NORSK GEOLOGISK TIDSSKRIFT 46

FAULT VEIN MINERALIZATION AS THE RESULT OF SHEARING IN NORWEGIAN BASEMENT ROCKS

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Abstract. A study has been made of a mainly quartz-epidote-clinochlore vein mineral assemblage associated with a tear fault affecting southern Norwegian basement gneisses. It is concluded that retrogressive shearing breakdown of the gneiss mineralogy resulted in the liberation of chemical components, which largely contributed to the vein mineral assemblage developed in nearby joints.

Introduction

The vein mineralization herein discussed has been described from a part of the Hestbrepiggan area. This area lies immediately to the north of Höydalen in Böverdalen in the northern part of the Jotunheim mountains, South Norway (latitude and longitude on Fig. 1; see also Banham and Elliott 1965, Fig. 1).

The Hestbrepiggan area consists of an essentially granitic and gneissose basement, the Basal Gneisses of Norwegian literature. To the southeast, the gneisses are overlain by metasedimentary, Eocambrian-Silurian rocks whose contact with the gneisses is a thrust unconformity.

Before the deposition of the lower Palaeozoic sediments, the Basal Gneisses had been deformed (N-S pressures) and metamorphosed in the almandine-amphibolite facies. During a later (Taconic) period of deformation (NW-SE pressures), both sediments and gneisses were metamorphosed in the greenschist facies (quartz-albite-epidote-almandine sub-facies). Then followed an important (Svalbardian?) period of brittle deformation (N-S pressures, again), and retrograde metamorphism (quartz-albite-muscovite-chlorite sub-facies) occurred in association with tear faults and thrusts in both the Basal Gneisses and the overlying metasediments.

The most important dislocation of this date occurred along the 40° striking, Breidalen Tear Fault (see Fig. 1). This fault cuts the metasediments in the western part of the area, but its effects are mainly seen in the Basal Gneisses, where it possibly follows a plane initiated at the close of the main Precambrian deformation.

In detail, there is no simple fault plane, but a shear zone, up to 1200 m wide, within which the fundamental acid gneisses have been intensely deformed, a new foliation developed, and pronounced retrograde metamorphism has occurred. Furthermore, throughout the Basal Gneisses occur minor shear zones and joints whose orientations and displacements suggest that they are second and third order shears dependent upon the first order Breidalen tear fault. It is within such joints marginal to the main shear zone that quartz, epidote, clinochlore, etc. mineralization has occurred.

Faults and joints

The pattern of fractures developed in the Hestbrepiggan area is rather complex and will be the subject of a more detailed study at a later date.

Although there is some evidence that many fractures were initiated during earlier periods of deformation, it is certain that the vast majority were produced by, or were reactivated during, the last phase of brittle deformation. The key to the fracture pattern lies in the presence of faults whose sense of movement is detectable. That the Breidalen tear fault is sinistral is indicated not only by the large

