Variation In Gold Content Of Minerals Of The Marysville Quartz Diorite Stock, Montana

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Geochimica et Cosmochimica Acta, 1967, Vol. 31, pp. 225 to 235. Pergamon Press Ltd. Printed in Northern Ireland

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(*Received* 19 *July* 1965)

Abstract—Neutron activation analysis for gold has been carried out on 135 mineral samples from throughout the Marysville stock with the following results: (1) the gold content of 44 biotites ranges from 0·002 to 0·924 ppm with an average of 0·076 ppm; (2) 37 hornblende samples gave a range of 0·003–0·823 ppm and an average of 0·100 ppm; (3) for 44 magnetite samples the range was 0·003–0·329 ppm and the average 0·037 ppm; (4) 10 quartz-feldspar samples varied from 0·006 to 0·176 ppm with an average of 0·065 ppm.

High gold values mainly occur near the edge of the stock and the lowest values in the center of the stock. The highest values are found near the old gold mines located along the periphery of the stock.

Because it could not form bonds in crystallizing minerals, the gold was concentrated in the residual fluids of the Marysville magma and was finally deposited in quartz veins at the edge of the stock. The gold in the minerals is probably entrapped as uncharged gold atoms. The amount of gold in a given mineral was determined by the structure of the mineral and the concentration of gold in the magma at the time of crystallization of that mineral.

INTRODUCTION

IN recent years a great deal of information has become available on the average trace element content of various igneous rock types. Also the effects of magmatic differentiation on the trace element content of major mineral phases has been studied. Little is known, however, about the variation in trace element content of individual intrusive igneous bodies which are relatively homogeneous in chemical and mineralogical composition. Studies by SLAWSON and NACKOWSKI (1959), PARRY and NACKOWSKI (1960), THEOBALD and HAVENS (1960), PUTMAN and BURNHAM (1963), and others have indicated that high concentrations of certain trace metals occur in rocks and minerals which are associated with ore deposits of these elements. This work has dealt mainly with copper, lead and zinc. Development of the neutron activation method of analysis, which is particularly sensitive for gold, now makes it possible to study the amount and distribution of gold in rocks and minerals. This paper reports on the variation in gold content of the minerals of a small, generally homogeneous stock which has a number of old gold mines around its periphery. The main purposes of the study were (1) to determine the amount of variation in gold content of the major minerals throughout the stock (in two dimensions) and (2) to ascertain

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if a relationship existed between the gold content of the minerals and their proximity to the gold mines.

LOCATION, HISTORY AND GEOLOGY OF AREA

The Marysville stock is located in the Northern Rocky Mountains about twenty miles northwest of Helena, the state capital of Montana. The stock is approximately four square miles in surface area and may be related to the Boulder batholith, whose northern boundary is eight miles south of the stock. Placer gold deposits were first worked in the Marysville area in 1864 and mining of lode veins began in 1876. Total gold production from the district is valued at about $35,000,000, with half of this coming from the Drumlummon Mine. Other mines of importance were the Belmont, Cruse, Bald Butte, Penobscot, Empire and Gloster, all of which are located at or near the edge of the stock. The ore deposits are steeply dipping veins bearing gold and silver and occur in both the stock and the surrounding contact metamorphic rocks. The veins are near the edge of the stock with no veins known in the interior of the stock. They die out quickly with depth and none of them, with the exception of the Drumlummon veins, were worked below a depth of 500 ft.

The stock is generally coarse-grained and shows very little variation in mineral content. Grain size decreases towards the center of the stock. The major minerals are plagioclase feldspar (44%), quartz (20%), orthoclase feldspar (13%), biotite (7%) and hornblende (5%). Magnetite makes up two per cent and trace minerals and alteration products comprise the rest of the rock. BARRELL (1907) and KNOPF (1913) called the rock a quartz diorite while KNOPF (1950) considered it to be a granodiorite. A detailed description of the geology of the area with emphasis on the effects of contact metamorphism by the stock may be found in the publication by BARRELL.

