ON THE OCCURRENCE OF KYANITE IN THE ECLOGITES OF THE SELJE AND ÅHEIM DISTRICTS, NORDFJORD

By
M. A. Lappin

(Geology Department, King's College, Newcastle on Tyne, University of Durham.)

Abstract: Kyanite is recorded for the first time in Norwegian eclogites and localities are indicated. The alteration of kyanite to a corundum-oligoclase kelyphite or to zoisite, during an amphibolite facies metamorphism of eclogite, is briefly described.

Introduction

The field association and mineralogical variations of the eclogites of Sunnmøre and Nordfjord were first described by Eskola (1921). He noted the occurrence of eclogites both as small lenses in amphibolite facies gneisses, and as contorted layers in some of the dunites of Sunnmøre.

The essential minerals of the eclogite facies are garnet, clino-pyroxene, ortho-pyroxene, olivine, kyanite and quartz. Kyanite, however, did not occur in any of the specimens which Eskola studied. In his classic paper he also described the common alteration of eclogite to amphibolite through the development of diopside-plagioclase, or hornblende-plagioclase symplectites from clino-pyroxene, and hornblende kelyphites from garnet.

During the summers of 1958—59 the writer has studied the rocks of the Selje and Åheim districts and has found many kyanite eclogites. The more important localities are indicated in figure 1.

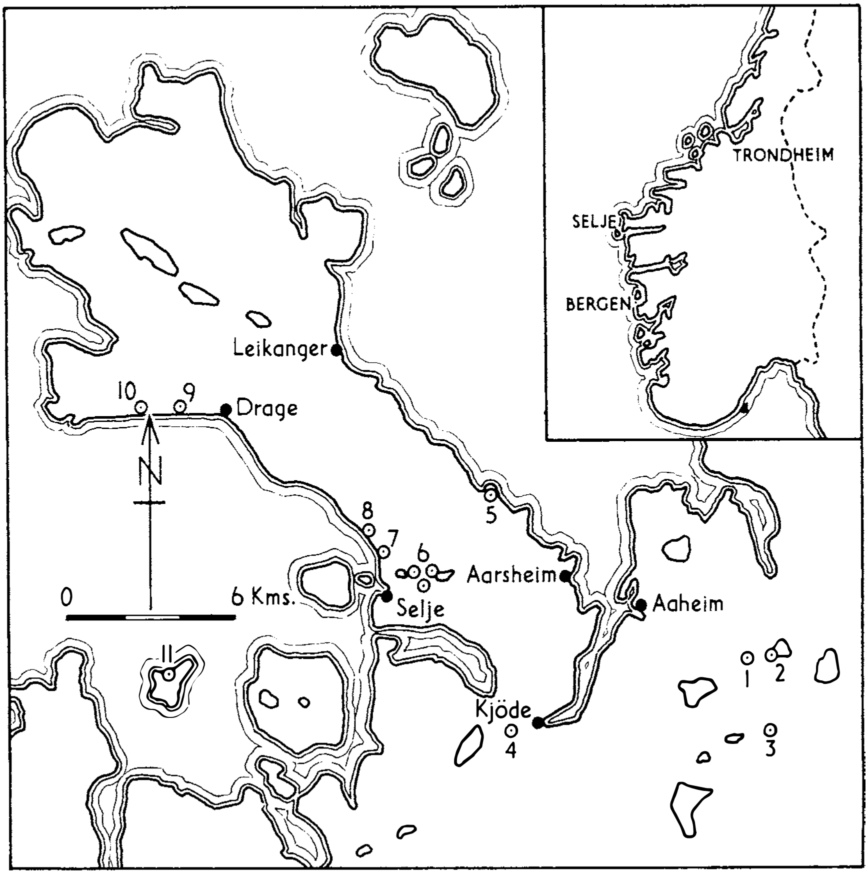

Fig. 1.: LOCALITIES.
1. 400 metres N.E. of Ekremsæter farm, Almklovdal. 2. The south shore of Sæter Vatn, Almklovdal. 3. 300 metres E. of Kasen farm, Almklovdal. 4. 1.25 kms. W.S.W. of Kjøde (zoisite eclogite). 5. Shore section on Sandviknæs, 4 kms. N. E. of Årsheim. 6. A series of small lenses traced from Dybedalsvatn to the small lakes about 1 km. N.W. of Selje. 7. Shore section at Pileberg 1.5 kms. N. of Selje. 8. Shore section between Lisæter and Skorbø, 4 kms. N. of Selje. 9. Shore section 1 km. E. of Drage. 10. Path to indre Fuhre, 4 kms. E. of Drage. 11. North coast of Silden island.

