SCHISTOSITY OF CUTTING PEGMATITES AND ITS RELATION TO THE FOLD PHASES IN SÄLSÖ, SOUTHWESTERN FINLAND

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Cutting pegmatites with a schistosity parallel to the axial plane of the folds in the surrounding gneisses have been studied on Sälsö, Sottunga commune, one of the Åland islands in southwestern Finland. The schistose pegmatites probably formed at the culmination of an orogenic phase when the strain reached the point of fracture of the gneisses. Pegmatite material then filled the opening joints and crystallized under the same stress that folded the country rock.

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Introduction

During field work on Sälsö, Sottunga commune, one of the Åland islands in southwestern Finland, Lennart Laurén observed sharply cutting pegmatites that contained longish magnetite aggregates oriented parallel to the axial plane of the folded country rocks (Laurén 1968, 1969). He suggested the following alternative explanations for this puzzling occurrence; he did not discuss it in detail, however, because he was principally concerned with the origin of the magnetite in the pegmatites. He wrote (Laurén 1969, p. 112): »It is very improbable that the folding (and the development of the axial foliation) occurred after the formation of the pegmatite. A more plausible explanation is that the magnetite grains have grown along an axial plane direction which existed before the pegmatite. Another possibility is that the leptite gneiss was first folded. Then the pegmatite began to form, but the deformation continued with the same stress directions, causing an orientation of the magnetite grains. This explanation presumes a very constant direction of the stress field during a considerable elapse of time, which to the author seems rather unlikely».

While studying the problem in the summer of 1974, I found that the schistosity of the cutting pegmatites is often almost parallel to the axial plane of the folds in the country rock and thus might throw some light on the geological evolution of the area. A paper discussing the subject was read at Gothenburg in 1976 (Edelman 1975).

Outline of the geology

The Sälsö area consists of Precambrian rocks, principally highly metamorphic gneisses, amphibolites, and different types of