SAMPLE COLLECTION AND PREPARATION

Twenty-eight rock samples were collected from various parts of the stock by use of a grid sample pattern. Thirty additional samples were collected from the vicinity of the major mines and from the periphery of the stock. Figure 1 shows sample locations and numbers. Fresh chips of each rock sample were pulverized with a stainless steel mortar and pestle. The resulting powder was sieved to −100 mesh with silk bolting cloth. Magnetite was extracted and purified with a hand magnet. Hornblende and biotite were separated from the powder and from each other by use of a Frantz isodynamic separator. Final purity of the magnetite, hornblende, biotite and quartz-feldspar fractions varied from 90 to 99%, with most samples estimated to be about 95% pure. For various reasons, pure fractions were not possible in some cases. A total of 44 magnetite samples, 37 hornblende samples and 44 biotite samples were selected for analysis. Ten quartz-feldspar and five whole rock samples were also run.

ANALYTICAL METHOD

The nuclear reactor at the University of Missouri, Rolla, Missouri, was used for activation. Samples weighing 0·2 g were sealed in a plastic sheet and then enclosed in a polyethylene bottle for irradiation. Because of the large number of samples to be analyzed, a standard was not run with each sample. This cut down on the time

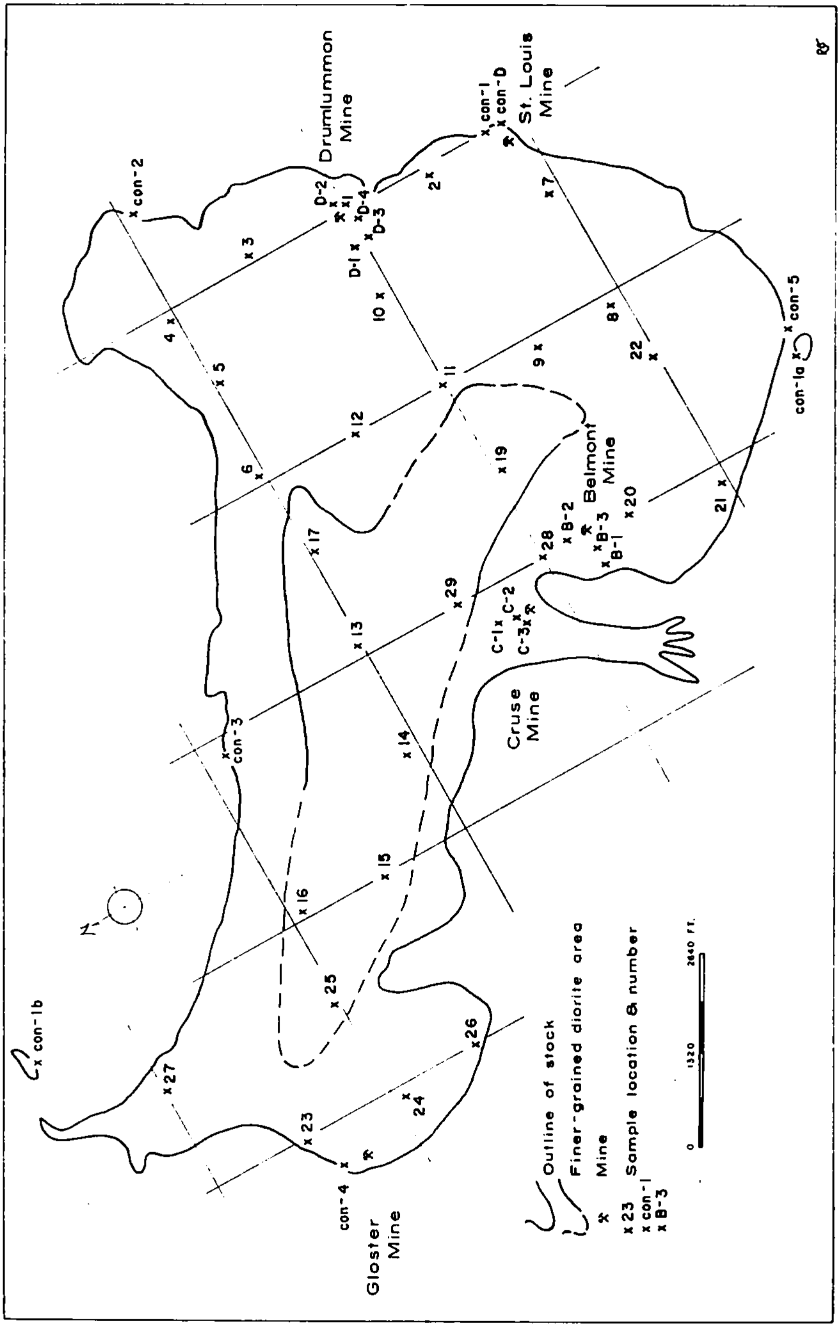

Fig. 1. Outline of Marysville stock and sample locations.

needed for analysis, but also resulted in poorer precision for the method. Irradiated samples were compared with standard samples run by themselves in the various core positions. Irradiations were carried out at a flux of about 3 $\times$ 10^{10} n/cm^2 sec for ten hours. The samples were allowed to decay for 80 hr and were then counted on a 400 channel pulse-height analyzer connected to a $1\frac{3}{4}$ $\times$ 2 in. thallium-activated sodium iodide scintillation crystal.

The samples were first compared with gold foil standards. Results were found to be high, as has been reported by VINCENT and CROCKET (1960a). Next the gold content of a granite was determined by analyzing five different samples and comparing them with the CAAS sulfide standard (WEBBER, 1965). Good precision was obtained, giving an average gold value for the granite of 0·032 ppm. The granite was then used as a standard and the samples were compared with both the granite and the CAAS sulfide. Although both standards gave reasonable results for the unknowns, it was found that the granite gave more consistent results, perhaps because it is closer in chemical composition to most of the samples. The results reported here are based on comparison with the granite standard.

