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HYDROTHERMAL ALTERATION ALONG THIN VEINLETS IN THE RØNNE GRANODIORITE

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Synopsis

The Rønne granodiorite constitutes the south-western part of the Precambrian of Bornholm. In places Rønne granodiorite is cut by thin and straight veinlets, which are about 1 mm wide, dark green in colour, and composed of epidote, chlorite, and sphene. The veinlets are bordered by a 1–2 cm wide zone of alteration, in which the normal dark grey colour of the Rønne granodiorite is changed to red. This change in colour is due to numerous minute grains of hematite or limonite finely dispersed through the feldspars. The iron necessary probably originated partly from alteration of some of the ilmenite content of the Rønne granodiorite to sphene, and partly from a change in the chemical composition of the primary biotite of the Rønne granodiorite. The zones of alteration also differ from unaltered Rønne granodiorite in having 2 % epidote in rather large grains, and in showing increased sericitization of feldspars, especially the potassium feldspar. The veinlets and the corresponding zones of alteration were probably formed by hydrothermal solutions.

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Introduction and field setting

The Rønne granodiorite is the darkest coloured and least silicic of the Precambrian granitic rocks of the island of Bornholm, which lies in the Baltic Sea and constitutes the south-eastern part of Denmark. Rønne granodiorite occupies the south-western part of the Precambrian of Bornholm. (Fig. 1).

The Precambrian of Bornhom has been thoroughly described by K. Callisen (1934) and more recently by H. I. Micheelsen (1961), but neither of these authors describes alterations along veinlets in Rønne granodiorite. These alterations however have been known for some time. Professor A. Rosenkrantz of the University of Copenhagen has collected some hand specimens clearly showing the alterations from quarried blocks in the quarry at Klippegård, but he has not seen these alterations in place in the granodiorite. In 1963 Professor H. Sørensen of the University of Copenhagen drew the author's attention to these alterations and suggested that a study of the alterations would imply the use of reflected-light microscopy. Therefore when the author was in Bornholm in June 1963 he visited the quarry at Klippegård. He collected a number of specimens for further investigation of the alterations, but did not succeed in finding the alterations in place in the walls of the quarry. However H. I. Micheelsen (personal communication) has seen this kind of alteration along veinlets in place in the Rønne granodiorite in a quarry situated somewhat south of Klippegård. He recorded the strike of the veinlets as N 175° E and their dip as 80° W. Although the strike of the veinlets is relatively consistent, the veinlets are somewhat wavy and often branch. The branches however soon take up the same direction as the veinlets from which they originated.

Macroscopic description of hand specimens

The Rønne granodiorite is a medium-grained rock with a dark grey colour. Except for a few centimetres nearest to the surface, where the rock is weathered and has attained a brownish-red colour, the Rønne granodiorite generally has a very fresh appearance.

