CORONAS AROUND OLIVINE IN A SMALL GABBRO INTRUSION, BAMBLE AREA, SOUTH NORWAY

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Coronas around olivine in a small gabbro intrusion are described as consisting of two sets of orthopyroxene-amphibole rims, occasionally with an additional outer rim of garnet. The first set is believed to be of deuteric origin, the second set, and the garnet, of regional metamorphic origin.

INTRODUCTION

Chemical reactions between minerals often result in corona structures. Well known are the coronas around olivine in olivine gabbros and troctolites; and anorthosites, eclogites, and serpentinites frequently show coronas around garnet and pyroxene. The reactions may take place in steps with several successive shells as the result.

Coronas around olivine have been thoroughly studied, and their mode of origin has been widely discussed. Sederholm (1916) mainly discussed a secondary versus a primary magmatic origin for the coronas. He concluded that they are secondary, and said that they are only found in areas which have undergone a later metamorphism, i.e. *regional metamorphism*. Vogt (1921) used for their formation the term *deuteric* as defined by Sederholm, i.e. as a synonym of *autometamorphic*. Brögger (1934) also used the word deuteric, but in a very wide sense, considering a metamorphism to take place soon after the consolidation of the rock. Later authors (Shand 1945, Murthy 1958) have sharply rejected the term deuteric, maybe partly because of a slight change in the meaning of the word so that it has come to be regarded as being more synonymous with *late magmatic*. Shand was thinking in terms of *thermal metamorphism,* Murthy (and Gjelsvik 1952) in terms of *regional metamorphism*. Undoubtedly *contact metamorphism* can also give rise to coronas (Huang & Merritt 1954).

From the diffferent geological settings there are many varieties of regional metamorphic coronas around olivine (Murthy 1958), but very commonly orthopyroxene constitutes the inner corona against olivine, proving that the corona formation is the result of a reaction of high metamorphic facies (hornblende granulite facies, Winkler 1965). However, coronites are frequently found in areas which belong to a lower facies (e.g. Bamble and Solör areas, South Norway). In these areas the metamorphism started soon after the crystallization of the magma, while the rock was still hot, and took place during the further cooling, and it might therefore be difficult to distinguish the effects of an autometamorphism from the effects of the regional metamorphism.

Water is a very important factor in the metamorphism, as pointed out by Reynolds & Frederickson (1962). Water acts as a catalyst and the reactions are extremely slow, i.e. they stop, under water deficient conditions. The basic rocks originally contain very little water, insufficient for most metamorphic reactions to take place. According to varying amounts of water supplied during metamorphism, the reactions stop at different stages, and it is possible to follow step by step the metamorphism from the corona stage (where the corona formation is the only metamorphic alteration), through stages where the replacement of clinopyroxene by hornblende and the recrystallization of plagioclase are gradually increasing, to completely recrystallized amphibolites (Brögger 1934, Gjelsvik 1952).

CORONAS OF THE HIÅSEN GABBRO

The present observations concern corona structures in a small gabbro intrusion, approximately 1 km across, forming the hill Hiåsen in the Bamble area, South Norway. The metamorphic alteration took place during a retrograde metamorphism soon after the congealing of the magma. As the water had access along cracks and minute fractures of the rock, the degree of alteration varies considerably within the intrusion; in fact, great variations in alteration may occur even within a thin section. The alteration is so strong that only a few of the samples are coronites (even these have no olivine left), and all stages to the completely recrystallized amphibolites are found within the intrusion.

Typical coronas from Hiåsen are shown in Fig. 1.

The general features of these olivine pseudomorphs are as follows: Around a granular aggregate of orthopyroxene with large amounts of iron ore, is a rim of radially arranged orthopyroxene without ore. Outside this is a rim of amphibole, partly containing vermicular spinel. A radial arrangement of the amphibole grains can also be seen. It is clear that the orthopyroxene is replacing olivine and the amphibole is replacing plagioclase, so that the original border olivine-plagioclase is now represented by the border orthopyroxene-amphibole.