Because of the lack of standards with known gold content, the accuracy of our results is unknown. The results are of the same magnitude as those previously reported for igneous rocks and minerals by DEGRAZIA and HASKIN (1964) and VINCENT and CROCKET (1960a, 1960b). The precision of the method was estimated by making duplicate analyses on 19 random samples. The average deviation of a single value from the mean of the duplicates was 34% while the greatest deviation was 59%. A few apparently erratic results were found among the 145 analyses carried out. Additional material for these samples was re-run two more times and final values were obtained by averaging the two best results.

RESULTS

The results of the gold analyses are given in Table 1 and are plotted and contoured on the stock in Figs. 2–5. Areas with gold values higher than 0·080 ppm are stippled in the figures. Figure 2 shows the gold content of biotite throughout the stock. It ranges from 0·002 to 0·924 ppm. The gold appears to be concentrated near the Drumlummon, St. Louis, Belmont and Cruse mines, with the highest gold value occurring near the Drumlummon Mine. Some fairly low values occur near the various mines also. Four high values occur in three other areas where no mines are located. Most of the high values are near the edge of the stock. Similar relationships are found for the gold content of hornblende, shown in Fig. 3. In this case a high value occurs near the Gloster Mine in addition to high values near the Cruse, Belmont, St. Louis and Drumlummon mines. The range in gold content of hornblende is 0·003–0·823 ppm, with the highest value again occurring near the Drumlummon Mine. The hornblende values indicate a concentration of gold in the southern portion of the stock as well as towards the edge of the stock.

Figure 4 is a plot of the gold content of magnetite, which varies from 0·002 to 0·329 ppm. High gold values are found near the Belmont and Cruse mines, but the closest samples have low values. Again the gold appears to be concentrated in the southern portion of the stock. High values do not occur near the richly productive Drumlummon Mine, in contrast to what was found for biotite and hornblende, and