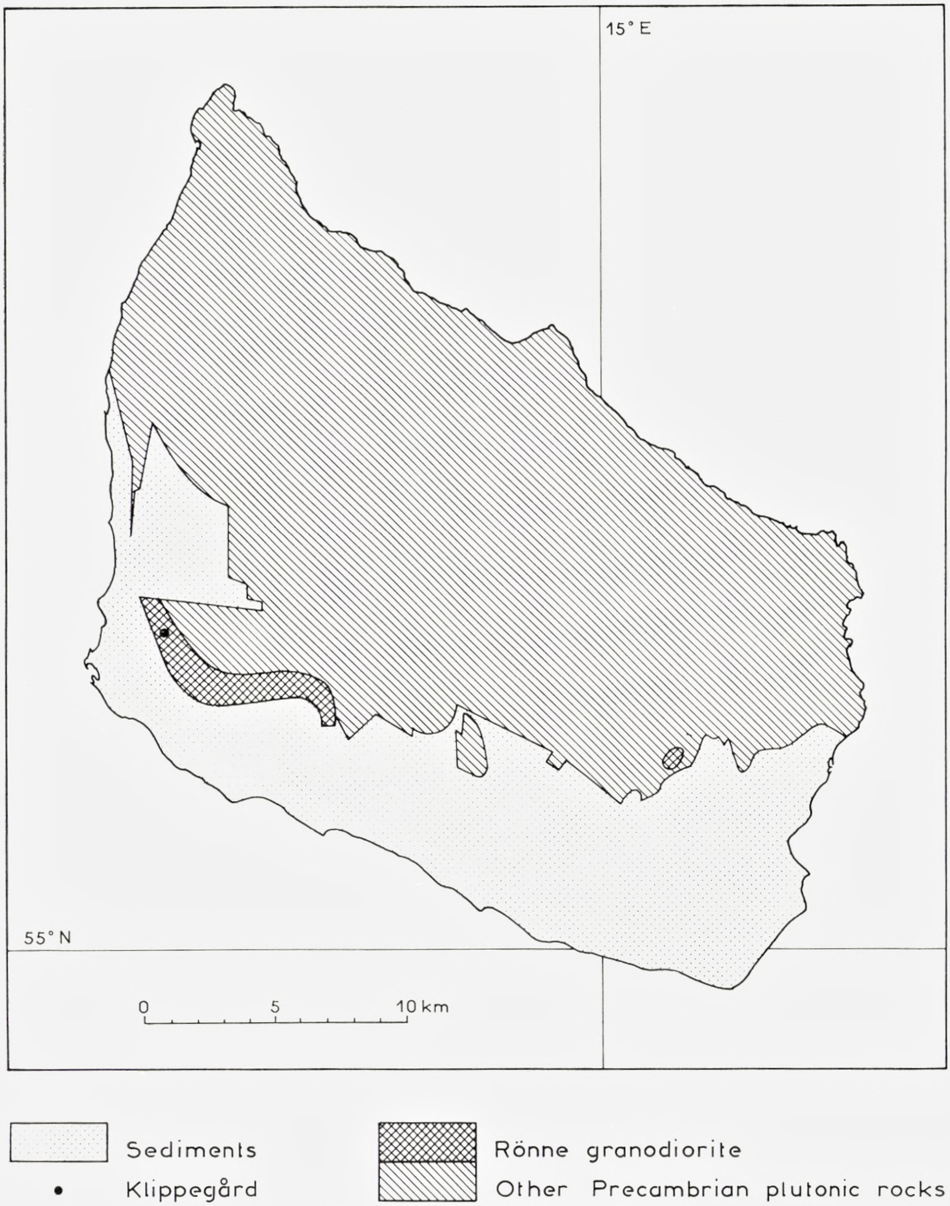

Fig. 1. Sketch map of Bornholm.

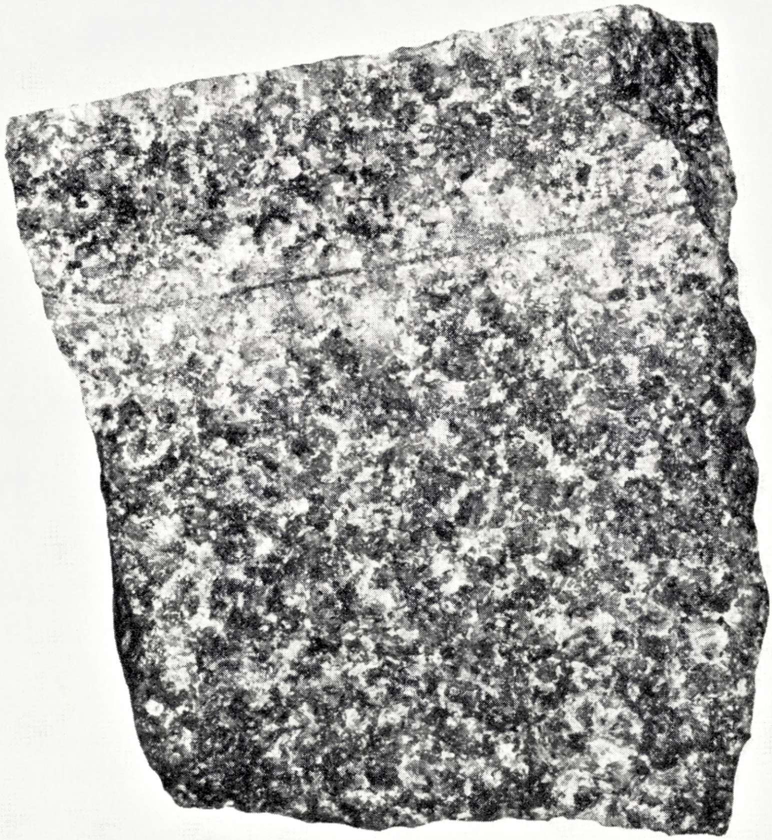

Fig. 2. Hand specimen showing the alteration. In the upper half of the figure can be seen a veinlet with adjacent zone of alteration. The upper surface of the specimen is broken along a veinlet, and part of the adjacent zone of alteration is therefore seen on top of the specimen. Natural size. C. Halkier phot.