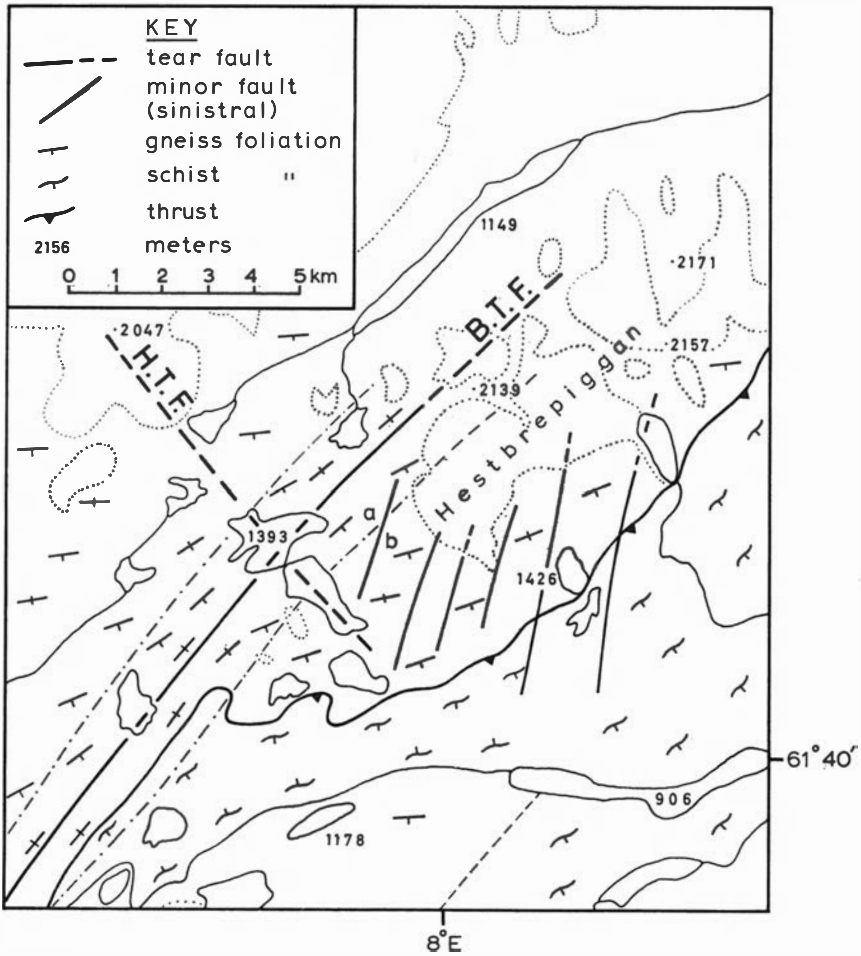

Fig. 1. Outline geological map of a portion of the Hestbrepiggan area. Ornament: B.T.F. — Breidalen tear fault; H.T.F. — Hålåtinden tear fault; a and b are sample localities (see Fig. 4); the approximate limits of fault/vein mineralization are shown by dash and dot lines; dotted lines are glacier limits.

scale sinistral rotation of the gneissose foliation (Fig. 1), but also by steeply plunging, overturned folds within the shear zone. The presumed complementary dextral shear, the 140° striking Hålåtinden tear fault on the other hand, shows little evidence of rotation or dislocation.

Apart from these major structures, however, there are minor shear zones from a few cm to tens of metres wide. One set in particular is developed in massive granite immediately to the south of the Breidalen tear fault, strikes at roughly 15° and has a sinistral sense of displacement. Using the experience and terminology of McKinstrey (1953) and Moody and Hill (1956), it is possible to construct on the basis of this evidence an hypothetical scheme of all possible first, second, and third order shear directions (see Fig. 2).

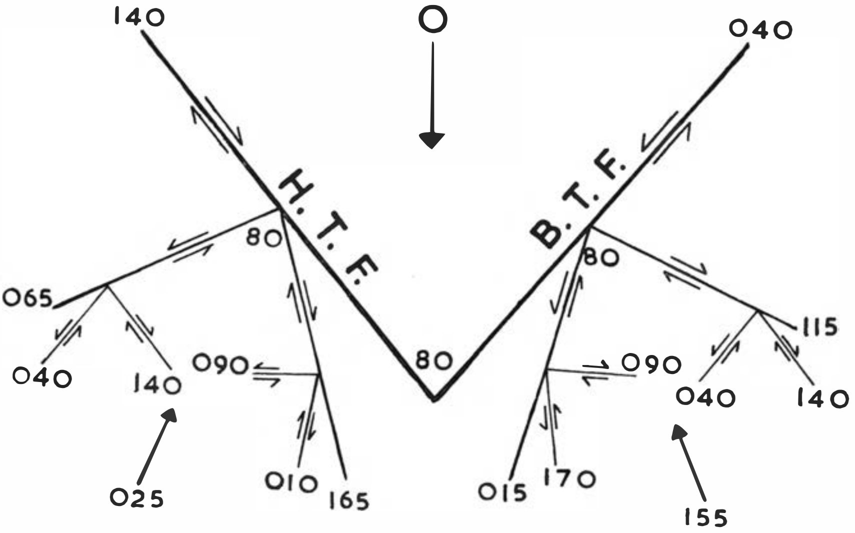

Fig. 2. Hypothetical system of first-third order shears based on the mapped sinistral Breidalen tear fault (B.T.F.) and 015° trending faults and joints and the (dextral) Hålåtinden tear fault (H.T.F.).