Table 1. Gold content of Marysville rocks and minerals

Sample number	Biotite (ppm)	Hornblende (ppm)	Magnetite (ppm)	Quartz-feldspar (ppm)	Whole rock (ppm)
1	0·005	0·823	0·055	0·037*	0·089
2	0·015	0·033	0·012		
3	0·029	0·046	0·014		
4	0·004	0·005	0·006		
5	0·015	0·015	0·052*		
6	0·004	0·024	0·019		
7	0·005	0·060*	0·032		
8	0·017	0·300	0·120*		
9	0·180*	0·165	0·086*		
10	0·019	0·012*	0·008		
11	0·044	0·219	0·003*	0·006	0·004
12	0·013		0·033		
13	0·044		0·004	0·026	0·010
14	0·037		0·011		
15	0·094	0·067			
16	0·004		0·066*		
17	0·107*		0·029		
18					
19		0·032			
20	0·154*	0·212	0·154		
21	0·002	0·165	0·011		
22	0·032	0·025	0·008	0·055	
23	0·010	0·005	0·034		
24	0·021	0·129	0·061		
25	0·046*		0·020	0·040	0·015
26	0·141	0·003	0·329		
27	0·050	0·167	0·200		
28	0·018	0·113	0·004		
29	0·150*		0·098	0·176	
B-1	0·056	0·035*	0·011	0·144	
B-2	0·012	0·026	0·006		
B-3	0·054		0·014		
C-1	0·014	0·012	0·017		
C-2	0·026*	0·276*	0·002	0·080	0·053
C-3	0·038		0·009		
D-1	0·159	0·008	0·002		
D-2	0·924*	0·179*	0·003	0·070*	
D-3	0·004	0·010	0·015		
D-4	0·290*	0·056	0·003		
CON-1	0·304*	0·021	0·007		
CON-1a	0·012	0·022	0·007		
CON-1b	0·011	0·110	0·013	0·011	
CON-2		0·007	0·002		
CON-3	0·018	0·022	0·030*		
CON-4	0·007	0·025	0·004*		
CON-5	0·113	0·024	0·011		
CON-D	0·037	0·231	0·026		
average	0·076	0·100	0·037	0·065	0·034

* Average of two runs.