The veinlets along which the Rønne granodiorite is altered have a very straight course in hand specimens. The width of these veinlets is constant and very close to 1 mm. Their colour is dark green. The veinlets are bordered by a zone of alteration in which the normal dark grey colour of the Rønne granodiorite is changed to red, and these altered zones have a certain superficial resemblance to pegmatites which are also found in the granitic rocks of Bornholm. The resemblance however is only due to similarity in colour between the zones of alteration and these pegmatites. There is no change in grain size between unaltered Rønne granodiorite and the altered zones. Closer study reveals that the change in colour has affected only the feldspar content of the rock, while quartz and the mafic minerals are unchanged in colour.

The width of the altered zones varies from about 1 cm to about 2 cm. The width is however not constant for any one veinlet, there being a considerable pinch and swell. The borders of the altered zones are not sharp but diffuse, and the zone of alteration grades imperceptibly into unaltered Rønne granodiorite. (Fig 2).

In the hand specimens the distance between two adjacent veinlets may be as little as $2^1/_2$ cm so that the corresponding zones of alteration are separated by only $^1/_2$ to 1 cm of unaltered rock.

Microscopic description of thin- and polished sections

The mineralogical composition of the Rønne granodiorite places the rock near the border between granite and granodiorite, potassium feldspar and plagioclase being present in about equal amounts, but with the plagioclase, which is an oligoclase averaging 28 $^0/_0$ An, just slightly predominating. The mode of Rønne granodiorite is shown in the table below.

The veinlets along which the Rønne granodiorite has been altered are filled with epidote, chlorite, and sphene. Epidote is the main component and constitutes about 75 $^0/_0$ of the vein material. The epidote grains may reach a size of 0.4×0.2 mm, but are generally considerably smaller. Chlorite and sphene amount to about 20 $^0/_0$ and 5 $^0/_0$ respectively. Along part of their course the veinlets are sometimes bordered by a narrow zone of fine-grained quartz, the average diameter of the quartz grains being about 0.02 mm. (Plate 1, Fig. 1). This zone of fine-grained quartz is however absent along the margin of some of the veinlets.

The composition of the red-coloured zones of alteration adjacent to the veinlets has been determined by point counting. The results found are in good agreement with the composition of unaltered Rønne granodiorite found by Micheelsen (1961). Micheelsen's values for unaltered Rønne granodiorite and the values for the zones of alteration determined by the author are given in the table below:

	Rønne granodiorite	Zones of alteration
Potassium feldspar	29 %	$29^1/_2$ %
Plagioclase	30 %	30 %
Quartz	21 %	$21^1/_2$ %
Hornblende	10 %	$8^1/_2$ %
Biotite	5 %	$4^1/_2$ %
Ore minerals	3 %	2 %
Sphene	1 %	1 %
Apatite	1 %	1 %
Epidote	0 %	2 %
	100 %	100 %

The most striking difference is the appearance of 2 % epidote in the altered zones. Epidote is a mineral which is generally lacking in unaltered Rønne granodiorite, although a few small grains may occasionally be found in the cores of sericitized plagioclase. Very minute crystals identified by the author as epidote can also be found as inclusions in quartz and more rarely in feldspars (see p. 9). Larger grains of epidote are never found in unaltered Rønne granodiorite, but in the zones of alteration may attain sizes exceeding 0.1×0.05 mm. In the zones of alteration epidote is found in both plagioclase and potassium feldspar, as well as in hornblende and along the grain boundaries of all the minerals present in the rock. However epidote is somewhat more abundant in plagioclases.

The differences in amounts of the minerals present in both unaltered and altered Rønne granodiorite are not in excess of what must be expected from two different samples of even the most homogeneous of rocks.

Although there is no significant difference in the amount of biotite between unaltered and altered rock, there is a difference in the appearance of the mineral. In unaltered Rønne granodiorite the biotite shows pleochroism from yellowish-brown to brownish-black and almost opaque. In the altered zones the biotite has changed to yellow in the lightest position and dark green and more translucent in the direction parallel to the cleavage traces. This indicates that the iron content of the biotite has decreased.

Sericitization of feldspars is generally only incipient in the altered zones, although the feldspars always have a somewhat cloudy appearance, and more pronounced sericitization may be found, especially in the cores of plagioclases. With respect to the plagioclase there is no great difference from unaltered Rønne granodiorite, where rather strong sericitization can also be found in the cores of plagioclases. The potassium feldspar however is clearly more affected by sericitization in the altered zones than is the case in unaltered Rønne granodiorite, where the potassium feldspar is generally completely fresh.