Field Association

Eclogites occur as small lenses in the gneiss and appear to be concentrated along certain structural horizons. Thus, the eclogites of the shore section immediately north of Selje can be traced in the steep east-west limb of a synformal fold as far as Årsheim (fig. 1). Eclogite-bearing horizons also occur in the northern shallow dipping limb (strike N.N.W. — S.S.E.) of this fold and can be seen in a strike section exposed in the cliffs between Selje and Drage. Kyanite eclogites occur in these zones and a series of kyanite-bearing lenses has been traced along the strike for a distance of one kilometer (locality 6. Dybedals Vatn).

Characteristically, kyanite occurs only in lenses of coarse-grained eclogites (garnet between 1 and 1.5 cms. in size) and in the coarser bands of finer grained types. It is usually associated with quartz and has not been seen in the more basic, orthopyroxene eclogites of the gneisses or in the garnet bearing rocks of the dunites. The only stable mineral association is quartz-kyanite-garnet-clinopyroxene. One kyanite-bearing specimen from Silden (locality 11) does not, however, contain quartz. Kyanite rarely forms more than 5 per cent of the rock. It may occasionally be uniformly distributed throughout a lens but is more generally found in apparently random patches or associated with quartz or pyroxene-rich layers. Kyanite is unmistakable in hand specimen for it occurs as interstitial, blue streaks, or as blue, ideomorphic laths up to 8 mms. in length.

The alteration of kyanite

The alteration of kyanite is not widely reported in literature. Tilley (1936) discussed some petrogenetic implications of this problem and concludes that kyanite may be replaced by anorthite (in plagioclase), zoisite or clinozoisite depending on local conditions. He recognises, following Brière (1920) that kyanite eclogites are generally altered to kyanite-free amphibolites without change in bulk composition. These observations apply also to the Norwegian kyanite eclogites where kyanite is completely replaced during amphibolitisation. In partially altered eclogites, however, kyanite is often surrounded by a pale pink reaction rim; or is replaced by a white zoisite. These two types of alteration can generally be observed in one thin section but since they are separated in time and manner of replacement they are described separately.

1. In the first type of alteration a very fine, hair-like kelyphitic rim is developed which consists of small, colourless, lath-like crystals of high refractive index and low birefringence set in a base of plagioclase.

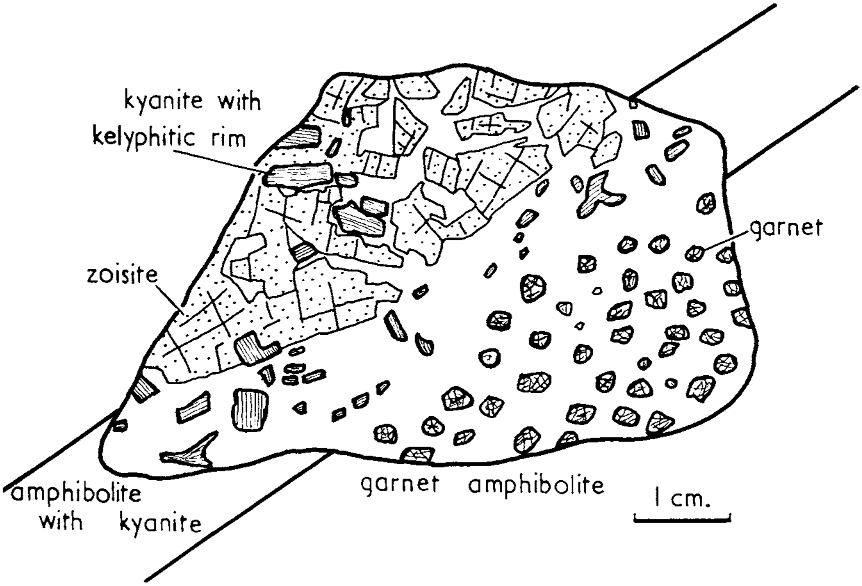

Fig. 2. A cross-section of a kyanite-zoisite vein in a garnet amphibolite (drawn from a photograph).

An X-ray powder photograph of such a pinkish kelyphite indicates a mixture of oligoclase and corundum. All stages of replacement of kyanite by this pervasive kelyphite have been seen. Often some recrystallisation of this kelyphite occurs with the formation of transverse, chain-like aggregates, or larger barrel-shaped crystals, at the flared edges of the kelyphite (plate I, fig. 2 and plate II, fig 1). Available evidence indicates that corundum is unstable in over-saturated rocks. It is only a transient stage in the amphibolitisation of kyanite eclogites as the corundum kelyphite is always surrounded by a wide, clear zone of recrystallised plagioclase (plate 2, fig. 2) and is eventually absorbed in the surrounding hornblende-plagioclase symplectite.

