DIFFERENTIATION PRODUCTS IN QUARTZ DIA- BASE MASSES OF THE SILVER FIELDS OF NIPISSING, ONTARIO.

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Discussing in this journal¹ the origin of the cobalt-silver ores of Nipissing, Ontario, the writer gave reasons for believing that the ores were originally constituents of a magma which had a composition near that of quartz diabase. It was pointed out that the mode of occurrence of certain salic and mineralized portions of the diabase is that which would result from a process of differentiation during cooling. The nature of the fissures and degree of stability of the minerals in the surrounding rocks were suggested to be the chief factors controlling the nature of the deposits formed when the highly differentiated mineral bearing solutions from the diabase magma escaped and became mixed with the ground water. The summary of the paper was as follows:

It has been shown that cobalt ores have been deposited from solutions which followed the formation of veins of aplite in the diabase. Since in all the silver deposits in the district the silver minerals are intimately associated with cobalt minerals, the silver is believed to have the same origin.

It is suggested that the metallic sulphides and arsenides have concentrated from the diabase magma by extreme differentiation. The Keewatin igneous rocks have assisted in the ore deposition on account of their content of calcite and unstable minerals. The Huronian sediments are composed for the most part of stable minerals with very little calcite, and their chief function has been that of a recipient for the ores. If these conclusions are correct, we may expect to find similar ore deposits where the diabase sills are associated with Keewatin igneous rocks, and especially valuable deposits where Huronian sediments are also present.

¹R. E. Hore, "Origin of Cobalt-Silver Ores of Northern Ontario," Vol. III., No. 7, 1908, pp. 599-610.

The term "differentiation," here used in the general sense of writers on the theory of solutions, was misinterpreted by some who use it in a more special sense when discussing ore deposits, and it was therefore found advisable to describe² the supposed process in more detail as follows:

There has been apparently no igneous activity since the complete solidification of the diabase magma. It is suggested, therefore, that the silver and cobalt were present in that hot solution, which was composed largely of the constituents of silicates, etc., with water vapour and other gases. When, on cooling, the greater part of the magma had solidified, the minor still fluid portion contained a higher percentage of salic components (forming feldspars and quartz) and of water vapour, carbon dioxide, silver, etc. Such differentiated fluid materials were tapped by the opening of fissures in the cooling solid mass. According to local conditions of temperature and pressure and the mobility of the materials, they escaped through or were deposited in those fissures. The feldspars were apparently deposited, for the most part, at high temperature in the diabase fissures. Other constituents, in some cases, escaped into the surrounding rocks. Some deposition was doubtless caused simply by loss of heat and relief of pressure, some by mixing with the ground waters. According to the character of the rocks penetrated by the metalliferous solutions, and the nature of the fissures in them, the ores were there more or less concentrated.

For such differentiation of a rock magma, the writer has elsewhere called attention to the possibility of the failure of the constituents of the solution to mix in all proportions. Since, however, similar end products might be produced whether separation into two solutions took place or not, the relative solubilities and miscibilities need not here be discussed.

Three field seasons have passed since the article in this journal on the origin of the silver ores was written, and many new discoveries have been made. In reading the above summary, therefore, it is interesting to note that without exception these deposits occur in or near diabase masses, that of the mines in the younger camps that are on a shipping basis are all in localities where the diabase intrudes Keewatin greenstones, and that by far the most productive of these deposits is one in the Huronian sediments.

² *Canadian Mining Journal*, April 15, 1909.

There seems little reason to doubt, therefore, that while there are a great many features connected with the silver deposits which are not yet understood, the hypothesis here outlined is still tenable.

That the association of the deposits with the diabase masses is a result of common origin is especially evident, and recognition of this fact has resulted in more careful investigation of these rocks. It might have been expected that they would be found to have unusual characters; but study has shown that they are in chemical and mineralogical composition the most common type of quartz-diabase. Very similar types are of widespread occurrence in North America, and almost identical ones from South America and England have been described. Aside from the actual ores themselves, there is as yet little to distinguish the quartz-diabase of Nipissing from those of other regions. More refined methods of investigation may bring out some characteristic features, and in the meantime it is of interest to assemble the available data. Table I shows the available analyses, and the chief mineral constituents of the rocks analyzed.

The aplitic differentiation products of quartz-diabase in James Township, and their connection with cobalt and silver ores, was described by Dr. A. E. Barlow¹ in a paper which appeared at the same time as that of the present writer. He also gave arguments in favor of a genetic connection of the ores with the diabase. Mr. J. B. Tyrrell, in discussing the two papers, is of the same opinion. The influence of the intruded rocks has not been discussed by either of these gentlemen, nor by any of the writers since the publication of the views of Professor Van Hise and Dr. Miller, which have already been referred to.

