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## Pegmatitic cordierite from the Owl Mts (Sudetes)

**ABSTRACT:** The first reported cordierite from pegmatitic formations of the Sudetes Mts reveals a high concentration of FeO and small amount of BeO. Both crystallochemical formula and unit cell parameters of this cordierite were calculated. The distortion index  $\Delta = 0.18$  suggests that the investigated cordierite presents an intermediate form between the high and low variety. Studies of fluid inclusions reveal its crystallization under the conditions characterized by pressure about 2 kbars, and temperatures at the range of 700–750°C.

### INTRODUCTION

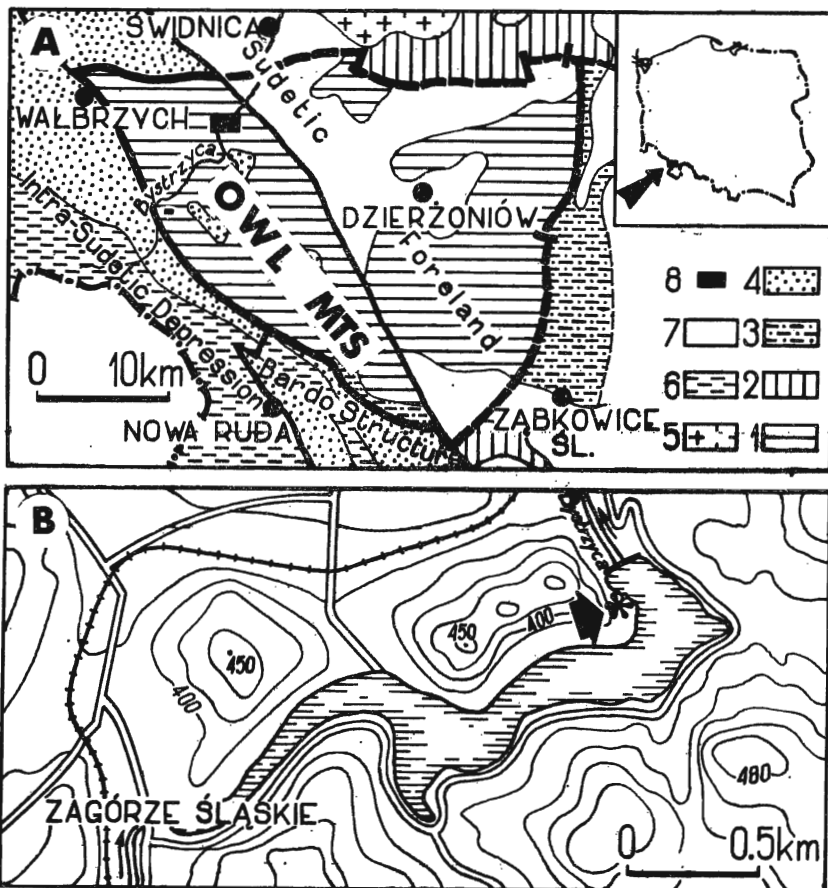
The investigated cordierite was found in a pegmatite that forms a vein-like nest within the Precambrian gneiss formation of the Owl Mts, Central Sudetes. This pegmatite is exposed at 4 km north-east of the village Zagórze Śląskie (Fig. 1A, B), near to the dam on the Bystrzyca stream (cf. Fig. 1B). The relatively coarse grained pegmatite (Fig. 2) contains mostly plagioclase, potassium feldspar, quartz and biotite, as well as accessory apatite, black tourmaline, almandine, and muscovite. The most enriched in cordierite (approximately several per cent of rock by volume) is the central part of the nest.

In the Owl Mts, cordierite has hitherto been identified only in the gneiss formation itself, in its part exposed between Wałbrzych and Świdnica (Smulikowski 1952, Grocholski 1967), north-west of the investigated occurrence (cf. Fig. 1A). In other localities in the Sudetes Mts, cordierite was only described from the Rumburg and Izera massifs, and from the contact zone of the Kłodzko-Złoty Stok and Karkonosze Variscan intrusions (Traube 1888, Wieser 1958, Dziejczowa 1960, Kozłowska-Koch 1965).

