GRAPHITE IN PEGMATITE

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INTRODUCTION

Graphite occurs disseminated through a small pegmatite lens which is intruded into limestone in the City Quarry, Lewiston, Maine. The mineral is not commonly reported in the pegmatites of Maine as there is but one paper known to the writer concerning graphite in Maine pegmatites (27). Landes (17*a*) lists graphite among the numerous minerals of the hydrothermal stage in the pegmatites of Maine. Bain (2) has indicated his belief in the same manner of origin for the Louisa, Quebec, graphite deposits. There are numerous other published accounts of the association of graphite with the contact zones between granitic and sedimentary rocks, or their metamorphosed equivalents. It is probable that the graphite of the City Quarry pegmatite represents a hydrothermal product.

LOCATION

The city of Lewiston is located in the southwestern part of Maine, in Androscoggin County, on the left bank of the Androscoggin. It is 32 miles from Portland, and 34 miles from Augusta, the state capital. The quarry is located in the southern part of the city in a low hill known locally as "West Rose Hill." The quarry faces the Maine Central Railroad line to Brunswick, about one mile from the Lewiston Lower Station. The graphite-bearing pegmatite is in an abandoned quarry opening on the northwest slope of the hill along the road connecting the quarry with Lisbon street.

GENERAL GEOLOGY

The bed rocks of the Lewiston region are predominantly metamorphic rocks, including quartz-mica schists, gneisses of regional and injection origin, slates, and crystalline limestones, all of which are intruded by granites, pegmatites and "trap" dikes. Field relations between the various rock types are obscured by glacial cover so that complete correlation is difficult. The crystalline limestones of the City Quarry are possibly pre-Ordovician in age and have been intruded by at least two pegmatites of different age, and by at least 16 basic dikes. (These limestones will be tentatively named the *Lewiston* limestone.)[1] There are obvious differences noted in the intruding dikes, especially the melanocratic types, and it seems as though there were several periods of injection. Slight differences are also noted in the leucocratic dikes.

THE PEGMATITES.—The pegmatites of Maine, especially in the southwestern part of the state, have been described in numerous articles, and are of interest because of the large number of gem tourmalines, beryls, apatites, etc., and the great variety of rare minerals that they have yielded. The best known localities of these pegmatites are in Androscoggin and Oxford counties. Landes (17*a*) subdivides the pegmatites in general into acid, intermediate, and basic. He includes both simple and complex pegmatites under the acid division. The complex pegmatites show lithium, fluorine, beryllium, boron, phosphorus, *graphite,* rare earths, ore minerals and quartz vein phases. The writer accepts Landes's classification in general but because of the lack of the minerals typical of the complex pegmatites prefers to separate the acid pegmatites encountered here into tourmaline-free and tourmaline-bearing pegmatites. The graphite of the City Quarry occurs in a tourmaline-free pegmatite.

GRAPHITE-PEGMATITE LENS.—The graphite bearing pegmatite lens averages about two and one-half feet in thickness and about seven feet in width. It is exposed in limestones in an old working now filled with paving bricks. About ten feet of the limestone are exposed above the pegmatite lens. The limestone immediately around the graphite-bearing lens is badly weathered and is iron stained, but the limestone directly overlying the lens is fairly fresh. This limestone is massively bedded. The uppermost bed is about 26 inches thick and laminations in it are well-defined by the parallelism of biotite and phlogopite plates. Parallel vertical fractures set off this fresh limestone from the altered rocks on both sides. Below the 26 inch bed there is an 80 inch bed which shows slight parting into three distinct beds.

The calcite plates of the limestone are of large size and are intimately associated with mica. Numerous thin veinlets of milky quartz traverse the limestone, in places conforming with the bedding. Slender green hornblende needles one and one-half inches in length are included in these quartz veins. There are also scattered zones of pyrrhotite. The contact between the pegmatite lens and

[1] A paper discussing the general geology of the Lewiston quadrangle is in progress. Priority is sought for the name Lewiston limestone.

the overlying limestone is sharp. There are no noticeable garnet zones similar to those that occur in the larger quarry.

The pegmatite pinches out sharply to the right and left of the lens and can be traced as a thin pegmatite (or aplitic) vein to the right for more than eight feet. Where this veinlet thins down to less than in inch in thickness scattered grains of graphite are found. The graphite-bearing portion of this thin vein is cut by a series of milky quartz veins that contain schorl and garnet.

Another mass of pegmatite occurs in the pit below the graphite-bearing zone. It is apparently separated from the latter by several feet of limestone. Schorl is abundant in this lower pegmatite. The writer has been unable to find any direct connection between this tourmaline-bearing lower pegmatite and the graphite-bearing upper pegmatite. The lower one includes several large xenoliths of limestone which do not show any strong development of garnet or other contact minerals against the pegmatite contact.