In the fall of 1908, the writer interested Messrs N. L. Bowen and J. A. Dawson in the examination of some of the rocks from the Nipissing silver camps. Mr. Bowen analyzed a number of

¹A. E. Barlow, "Origin of Silver of James Twp.," *Jour. Can. Min. Inst.*, Vol. XI., 1908, pp. 256-273.

specimens of the igneous types and presented his results in paper at the 1909 meeting of the Canadian Mining Institute. Mr. Dawson investigated the associated sediments, but has not yet published his results. I have to thank him for a hitherto unpublished analysis of Huronian shale given below.

Recently the writer presented a petrographic description¹ of the diabase and its differentiation phases. This is necessarily incomplete, but gives the most prominent features as they appear after an examination continued for the greater part of four field seasons, and including occurrences in most of those localities in Nipissing in which silver and cobalt minerals have been found.

Quite recently there have appeared two papers on the same subject. One of these is by Mr. W. H. Collins,² of the Canadian Geological Survey, who spent the field seasons of 1908 and 1909 in the Gowganda and Montreal River districts. The second is by Mr. N. L. Bowen,³ who in 1909 was working for the Ontario Bureau of Mines in the vicinity of Gowganda.

That the composition and modes of occurrence of the diabase masses observed by these gentlemen are similar to those observed by the writer, is evident from their descriptions. They have each, however, found locally developed some different modes of occurrence which have influenced their views on the origin of what I have called differentiation products. With regard to the form of the diabase masses both these writers emphasize the statement that all are sills or dykes. While this holds true for most cases it should be remarked however that many of the masses are not simple sills but have rather the character of asymmetric laccolites, and that other masses show no sheet-like form and in surface exposures more nearly resemble stocks.

Finding that in certain places the more siliceous albitic red rock or granophyre is at the contact with overlying shales, Mr. Bowen

¹R. E. Hore, "Diabase of the Cobalt District, Ontario," *Jour. Geol.*, Vol. XVIII., No. 3, April-May, 1910.

²W. H. Collins, "Quartz Diabases of Nipissing District," *ECONOMIC GEOLOGY*, Vol. V., No. 6, Sept., 1910, pp. 538-550.

³"Diabase and Granophyre of the Gowganda Lake District, Ontario," *Journal of Geology*, Vol. XVIII., No. 7, Oct.-Nov., 1910, pp. 658-674.

TABLE I.
ANALYZED SPECIMENS OF DIABASE, QUARTZ-DIABASE, QUARTZ-GABBRO, GRANOPHYRE, AND APLITIC SODA GRANITE FROM NIPISSING SILVER FIELDS.

