, renamed here Helena dolomite, the Marsh formation, and the Greenhorn Mountain quartzite, a newly recognized formation. The stock has profoundly metamorphosed the Empire formation and the Helena dolomite through which it cuts. The metamorphism of the Helena "limestone" was described by Barrell in his classic memoir on the district, but not that of the Empire formation, which was transformed into striking cordierite hornfelses. Scheelitic, scapolitic, vesuvianitic, and cordieritic metamorphism not previously recorded are here briefly described.

INTRODUCTION

During recent years the writer, assisted by Eleanora B. Knopf, has been mapping the northern portion of the Boulder bathylith of Montana and the rocks that make up its framework. The Boulder bathylith, though generally considered to be well known, has never been mapped petrographically. It is shown on the various maps so far published as quartz monzonite "qm," which procedure has been a notable labor-saving device. The bathylith in reality is composite, consisting of granodiorite, quartz monzonite, tonalite, white granite, muscovite granite, alaskite, aplite, graphophyre, diorite, and gabbro. During the course of this recent work the Marysville stock, its contact aureole, and the surrounding rocks were examined. Many stocks occur around the border of the Boulder bathylith, but the Marysville stock is best known, because of the important precious metal mining district geographically associated with it and because of Barrell's classic memoir on the district, in which he independently developed the hypothesis of magmatic stoping and made a penetrating study of the contact metamorphism produced by the stock. The relationship between Boulder bathylith, Marysville stock, and the geographically associated gold-silver veins has given rise to three hypotheses, one of which appears to be greatly strengthened by newly found evidence. The rocks surrounding the Marysville stock belong to the Belt series, in fact the type section of the Empire "shale" is within the district; these Beltian formations have necessarily been examined in detail. The Empire has never been described before; the Helena "limestone" is shown to consist mainly of dolomite and is therefore here renamed the Helena dolomite; the Marsh "shale," said for 50 years to be 300 feet thick, proves to be a formation 3000 feet thick; and a newly recognized Beltian formation, the Greenhorn Mountain quartzite, which conformably overlies the Marsh formation is described.

General Geologic Setting

The northern end of the Boulder bathylith is on the Continental Divide just south of Mullan Pass. Six miles north is the Marysville stock, a body of granodiorite of 3 square miles surface exposure, which is intrusive into the Precambrian Beltian formations—the Empire formation and the Helena dolomite. In view of its small size the stock has produced a remarkable contact aureole one-half to 2 miles wide, consisting mainly of banded calcic hornfelses (Fig. 1).

The town of Marysville, now a ghost of its former self, is 20 miles northwest of Helena, with which it is connected by a first-class highway.

Empire Formation

The Empire formation, or "shale" as Walcott (1899, p. 207) called it, was named from its exposure west of the Empire mine, at the head of Lost Horse Gulch in the western part of the Marysville district. The lowermost beds exposed here are intruded by the granodiorite of the Marysville stock. All rocks in the type section are hornfelsed, dark-weathering, and are crackle breccias ramified with tremolite veinlets and quartz veins. They are well within the contact-metamorphic aureole of the Marysville stock and are overlain conformably by white diopsidic hornfels ($d=3.01$) of the Helena dolomite. Walcott mentioned that the Empire shale is well shown also on the summit of Drumlummon Hill, in the eastern part of the Marysville district, but the rock there proves to be a superb scapolite-diopside hornfels ($d=3.10$).

Barrell (1907) in his classic account of the Marysville district, ignored the type section of the Empire and described the formation as exposed on Long Creek in the north-central part of the Marysville area, outside of the contact aureole, where "it consists of finely laminated, soft limy shale, grayish green or buff-colored, with a few reddish bands." As seen by the writer, the Empire there consists of pale greenish hard argillite ($d=2.67$) alternating with mud-cracked rose or lavender argillites. The top of the Empire is prevailingly light-colored and weathers pale buff and yellowish. The buff-weathering habit of the uppermost part of the forma-