The joint directions actually measured (100 at each of 37 localities, to date) fulfil predictions to a satisfactory extent, particularly in view of the long and complex structural history of the area. The full results of this survey will be presented when completed; it is sufficient here to note the directions of the vein bearing joints (see Fig. 3) and their resemblance to the hypothetical scheme.

From this study, it may reasonably be concluded that vein mineralization in the region of the Breidalen tear fault occurred during

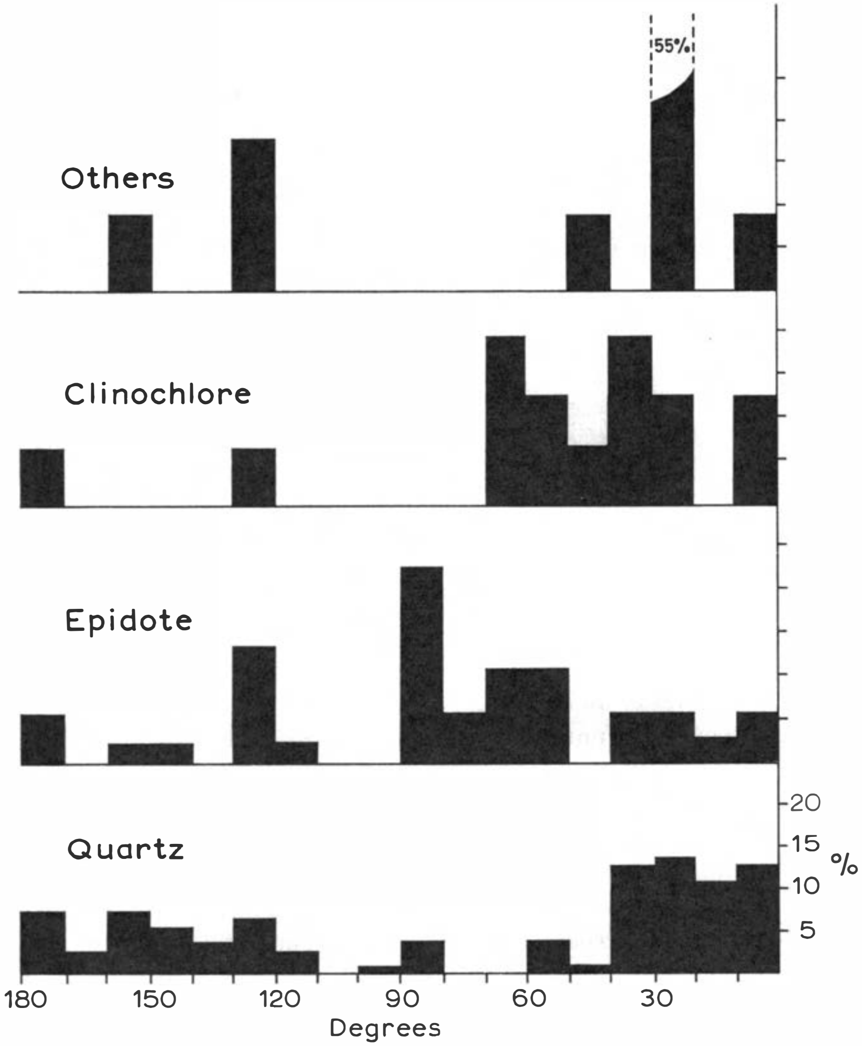

Fig. 3. Orientation of joints bearing vein minerals. Certain directions are evidently preferred, and these may at least tentatively be correlated with the hypothetical directions (Fig. 2), especially if allowance is made for the local deviations obscured in a general diagram.

or after the latest movement along that fault and its associated second and third order shears.

