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COLLOFORM MAGNETITE IN A CONTACT METASOMATIC IRON DEPOSIT, VANCOUVER ISLAND, BRITISH COLUMBIA¹

JOHN S. STEVENSON AND W. G. JEFFERY

ABSTRACT

Colloform magnetite has recently been found in the magnetite orebodies on the Empire Development property at the northern end of Vancouver Island, British Columbia. Magnetite with colloform habit is very unusual and none, as far as the writers know, has been described from limestone. The colloform magnetite occurs as pockets of nodular masses within pipe-like orebodies of predominately coarsely crystalline magnetite in limestone close to a diorite stock. The magnetite is associated with typical skarn minerals.

The colloform magnetite possesses all the textural features ascribed to deposition through colloidal processes, and the deposits appear to have been formed by gel metasomatism of limestone. The writers conclude that the iron for the colloform magnetite was carried in HCl solution, replaced the limestone, and was precipitated as a colloid during an intermediate state of aggregation that existed between the state of ionic solution and the precipitate.

INTRODUCTION

COLLOFORM magnetite has recently been found in limestone on the magnetite iron property of the Empire Development Company on the northwest slope of Merry Widow mountain, 25 miles from Port McNeill at the northern end of Vancouver Island. Magnetite with colloform habit is indeed unusual, and none, as far as the writers know, has been described from limestone.

DESCRIPTION OF THE DEPOSIT

Magnetite production at the Empire property has come from three open pits, which in order of size are the Merry Widow, Kingfisher Central, and Kingfisher East orebodies. Total production from these, from the start of production in 1957 to the end of 1962, has amounted to 3,328,195 tons of ore.

The geological setting of the deposit has been described in detail by Jeffery (6), and only the pertinent geological features are described here.

The magnetite orebodies occur as replacements of limestone and volcanic rocks close to and along the contact of a monzonite-diorite stock. The magnetite is associated with typical skarn-type minerals that include quartz, calcite, and the usual lime-silicates: brown garnet, epidote, tremolite, actinolite, diopside, and zoisite. The deposits generally have some associated sulfide minerals scattered throughout: these include pyrrhotite, pyrite, chalcopyrite,

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and minor sphalerite and arsenopyrite. In some places chalcopyrite content is sufficient to constitute copper ore.

The Merry Widow magnetite orebody occurs as discontinuous sheets and lenses close to and concordant with the easterly dipping diorite contact, and the ore is mostly in metamorphosed volcanic rocks, although some ore extends into the uppermost beds of the underlying limestone. The Kingfisher orebodies, on the other hand, are wholly enclosed within crystalline limestone at distances between 1,000 feet and 1,200 feet from the contact. The enclosing limestone consists of gently undulating beds that range in thickness from 6 inches to about 4 feet and dip 30 degrees northwesterly toward the diorite contact. The orebodies are in the form of steeply plunging, nearly circular, pipes of massive magnetite with clean, sharp contacts with the enclosing limestone. The Kingfisher Central pit is between 150 and 200 feet in diameter and the Kingfisher East approximately 100 feet across; they have been mined to a depth of about 300 feet.

Throughout the development of these pits, after blasting of successive benches, a search through the ore as it was being removed would reveal masses of magnetite with a coarse mammillary texture (Figs. 1, 2). It appears that the mammillary magnetite occurred in pockets throughout the orebody, which was otherwise composed of non-colloform, crystalline magnetite. In the Merry Widow orebodies, colloform magnetite has been found, but only where one of the orebodies extends a short distance into limestone.

Some specimens exhibit rounded intersecting nodules 1 to 2 inches across with smoothly "crackled" surfaces, and, in these, the mammillary surface as a whole would appear to lie in one plane. Other specimens show similar features except that a greater amount of curvature of the main mammillary surface is developed so that the magnetite appears as large kidney-shaped boulders. In these the mammillary surfaces may extend through 180 degrees in some specimens rather than appearing to lie on a plane, and to have more the appearance of coalescing spheroids. Sections through the nodules or spheroids show concentric banding and a radiating structure (Fig. 2). The outer concentric layers are thin, fine-grained and dense, whereas in those toward the center of a nodule the magnetite is coarser and the banding wider and less prominent (Fig. 3). The radiating structures are produced by long, blade-like crystals of magnetite $\frac{1}{2}$ to 2 mm in width and up to 4 cm in length that commonly extend without interruption through several of the concentric bands (Fig. 2). The magnetite is also characterized by concentric and radial fractures now filled with calcite (Fig. 3); these appear to be contraction or, as they have been termed by Bastin (1), syneresis cracks.

