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The 1988 Swedish Annual Meeting of the IGCP–TCAPO project

The meeting was held in Lund 13–14 December 1988 and was attended by Caledonide geologists from Sweden, Norway and Finland. Four contributions were presented in addition to those found as extended abstracts on the following pages. Richard E. Binns presented new mapping results from the Finnmark-Troms connection, critical to the southward extension of Finnmarkian diastrophism, Björn E. Schouenborg described basement–cover relationships in westernmost Trøndelag, Dan Zetterberg reported mapping results from the Middle and Upper Allochthons of the Abisko National Park and Jyrkki Lehtovaara reviewed Finnish Caledonide geology. – *P.-G. Andréasson.*

Syn-deformational emplacement of plutons in the Caledonian Sunnhordland Batholith, W. Norway

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Several papers have recently discussed the control on the shape and internal structure of batholiths exerted by movement along major shear zones (Castro 1986; Hollister & Crawford 1986; Hutton 1988) and how the deformation can be recognized as syn-magmatic (Blumenfeld et al. 1986; Blumenfeld & Bouchez 1988). This paper briefly summarizes some of the deformation phenomena developed during emplacement of early plutons in the Caledonian Sunnhordland Batholith (SB) in W. Norway (Fig. 1).

Three plutonic units (I, II, III) have been distinguished (Andersen & Jansen 1987). Unit I comprises gabbros, locally with ultramafic cumulates and diorites. Unit II consists of one major pluton, the Reksteren granodiorite (Fig. 1). The emplacement of units I and II, was associated with deformation characterized by rotational strains. The granites and granodiorites of the younger Unit III, are sharply crosscutting, and represent permitted intrusions. The emplacement of Unit III will not be discussed further here.

Unit I is the oldest unit in the SB and it intruded already deformed ophiolitic and island-arc rocks and bimodal volcanic rocks (Brekke et al. 1984). Two of the plutons, the Stolmen Gabbro (SG; Rykkelid 1987) and the Vardafjellet Gabbro (VG), have been mapped in detail. Both plutons have high-grade migmatitic aureoles. Partial to near complete melting occurred in original shales and arkosic sandstones adjacent to the mafic intrusives. Interlayered limestones, calc-silicate lithologies, quartzites and conglomerates are, however, locally well preserved in the Møkster area (Fig. 1). Neosomes vary from light-coloured granite with a near minimum-melt composition to dark biotite-rich rocks with minor K-feldspar and intermediate plagioclase composition. The descriptions below are from the VG on Bømlo and Stord unless otherwise stated (Fig. 1).

The emplacement-related deformation in the envelope of Unit I plutons is recorded by the structural pattern developed during the formation of the aureoles. The intensity of the structural fabric in the cordierite-sillimanite-biotite bearing migmatites at Bremnes (Fig. 1), is partly controlled by the amount of melt present during the deformation. A similar variation in fabric intensity has been described from other syn-deformational migmatite complexes, and Blumenfeld & Bouchez (1988) described how the anisotropy of rocks deformerad in the magmatic