Petrography of City Quarry Pegmatite.—The feldspar of the pegmatite is predominantly orthoclase, accompanied by small amounts of microcline and albite-oligoclase. Alteration of the feldspar to a kaolin-like product is pronounced. Quartz occurs in granulitic texture but there are also some cataclastic zones of small anhedrons of the same mineral. The grains of these zones show wavy extinction. Zoisite is the most common secondary mineral developed in the pegmatite and shows the characteristic "ultra blue" interference colors. Several small, isolated patches of calcite enclosed by quartz occur in the pegmatite. A few subhedral forms of a pyrabole, whose extinction angle is near diopside, show frayed or ragged ends against both feldspars and quartz.

Graphite is distributed rather uniformly through all the pegmatite slides. (This feature is in keeping with the rather general distribution of graphite throughout the pegmatite lens.) There are several occurrences of graphite in feldspar cleavages, the graphite showing a greater affinity for altered feldspar than for fresh plates. Boundaries between anhedral quartz grains are crossed by the graphite, and the latter mineral completely encircles some quartz grains, especially where the latter occurs in cataclastic zones. The cleavages of the pyrabole are penetrated by graphite. Where associated with zoisite the graphite shows fairly sharp boundaries, although there are a few scattered grains of zoisite that include apophyses of graphite.

Graphite appears to be definitely later than the feldspar, quartz and pyrabole, and is contemporaneous with, or later than the zoisite.

THE LIMESTONE.—The limestone overlying the pegmatite shows very little graphite. No garnets were observed in the fresher limestone beds nor in the slides. The minerals accompanying the calcite of the limestone are pyrrhotite, actinolite, a small amount of diopside, zoisite, biotite, small amounts of muscovite, and brown mica probably phlogopite. The minerals are uniformly distributed through the limestone with the exception of the brown mica which is more abundant near the pegmatite contact.

Pyrrhotite apparently formed early. The actinolite encloses calcite in some portions of the slide and shows a thin zone of a highly birefringent mineral around the edges due to solution. Zoisite replaces both calcite and actinolite occurring in small equidimensional grains with distinct cleavage, low extinction angle and a low order of grayish blue interference colors.

Graphite, occurring in small amounts in the limestone, enters the cleavages of actinolite, mica and calcite.

GENERAL DISCUSSION OF GRAPHITE

A general discussion of graphite, its modes of occurrence and the theories of origin, is deemed advisable at this point.

MODES OF OCCURRENCE.—Graphite is widely disseminated geographically and geologically, occurring in many kinds of rocks, and apparently, originating in many different ways. A survey of the available articles from a voluminous literature on the subject suggests the following occurrences.

Miller (22) mentions two publications describing graphite in unmetamorphosed sediments. Weinschenk (34) states that graphite is rare in eruptive rocks but the mineral has been found in pegmatites. Lindgren cites Spencer's description of the occurrence of graphite in dikes near Franklin Furnace (20). The iron-bearing basalt of Ovifak, Greenland, carries graphite. Lee (18) has observed it in diabase intrusions in New Mexico. Holland (15) and Alling (1) describe occurrences in syenite and numerous other occurrences might be cited. The chief habitat, however, seems to be in altered limestones and schists where the graphite may have been formed either by volatile emanations from the magma or by metamorphism of the carbonaceous materials in the original rocks.

Numerous occurrences of this more general type are found in the literature and include areas where pegmatites intrude biotite-hornblende schists, amphibolites, quartzites, normal quartz schists, feldspar-quartz schists, garnetiferous-quartz schists, mica schists, limestones, marbles, etc. The occurrence of graphite associated with pegmatite intrusives in the above types of rocks is by no means restricted to the contact zones between the pegmatite and the host. Graphite may be disseminated through the intrusive or intruded rock.

In addition to the general occurrence in limestone, the outstanding type being the Ceylon vein type, Winchell (38) describes veins of graphite in faulted Paleozoic limestones of Ruby Range, Dillon, (Montana) area. Coleman (10) states "... a curious breccia of small gneiss fragments cemented by a black material like chert is found in loose black bands. In one such band of faulting and crushing small amounts of solid graphite—were observed." At Passau, Bavaria, graphite occurs in a crushed schistose rock.

Finally, two extremely rare types of occurrences have been cited, viz., graphite in meta-arkose in southern Adirondack area and finely disseminated through a zone of serpentinous dolomites of the Grenville district (37).

Mineral Associates.—The mineral associates of graphite are as varied as its modes of occurrence. In Ceylon graphite (5) is accompanied by apatite, rutile and pyrite; in the Adirondack contact zone deposits, by scapolite, pyroxene and vesuvianite; in the Adirondack schist deposits, by apatite, quartz, pyrite and muscovite; in the Buckingham and Grenville Township deposits (Quebec) (37), by apatite, pyrite, scapolite, biotite, titanite and wollastonite; at Dillon, Montana, it is accompanied by garnet; tourmaline is an associate in the Seward Peninsula (13) (23) deposits; quartz, biotite and microcline are cited by Winchell (38) in his study of the Dillon area; and in the Amherst township, Quebec, area, Wilson (36) listed pyroxene, quartz, titanite, wollastonite, diopside, orthoclase and calcite.