2. The second type of alteration produces white, elongate plates of zoisite which forms streaky aggregates in partially amphibolitised kyanite eclogites. Zoisite occurs only in these rocks and is not a primary mineral of the kyanite eclogites. It must, then, be regarded as a partial replacement of kyanite. In this context two specimens are of special interest.

The first, is a small, irregular vein-like mass in an amphibolitised eclogite lens from Lisæter (locality 7). The field relationships of this

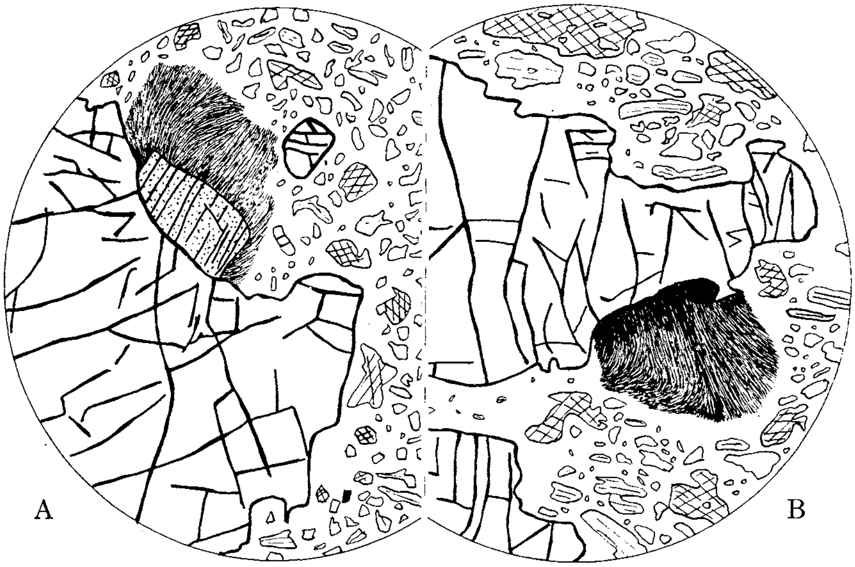

Fig. 3. Large, late zoisite plates cut and replace A) kyanite with its surrounding corundum-plagioclase kelyphite and B) a corundum-plagioclase kelpyhite. Kyanite-zoisite vein in amphibolitised eclogite from locality 7. (× 50).

vein are not clear but it is obviously of replacement origin. The main mass of the vein is made up of pale green plates of zoisite, the individual crystals of which attain dimensions of about 2 cms. by 1 cm. by 0.5 cms. These plates are elongate and striated parallel to the 'b' crystallographic axis. Kyanite, often with a fine corundum bearing kelyphitic rim, occurs as inclusions in zoisite; and at both the ragged edges of the vein and within the immediately surrounding amphibolite (figure 2). Garnet is not seen in a centimetre wide zone around this vein and, since the vein has apparently been developed in a uniform textured eclogite, the garnet must have been absorbed.

The zoisite plates cut across kyanite laths and their surrounding kelyphites and are thus of later origin (figures 3 a & b). The absence of garnet near this vein suggests that zoisite has been formed by a reaction between garnet and kyanite (or its alteration products corundum and plagioclase). Later reactions associated with the final amphibolitisation of the eclogites have resulted in the local replacement of zoisite by muscovite or by another zoisite mineral characterised by anomalous birefringence colours.

The second specimen collected, E.N.E. of Kjøde (locality 4), is a zoisite eclogite which could be compared with the zoisite eclogites of the Fichtelgebirge region, Bavaria. Since this specimen contains only a small amount of kyanite it may be regarded as an extreme variant of the Silberbach zoisite eclogite which was exhaustively described by WOLFF (1942).

Zoisite forms up to 10% of the Kjøde specimen and occurs as white, randomly orientated laths up to 3 cms. by 0.2 cms. by 0.1 cms. in size. It contains abundant inclusions of rutile and quartz. The manner in which the zoisites cut through single crystals of both garnet and clino-pyroxene indicates that zoisite has formed later than both these minerals. A few, bladed kyanite crystals have been observed in this lens and it is probable that zoisite is again replacing kyanite. Zoisite laths were not seen in the amphibolitised borders of this eclogite and have probably been replaced during the later amphibolitisation of this body.