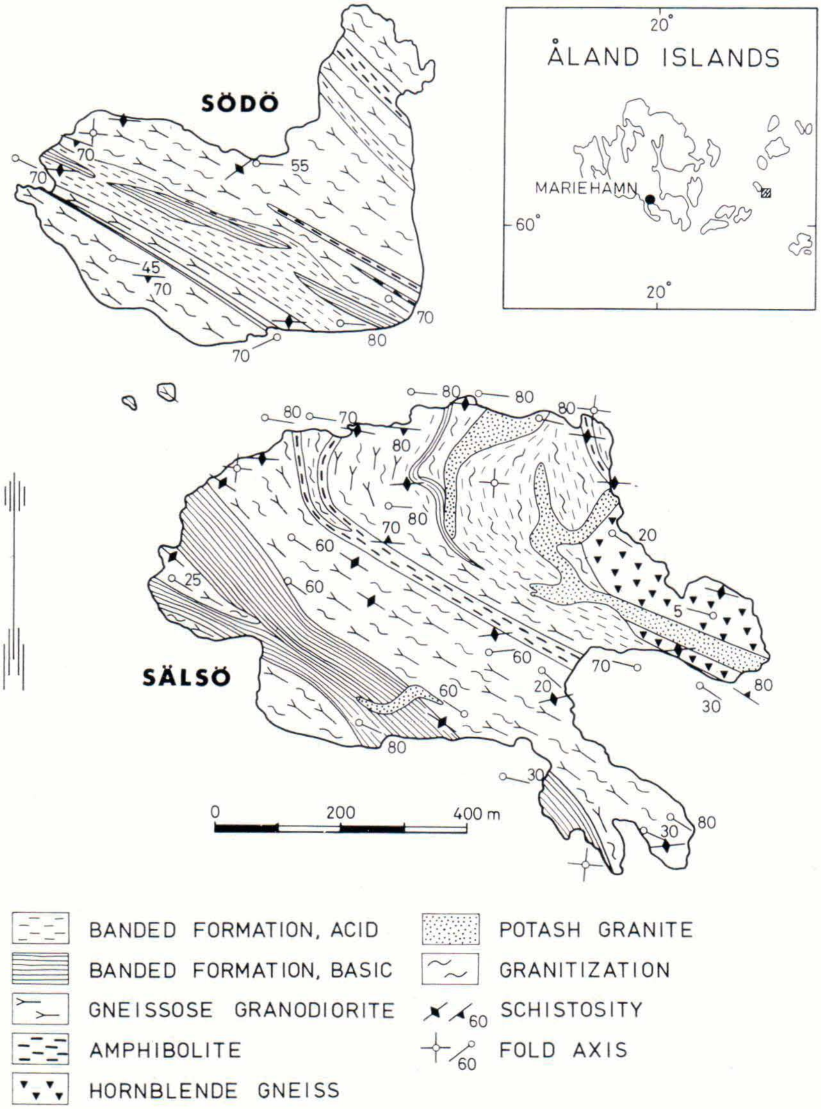

Fig. 1. Geology of the Sälsö area according to Laurén (1969) completed with structural observations.

granitic and granodioritic rocks (Fig. 1). They form zones striking about 120° (counted clockwise from the north) with a large Z-shaped fold in the northern part of Sälsö. The main rocks — gneisses and amphibolites — are commonly intermingled and form banded formations that in many places are veined and granitized. Lenses and zones of gneissose granodiorite are common but their origin is obscure. Some of them seem to be recrystallized paragneisses but others may be magmatic rocks genetically associated with a few small hornblende gabbros not marked on the map. The gneissose granodiorites are commonly granitized.

Potassium granites form longish or branching intrusives with sharply cutting contacts. Irrespective of the direction of the contacts, they have a schistosity or a lineation striking about 90°. In thin section they show

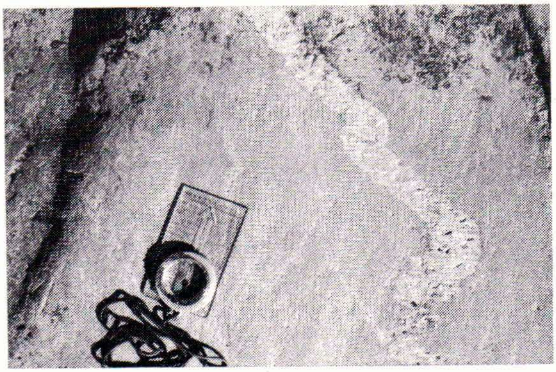

Fig. 2. Pegmatite dyke with feldspar laths striking east or parallel to the axial plane of the folds. Small notches in the contacts show minute displacements along axial plane joints. Northeastern part of Sälsö.

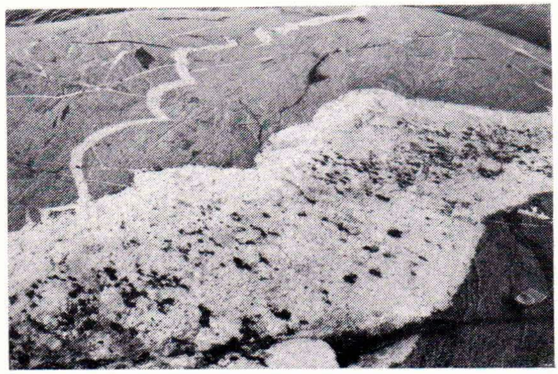

Fig. 3. Pegmatite with magnetite aggregates (black spots) parallel to the axial plane striking east. In the curved branch the feldspar laths have the same attitude as the axial plane. Skerry west of Sälsö outside the map in Fig. 1.

granulated zones and biotite flakes oriented in parallel, indicating that they consolidated under stress.

Several types and generations of pegmatites are present. One of the pegmatites is cut by a microcline granite with a distinct lineation and is hence older than it. The schistose pegmatites, on the other hand, cut the microcline granites and are hence younger than they. A genetic classification of the pegmatites is, however, beyond the scope of this paper.

The schistose pegmatites

The schistose pegmatites are of different kinds. The schistosity is megascopically visible as a parallel orientation of feldspar phenocrysts, biotite flakes, or aggregates of magnetite. In thin section it is further exhibited by thin crushed zones. The principal types of pegmatites are: 1) uniformly thick and mostly straight dykes (Figs. 2 and 3); 2) irregular dykes or bodies (Fig. 4); 3) veins in veined gneisses; and 4) coarsened recrys-

Fig. 4. Detail of an irregular pegmatite cutting folded gneisses. Black magnetite lenses in the pegmatite are parallel to the axial plane in the surrounding gneisses. Northeastern point of Sälsö.