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## METHODS AND RESULTS OF INVESTIGATION

The collected specimens of cordierite from Zagórze were investigated in thin sections for a transmitted light microscopy, while its composition was determined by chemical and spectral emission analyses. The X-ray study was made on the *DRON-1* diffractometer using  $\text{CuK}\alpha$  radiation in the range  $2\theta = 4-65^\circ$ . Moreover, the X-ray powder pattern was made in



A — Geological sketchmap of the Owl Mts block in the Central Sudetes (inset shows position of the area in Poland); the map simplified from Sawicki & Teisseyre (1969)

The Owl Mts block, triangular in shape (outlined with a heavy line), and built up of the Precambrian gneisses, is cut by a Tertiary fault, and its thrown down part is included into the Sudetic Foreland

1 the Owl Mts gneisses, 2 ultrabasic rocks, 3 cataclazites and mylonites, 4 Lower Carboniferous (Culm facies), 5 Strzegom granitoids, 6 Permian (Rotliegendes facies), 7 Tertiary and Quaternary, 8 investigated area (cf. Text-fig. 1B)

B — Location map of the investigated cordierite-bearing pegmatite at Zagórze Śląskie

The completely disordered cordierite crystallizes as the first, metastable (at lower temperatures) phase, which after long heating alters into intermediate, partly ordered phase featured with  $\Delta = 0.20$  (Miyashiro 1957). The distortion index of investigated cordierite amounts  $\Delta = 0.18$ , which proves its considerably high degree of structural deviation (Fig. 3). The value of width index  $W_{1/3} = 0.46$  (Fig. 4) permits to ascertain the same conclusions; on the other hand, however, it characterizes better a dependence of structural deviation on the temperature.

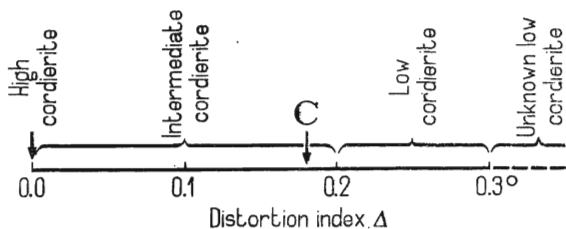


Fig. 3. Structural states of cordierite as a function of the distortion index ( $\Delta$ )  
C — cordierite from Zagórze

The infrared absorption spectrum of the investigated cordierite shows the first absorption band characteristic of the ring silicates with six-member rings [ $\text{Si}_6\text{O}_{18}$ ] occurs in the region  $1250\text{--}952\text{ cm}^{-1}$  (Fig. 5), where formerly noted (Plyusnina 1967) two maxima of absorption should be expected at  $1177$  and  $961\text{ cm}^{-1}$ . The shifts of absorption maxima in investigated cordierite in more short-wave part of the spectrum, *viz.*  $1185$  and  $969\text{ cm}^{-1}$ , result from a considerable content of light cations in the silicate rings. Probably, Al and Mg replaced here the relatively heavy Fe-cations.

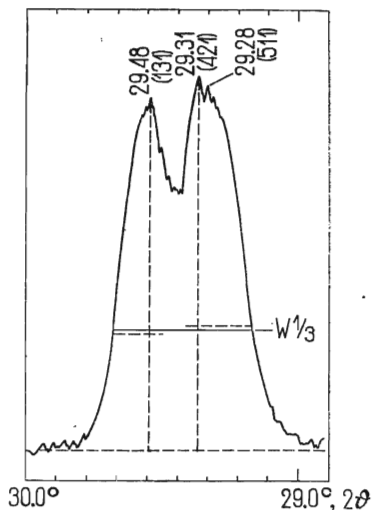


Fig. 4. Definition and procedure of measuring the width index  $W_{1/3}$  in X-ray powder pattern of cordierite from Zagórze

The second absorption band characteristic of bonds in six-member silicate rings exists in range  $806$  to  $769\text{ cm}^{-1}$ . Absorption maximum in the investigated cordierite is found in long-wave part of the spectrum ( $775\text{ cm}^{-1}$ ), being the result of a considerable high replacement of Si by Al in the rings [ $\text{AlSi}_5\text{O}_{18}$ ]. The absorp-

tion maxima 581 and 535  $\text{cm}^{-1}$ , known from some cordierites (Newton 1966) were not observed in the spectrum, probably because of a low concentration of beryllium.