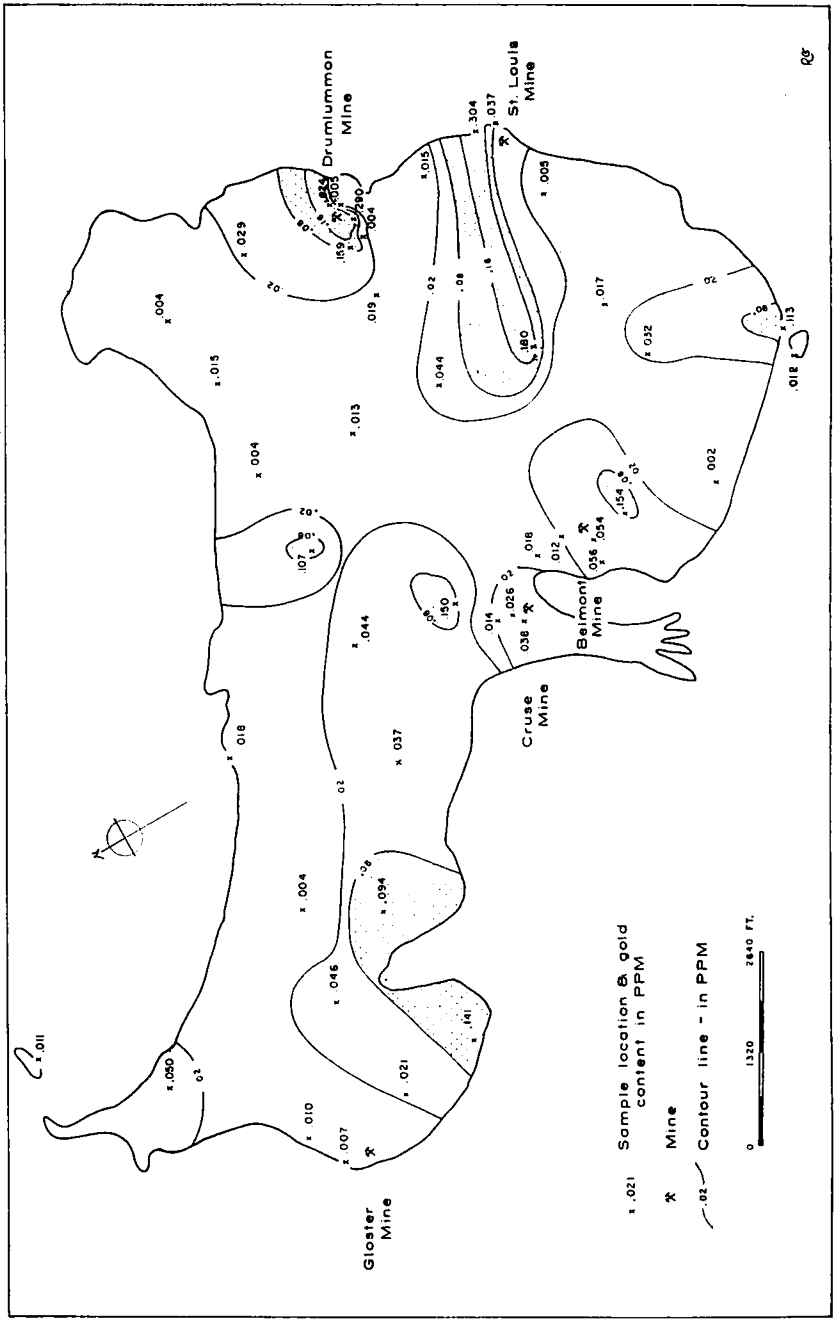

Fig. 2. Gold content of biotite, Marysville stock.