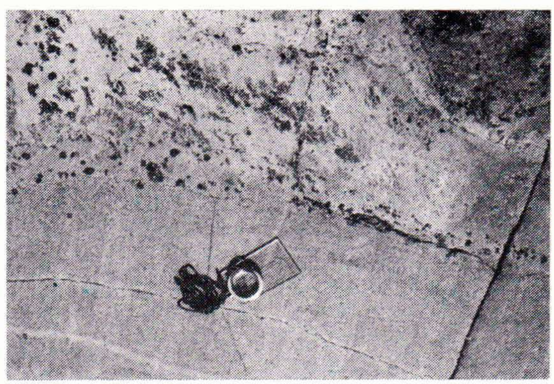

Fig. 5. A granitized zone in a gneiss close to the pegmatite in Fig. 4. Remnants of the gneiss and recrystallized dark minerals strike almost east; they are oblique to the banding but parallel to the axial plane of adjacent folds. Northeastern point of Sälsö.

Fig. 6. A granitized zone in a gneiss passing diagonally right across the photo. The dark biotite scales strike about east; they are oblique to the banding but parallel to the axial plane of the second folding. Southern shore of the eastern cape of Sälsö.

tallized portions in gneisses (Figs. 5 and 6). The following gives a few examples of these pegmatites.

On the northern shore of Sälsö, east of the harbour, a pegmatite occurs in a pink medium-grained, schistose granite (Fig. 2). Large feldspar grains and elongated quartz aggregates in the pegmatite lie parallel to the schistosity of the surrounding granite. Thin sections show large microcline grains surrounded and cut by zones consisting of granulated quartz and late sericite scales. The pegmatite is cruciform, and the branches are of different appearance depending on their angle with the schistosity of the granitic country rock. The branches parallel to the schistosity of the granite are thin and with straight contacts, whereas the dykes that are nearly perpendicular to the parallel structure of the granite are thicker and have somewhat crenulated contacts (Fig 2). The crenulation is due to small dislocations parallel to the axial plane. In thin section the dislocations appear as crushed zones.

Another pegmatite on the northeastern point of Sälsö cuts the folded gneisses (Fig. 4). It forms an irregular and angular dyke with sharp contacts. Lens-shaped aggregates of magnetite lie close to the contacts of the pegmatite and are parallel to the axial plane of the folded gneisses. Thin sections show that the pegmatite contains large microcline grains surrounded and cut by zones of granulated quartz. Some parts of the gneisses close to the above-mentioned pegmatite are strongly granitized and exhibit axial plane schistosity due to the untransformed remnants of the gneiss (Fig. 5). The gneisses commonly display older schistosity parallel to the layering. Granitic or pegmatitic portions of different sizes occur in the gneisses on Sälsö. As a rule these recrystallized portions exhibit a new schistosity striking about 90°, thus making an angle of roughly 30° with the banding (Fig. 6).

In brief, these observations show that some of the pegmatites, granitic veins and strongly recrystallized portions of the gneisses as well as the pink microcline granite have a steep schistosity striking about 90°. This indicates a northerly direction of maximum stress. The northward-striking branches of the pegmatite on the northern shore are crumpled (Fig. 2), whereas the eastward-striking ones are thin and compressed from the sides; these facts are consistent with the northerly stress. Hence, the maximum stress was northward during the orogenic phase when the pink granite, schistose pegmatites and granitized portions of the gneisses were formed. The schistosity and microscopic crush zones in the pegmatites indicate that the stress continued during and after the emplacement of the pegmatites. Thus the pegmatites were intruded in joints opened by the northerly stress. The same stress folded the gneisses and gave them the axial plane striking 90°.

Folding and fracturing seem to have alternated during the same deformation phase. When the strain, or rather the rate of strain, reached its maximum, the rock could not yield rapidly enough to folding and broke.

In other words, when the rock passed the point of fracture in the stress-strain diagram folding was replaced by fracturing. When the fractures had formed, the stress differences became balanced and the pressure in the joints was hydrostatic as long as they were filled with fluid or magma. When these crystallized, the stress field was again built up giving rise to schistosity and later to minute crush zones in the pegmatites. Hence, in this case, fracturing indicates the culmination of deformation and not a change in PT-conditions nor uplift of the crust from the zone of flow to the zone of fracture.