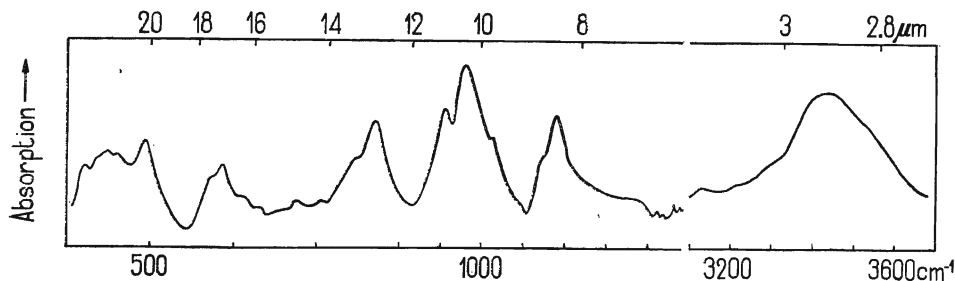


Fig. 5. IR absorption spectrum of cordierite from Zagórze.

A wide maximum of absorption in region 3600–3300  $\text{cm}^{-1}$  registered in the spectrum (Fig. 5), evidences the content of water which occurs only in the form of  $\text{H}_2\text{O}$  molecules within the channels parallel to the  $z$ -axis.

#### THERMOMETRIC AND BAROMETRIC INVESTIGATIONS

Parameters (temperature and pressure) of mineral-forming environment during the formation of cordierite were defined on the base of analyses of the inclusions (cf. Fig. 6). Primary and secondary inclusions were distinguished in regard with their form and disposition into the crystal.

Primary inclusions, attaining dimensions 5–7  $\mu$ , are isometric (Fig. 6a-b). Relation between disposition of these inclusions into the crystal individual and its particular growth zones was not observed, and they should therefore be referred to as azonal inclusions *sensu* Ermakov (1972).

Secondary inclusions, attaining dimensions 7–10  $\mu$ , are of the tabular type (Fig. 6c-e), and they are more frequently found than the primary ones. Secondary inclusions are arranged perpendicularly to zones of pinite which fills fractures in

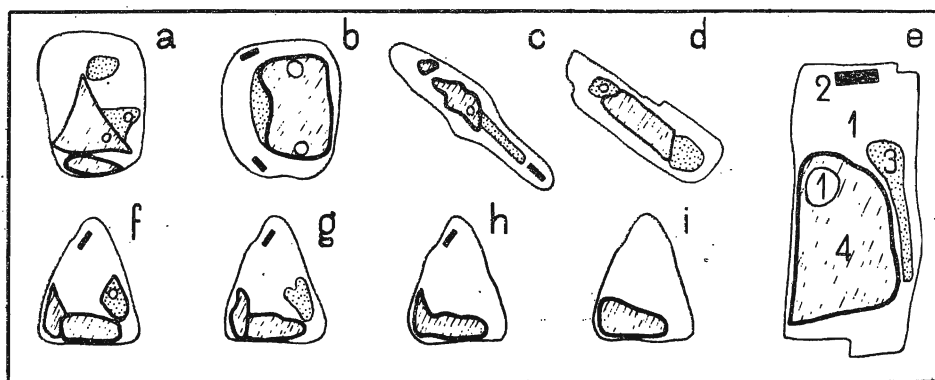


Fig. 6. Polyphase inclusions in cordierite from Zagórze

a-b primary inclusions, c-e secondary inclusions

f-i the course of homogenization of primary inclusions: f at room temperature, g at 350°C, h at 510°C, i at 690°C

1 liquid, 2 black, opaque minerals, 3 yellow-green melt, 4 white, transparent melt

the cordierite grains. The origin of these inclusions is connected with the healing of fractures in the mineral.

The phase composition of primary and secondary inclusions are similar. They are polyphase, and bear liquid (sometimes liquid and gas), and one or several solid phases. The solid phases were determined as: yellow-green, isotropic silicate melt; white, transparent silicate melt with relief higher than this of yellow-green melt; and black, opaque minerals which have short, column-like form. Melts amount 20–60% of inclusion volume.