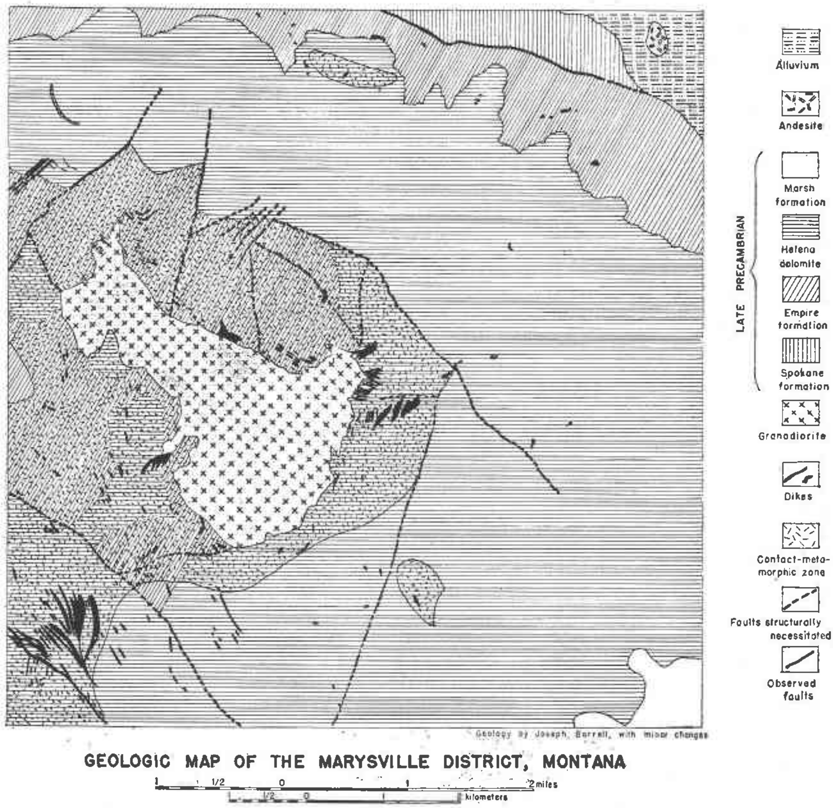

FIG. 1

tion necessitates special care in distinguishing the Empire from the overlying Helena dolomite. As the section in this locality is bottomed by a fault, Barrell could measure only 520 feet in the Empire and accepted Walcott's figure of 600 feet as the total thickness of the Empire. However, the base of Walcott's section, as already mentioned, is an intrusive contact.

According to Pardee (1933, p. 126) the Empire consists mainly of siliceous greenish-gray shale. As measured in White and Avalanche gulches in the Belt Mountains, where the stratigraphic relations are well shown, it "appears to be about 1000 feet thick."

The Empire formation was found during the present work to be best exposed in a section that extends east-west through U.S.G.S. bench mark 4450 in the Scratchgravel Hills, just northwest of Helena. It consists of pale-green argillite, deep-red (brick-red, maroon, and lavender) argillites identical in appearance with those in the underlying Spokane formation, and fine-grained light-green and white quartzite. The thickness of the Empire is about 1000 feet.

The quartzite beds, which have not been mentioned in previous descriptions of the Empire, distinguish the formation from the underlying Spokane. The Empire overlies the Spokane conformably and the first appearance of quartzite in the section is taken to mark the bottom of the Empire. The lower quartzites are feldspathic rocks ($d=2.64$) and weather tawny, whereas those from the top, like the associated argillite, are buff-weathering. The transition to the overlying Helena dolomite is abrupt, taking place within a stratigraphic thickness of 20 feet.

The Empire formation is hornfelsed in much of the region here considered. Dark cordierite hornfels is common, as befits the general pelitic nature of the Empire formation, but interbeds of white calc-hornfels occur. Notable are the coarse cordieritic hornfelses on the north side of Ottawa Gulch in the Marysville district; large fine outcrops show well-developed cross-lamination extending across beds 6 to 12 inches thick, the cordierites being localized along the diagonal structures.