This double corona type, with an inner rim consisting of orthopyroxene and an outer rim of amphibole with spinel is very common, especially in this area. Reynolds & Frederickson (1962) observe that the vermicular spinel is concentrated near the amphibole-orthopyroxene boundary, while Brögger (1934) states that more frequently it is concentrated along the border to plagioclase. In Hiåsen there is always a rim without spinel along the orthopyroxene corona. In some cases this pure part differs from the rest of the amphibole rim in that it consists of smaller grains in a fairly prominent radial arrangement, and a discontinuity can be seen within the amphibole corona, Fig. 2. Although this is not always so, as the coronas are obviously very

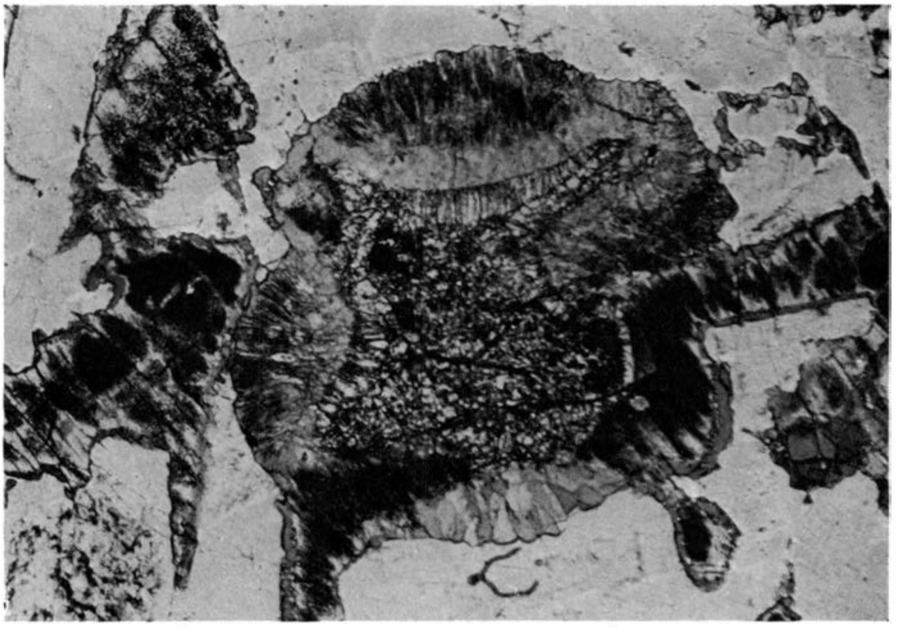

Fig. 1. Olivine pseudomorph showing typical coronas. From the center and outwards: Core of orthopyroxene and iron ore, rim of orthopyroxene, rim of amphibole where the outer part contains vermicular spinel. Note the heavily clouded augite. See the text. Plane light, ×40.