Homogenization of primary inclusions (Fig. 6f-i) shows that at temperature above 300°C the silicate melt obtain plasticity, and at temperature range 340 to 360°C the liquid droplets, previously entrapped in the melt, liberate from it. At temperatures 500–520°C, homogenization of yellow-green silicate melt in liquid phase was noted. Simultaneously white silicate substance began partly to melt, and its separate grains join themselves to form one aggregate. At temperatures 680–700°C, the disappearance of black minerals was observed. White silicate substance melted at above 700°C, and small part of melt reacted with liquid phase. Complete homogenization was not achieved till 800°C.

A similar absence of complete homogenization in inclusions from pegmatitic minerals was recognized by Bazarov & *al.* (1975), who explained that phenomenon by kinetics of dissolution of silicate melt in solution bearing low concentration of alkali components. The temperature of the melting of white silicate melt (700–750°C) was accepted as a minimum crystallization temperature of cordierite from Zagórze.

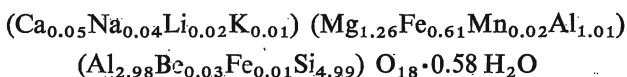
The pressure conditions during the formation of the investigated cordierite were evaluated using data of water content in structural channels. The amount of water in that mineral indicates the physico-chemical environment during crystallization, while the loss of water is not a univariant reaction, but it takes place gradually over an extended pressure-temperature field (Schreyer 1965). The investigated cordierite contains 1.68wt% of H<sub>2</sub>O, and probably it crystallized at 700–750°C. The pressure corresponding to these values may be accepted as approximately 2 kbars (cf. Schreyer & Yoder 1964).

## CONCLUSIONS

The structure of investigated cordierite is considerably complicated. The value of distortion index  $\Delta = 0.18$  suggests that this cordierite represents an intermediate form between the high and low variety. Moreover, the hexagonal structure was considerably deformed in the investigated specimens. The value of distortion index falls into the range characteristic of pegmatitic cordierites (Schreyer 1966), and it is lower than the value typical of metamorphic cordierites. High value of width index  $W_{110} = 0.46$  suggests a slow cooling rate during formation of the mineral. The varied processes are therefore thought to have influenced a considerable complication of the structure of the investigated cordierite.

The most of Mg-rich cordierites occur in metamorphic rocks, while the most of Fe- and Mn-rich cordierites preferably appear in pegmatites (Schreyer 1965). The pegmatitic cordierites may moreover contain considerable amounts of Li and Be that substitute other cations in the framework. A high concentration of FeO and a small amount of BeO and Li<sub>2</sub>O suggest influence of heterochemical, metamorphic processes connected presumably with anatectic differentiation.

The possibility of replacing of Mg by Li in accordance with scheme  $\text{Li} + \text{Al} \rightarrow 2\text{Mg}$  were pointed by Ginzburg & Stavrov (1961). Another replacement  $\text{BeAl}_2 \rightarrow \text{Mg}_2\text{Si}$  was postulated by Newton (1966). Cordierite with content of 1.7–1.9wt% of BeO was reported by Černý & Povondra (1966), who suggested replacement  $(\text{Na}, \text{K}) + \text{Be} \rightarrow \text{Al}$ . The latter scheme were confirmed by infrared investigations (Plyusnina 1967). The crystallochemical formula of the investigated cordierite may therefore be calculated as follows:



The presented results suggest a metamorphic origin of the cordierite-bearing pegmatite. The main stage of crystallization of pegmatitic minerals proceeded relatively slowly at temperatures over 700° C under pressure of about 2 kbars. Its formation was probably connected initially with anatectic differentiation and subsequently with activity of potassium-, boron- and fluorine-bearing solutions.