Vein mineralization

The three most important minerals within this type of vein are, in order of importance, quartz, epidote,* and clinochlore.* Other minerals that occur to a much lesser extent are: magnetite, muscovite, pyrite, galena, pink garnet, and stilbite.* These minerals are to be found mainly within veins in two zones up to 800 m wide on either side of the Breidalen tear fault (see Fig. 4, a and b).

Joint/Vein	a(%)	b(%)
Clear joints	28	88
Quartz.................	45	11
Epidote	14	tr
Clinochlore	5	1
Others	8	nf
	100	100

Fig. 4. Incidence of joints and vein minerals at two localities; (a) within fault-veined zone, and (b) a short distance outside; see map, Fig. 1. Over 100 joints investigated at each locality.

Quartz, epidote, and clinochlore occur either as single or multiple veneers upon the joint faces already described. The other minerals occur either as scattered single crystals (magnetite, garnet, galena, for example) or as small pockets (muscovite, magnesite, stilbite, for example).

There would seem to be two possible interpretations of the areal distribution of this late phase of vein mineralization. First, and in perhaps the most orthodox way, it may be supposed that veins have resulted from the activities of 'mineralizing agents', which possibly arose from some late intrusion up the plane of the fault. Against this hypothesis, it may be said that no late intrusions are observable in the fault zone and, furthermore, that the tear fault is not a readily penetrated zone of weakness, but is rather a region where intense compaction has occurred. The mineralization in question occurs immediately outside the shear zone, it will be recalled; although joints up which agents of igneous source could have penetrated are by no means restricted to the vicinity of the tear fault.

* Identifications confirmed by X-ray photography (powder method).

Secondly, it may be supposed that vein mineralization is penecontemporaneous with, and the direct consequence of, shearing and retrograde metamorphic reactions in the region of the Breidalen tear fault during the last phase of brittle deformation in the area. The nature of this retrograde metamorphism is thus of some consequence.

Retrograde metamorphism associated with the Breidalen tear fault

The granites and gneisses of the Hestbrepiggan area consist essentially of quartz, alkali-felspars, and biotite, with secondary muscovite, epidote, and chlorite (modal analyses, Fig. 5). Within the gneisses, there are several small pods of amphibolite, which consist essentially of hornblende, biotite, and epidote. The general E-W foliation of the gneisses is best defined by the planar arrangement of biotite grains and aggregates. Towards the Breidalen tear fault, this foliation is sinistrally rotated (about a steep axis) until, within the shear zone, it becomes dislocated along increasingly numerous, muscovite-bearing planes which form a new foliation parallel to the plane of the fault.

Mineral	1	2	3	4	19	20	21	22	91	77
Quartz	34	38	nf	43	47	56	47	46	22	39
K-felspar	38	18	nf	18	15	17	15	26	19	18
Plagioclase.......	15	13	2	13	10	17	3	17	7	25
Biotite	6	18	11	5*	9*	5*	3*	2*	6*	3*
Muscovite	3	3	nf	20	18	4	32	9	42	12
Epidote	4	10	4	tr	nf	1	nf	nf	3	2
Hornblende	nf	nf	83	nf	nf	nf	nf	nf	nf	nf
Magnetite	tr	tr	tr	tr	tr	tr	nf	tr	1	1
	100	100	100	99+	99+	100	100	100	100	100

Fig. 5. Modal analyses of basement and fault zone lithologies (conducted after the manner of Chayes 1956). Standard deviation = 2.45 or less per analysis.
1. Average of 16 foliated granite samples
2. Average of 11 biotite gneiss samples
3. Unaltered amphibolite (sample 7)
4. Average of 6 sheared, schistose gneisses

19–22, 91, 77. Individual analyses of schistose gneisses

* biotite heavily chloritized.