X-ray powder photographs and optical data for the three types of zoisite: — from the altered kyanite eclogites, from the kyanite-zoisite vein, and from the zoisite eclogite, indicate that these minerals are identical. The composition can be refered to β zoisite although some of the optical properties are rather anomalous.

The time relationships of the crystallisation of zoisite seem to be variable. In kyanite eclogites it forms after development of the corundum-oligoclase kelyphites but before or during the early stages of amphibolitisation. Zoisite is, however, affected by the amphibolitisation of the zoisite eclogites and in these rocks its crystallisation precedes this phase of the metamorphism.

Conclusions

1. The discovery of kyanite in the eclogites of Nordfjord removes the main anomalous feature of the Norwegian eclogite association. A direct comparison can now be made with the classic eclogite-bearing regions of Germany (Bavaria), Austria (the Tirol and Karnten provinces), and the Alpine regions of Switzerland, France and Italy. In these areas, eclogites occur as lenses or layers in gneisses and schists of various facies, but as in Norway the following mineral associations are characteristic.

quartz – kyanite – garnet – clinopyroxene.
quartz – garnet – clinopyroxene.
garnet – clinopyroxene.
garnet – clinopyroxene – orthopyroxene.

So far as it is known to the writer, Glenelg, Scotland is the only major European locality in which kyanite does not occur.

2. In the early stages of retrogressive metamorphism, kyanite is replaced by a corundum-oligoclase kelyphite. During the amphibolitisation of the eclogites this kelyphite is taken up by the plagioclase of the surrounding plagioclase- hornblende symplectites. β zoisite forms directly from kyanite, and possibly garnet, during amphibolitisation.

3. Zoisite and the amphibole smaragdite have sometimes been considered as primary minerals in the eclogite facies. The main evidence for this view seems to be textural, in that both minerals occur as well formed, randomly orientated laths in granular eclogites. Commonly, also, these minerals are affected by the late amphibolitisation of the eclogites and have, thus, been regarded as an early, and hence, primary phase.

This interpretation does not seem to be valid in the zoisite eclogite described above, even though the zoisite has all the apparent 'primary' characters. It has been demonstrated that zoisite, a) crystallised after both garnet and clino-pyroxene, b) occurs with accessory kyanite, and c) is identical with the zoisite formed by the alteration of kyanite. This porphyroblastic zoisite should also be regarded as a replacement product of kyanite. It is suggested that zoisite, and by analogy, smaragdite are not primary minerals of the eclogite facies, but that their good form and random orientation is a function of local conditions which have allowed recrystallisation. This alteration is not necessarily of different grade to the more common, pervasive alteration (the formation of symplectites and kelyphites) of the eclogite minerals even though they may be separated in time. Local variation in the vapor pressure and the physical properties of the rocks are probably critical factors which determine the course of the alteration processes.

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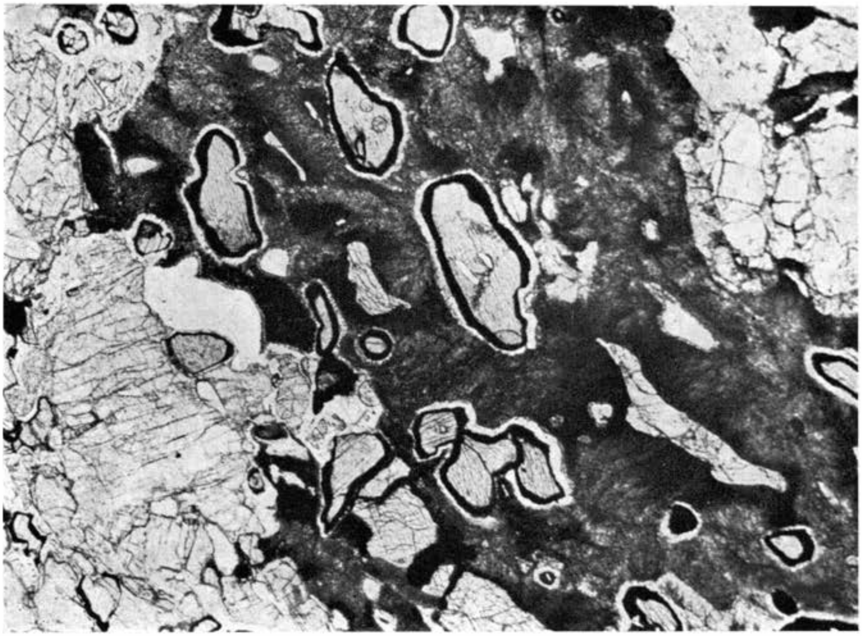

Fig. 1. Kyanite laths surrounded by an inner corundum and an outer plagioclase zone, the laths are set in a finely crystalline diopside-plagioclase symplectite which is the result of the alteration of a pyroxene rich layer. Foliated garnets and zoisite occur in the east and west fields. (locality 1). ($\times 30$).