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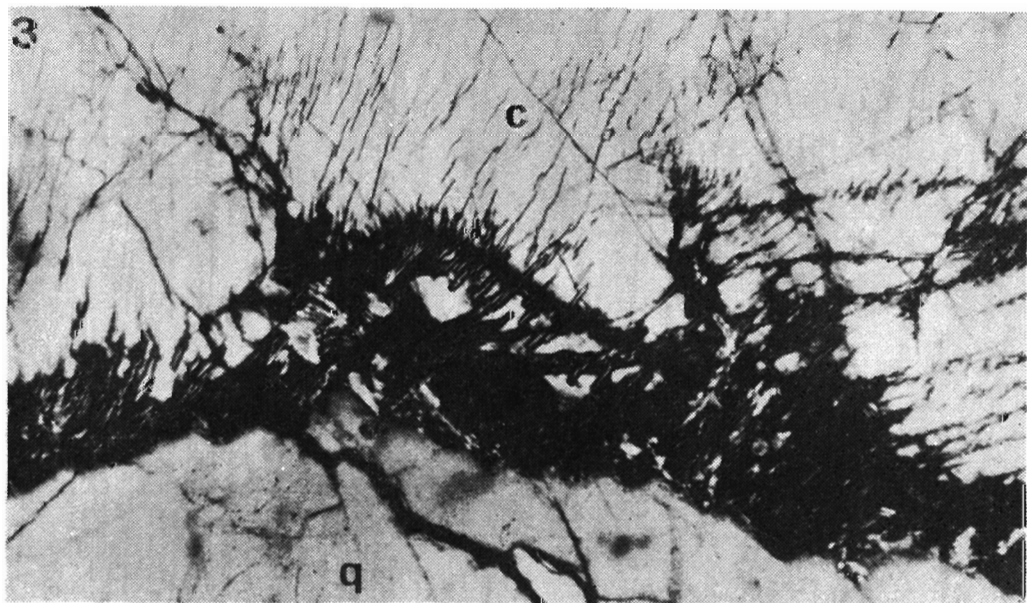
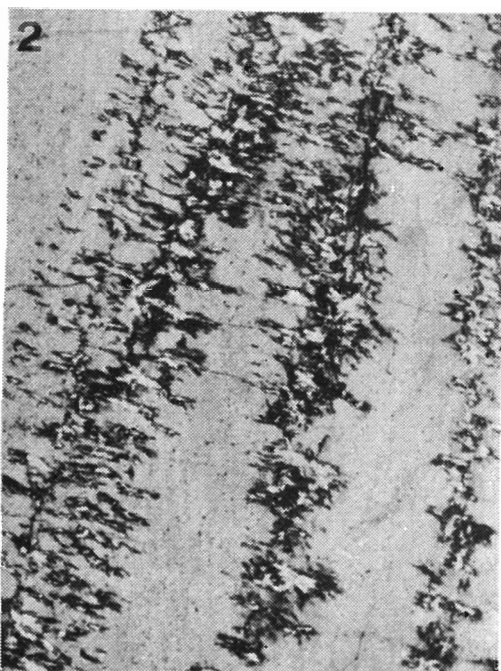
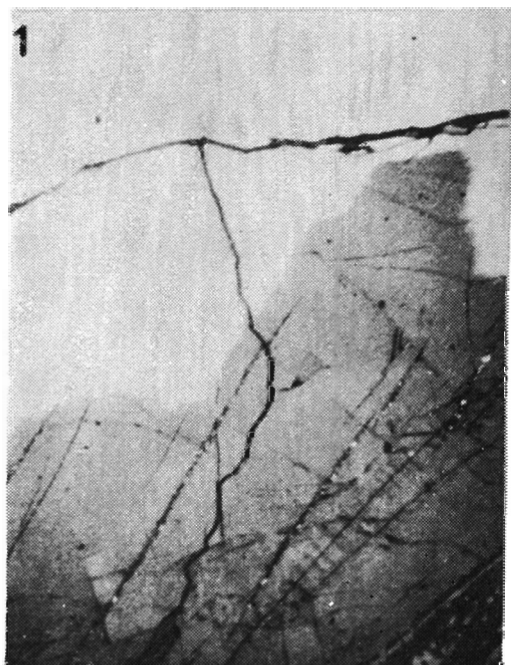
## KORDIERYT Z PEGMATYTU W ZAGÓRZU ŚLĄSKIM (GÓRY SOWIE)

(Streszczenie)

Przedmiotem pracy jest analiza kordierytu znalezionej po raz pierwszy w Sudetach w obrębie utworów pegmatytowych. W minerale tym napotkanym w odsłonięciu koło zapory w Zagórzcu Śląskim w Górach Sowich (patrz fig. 1–2) stwierdzono znaczny udział członu żelazawego (ponad 7% wag. FeO) oraz niewielkie domieszki BeO i  $Li_2O$  (tab. 1). Wyznaczono także (patrz tab. 1 oraz fig. 3–5) wzór krystallochemiczny i parametry komórki elementarnej badanego kordierytu, który reprezentuje odmianę pośrednią między wysoko- a niskotemperaturową. Odmiana ta wykazuje znaczny stopień zniekształcenia struktury sieciowej.