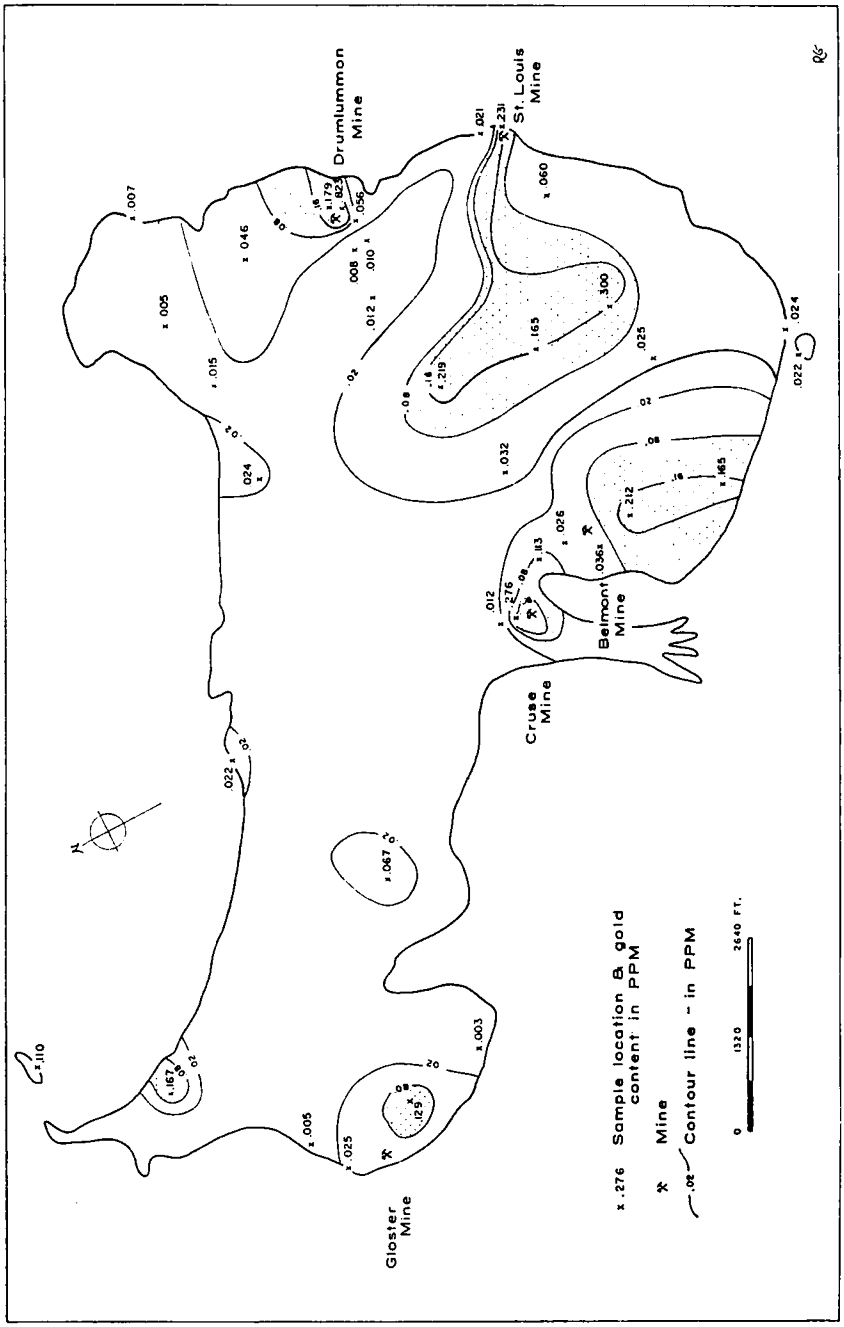

Fig. 3. Gold content of hornblende, Marysville stock.

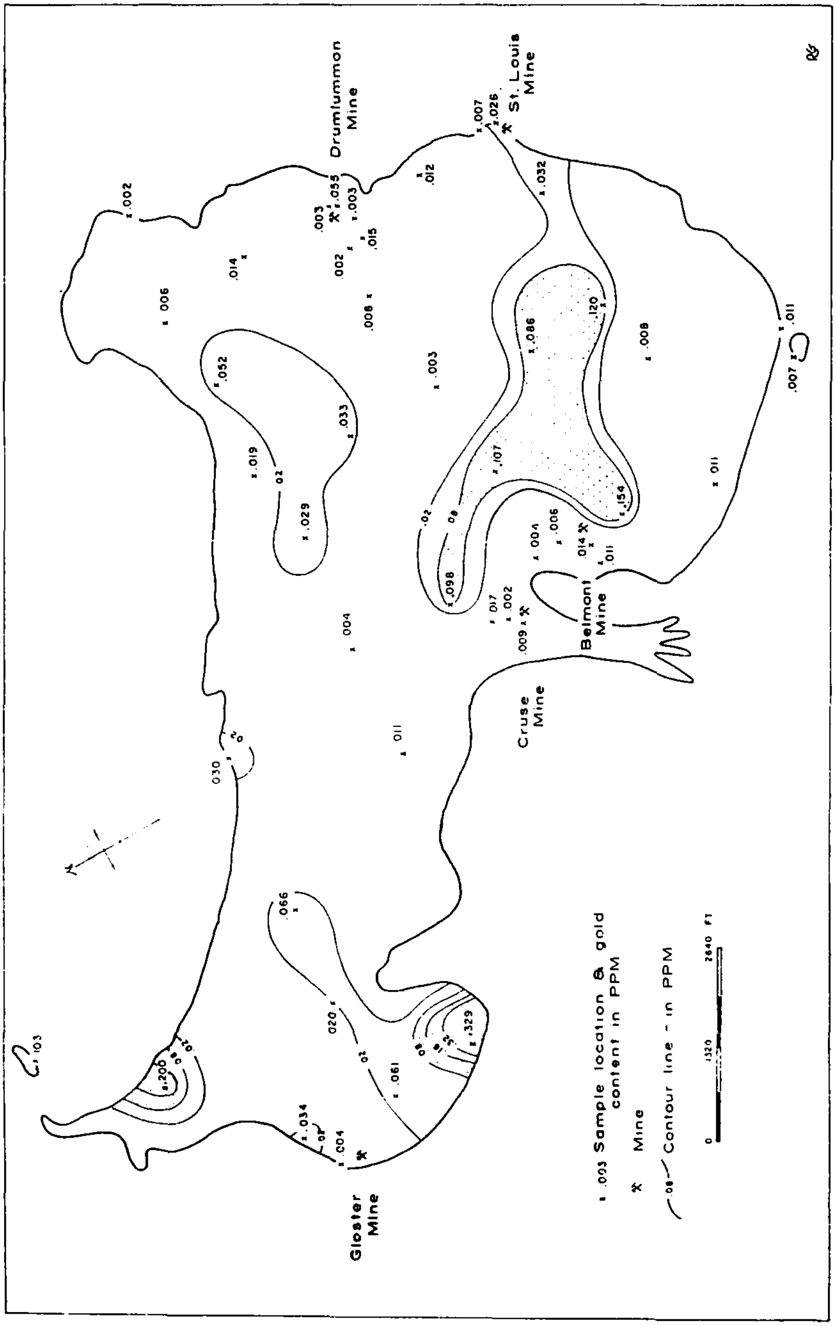

Fig. 4. Gold content of magnetite, Marysville stock.