The explanation presented here is contrary to my earlier interpretation of the origin of amphibolitic dykes (Edelman 1949 p. 24, 1960 p. 80). In that I interpreted these dykes as intrusions in joints that formed during a quiet phase of orogeny when the region was uplifted into the zone of fracture in the mountain chain. There seems to be good reason for re-examining the old explanation in the light of this new idea.

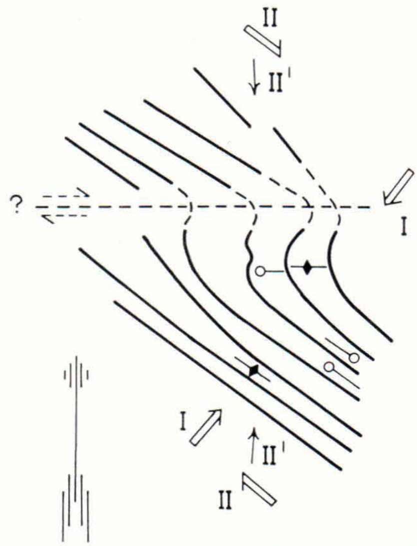

Fig. 7. Tectonic sketch of the Sälsö area. The first orogenic stress, I, folded the supracrustal rocks isoclinically with a horizontal or flat axis. The steep layers could then be bent into a Z-fold with a steep axis. This fold was probably caused by a force couple, II, with a secondary stress, II′, The axial plane of folding I strikes about 120°, that of folding II strikes about 90°. The dashed line indicates a possible fault.

Main structures

A comparison of the pegmatite structures with the main structures in the present area may give an idea of the structural evolution of the area. The geological map (Fig. 1) shows that the steep gneiss zones generally strike about 110°—120°. In the northeastern part of Sälsö the strike turns almost to the north in a large Z-shaped fold with s steep axis. The fold axes in the Sälsö area have a distinct maximum at about 90°—100° with an almost vertical plunge and a less pronounced maximum at about 120° or 300° with plunges of 0°—20° to the southeast or northwest. Folds with horizontal or flat axes are of course under-represented in relation to folds with steep axes on flat exposures. The general strike of the steep gneiss zones shows that the flat axes are connected with the first folding phase, which tilted the layers into a steep position. This folding was caused by a maximum stress in the direction of 30°.

The layers could not be folded around the steep axes to the Z-shaped fold until they had attained a vertical position during the first folding phase. The axial plane of the steep axes strikes about 90° (Fig. 7) and is parallel to the schistosity of the pegmatites and the pink granite. Hence the second phase of folding is associated with granitization, microcline granite and schistose pegmatites. Between the two folding phases the stress must have changed direction from 30° to 0°.

The small Z-folds and clockwise-rotated fragments in the gneisses and amphibolites which are rather common in this area, can all be explained as results of either a northerly stress or a right-hand force couple almost along the strike of the gneiss zones. Laurén (1968, Fig. 50) proposed a force couple striking east, but one striking east-southeast explains more successfully the northerly stress (Fig. 7).

The pink microcline granites were emplaces in the spaces that opened up during the second folding phase. The shapes and positions of the two northern granites in the Z-fold agree well with the interpretation now proposed. The S-shaped southern granite lens differs from the main pattern but it could be a filling in a tension joint whose ends were turned by right-hand shear movements. Far-fetched though it may seem, this explanation should not be disregarded out of hand.

The following picture emerges from a summary of the structural evolution of the area. A supracrustal series of sedimentary and volcanic rocks was first folded isoclinally by a stress from 30°. The fold axes due to this phase are horizontal or flat and the sub-vertical axial plane strikes 120°. In the course of this folding the rocks were metamorphosed into gneisses and amphibolites. During the second phase of folding a right-hand force couple nearly parallel to the then steep banding or a northerly stress bent the zones of the different rocks into a Z-shaped fold in the northeastern part of Sälsö. All the minor folds associated with this Z-fold have steep axes and a vertical axial plane striking about 90°. When the strain reached its maximum during the second folding phase the fracture strength of some rocks was exceeded and joints were formed. Granitic fluids filled the opening joints or spaces and crystallized as granites and pegmatites. It was this stress that caused the schistosity in these rocks. Hence, folding and fracturing, which alternated during this deformation phase, were both products of the same stress.

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