Helena Dolomite

The Helena dolomite as it is here renamed was originally called the Helena limestone by Walcott (1899, p. 207); it consists largely of buff-weathering dolomite. This buff-weathering feature has been mentioned by all later investigators as typical of the formation, but no one has mentioned its dolomitic composition. The rock is dark gray on fresh fracture, is aphanitic, is non-effervescent on being touched with cold, dilute HCl, is compact and non-porous, and ranges in density from 2.76 to 2.82. Silica, as kindly determined by Dr. George Switzer on typical material ($d=2.78$), runs 32.6 per cent.

The Helena dolomite is transformed around the border of the Boulder bathylith and the Marysville stock into wide aureoles of white and cream-colored diopsidic and tremolitic hornfelses; in other words, into calcic and highly magnesian hornfelses. In fundamental studies of contact metamorphism it is of course important to know the composition of the unaltered rock, but in the Marysville memoir the Helena dolomite is described as an impure limestone. Harker and Marr (1893) appear to be the only geologists who have recorded that after finding abundant calcium-magnesium silicates in the specimens collected from metamorphosed limestone they went back into the field and re-examined the unmetamorphosed beds and found them to be dolomitic.

The formation contains subordinate limestone, which weathers gray or "bluish" gray, some siliceous limestone oolite, and beds of edgewise conglomerate up to 2 feet thick. Particularly notable are the *Collenia* biostromes, up to 10 feet thick, that occur at intervals from bottom to top of the formation; they have not been previously recorded as occurring in the Helena dolomite. In the Marysville district a large *Collenia* biostrome is exposed near Sawmill Creek on the abandoned right-of-way of the Northern Pacific Railway.

The thickness of the Helena "limestone" at Marysville was tentatively estimated by Barrell to be 4000 feet, and recent measurement along what appears to be a more favorable section south of the district confirms that figure.

MARSH FORMATION

The Marsh formation overlies the Helena dolomite conformably, as is well shown in excellent exposures on South Park Street in the heart of Helena. Here it consists of maroon mud-cracked shale (or argillite) and thin interbeds of mud-flake breccia and quartzite. It is only 250 feet thick here and is overlain disconformably by the Middle Cambrian Flathead quartzite.

The type section of the Marsh formation is at the mouth of Marsh Creek just outside of the Marysville map-area. The stratigraphic relations are not well shown there however, and Barrell ignored the type section. According to Walcott (1899, p. 208) the Marsh formation at the type locality is 300 feet thick and constitutes the topmost portion of the Belt terrane and this characterization, though wholly inadequate, has now done duty for 50 years.

By mapping the Marsh formation from Helena northwestward to Marysville, it is found to increase in thickness to 3000 feet and to be overlain conformably by a great thickness of quartzite, here named the Greenhorn Mountain quartzite. The top of the Marsh formation on the north flank of Greenhorn Mountain is a deep-maroon argillite, ripple-marked and mud-cracked and interbedded with thin quartzites 1 to 2 inches thick.

Deep red argillites, maroonish, purplish and violet, are common constituents of the Marsh, but quartzites in belts as much as 500 feet thick, cross-laminated siltstones, and laminites carrying casts of salt crystals are interbedded with them. The red argillites can not be distinguished from the similar argillites prominent in the Empire and Spokane formations. Probably the most distinctive lithic member in the Marsh formation is the dark red quartzite that weathers to a deep blackish red.

Greenhorn Mountain Quartzite

Above the Marsh formation and below the Flathead quartzite on Greenhorn Mountain is 1800 feet of quartzite. This figure is a minimum, as the top of the section is bounded by the erosion surface on which rests the Flathead quartzite of Middle Cambrian age. The pre-Flathead quartzite constitutes the country rock of the Continental Divide, making up the massive bulk of Greenhorn Mountain, 7500 feet in altitude, which forms the highest summit between Mullan Pass and Marysville. This newly recognized formation of the Belt group is therefore called the Greenhorn Mountain quartzite. The quartzite is notably feldspathic, the feldspar consisting of clear limpid microcline. In this feature the Greenhorn Mountain quartzite differs essentially from the Flathead quartzite, which is pure quartzite. The lower portion of the formation is massive quartzite, in places showing festoon cross-lamination, whereas the upper third is well stratified in beds of uniform thickness ranging from 1 to 2 inches.