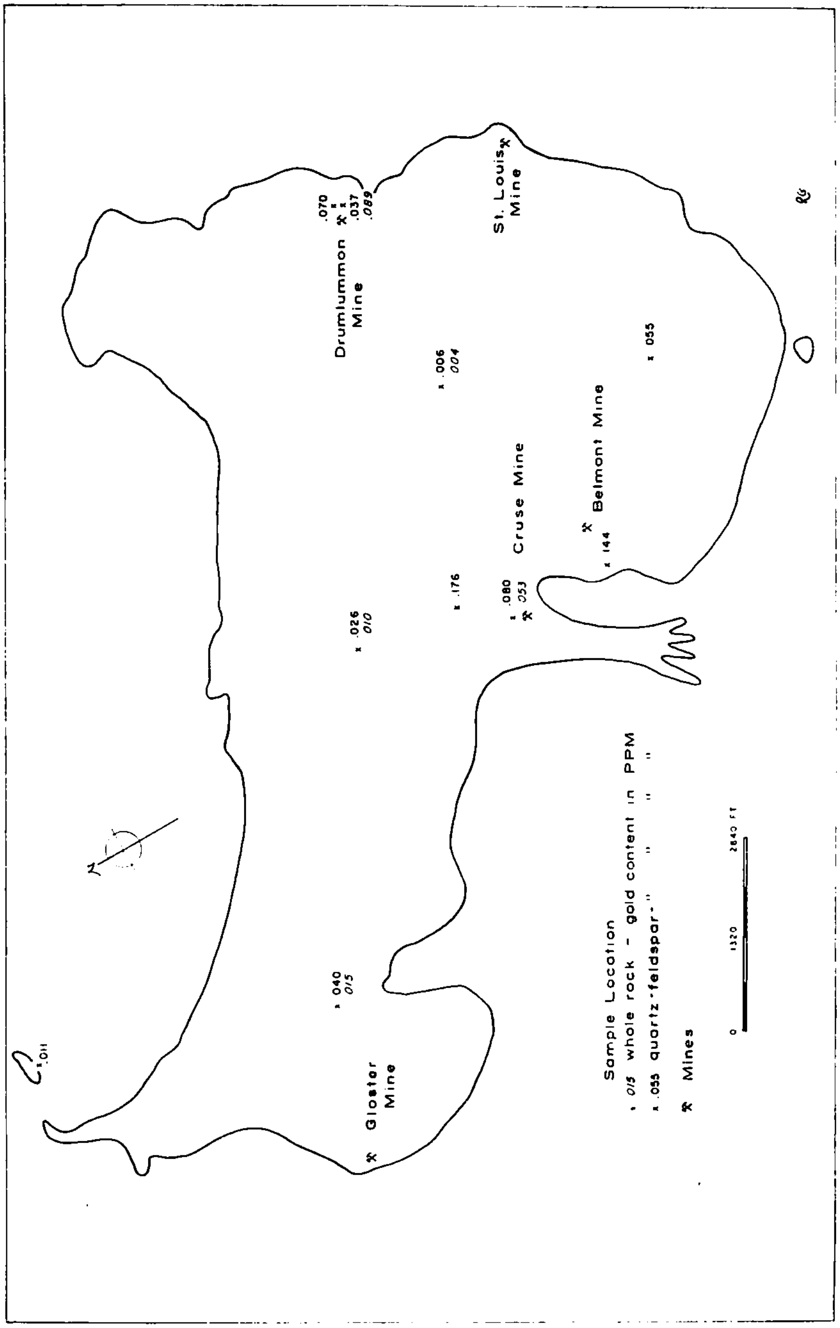

Fig. 5. Gold content of whole rock and quartz-feldspar samples, Marysville stock.