It will be noted that apatite and pyrite are associates in three of the above listed localities but since these may be regarded as flood minerals they cannot be used to determine the mode of origin except perhaps that the presence of apatite may be used to argue for changes in temperature due to the presence of mineralizers. The major suite of minerals is characteristically a contact type and on the basis of mineral associates one might believe that pyrometasomatic origin is indicated.

THEORIES OF ORIGIN.—Clark (7) indicated that since many different methods have been suggested for the formation of graphite in various rocks, the older classification of organic and inorganic graphite no longer can be suitably adopted. He suggested a classification of graphite deposits, as, (a) Bedded deposits, (b) Disseminated deposits, (c) Veins or vein-like deposits, including fissure veins, contact deposits and pegmatite deposits, and (d) Deposits with native iron and in meteorites. The City Quarry graphite-bearing pegmatite would be regarded as a vein-like deposit, and would be chiefly a pegmatite type, and in part, contact type.

Alling (1) states that the pegmatite of the Ticonderoga township graphite deposits comes in direct contact with the limestone without affecting it in any appreciable way. He says:

> The even distribution of the graphite through the crystalline limestone renders it probable that the carbon formed an original constituent of the limestone.

The conversion to graphite, the recrystallization of the limestone, the development of pyroxene, are the results of dynamic metamorphism, and to some extent to contact effects of neighboring masses of granite. Lindgren states that recrystallization of carbonaceous matter in metamorphosed sediments is due perhaps to intense regional metamorphism. Smith (27) regards the graphite in a Maine pegmatite as a conversion and concentration product of carbonaceous particles of sedimentary origin through the agency of heated vapors from the pegmatite magma. One might interpret Winchell's (38) discussion of the graphite of the Dillon, Montana, area as an expression of belief in organic origin for he rules out the carbide theory of graphite because carbides are extremely unstable in the presence of oxygen.

On the other side of the argument De Launay (11) after describing the xenoliths of crystalline limestone within the Alibert syenite states his conclusions as:

> No known reaction will explain such a concentration. Thus the Siberian graphite seems to be of a new kind, of a deep-seated inorganic origin, probably of like origin with that of Ceylon.

De Launay's conclusion does not, however, agree with the organic theory advanced for the same deposits by Jaczewski (16) although the latter found support for his theory with Clark (7) who held that the explanation was reasonable in view of the fact that graphitic schists or limestones might have been assimilated by the magma. Wilson (36) lists the order of crystallization of the minerals associated with the graphite as scapolite, wollastonite, orthoclase, titanite and diopside, then graphite and calcite which are contemporaneous, or with calcite a little later. On a later page in his article he lists three modes of origin: (a) recrystallization of carbonaceous material contained in the Grenville limestone; (b) derived from igneous rocks intruded into the limestone; and (c) from carbon dioxide of the limestone by reduction. Finally, Bain (2) states:

> The graphite is plainly introduced material and is replacing earlier silicate minerals notably uralite and chlorite formed by alteration of pyroxenes of the skarn. Intimate relation of the alteration of the diopside and replacement of the alteration products seems to indicate that the same solutions are responsible for both processes. . . . since the graphite is found as a replacement of the alteration products of these silicates (lime silicates) the carbon could not possibly be derived from CO_2 liberated by the silication of the carbonates original to the limestone but must have been a direct late stage magmatic emanation from the magma along with the silici-alkalic solutions producing the alteration of the skarn.

Thus the pendulum of paragenetic thought swings from one view of origin to the other and back again.

Origin of City Quarry Graphite.—Recrystallization of the limestone and the subsequent development of large calcite plates is due in part to regional metamorphism, and in part, to heat of the intruding pegmatite. The platy minerals, pyraboles and micas, occur in both limestone and pegmatite. There is pronounced parallelism of the mica plates especially near the contact. The immediate contact between the limestone and the pegmatite is sharp. There is no garnet zone, and no definite evidence of melting. These two features seem to indicate very little change in composition except the expulsion of CO_2 from the limestone. "The proof that the additions are from the magma, and not from the substances leached from the wall rock is strongest when the inclusions of limestone inside an igneous rock are garnetized." (12) May one argue conversely then and say that the absence of the garnet zone is indicative of absorption of the limestone? The exchange of materials between the intruded and host rock is undoubtedly greatest on the cooler side—the host. The intrusive received from the host limestone, CO_2, calcium and magnesium, in exchange for silica which causes silication within the limestone and formed actinolite, zoisite, diopside, etc. The CO_2, freed from the calcium carbonate by the invading pegmatite formed graphite by deoxidation. The writer does not believe it was a part of the original pegmatite magma.

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