In the outer parts of the shear zone, 'knots' of quartzo-felspathic material are surrounded by a muscovite and quartz matrix. Towards the central part of the shear zone, these knots decrease both in number and size, and the rock becomes proportionately enriched in muscovite and quartz. The replacement of felspars by muscovite is clearly shown in microscope section. Also, the proportion of perthitic albite within the alkali felspar increases with deformation (cf. CHAYES 1952), as does the incidence of microcline twinning. At the presumed region of maximum shear, no felspar or biotite remain, and bands of muscovite schist alternate with contorted lenses of quartzite.

Within the shear zone in upper Breidalen, there are rocks consisting of muscovite, chlorite, magnetite, and calcite in the main, with cataclastic inclusions of quartzo-felspathic material. It is suggested that these muscovite-chlorite schists represent the sheared equivalents of the amphibolite pods already noted in the unsheared gneisses. During the production of these low grade, sheared, simplified, platey, and banded rocks from the Basal Gneiss lithologies, several reactions must have occurred and certain chemical components lost from the system. It is suggested on the basis of field and petrographic studies that the following reactions moved from left to right, in approximate order of increasing shear:

1) 3 K-felspar + 4 (OH) → Muscovite + 4K + 12Si
2) 1.6 Biotite + 1.6 (OH) → Chlorite + 6.4K + 1.6Al + 6Si
3) 2Ab + K-felspar + 6 (OH) → Muscovite + 4Na + 12Si
4) 2An + K-felspar + 6 (OH) → Muscovite + Epidote + Si
5) 3Biotite → Muscovite + 4K + 15 (Mg, Fe) + 8 (OH) + 12Si
6) 2 Biotite + Epidote → Muscovite + 2K + 10 (Mg, Fe) + 2 (Ca, Fe) + 6 (OH) + 15Si

and, possibly, in regions of extreme shear, muscovite dissociates:

7) Muscovite → 6Si + 2K + 6Al + 4 (OH)

Although reactions 5–7 produce water, its volume would be very largely limited by the low initial biotite mode, and to satisfy reactions 1–4 additional water must have entered the system.

The excess cations (Si, Al, Mg, Fe, Ca, K, and Na) liberated by reactions 1–7 are believed to have been lost from the system and to have contributed largely to the vein minerals found within joints outside the shear zone. (Na and K do not enter into the vein minerals in appreciable amounts. K migration probably resulted in the commonly observed, late stage, slight enlargement of K-felspar grains and marginal replacement of quartz in the granitic gneisses. Similarly, Na may have contributed to the large volumes of albitic 'perthite' lamellae and rims of the alkali felspars, particularly those near the shear zone. It should perhaps also be noted here that a large proportion of 'excess' Si must have been fixed within the many sheared quartzite bands within the shear zone itself.)

Vein petrogenesis

In terms of ions, the three main vein minerals (quartz, epidote, and clinochlore) consist of Si, Al, Fe, Ca, Mg, and OH; that is, precisely those cations liberated by reactions 1–7 in the shear zone, together with hydroxide anions. The vein minerals of lesser importance also consist mainly of one or more of these freed cations, plus C, S, and Cl (magnesite, pyrite, galena, and stilbite; oxygen is assumed to have been everywhere available).

The rough chemical balance appears to be reasonably good; it is felt that the number of variables prevents more than a qualitative study of chemical gains and losses, although note has been taken of variations in vein mineral abundances alongside differing lithologies within the shear zone. In particular, it is noticeable that in the vicinity of the chloritic, ore-rich schists of upper Breidalen the vein minerals show a local predominance of epidote and clinochlore. There can be little doubt that shearing breakdown of basic amphibolites has caused an increase in the amounts of Ca, Mg, and Fe, especially, locally available for vein mineral formation.

The possible method of transfer of chemical components from the shear zone to joints in the surrounding rocks requires some comment. Certainly, the mineralizing agents were very penetrative; minute veins often infil joints to the extent of several metres, but may not exceed 2 mm in thickness throughout. Further, mineralization occurs up to 800 m from the shear zone, although minor shears have almost certainly contributed to local veins. Again, vein mineral crystals are usually very fine (under 1 mm), although crystals of the main minerals occasionally exceed a few mm.