The most abundant of the ore minerals in Rønne granodiorite is ilmenite. The appearance of the ilmenite, greyish-brown colour, strong anisotropy, reflection pleochroism, and the lack of internal reflections, indicates that the composition is rather close to pure $FeTiO_3$. In unaltered Rønne granodiorite some ilmenite grains are surrounded by a thin rim of sphene, and occasionally a somewhat more advanced alteration of ilmenite to sphene is seen. The majority of the ilmenite grains in unaltered Rønne granodiorite however do not show a relationship with sphene.

Compared with the unaltered Rønne granodiorite the altered zones have a more pronounced alteration of ilmenite to sphene. Most of the ilmenite grains have at least a partial rim of sphene, and often the ilmenite grains show more advanced alteration to sphene. Immediately adjacent to the veinlets ilmenite grains are seen to be almost completely altered to sphene, so that only small ilmenite islands are left as replacement remnants in the sphene. (Plate 1, Fig. 2).

Although the stronger alteration of ilmenite to sphene in the altered zones might at first suggest correlation with the change in ore content from 3 % in unaltered Rønne granodiorite to 2 % in the zones of alteration, the difference in ore content in the countings is believed to be casual and not to reflect the increase in alteration of ilmenite. This view is strengthened by the fact that the decrease in ore content is not balanced by a corresponding increase in the sphene content.

None of the differences between unaltered and altered Rønne granodiorite so far described could account for the macroscopic change in colour from dark grey to red. In the search for a reason for this change in colour notice was paid to some long and very thin needles rather frequently found in quartz. The needles are arranged in three directions, often making angles of about 60° with each other. The length of the needles may exceed 75 μ while their width is less than 1 μ. Partly because of the extremely small width, and partly because the needles in polished sections have always been found in positions making angles with the polished surface, it is not possible to give an adequate description of the needles. They appear dark in thin sections and are luminous white in polished sections. These needles are believed to be rutile. Such rutile-like needles are found both in unaltered and altered Rønne granodiorite and they do not seem to influence the colour of the quartz, as the quartz in Rønne granodiorite, altered or unaltered, is completely colourless. Rutile-like needles are shown in Fig. 1 of Plate 2.

Careful inspection reveals that rutile-like needles are not only found in quartz but occasionally also in potassium feldspar. This applies to both altered and unaltered rock. In potassium feldspar however, the needles are not so numerous as they are in quartz. They are more irregularly distributed and not confined to three directions.

Rutile-like needles are not the only inclusions found in quartz. Some well-developed but very minute crystals, the size of which is about $1 \times 2^1/_2\ \mu$, are also frequently visible. These minute crystals however are generally arranged in pearl-like stringers, often with en echelon pattern. The length of the stringers is of the same order of magnitude as the needles, and like the needles the stringers are also arranged in three directions, often making angles of about 60° with each other. In transmitted light these minute crystals show a high relief and are almost colourless but with a yellowish or greenish tint. In addition to these minute grains there are also grains somewhat larger than $1 \times 2^1/_2\ \mu$ found as inclusions in the quartz. These larger grains are more heavily coloured in brownish or greenish tints and are identified as epidote. The author considers that the minute grains are also epidote, but the extremely small grain size does not permit precise identification. The very minute and the slightly larger grains are present as inclusions in the quartz of both altered and unaltered Rønne granodiorite. The much larger epidote grains with a size of 0.1×0.05 mm referred to on page 7 are present only in the altered zones.

The well-developed crystal form of the minute epidote grains is especially pronounced in polished sections, because the relations here are not blurred by the third dimension. These epidote stringers are very beautiful in polished sections because they are accompanied by strong Newtonian colour phenomena. (Plate 2, Fig. 2).

The minute crystals of epidote occur in both altered and unaltered Rønne granodiorite, and are present not only in quartz, but also in feldspars, potassium feldspar as well as plagioclase. In feldspars however the arrangement in pearl-like stringers is generally lacking and is never so pronounced as in quartz.

These inclusions have been observed already by Callisen (1934). On p. 25 under the description of quartz in Rønne granodiorite she states: "Häufig findet man kleine, feste, braunviolette oder dunkelbraune Körper mit guter Kristallbegrenzung, welche — nach dem meistens hexagonalen Querschnitt, der hohen Lichtbrechung und dem Fehlen des Pleochroismus zu urteilen — aus Titaneisen bestehen. Im Basisschnitt erscheinen sie als zierliche Perlenreihen, die sich unter einem Winkel von 60° schneiden." And p. 26 under the description of potassium feldspar in the Rønne granodiorite Callisen says: "Kleine Blätter aus Titaneisen und dünne dunkle Nadeln, die nicht genauer bestimmt werden können, kommen ziemlich oft vor, wenn auch bei weitem nicht so zahlreich wie im Quarz."