In extant geologic maps the Greenhorn Mountain quartzite has been included with "undifferentiated Devonian and Cambrian" strata, with the result that the Flathead, which averages 100 feet in thickness with little deviation from this thickness a over distance of scores of miles, is implied to have a thickness on Greenhorn Mountain of several thousand feet.

Dacite and Rhyolite

Subsequent to the uncovering of the Boulder bathylith, dacite was erupted in large volume in the region between Marysville and Butte. Significantly the dacite encloses auriferous veins, proving that a gold metallization took place long after the great metallization produced by the Boulder bathylith.

A striking rhyolite, white and dotted with phenocrysts of coal-black quartz, occupies much of the area west and southwest of Marysville. It overlies the Oligocene clays near Mullan Pass, so is younger than the clays and judged from its relation to the present topography it is probably late Tertiary. Somewhat south of Mullan Pass, in the Rimini district, contemporaneous rhyolites are auriferous. Thus, in the general region of the Boulder bathylith there were at least three periods of gold metallization.

Granodiorite of the Marysville Stock

The Marysville stock is three square miles in extent. It cuts through the Empire formation and Helena dolomite, which it has profoundly metamorphosed. Its emplacement according to Barrell was effected chiefly by rifting off of large angular blocks and their subsequent engulfment in the magma, a process, as is well known, termed by Daly magmatic stoping.

The main rock of the stock is a normal medium-grained granodiorite. It was called "quartz diorite" by Barrell, but the type material contains 15.6 per cent of orthoclase, and "granodiorite" is more appropriate, as pointed out by Lindgren (1907). Granodiorite ($d=2.75$) as obtained in ideally fresh condition from a newly blasted cut on the main highway just below the Drumlummon mill, is of typical appearance, the only exceptional feature being the presence of orthoclase in poikilitic patches 15 mm. in diameter. The rock consists dominantly of a zoned plagioclase ranging from An_{40} to An_{15} in the peripheral zone, quartz, orthoclase, hornblende, and biotite; it has an ideal hypidiomorphic granular fabric. Closely similar rock carrying even more conspicuous poikilitic orthoclase occurs on Drinkwater Creek two miles northwest; both were taken from the marginal zone of the stock. Two specimens ($d=2.68$), taken by the writer from the interior of the stock carry less hornblende and biotite (about 5 per cent) and may indicate, as suggested by Cross (Barrell, p. 55), that a younger intrusion is present but this problem was not investigated.

Contact Metamorphism

General features.—The granodiorite is surrounded by a remarkable contact-metamorphic aureole one-half to two miles wide. Within this aureole the Empire formation has been transformed into dark cordierite hornfels and the Helena dolomite into white and other light-colored diopsidic and tremolitic hornfelses. The contact zone was carefully mapped by Barrell; the calcic hornfelses were the main concern during his penetrating investigation, and the cordierite hornfels of the Empire formation was not mentioned. In that study he drew a sharp distinction between simple contact metamorphism (purely thermal, without addition of new material) and contact metasomatism, during which new material was added to form the contact rock. This distinction was made later, in 1911, by V. M. Goldschmidt in his masterly treatise on contact-metamorphism in the Oslo district, Norway, and the distinction is now taken for granted. Barrell found that where pure thermal metamorphism and metasomatic effects occur together, the metasomatic alteration is demonstrably the younger and has followed fractures in the already thermally metamorphosed rocks. Tremolite and diopside were found to be the common minerals in the contact aureole. Later work has shown that scapolite is widespread throughout the contact zone, that vesuvianite tactites have formed, that the Empire formation was changed to striking cordierite hornfelses, and that scheelite was widely introduced by late pyrometasomatic activity.

Cordierite Hornfelses of the Empire Formation.—The Empire formation is well exposed on the north side of the upper part of Ottawa Gulch; it is here horizontal and highly metamorphosed. Some of the rocks are cordierite hornfels in which the cordierites on weathered surfaces resemble small fusulines; in other beds they are large, from $\frac{1}{2}$ to $\frac{3}{4}$ inch long. Large fine outcrops of hornfels show much cross-lamination extending across strata 6 to 12 inches thick; the cordierites are localized along the diagonal laminae. The hornfels ($d=2.69$) proves under the microscope to be made up essentially of quartz, microperthite, biotite, muscovite, and porphyroblastic cordierite notable for its brilliant yellow pleochroic halos.