No.	Locality.	Rock Name.	Chief Mineral Constituents.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O+	H ₂ O—	CO ₂	TiO ₂	S	P ₂ O ₅	BaO	H ₂ O	H ₂ O and CO ₂	NiO and CoO	FeO and Fe ₂ O ₃	Sum.	Collector.	Occurrence Described by	Microscopically Examined by	Analyzed by
1	Cross Lake, Cobalt, Ont.....	Olivine, diabase.	Calcic plagioclase, olivine, pyroxene, iron ores.	45.20	19.08	3.64	14.64	4.98	7.89	3.32	1.08	—	—	—	—	—	—	—	n.d.	—	—	—	99.83	W. G. Miller	W. G. Miller	C. W. Knight	A. G. Burrows
2	Cross Lake, Cobalt, Ont.....	Diabase.	Labradorite, augite, biotite, iron ores.	49.84	18.94	1.51	6.40	7.39	10.32	1.99	1.28	—	—	—	—	—	—	—	2.57	—	—	—	100.24	W. G. Miller	W. G. Miller	C. W. Knight	A. G. Burrows
3	Violet Mine, Cobalt, Ont.....			48.06	18.23	—	—	7.80	11.55	1.87	0.27	—	—	—	—	—	—	—	—	3.54	—	—	9.57	100.89	?	W. G. Miller	J. O. Handy
4	O'Brien Mine, Cobalt, Ont.....	Quartz-diabase.	Calcic plagioclase, augite, rhombic pyroxene, biotite, ilmenite and magnetite, quartz (in micropegmatite).	50.12	15.70	1.42	6.89	9.50	11.30	2.91	1.07	1.03	0.21	—	0.55	0.14	p.n.d.	none	—	—	—	—	100.84	R. E. Hore	R. E. Hore	R. E. Hore N. L. Bowen	N. L. Bowen
5	Kerr Lake Mine, Cobalt, Ont.....			50.80	19.42	0.97	6.67	5.78	12.68	1.60	0.37	0.86	0.25	—	0.43	—	p.n.d.	—	—	—	0.01	—	99.84	R. E. Hore	R. E. Hore	R. E. Hore	R. E. Hore
6	Silver Bar Mine, Cobalt, Ont.....			50.69	16.11	0.70	7.05	8.20	12.09	1.78	0.78	1.65	0.16	—	0.53	0.07	p.n.d.	—	—	—	0.11	—	99.82	R. E. Hore	R. E. Hore	R. E. Hore	R. E. Hore
7	University Mine, Cobalt, Ont.....			50.48	17.03	1.25	7.81	9.32	10.96	1.95	0.24	0.82	0.22	—	p.n.d.	—	p.n.d.	—	—	—	0.04	—	100.12	R. E. Hore	R. E. Hore	R. E. Hore	R. E. Hore
8	Bartlett Mine, Gowganda, Ont. .	Quartz-gabbro or (granophyric diabase), or (micropegmatitic diabase) No. 8 is weathered and contains calcite.	Uralitic pyroxenes, calcic plagioclase, sodic plagioclase intergrown with quartz (micropegmatite), biotite, ilmenite and magnetite.	48.41	19.29	1.33	8.27	4.70	4.93	5.92	0.41	—	—	2.41	0.88	—	p.n.d.	—	3.99	—	—	—	100.29	J. A. Dawson	J. A. Dawson	R. E. Hore N. L. Bowen	N. L. Bowen
9	Pense Twp., Nipissing, Ont. .			52.54	15.14	0.85	10.73	5.22	6.92	5.46	1.42	—	—	—	1.00	—	p.n.d.	—	1.76	—	—	—	101.05	R. E. Hore	R. E. Hore	R. E. Hore N. L. Bowen	N. L. Bowen
10	James Twp., Nipissing, Ont.			52.25	17.97	0.81	8.89	6.46	7.27	3.61	1.71	1.80	0.04	—	p.n.d.	—	p.n.d.	—	—	—	—	—	100.81	R. E. Hore	R. E. Hore	R. E. Hore	R. E. Hore
11	Lost Lake, Gowganda, Ont. .	Granophyre.	Sodic plagioclase, hornblende, quartz.	62.54	14.79	—	8.49	2.08	1.49	6.27	1.12	—	—	—	—	—	—	—	—	3.51	—	—	100.29	N. L. Bowen	N. L. Bowen	N. L. Bowen	N. L. Turner (SiO ₂ by N. L. Bowen)
12	University, Mine, Cobalt, Ont.....	Aplitic soda granite.	Albite, quartz, calcite, chlorite, titanite.	72.33	12.99	none	2.50	0.97	1.73	7.60	none	—	—	1.00	0.74	—	p.n.d.	—	1.09	—	—	—	100.95	R. E. Hore	R. E. Hore	R. E. Hore N. L. Bowen	N. L. Bowen
13	University Mine, Cobalt, Ont.....			73.07	14.88	0.04	2.93	1.30	0.66	6.17	0.46	—	—	—	0.41	—	p.n.d.	—	0.90	—	none	—	100.82	R. E. Hore	R. E. Hore	R. E. Hore	R. E. Hore
14	James Twp., Nipissing, Ont.			78.28	12.00	—	1.19	0.37	0.29	6.89	none	—	—	none	0.34	—	p.n.d.	—	0.61	—	—	—	99.97	J. A. Dawson	J. A. Dawson	N. L. Bowen R. E. Hore	N. L. Bowen
15	James Twp. Nipissing, Ont. .			58.84	11.24	—	0.47	0.35	12.19	6.91	none	—	—	9.84	0.26	0.13	p.n.d.	—	0.40	—	—	—	100.61	H. T. White	R. E. Hore	N. L. Bowen R. E. Hore	N. L. Bowen

TABLE II.
CHEMICAL COMPOSITION OF AN APLITE DYKE AND THE ASSOCIATED DIABASE AND SHALE.