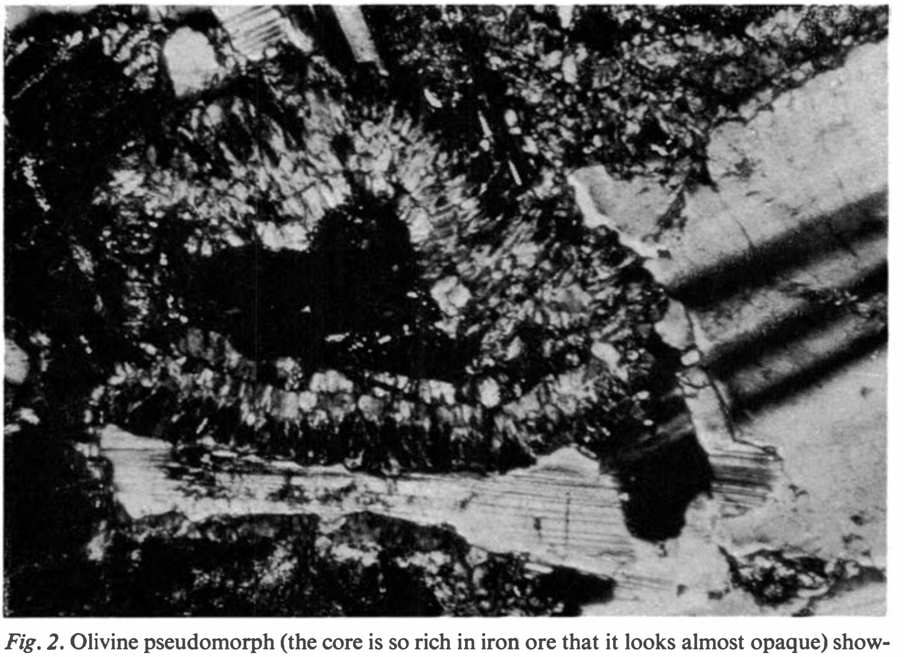

Fig. 2. Olivine pseudomorph (the core is so rich in iron ore that it looks almost opaque) showing a discontinuity in the amphibole rim, thus proving that there are two amphibole coronas. Crossed nicols, ×50.

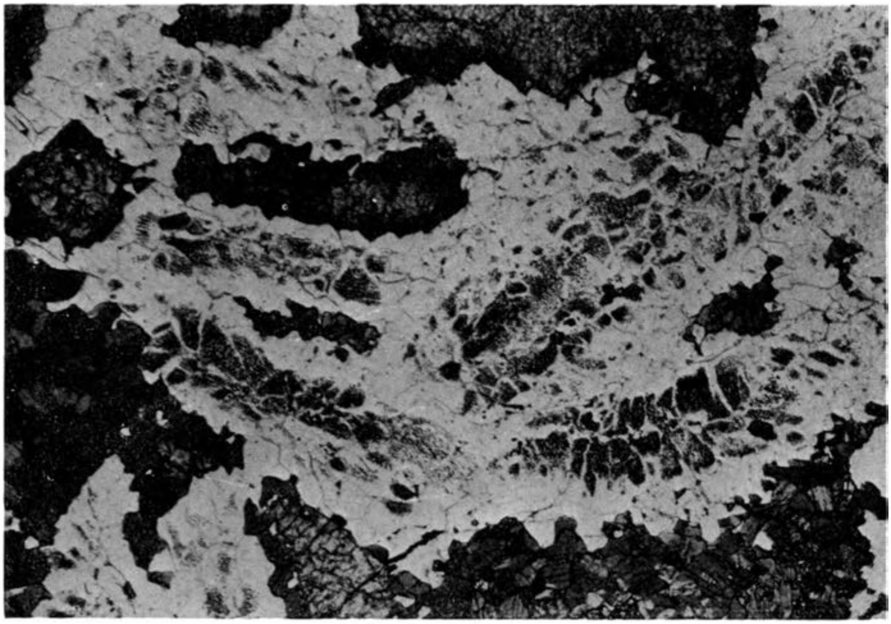

Fig. 3. Scapolitized gabbro. The whole plagioclase is converted to scapolite, but the clouding of the original plagioclase laths is preserved as vermicular spinel in the scapolite. The augite is to a large extent replaced by hornblende. Plane light, ×25.