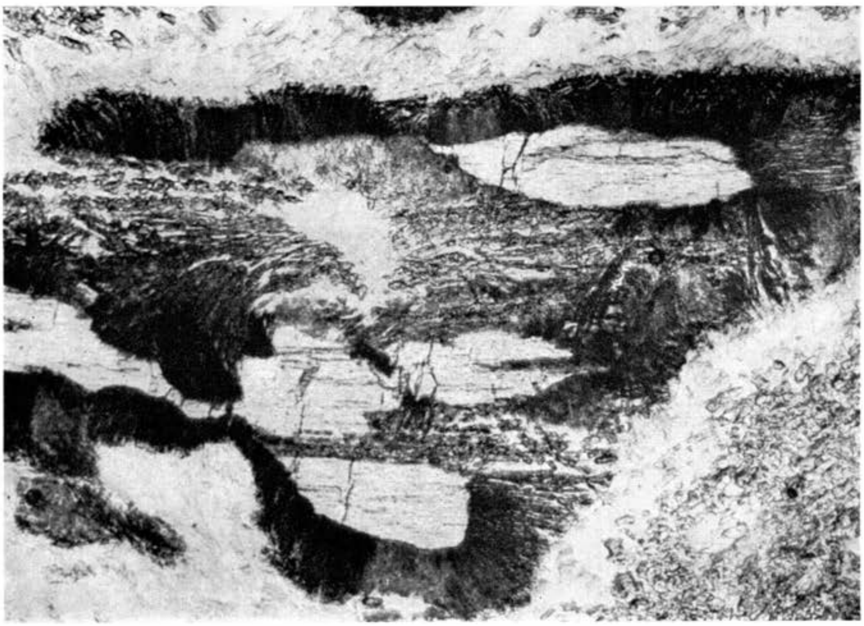

Fig. 2. A large kyanite which shows replacement by a fine, hair-like corundum-plagioclase kelyphite. This kelyphite recrystallises into larger crystals which form transverse aggregates. (locality 7). ($\times 30$).

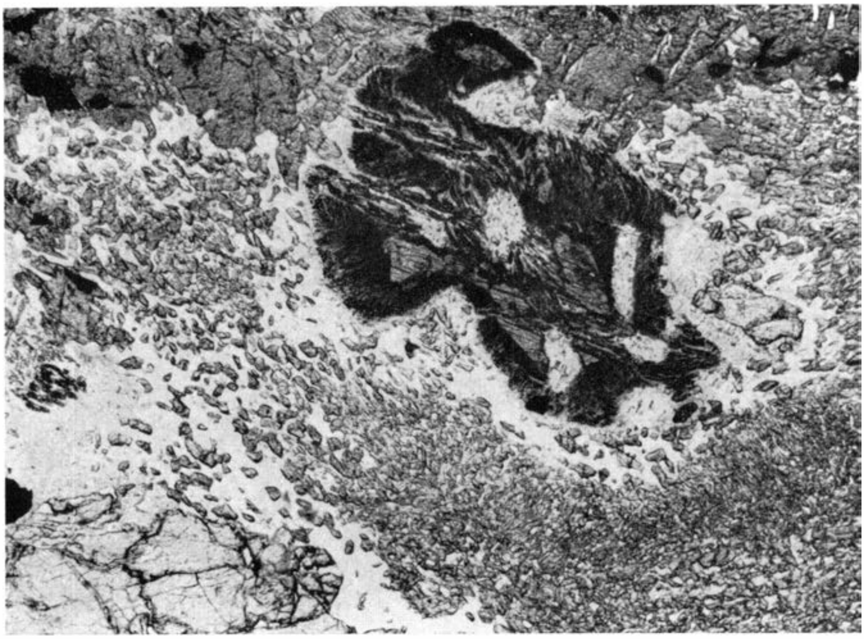

Fig. 1. A corundum-plagioclase kelyphite cored by residual kyanite set in a locally recrystallised hornblende-plagioclase symplectite. Note the plagioclase zone around the kelyphite and the large zoisite in the lower field (locality 7). ($\times 30$).

Fig. 2. A corundum-plagioclase kelyphite with rather lobate boundaries due to replacement by plagioclase. The kelyphite is surrounded by a wide zone of recrystallised plagioclase, the main groundmass is a fine grained amphibolite. (locality 6). ($\times 30$).