No.	Rock Name.	Locality.	Analyst.	SiO ₂ .	Al ₂ O ₃ .	Fe ₂ O ₃ .	FeO	MgO.	CaO.	Na ₂ O.	K ₂ O.	H ₂ O+.	H ₂ O—	CO ₂ .	TiO ₂ .	NiO and CoO	P ₂ O ₅ .	S.	Ba.	Sum.
1	Diabase	University Mine, Cobalt, Ont.	R. E. Hore	50.48	17.03	1.25	7.81	9.32	10.96	1.95	0.24	0.82	0.22	—	p.n.d.	0.04	—	—	—	100.12
2	Diabase	Silver Bar Mine, Cobalt, Ont	R. E. Hore	50.69	16.11	0.70	7.05	8.20	12.09	1.78	0.78	1.65	0.16	—	0.53	0.11	—	0.07	—	99.82
3	Aplitic Soda-granite. (Intrudes No. 1)	University Mine, Cobalt, Ont. (No. 1)	R. E. Hore	73.07	14.88	0.04	2.93	1.30	0.66	6.17	0.46	(0.90)		—	0.41	none	—	—	—	100.82
4	(Intruded by Shale.	No. 1.) Giroux Lake, Cobalt, Ont.	J. A. Dawson	55.97	19.35	1.95	7.07	3.34	0.74	2.73	5.08	2.84	0.02	0.02	0.74	—	0.26	0.04	none	100.25

studied the influence of the sediments in the formation of such a facies of the igneous rock. He concludes that the formation is due in the first place to a kind of differentiation in which the solutions escaping after most of the diabase had solidified, are "soda-bearing carbonate waters." His conclusion on this point is evidently similar to that of the writer as expressed above in the words, "when on cooling, the greater part of the magma had solidified, the minor still fluid portion contained a higher percentage of salic components (forming feldspars and quartz) and of water vapour, carbon dioxide, etc." His second conclusion, however, that such differentiation is not sufficient to produce granophyre but only to contribute to its formation by inducing alteration of the slaty sediments can be objected to both from a consideration of the theory of solutions and of facts observed in the field. The statement that the albitic rocks are especially characteristic of places where diabase intrudes shales, cannot without restriction be applied to the Nipissing silver field. There are, in the Temagami Reserve, numerous large masses of the red sodic facies of the diabase which are not near any argillaceous sediments. Some of the granophyric diabases are several miles from any exposed shale or slates and in localities where there is no good reason to believe that such rocks are or were present. The granophyric diabase which has developed between the slate fragments of the contact breccia at Foot Lake is evidently very similar to those which have been developed far from any such contacts.

It should also be noted that while differentiation in the dykes in Nipissing is not marked, there are other localities in which dykes of quartz diabase are in their central parts much higher in silica and alkalis than on the margin. The central parts of such dykes are almost identical with the micropegmatitic or granophyric diabases of Nipissing. Numerous occurrences of quartz-diabase (probably Keweenawan) dykes showing such characters were found in Rainy Lake District, Ontario by Professor A. C. Lawson, and in Michigan by Professor A. C. Lane.

In considering the effect of the igneous intrusives on the

sediments, the writer remarked on the very narrow zone of evident metamorphism. Both Mr. Bowen and Mr. Collins make the same statement, and it is evidently then a characteristic phenomenon. Mr. Collins mentions that he has found blocks of the intruded strata, which were evidently "torn off and enclosed by the fluid diabase, but as they always retain their angular outlines, there appears to have been no assimilative action." The writer also has found no evidence of extensive absorption of intruded rocks. Evidently the intruded rocks had some effect on the solidification of the magma; but the effect was slight, and not in a great degree dependent on the type of rock intruded. From the study of a very large number of contacts, it seems almost certain that when the diabase magma came to rest it was at a temperature very little above that of freezing. Before any great amount of heat was given off to the enclosing rocks, the fluid magma began to solidify, and became in a sense self insulated before any extensive fusing or overhead stoping took place.

In comparing the composition of the different facies of igneous rocks with that of intruded sediments, the analyses of Cobalt rocks in Table II are of interest. On the property of the University and Silver Bar Mines, and near the shore of Giroux Lake, there are outcrops of grey quartz diabase (1 and 2) traversed by a 50-foot-wide dike of aplitic soda granite (3). Specimen (1) was taken about 25 feet south of the aplite and specimen (2) several hundred feet farther west, and only a few feet above underlying shales. Workings in the mines near by show that the sediments under the diabase are dark shales, and exposures further west show similar shales (4). The rocks which originally overlaid the diabase have been completely removed by erosion. The specimen of shales (4) was taken from an island in the lake about 100 feet west of the diabase. The interval, including the immediate contact, is under water. Comparison of the quantities of the constituents in the three rocks can scarcely lead to the conclusion that the sodic aplite has been developed by the effect of the diabase on the shale, but

rather to the conclusion that the composition of the aplite is quite independent of the composition of the intruded sediments. It is a remarkable fact that not in any one constituent element is the quantity in the aplite intermediate between that in the diabase and that in the intruded shale. The rocks, which east of Giroux Lake overlie the diabase sill, are basic Kewatin greenstones and chemical composition differ from the diabase chiefly in the products of very extensive weathering.