the highest value occurs in the northern part of the stock. Figure 5 is based on only five whole rock samples and ten quartz-feldspar samples. The whole rock values vary from 0·004 to 0·089 ppm and the average of the analyses is 0·034 ppm. Gold values listed by SARMA *et al.* (1965) for the standard granite G-1 range from 0·0045 to 0·011 ppm and average 0·007 ppm. The two highest Marysville values occur near the Drumlummon and Cruse mines. The three lower values occur in the center of the stock. For the quartz-feldspar samples the range is 0·006–0·176 ppm. The two highest values occur near the Belmont and Cruse mines with the lowest values found in the center and northern portions of the stock.

DISCUSSION OF RESULTS

The concentration of gold in the various minerals is probably due to an inclusion or entrapping phenomena rather than to ionic substitution. Because of its oxidation potential, it would be difficult for gold to become oxidized and thus be able to take part in ionic substitution. KRAUSKOPF (1951) states that simple ionic gold can not exist in geological environments, although complex ions containing gold may form. RINGWOOD (1965) points out that Au^{+}, because of its relatively large electronegativity, would form a very weak covalent bond, and one which would prefer not to form. Thus the gold of a crystallizing magma tends to be concentrated in the residual fluids. The factors which would control the amount of gold entrapped in a given mineral would be the concentration of gold in the magma at the time of crystallization and the type of crystal structure formed by the mineral. More open crystal structures would entrap a greater amount of the uncharged gold atoms. Referring to the results presented here, we find higher amounts of gold in biotite and hornblende as compared to magnetite, which has a relatively closed structure. Also the magnetite may have formed before the silicates, at a time when the concentration of gold in the magma was fairly low. Because of their structures, quartz and feldspar would not be able to entrap very much gold even though the melt from which they formed was relatively enriched in gold.

The amount of gold found in the Marysville rocks and minerals and the relationship of the gold values to the mine locations indicate that the original Marysville magma was enriched in gold. As the magma cooled and crystallized, the gold was concentrated in the residual fluids. At the end of the crystallization, the gold was enriched to the extent of forming the ore veins found at the edge of the stock. Since the finer-grained portion is in the central part of the stock, as are the low gold values, it appears that the crystallization was from the inner portion outwards. This would account for the location of the veins. The southern portion of the stock probably crystallized last, as shown by the higher gold values found there and by the occurrence of most of the major mines in that area. The results thus support BARRELL's (1907) theory of a definite genetic relationship between the ore veins and the Marysville magma.

VINCENT and CROCKETT (1960a) have made a study of the gold content of rocks and minerals from the strongly differentiated Skaergaard intrusion of East Greenland. They analyzed seventeen whole rock samples and twelve mineral samples. With four exceptions, all the rocks and minerals contained between half and twice the value of 0·0046 ppm gold found for the chilled marginal gabbro (believed to represent the initial magma). Because of the constancy of the gold content of the strongly fractionated rocks, they conclude that there was no significant concentration of gold in residual fluids as the magma crystallized. However the highest gold content (0·073 ppm) was found in a late-forming rock and they state that this may indicate a concentration of gold in the last hydrothermal solutions. In discussing the mineral analyses, they conclude that gold shows no preference for any of the various silicate, oxide and iron sulfide minerals. They believe the gold in the Skaergaard rocks is strongly concentrated in the copper sulfide minerals, but give no analyses of these.

A possible explanation for the apparent concentration of gold in the residual fluids of the Marysville magma and not in those of the Skaergaard intrusion may be found in the original gold content of the two magmas. Our results indicate that the Marysville magma had a much greater amount of gold than did the Skaergaard intrusion. Thus at Marysville a great deal more gold was available for concentration and the effects of the process are more apparent. Why some magmas have much more gold than others is a question still to be answered.

Acknowledgements—The personnel of the University of Missouri at Rolla Nuclear Reactor Center, especially Dr. D. R. Edwards and Mr. Alva Elliot, were very helpful in providing advice and equipment for this study. The V. H. McNutt Foundation provided financial support. Most of the material presented here was submitted by Erwin J. Mantei as a Ph.D. dissertation to the University of Missouri at Rolla.

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