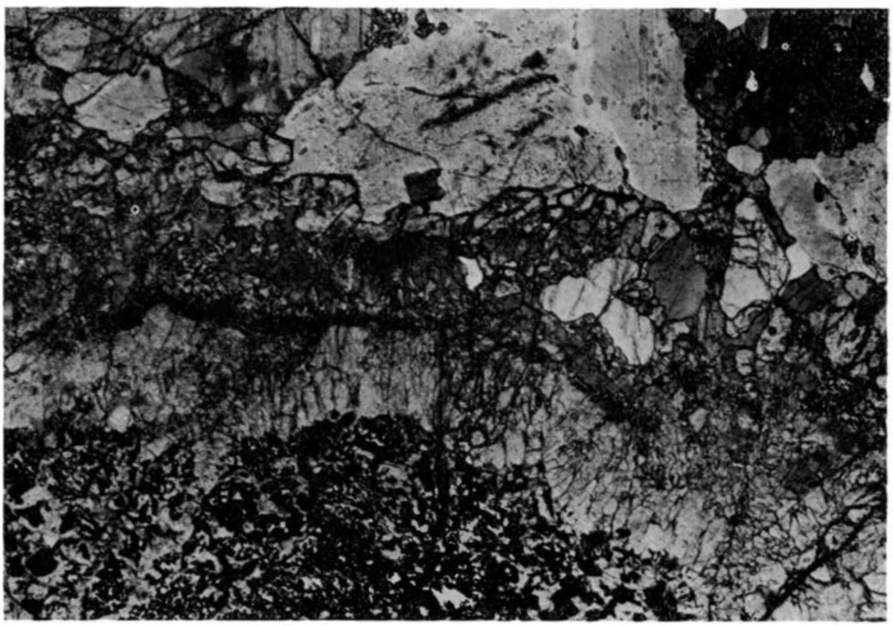

Fig. 4. Close-up of an olivine pseudomorph showing the later stage of the corona formation. Garnet is developing as a discontinuous outer rim, replacing both amphibole and plagioclase, and occasionally also in the amphibole corona along the border to orthopyroxene. The amphibole corona is highly recrystallized, the 'doubling' obliterated. The rim of orthopyroxene is still prominent. Plane light, ×65.

sensitive to metamorphism, the author believes that this was originally the case, i.e. *there are two different amphibole coronas.*

It is striking how the rims of pure orthopyroxene and the rims of pure amphibole are uniform and of constant width throughout the Hiåsen gabbro. Furthermore, they strictly follow the irregular outline of the original olivine grains. The outer amphibole corona (symplectite) tends to make the pseudomorph spherical, Fig. 1. This indicates that they were formed simultaneously, by a direct 'reaction' between olivine and plagioclase at the initial stage of the corona formation. It is then natural to consider the cores of the pseudomorphs (orthopyroxene plus ore) and the symplectite as similar, but somewhat different, 'coronas' formed at a later stage of the alteration and under somewhat different conditions. In the neighbouring Rundsaga gabbro intrusion, olivine pseudomorphs have no iron rich cores, indicating that the conditions were optimal for the first type of reaction to run until complete conversion of olivine to orthopyroxene.

Clouding of primary minerals is common in coronites and is believed to be of metamorphic origin. Murthy (1958) states that the corona formation is later than the clouding of plagioclase. This is only partly the case in the Hiåsen gabbro, where the clouding is very slight at the first stage of corona formation described above, but intense at a later stage when also garnet develops in the coronas.

Another important factor in this connection is the scapolitization of the plagioclase, which has taken place widely in this intrusion. Scapolitization is common in the area (Brögger 1934) and is generally considered a chlorine pneumatolysis in close connection with the magmatic activity, i.e. an autometasomatism. The scapolitization process belongs to the same high metamorphic facies since it is accompanied by alteration of augite into orthopyroxene. However, it takes place after the clouding of the plagioclase, Fig. 3, and therefore later than what is considered to be regional metamorphic features. This implies that *the magmatic phase had not come to an end before the regional metamorphic phase started.*

The conditions necessary for the corona formation can be summarized as follows:

1. Presence of small amounts of water
2. Elevated temperatures
3. High hydrostatic pressure, little shearing stress

The PT conditions just after the intrusion were probably favourable, and it is demonstrated that fluids of magmatic origin were introduced. Hence the author believes it correct to designate the first set of coronas described above (orthopyroxene and amphibole without spinel) as *deuteric* in the original meaning of the word. The second set (the iron rich cores and the symplectite) is believed to be the result of regional metamorphism.

The following step in the alteration of the rock by the regional metamorphism is development of garnet in the coronas (Brögger 1934, Reynolds & Frederickson 1962). In Hiåsen the garnet generally forms as another corona along the border between amphibole and plagioclase (replacing both), but it may also develop as small grains replacing amphibole along the border to orthopyroxene. At this stage the 'doubling' of the amphibole corona is completely obliterated as the vermicular spinel has partly vanished, and recrystallization has taken place and diminished the radial arrangement of the amphibole grains. The rim of pure orthopyroxene is still very prominent, Fig. 4.

By further metamorphism the coronas are replaced by aggregates of granular common hornblende. Even when there is no trace left of the original olivine or the pseudomorphs, the rock as such may be described as 'only slightly altered by metamorphism'. The clinopyroxene is still heavily clouded and has only narrow replacement rims of hornblende, and the clouding of the plagioclase is still prominent. Therefore it seems that the corona stage is a fairly short one in the alteration history of the rock.

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