The difference in the colour descriptions is easily explained as a result of the progress in manufacturing of polarizing microscopes since 1934. It is however difficult to understand why Callisen called these grains ilmenite when it was possible in transmitted light to observe the absence of pleochroism and the high refractive index of the grains. While the present writer's opinion that these minute grains are epidote might be open to some discussion because of the extremely small grain size, there is no doubt that the grains are translucent and not opaque.

Small opaque grains of Fe-Ti-oxides can be found in the hornblende and the biotite of both altered and unaltered Rønne granodiorite, but in unaltered Rønne granodiorite the quartz and feldspars generally are without opaque inclusions except for the rutile-like needles. Occasionally however, especially along fine cracks cutting through quartz or feldspar grains, some red internal reflections indicate the presence of minute grains of hematite or limonite.

In strong contrast to this general absence of opaque inclusions in the quartz and feldspars of unaltered Rønne granodiorite, most of the low-reflecting, translucent mineral grains in the altered zones are in reflected light seen to be peppered with small white spots. These spots are about 1 μ in diameter, and are surrounded by a halo of red internal reflections. It is considered that these small grains are composed of hematite or limonite. Because of the extremely small grain size it is impossible to distinguish between hematite and limonite. It is obvious however that the reason for the red colour of the feldspar in the altered zones lies in the presence of these small grains.

Several attempts have been made to prepare polished thin sections of the material, but all were unsuccessful as the sections became perforated by numerous holes before polishing was attained. Unfortunately therefore it is not possible to state anything about the distribution of these inclusions between plagioclase, potassium feldspar, and quartz. However as not all of the low-reflecting, translucent grains carry these inclusions surrounded by red internal reflections, and as the quartz macroscopically is completely colourless it is believed that the inclusions do occur only in the feldspars.

Conclusions

It is considered that hydrothermal solutions advancing along steep joints in the Rønne granodiorite have transformed the joints to veinlets about 1 mm wide filled with epidote, chlorite, and sphene, and caused the formation of a 1–2 cm wide zone of alteration along these veinlets.

In the zones of alteration a relatively large amount of epidote has been introduced. This epidote occurs in rather large grains in contrast to the minute crystals of epidote already present in unaltered Rønne granodiorite. The hydrothermal solutions have also caused a certain increase in sericitization of feldspars, especially the potassium feldspar, and have changed the colour of biotite in such a manner as to indicate that iron has been released from the biotite.

The solutions have also resulted in a much stronger alteration of ilmenite to sphene than is usually found in unaltered Rønne granodiorite. The Ti and Fe released by this alteration, and the Fe released from the alteration of biotite, might to some extent have migrated towards the veinlets, but probably most of the Fe was caught on the way through the feldspars, resulting in the formation of minute inclusions of hematite or limonite, which cause the red colour of the zones of alteration.

Acknowledgements

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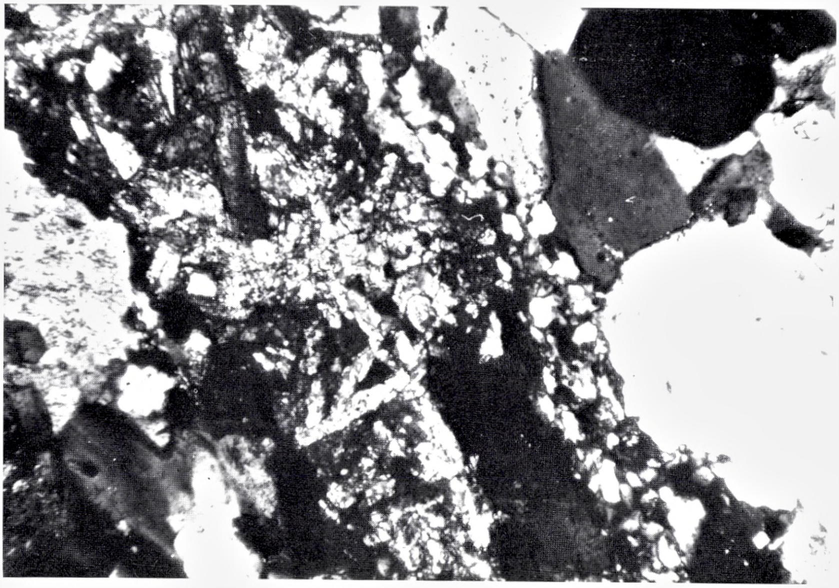

Fig. 1. Transmitted light, crossed polars. ×150.
NW–SE across the picture can be seen an epidote-, chlorite-, and sphene-filled veinlet. Towards NE the veinlet is bordered by a narrow zone of fine-grained quartz.