Calcic and Magnesian Hornfelses of the Helena Dolomite.—Within the contact zone shown in Fig. 1 the Helena dolomite has been converted into compact (non-porous) hornfelses, white, light-gray, and creamy in color. Most are extremely fine-grained, generally aphanitic but in places ranging to microcrystalline. They range in density from 2.81 to 3.15, the lighter rocks proving to consist chiefly of tremolite and the heavier of diopside.

The hornfelses are particularly well exposed along the highway on the north side of Silver Creek, where they abut upon the stock. Beds consisting wholly of tremolite hornfels ($d=2.91$) are interstratified with those made up wholly of diopside ($d=3.01$). Composition rather than proximity to the granodiorite contact appears to have been the factor controlling whether tremolite or diopside have formed,

Rarely are the minerals of the hornfelses megascopically recognizable. An exception is the vesuvianitic diopside hornfels ($d=3.12$) from the north end of the ridge between Drinkwater and Deer creeks; in this layered hornfels vesuvianite in euhedral crystals is localized along certain beds $\frac{3}{4}$ of an inch thick.

Because of the minute grain of the hornfelses every thin section is likely to afford a surprise. The first section examined during the present study was cut from the remarkable banded hornfels in Trinity Gulch. The hornfels proved to be made up of diopside and abundant spongiform scapolite, a mineral not previously recorded from the Marysville district. Later, superb scapolite-diopside hornfels was found to occur on the summit of Drumlummon Hill. The rock ($d=3.10$) is white, coarse-grained, and consists largely of diopside prisms 15 mm. long, which are idiomorphic against scapolite. The scapolite amounts to 10 per cent; its indices —$N_z=1.56$ and $N_x=1.542$—indicate a scapolite containing 55 per cent of the marialite molecule. Minor constituents of the hornfels are calcite, tremolite, phlogopite, muscovite, and seybertite, which has developed at the expense of the diopside.

Scheelite-bearing Contact Rocks.—As the result of the announcement by the writer in the "Helena Independent" on Sept. 26, 1941, that scheelite had been found in a garnet contact deposit on the margin of the Boulder bathylith west of Helena, scheelite was soon found throughout a wide region in contact zones, in old mines and prospects, and in the clean-up of the gold dredge operating on Prickly Pear Creek. Scheelite was found in the placers of Piegan Gulch in the northern part of the Marysville district, and soon after was found in place in many localities in the contact zone of that district. Additional finds were made by the writer in the summer of 1942, and these confirmed that scheelite had been introduced into the Marysville contact aureole at many places.

The scheelite occurs in two ways:

(1) With garnet as thin stratiform layers, which represent limestone beds in the Helena dolomite that had escaped hornfelsing and were later replaced by andradite garnet and scheelite; and (2) belts of calcic hornfels that have been permeated and replaced by epidote, garnet, amphibole, quartz, and scheelite. Typically, epidote predominates, and consequently the scheelitic tactites are dark-green rocks. Although some good scheelite ore has been found, the deposits so far known have not proved to be of economic value.

The principal development of scheelite-bearing garnet-epidote rock occurs on the ridge between Deer and Drinkwater creeks. Here in a belt of white calcic hornfelses 3200 feet wide are 30 scheelite-bearing zones ranging from 10 inches to 3 feet in thickness. The rocks of this belt were mapped by Barrell as Empire, but the prevalence of white calcic hornfelses, some of which show "molar-tooth" structure, proves that the section consists of hornfelsed Helena dolomite. The garnetiferous beds were briefly discussed by Barrell (Barrell, p. 134), but in 1901 no one knew that scheelite may occur as a contact-metasomatic mineral. These scheelitic tactites are somewhat unusual in that they have been formed by the garnetization and epidotization of thin-bedded diopside hornfelses.

Three stratiform layers of scheelitic tactite were found in a stratigraphic interval of 200 feet on the north flank of Mount Belmont. The most promising is 2 feet thick. The ore consists of epidote, quartz, amphibole, calcite, and scheelite.