Spectrochemical analyses were made of four separate layers from one of the magnetite nodules to determine the minor element content and also to determine whether there was any significant variation from layer to layer. Of the six elements reported, five were found to be practically the same in all layers, these values being as follows: Ba, <300 ppm; Co, 40 ppm; Cr, <100 ppm; Cu, <10 ppm; and Ti, <0.1 percent. Mn, on the other hand, was found to show a significant variation as follows, going from the outer layer to the core of the nodule: 650 ppm, 400 ppm, 400 ppm, 500 ppm. Two



FIG. 1. Specimen of colloform magnetite showing mamillary outer surface. Specimen 3 inches across.

conclusions may be drawn from these analyses. Firstly, the relatively very minor amount of Ti suggests considerable difference between this magnetite and the magmatic type found associated with gabbros. Secondly, the variation in Mn is a manifestation of the variation in composition to be expected in a colloidal precipitate.

COMPARISON WITH ESPANOLA, ONTARIO, COLLOFORM MAGNETITE

Colloform texture is known in many minerals, some of which are found in limestone, but the writers know of no other occurrence of colloform magnetite in limestone. However, one occurrence of colloform magnetite, this in a vein

in peridotite, has been recorded. This was found near Espanola in Monogowin township, Sudbury district, Ontario (11, 12, 13).

A specimen of this magnetite was obtained from the Royal Ontario Museum through the kindness of Dr. V. B. Meen. Texturally it is very similar to the colloform magnetite from the Empire deposits, although the mammillary features are not quite so conspicuously developed. However, the geology



FIG. 2. Specimen of colloform magnetite broken to show internal radial structure. Specimen 3 inches across.

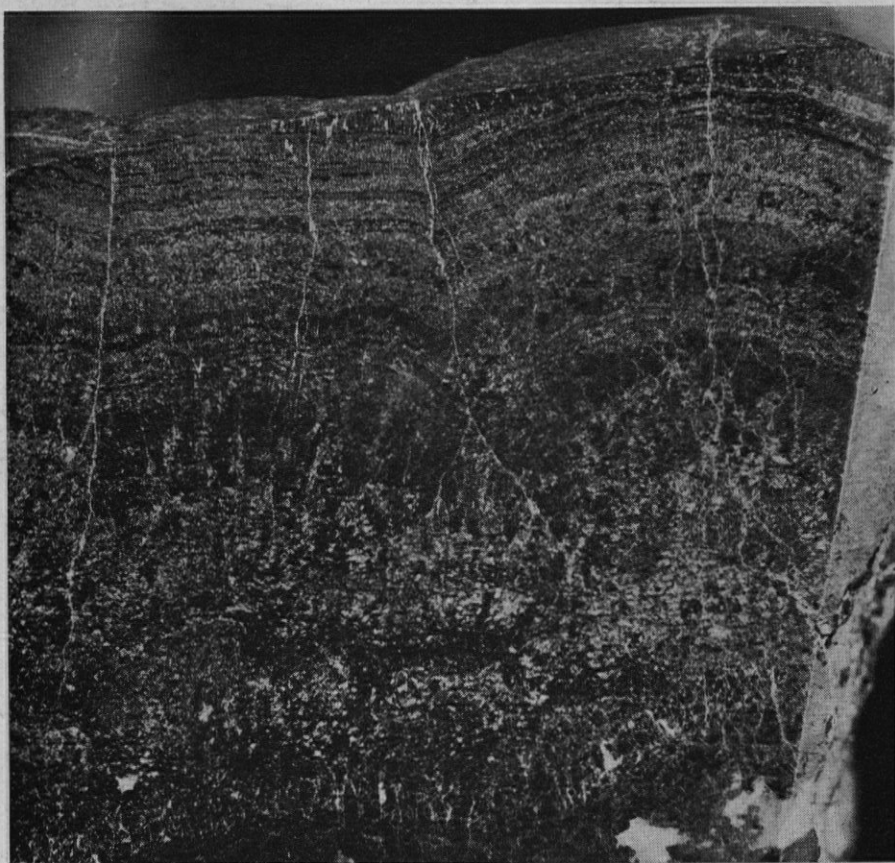


FIG. 3. Polished surface of colloform magnetite showing colloform banding and radial syneresis cracks filled with calcite. Specimen 2 inches across.

is very different. The Espanola magnetite is in a vein 2 to 4 inches wide that cuts a peridotite boss about 1,000 feet in diameter, about 4,000 feet from a granite-peridotite contact. Furthermore, the magnetite is coated by crusts and cut by veinlets of white porcelaneous serpentine. Concerning its origin, Moore (12, p. 390) says, "one wonders whether the vein may originally have been goethite that became magnetite at the time the granite was injected." However Moore did go on to say that X-ray studies showed no evidence of pseudomorphism after a hydrous oxide. This same magnetite occurrence was later briefly mentioned by Phemister in a report on the Owen Nickel property on which the vein occurs (13).