Na podstawie obserwacji mikroskopowych płytek cienkich (por. pl. 1–2) oraz badań inkluzji fluidalnych w kordierycie (por. fig. 6) stwierdzono, że pegmatyt z Zagórzca Śląskiego krystalizował w warunkach wysokotemperaturowego metamorfizmu związanego prawdopodobnie z procesami anateksis.

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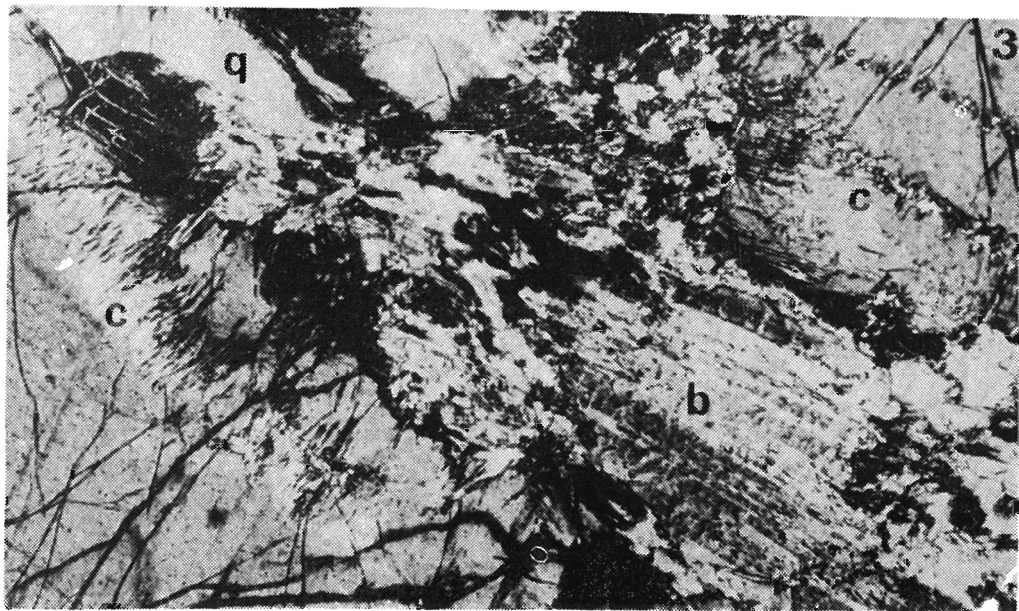
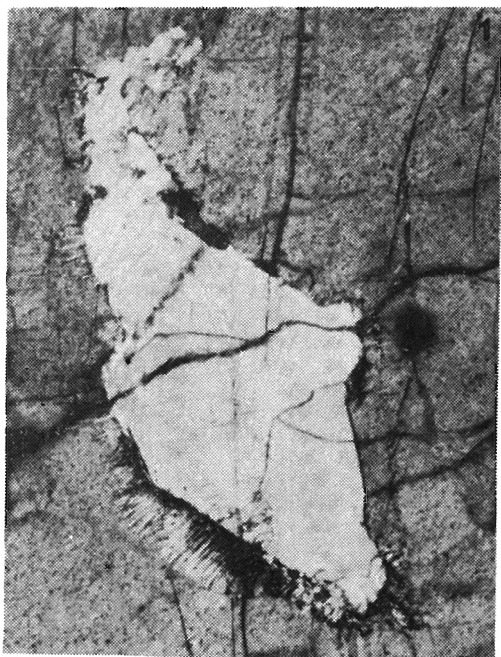


1 Cordierite with twinning according to (110); nicols crossed,  $\times 26$ .

2 Fractures in cordierite filled with aggregates of pinite; nicols crossed,  $\times 64$ .

3 Edge of the cordierite grain (c) corroded, and surrounded by chlorite; at the contact, quartz (q) is present; nicols crossed,  $\times 64$ .





1 Inclusion of quartz in cordierite (corrosion at the contact is visible); nicols sed,  $\times 75$ .

2 Fractures in feldspar filled with tourmaline (*t*); nicols crosse.,  $\sphericalangle 50$ .

3 Biotite (*b*) and quartz of the second generation (*q*) intersecting two grains of cordierite (*c*); nicols crossed,  $\times 50$ .