The Gold Veins.—The veins formerly so productive yielded gold and silver. Their general features, including their remarkable lamellar quartz and calcite gangue, were described earlier (Knopf, pp. 64–68) and indicate, contrary to the interpretations of Weed and Barrell, that they are not genetically allied to the Marysville stock.

The geographic association of the veins and the stock appears to have been determined by structural control. Bruce (1937, p. 378) has pointed out that the proximity of ore bodies to exposed igneous rocks has been commonly determined by "structural factors only and has no genetic significance."

If the gold-silver veins of the Marysville district are genetically related to the intrusion of the granodiorite stock, scheelite could be expected to occur in the veins, in view of the widespread introduction of scheelite into the contact-metamorphic aureole.

During the present investigation some thousands of feet of the workings of the Drumlummon mine, the principal mine in the district, were rayed with an ultra-violet lamp, but no scheelite was found. This result was not unexpected however, as the scheelite deposits are pyrometasomatic and the veins are clearly of epithermal type in the classification of Lindgren (1933, pp. 450, 463).

Relationship of Marysville Stock, Gold Veins, and Boulder Bathylith.— Three solutions of this problem have been given, in 1907, 1913, and 1933. According to Barrell (1907) the Marysville stock, lying 6 miles north of the northern end of the Boulder bathylith, is an outlier of the bathylith. The chief evidence cited in support of this idea is that the Marysville granodiorite is petrographically and chemically like that of the rock of the bathylith as represented at Butte (Barrell, pp. 24, 55). However, this evidence is not necessarily conclusive, especially in view of the composite nature of the Boulder bathylith, which ranges from tonalite through granodiorite, quartz monzonite, and granite to alaskite. The associated precious-metal veins were thought to have been produced by contraction effects on the margin of the stock and to have been filled by mineral matter deposited from emanations released from the solidifying magma.

In 1913 the idea was advanced that though the Marysville stock is an outlier of the Boulder bathylith, the geographically associated gold-silver veins are not genetically allied to the stock (Knopf, pp. 62–68). The veins were shown to differ greatly in their principal features from the deposits genetically allied to the bathylith. They are essentially unlike in metal content, in persistence of ore in depth, and in the remarkable lamellar or platy nature of their quartz-calcite gangue. They are in fact identical in their chief properties with the precious-metal veins that are inclosed in the dacite lava piles, which rest on the eroded surface of the bathylith.

In 1933 a new solution was offered by Pardee and Schrader (1933, pp. 20, 29, 69). They accepted the idea that the Marysville veins were formed during an epoch of ore deposition that was later than the metallogenesis accompanying the cooling of the Boulder bathylith, but they maintained that the veins are genetically related to the Marysville stock.

Consequently the stock is considered to be younger than the Boulder bathylith [the date of whose emplacement has not yet been more closely established than "late Cretaceous-early Tertiary"] and they considered that the age of the stock is probably Oligocene.

The recent discovery that scheelite has been widely introduced into the contact zone of the Marysville stock greatly strengthens the conclusion that the Marysville stock, as Barrell first pointed out, is an outlier of the bathylith. Whether the "outlier" is a cupola on the bathylith or is a crosscutting stock is not determinable. Further evidence that the two igneous masses are essentially of the same age is that the contact-metamorphic effects produced by bathylith and stock on the Helena dolomite are identical both in intensity and in extent.

The epithermal nature of the gold-silver veins indicates, as it did in 1913, that the precious metal deposition is younger than the metallogenesis of the Boulder bathylith. This conclusion has gained further strength from the fact, which was not known in 1913, that gold occurs in many places in the extensive dacite-covered area a few miles south of Marysville. As the dacites, which are supposedly late Miocene in age, rest in places on the eroded surface of the bathylith, a long span of time must have elapsed between the intrusion of the Marysville stock and the subsequent deposition of the gold-silver veins associated with it.

Nearly fifty years have been required to formulate a reasonable answer to the problem of the relationship between Boulder bathylith, Marysville stock, and the geographically associated gold-silver veins; perhaps when, as physicists promise us, five grams of a rock will suffice for a determination of its absolute age, the answer will come more rapidly and more positively.

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