There is no evidence for large bodies of mobile mineralizing material; even distribution of vein minerals is the rule. Moreover, the host rock in the vicinity of veins shows little or no alteration, such as might occur if large volumes of hot, wet materials had passed along the joints. It is suggested, conversely, that chemical components were transferred from the shear zone to veins in surrounding rocks by particular diffusion promoted by the shearing gradient and perhaps assisted by the presence of small quantities of various volatile phases.

Conclusion

A vein mineral assemblage consisting mainly of quartz, epidote, and clinochlore occurs within joints in gneisses on either side of the Breidalen tear fault shear zone. Felspathic, biotitic, and amphibolitic gneisses near the fault have been sheared and retrogressively metamorphosed to muscovite, chlorite quartz rocks. It is believed that the chemical components so liberated contributed largely to the vein mineral assemblage found immediately outside the shear zone.

Addendum

During July and part of August, 1965, the writer was enabled by a generous grant from Norges Geologiske Undersøkelse, here gratefully acknowledged, to visit many localities in the NW Basal Gneiss Area of southern Norway. Both late stage shearing and superficial joint-veins (bearing large proportions of quartz, epidote, clinochlore, etc.) were noted as being widespread. It is at least possible that these phenomena are genetically related, as they appear to be in the Hestbrepiggan area.

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PLATE 1

Fig. 1. Epidote and quartz intergrown on a joint face in Breidalen vein mineral zone. × 1.15.

Fig. 2 Muscovite (foliation) cutting biotite (foliation) (length of plate 2.5 mm). Breidalen shear zone.

Fig. 3. K-felspar cut by shear bearing muscovite (length of plate 3 mm). Breidalen shear zone.

Fig. 4. Plagioclase cut by shears bearing muscovite (length of plate 2 mm). Breidalen shear zone.


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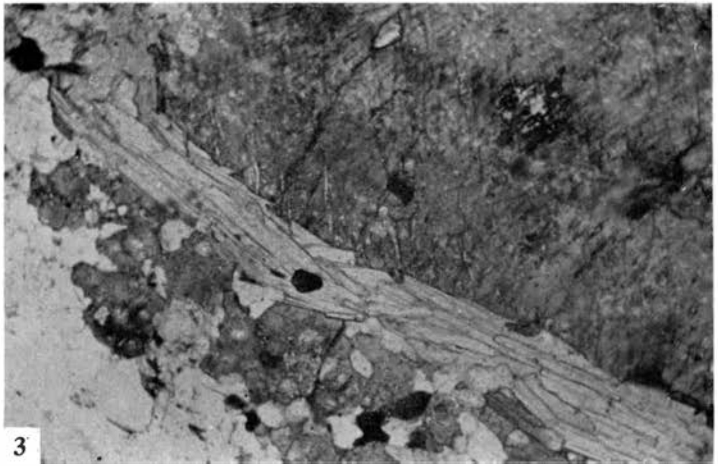
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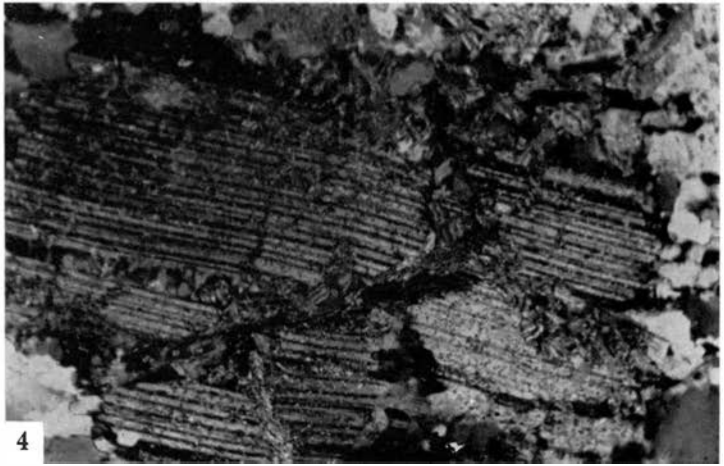
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