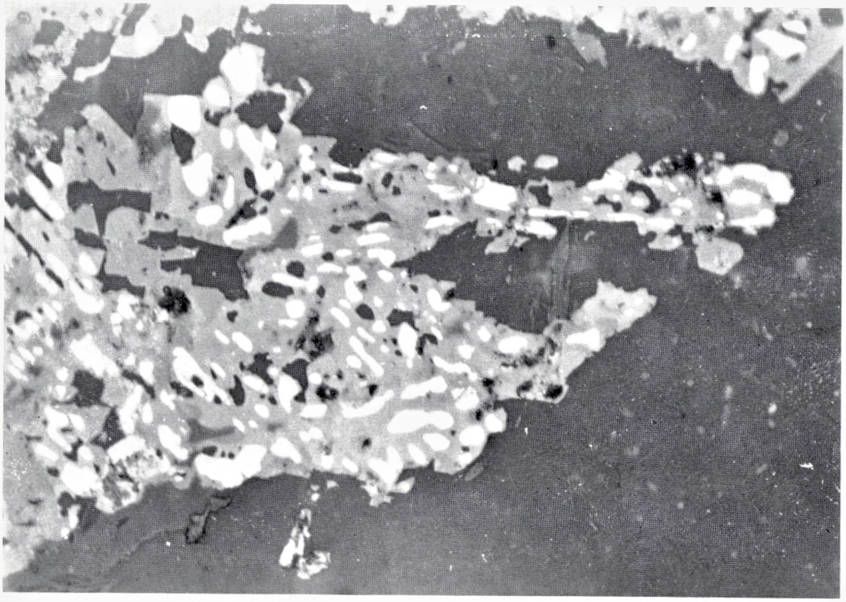

Fig. 2. Reflected light, polariser only. ×220.
Former grain of ilmenite adjacent to veinlet. The ilmenite is strongly altered to sphene, so that only small ilmenite islands are left as replacement remnants in the sphene.

Fig. 1. Reflected light, polariser only. ×800. Oil immersion.
Rutile-like needles arranged in three directions in quartz.

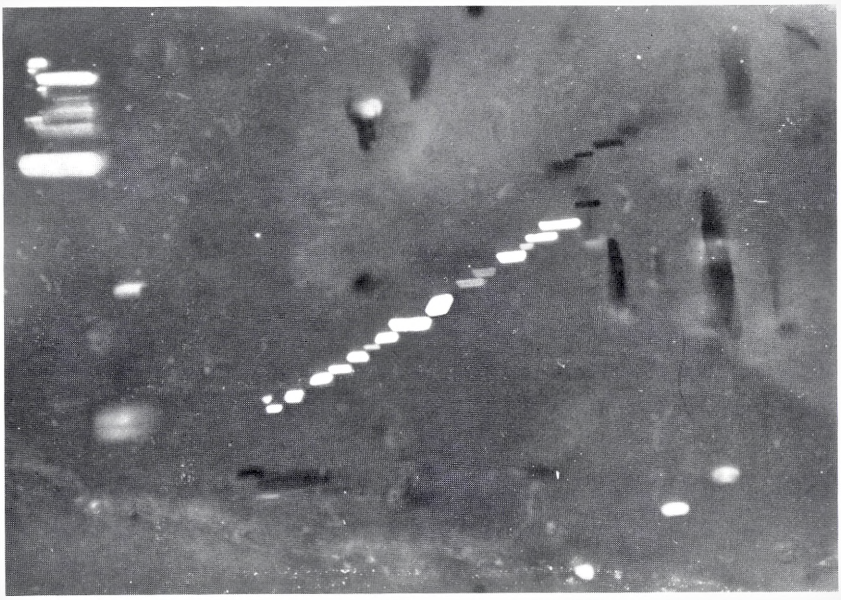

Fig. 2. Reflected light, polariser only. ×800. Oil immersion.
Pearl-like stringer of minute epidote crystals arranged en echelon in quartz.