The four specimens were collected by the writer, the analyses were made by the methods recommended by H. S. Washington.

In connection with the differentiation process, Mr. Collins remarks that "the diabasic magma behaves as a homogeneous mixture or, more probably, a mutual solution of two chemically and mineralogically definite rock species, designated diabase and aplite," of which diabase crystallized somewhat in advance of aplite, and "simultaneously they commenced to segregate from each other." He considers the quartz-diabase to be one of a confusing variety of hybrid rock forms resulting from incomplete segregation. The plausibility of this supposition he supports by the discussion of a number of optical mineral analyses of the rocks. It should be remarked, however, that the assumptions necessary in such a hypothesis are open to objection.

If such segregation takes place while constituents are in the liquid form it would be necessary to attribute to rock magmas characters very different from those solutions which have been carefully studied, and to reinterpret what is known concerning the miscibility of fused silicates. It would be equivalent to stating, for instance, that molten sodic plagioclases will mix with molten calcic plagioclase in a very limited degree, if at all. Such a statement is contrary to the interpretation put on facts which have been determined by experimental synthesis, and by examination of the end products formed in nature. If, as is generally believed, the common silicates are miscible in all proportions, then segregation results from differentiation during crystallization.

While considerable has been written concerning the formation of aplitic veins and micropegmatite by differentiation, the

possible formation of such rocks by secondary processes has been but slightly discussed in the papers above mentioned. This has probably been the case, not because there is no evidence of secondary origin, but rather, because that which points to primary origin seems to outweigh the other. It may be of interest, however, to consider some observations which suggest the possible importance of secondary formation.

The minerals of the aplitic veins and of the micropegmatite are of species which are often found in occurrences of undoubtedly secondary nature. Quartz is everywhere recognized as a common secondary as well as a common primary constituent of rocks. Feldspars are less often regarded as common secondary types; but they are by no means uncommon. Pink feldspars are quite frequently found filling amygdules in the Keweenawan volcanic rocks of Lake Superior. These feldspars have evidently been formed, like the chlorite, quartz and zeolites, by the weathering of the igneous rocks, and the rocks have a composition not far from that of the diabase of Nipissing. There is, moreover, in the literature abundant evidence that sodic feldspars are a characteristic product of the weathering of soda-lime feldspars, and that under the same conditions calcite is also commonly formed. On the other hand it is of interest to note that while secondary feldspars and quartz are very abundant in the Keweenawan extrusives, micropegmatitic intergrowths, as Dr. Lane¹ has pointed out, do not occur in those rocks. It is fair to deduce therefore that the micropegmatite in the Nipissing quartz diabase is an original structure and not the result of weathering. Other arguments leading to the conclusion that the micropegmatite of the Michigan quartz diabases is primary have been summed up by Dr. Lane and may be applied as well to that of Nipissing. Chlorite, the fourth chief constituent of the aplites, is not only a common secondary product, but in the form in which it here occurs it has never been found as a primary constituent. The fifth mineral, titanite, is also found as a sec-

¹Dr. A. C. Lane, "Diabases (Keweenawan) intrusive in the Huronian," Mich. Geol. Surv., Vol. VI., Part I., pp. 219-266.

ondary product from the alteration of titaniferous iron ores, and the diabase always contains such.

Another feature of the diabase masses which suggests the secondary origin of the aplites is the similar occurrence of small veins of epidosite. Such veins, made up chiefly of granular epidote, quartz, and a dark green hornblende, have been found in several localities in which there are cobalt minerals in the diabase. Such rocks in other localities are regarded as secondary products, and there is no special reason for classing these as primary. Some of the aplite veins are very similar to these epidosites in their mode of occurrence, and some of the aplites contain a few small grains of epidote. Many of the aplite veins, however, show marginal characters typical of contemporaneous veins, and all are formed of minerals similar to those which were last to crystallize in the quartz-diabase.

Summarily then, there are some portions of the diabase masses which may have been formed, long after the complete solidification of the magma, by weathering and redeposition. These same portions may however represent the end products in a process of differentiation, and since this hypothesis has the added advantage of correlating a number of other observed facts it is to be preferred.