ORIGIN OF THE EMPIRE COLLOFORM MAGNETITE

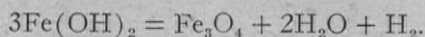
In considering the problem of the formation of the Empire colloform magnetite, we at first thought that a theory proposed by Shand might be applicable for this occurrence (14).

It is known that in deep-seated, gabbroic-type magmas, ferrous oxide is much more abundant than ferric oxide. The silicates that crystallize at an early stage contain a much smaller proportion of FeO to MgO than the magma as a whole.

As Shand (14, p. 635) states:

Since no independent ferrous mineral is formed there must be a relative concentration of FeO in the residual liquid . . . along with soda, silica water and other soluble oxides. . . . If the residual liquid is alkaline, as any solution must be which contains strong cations and weak silica-alumina anions, then the iron can only be present as a hydrosol of ferrous hydroxide, peptized by the alkali. . . . We must therefore conclude that the residual solution from gabbroic magma does not contain magnetite . . . but contains a ferrous hydroxide hydrosol.

The final stage must explain the oxidation of the ferrous hydroxide to magnetite. Shand was concerned with an explanation of the genesis of included iron ores or magmatic segregations within gabbroic rocks where external oxidizing sources were not available. For this Shand postulated a process of self-oxidation where the hydrosol loses water and the hydroxide is converted to magnetite according to the equation:



Thus for each molecule of magnetite formed, two molecules of water and a molecule of hydrogen are released. Water and hydrogen would be removed without a trace and therefore large amounts of water would be released in the process.

The theory postulated by Shand was based on purely theoretical grounds and he did not present any field evidence to support it. However, the mechanism described by him might explain such occurrences as the colloform magnetite at Espanola. The host rock there is peridotite, and the considerable amount of serpentine found both coating the nodules and veining them could account for the large amount of water released in Shand's process.

It would appear that, whereas Shand's theory may be invoked to explain the colloform magnetite in peridotite at Espanola, it is not equally applicable to the occurrences in limestone at the Empire mine. Rather, for these occurrences, the writers propose a modification of a mechanism for the formation of hydrothermal magnetite as presented by Holser and Schneer (5). In referring to the theory of Shand, Holser and Schneer (5, p. 382) say:

"Shand (1947) was forced to depend upon a ferrous hydroxide hydrosol for transport in an alkaline medium. However the instability of this sol at high temperatures has already been pointed out and the ineffectiveness of colloidal suspensions in the replacement process has been discussed in detail elsewhere." (4, p. 387-388).

Holser and Schneer have also concluded that HCl solutions are important in the formation of some magnetite deposits and that the deposition of this mineral in carbonate rocks is easily explained by the reaction between the acid solution and calcium carbonate.

Although they do not believe that colloidal suspensions are effective in the replacement process, nevertheless there is colloform magnetite in limestone at

the Empire mine. Furthermore, the colloform material here is exclusively in limestone, whereas other, preferentially banded, magnetite is in the adjacent volcanics.

Although doubtful of the effectiveness of colloidal replacement, Holser (4, p. 388) did note that Frondel (3, p. 396-403) has cited the well known condition for an intermediate colloidal state in emphasizing the importance of colloidal processes in replacement. It is therefore possible that the iron for the magnetite could have been carried in HCl solution as suggested by Holser and Schneer, but that, in crystallizing from an ionic solution, an intermediate colloidal state of aggregation may have existed long enough at the Empire mine for deposition of colloidal material in a limestone environment to have taken place.

The limestone of the Empire orebodies may have been rendered amenable to replacement because this limestone, although apparently massive, was probably in a zone of tension. This is suggested by the report (2, p. 96) that, in crosscuts driven immediately under the orebodies, the limestone beds are strongly buckled and contorted.

The nodular magnetite found in limestone at the Empire mine possesses all the features of a metacolloid, using the term for a crystalline substance of colloidal origin as recommended by Lindgren (7, p. 447). Features possessed by this magnetite that indicate its colloidal origin include: the concentric layering with a spheroidal outer free surface originally determined by surface tension in a viscous liquid; radial crystals that are not confined to one band as in selective replacement, but extend across several layers; and the concentric and radial syneresis cracks that form as a result of contraction when the gel hardens.

The Empire colloform magnetite may thus be assigned to the gel metasomatism type of replacement (8, 9). Although most gel replacement is thought to take place at relatively low temperatures, the associated skarn minerals and proximity to a diorite stock suggest that the colloform magnetite at the Empire was formed at relatively high temperatures. In fact it appears to be a field example of the type to which Lindgren referred when he said, in speaking of colloidal minerals, "but they may also develop at higher temperatures to a degree not formerly suspected" (10, p. 25).

As a mechanism of transportation and deposition, it is suggested that the iron for the colloform magnetite was carried in HCl solution, replaced the limestone, and was precipitated as a colloid during an intermediate stage of aggregation that existed between the state of ionic solution and the precipitate.

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