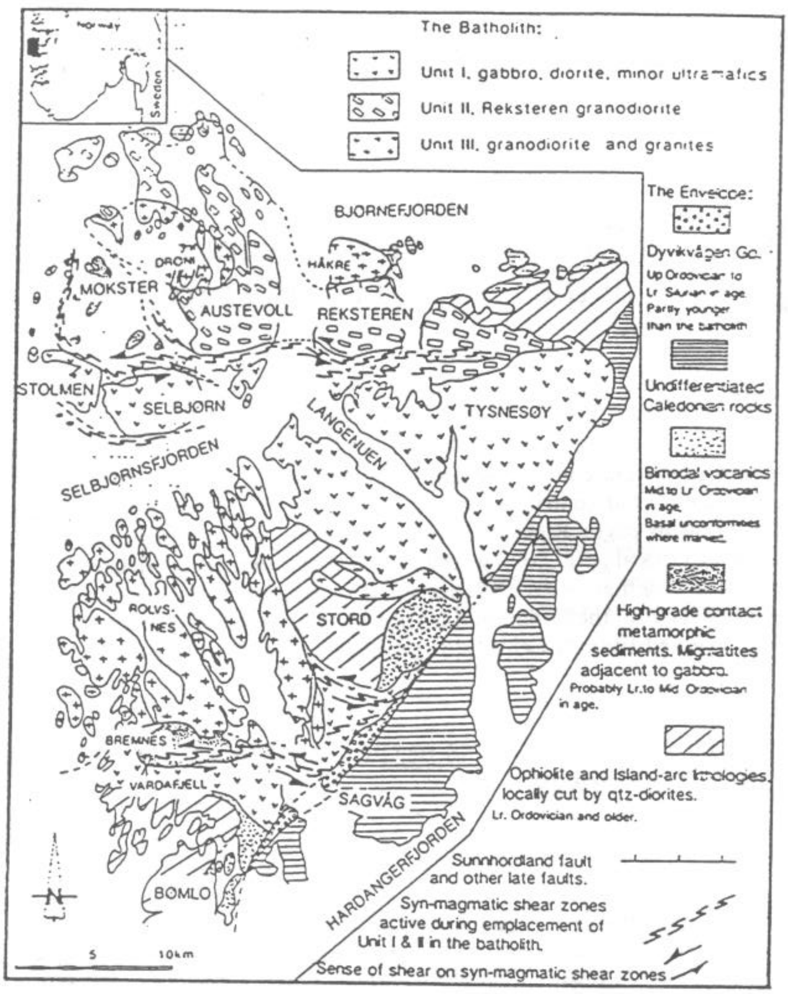

Fig. 1. Simplified geological map of the Sunnhordland Batholith, W. Norway.

stage was identified by SPO (shape-preferred orientation), S-C fabrics and phenocryst tiling. Rocks which originally contained a high melt fraction (MF), the diatexites, have a vague discontinuous banding defined by biotite-sillimanite-rich and quartz-feldspar-rich lamina. The granitoid layers usually have a granoblastic texture. Elongate quartz-aggregates, however, define a SPO fabric and an alignment of metasedimentary xenoliths, mainly calc-silicates, is common. The preferred orientation of the xenoliths defines a subhorizontal E-W lineation which is slightly oblique to the shear planes, and hence can be used as a kinematic indicator. The rocks which originally had a lower MF indicated by less neosom, the metatexites, have penetrative composite foliations defined by biotite-sillimanite-rich lamina (S-surfaces) and shear planes (C-surfaces). Quartz-feldspar aggregates define a more penetrative SPO than that of the diatexites. Post-kinematic retrograde metamorphism have commonly annealed the microtextures in the fabric which is a prominent feature at the scale of outcrop. Consequently, kinematic indicators have rarely been preserved at the scale of the individual minerals. At the scale of outcrop, however, kinematic indicators such as sheared veins and bands, SPO combined with composite S-C foliation and asymmetrical folds are generally present. The kinematic indicators define, with few exceptions, a sinistral sense of shear in the migmatites which form the roof of the pluton (Fig. 1) at Bremnes. The kinematic indicators show that the block north of the gabbro at Bremnes was thrusted towards the west during the emplacement of the VG.

The structures developed in the SG and its migmatitic sedimentary envelope north of Selbjørnsfjorden (Fig. 1) show a very pronounced fabric characteristic of rotational strain (Rykkelid 1987). The sense of shear is uniformly sinistral, but as the facing in this area generally is towards the south, the direction of thrusting in this case was towards the east. The opposing sense of shear in the Austevoll and the Bømlo-Stord areas suggests that large-scale conjugate shear zones may have been present during emplacement of Unit I plutons (Fig. 2).

Internal pre-solidus deformation in the VG. The cumulate layering in the central part of the VG provide good way-up structures. A marginal zone of non-layered gabbro occurs along the floor and the roof of the pluton. The marginal zone towards the roof is more differentiated and contains quartz-bearing gabbro and diorite. In the least deformed cumulates in the VG the pre-solidus deformation of the gabbro is shown by an E–W stretching fabric defined by plagioclase and SPO aggregates of hornblende. Veins of anorthosite are very common and form dilational veins with an orientation (180°/90° to 220°/90°) almost normal to the E–W stretching lineation. Small needles of primary hornblende have crystallized normal to the vein-walls. The relationship between the stretching lineation and the orientation of the veins is compatible with extension during late strain increments of sinistral shear. The veins are usually <2 cm wide, and are most frequent in thin (<15 cm) melanocratic cumulates which are interlayered with more plagioclase-rich gabbro. The dilational dykes can usually not be traced across the plagioclase-rich parts of the cumulate layering, and these layers must have been stretched homogeneously. The dark, pyroxene- and hornblende-rich cumulates, however, have fractured during the stretching and the dilational veins opened the extension cracks. The boudins of mela-gabbro separated by the anorthosite veins have rectangular cross-sections indicating that the viscosity contrast between the pyroxene-hornblende-rich layers and the interlayered plagioclase-rich material was considerable. The extensional veins are rooted in the plagioclase-rich parts of the cumulates, indicating that the latter contained appreciable amounts of interstitial melt during the deformation. In this model the interstitial melt would migrate into and open extensional fractures as the pyroxene-rich cumulates were inhomogenously stretched. The orientation of the stretching lineation and the dilational dykes as well as the displacement on a number of early faults and shear zones cut by later veins, show that the sense of shearing internally in the cumulates was sinistral. This is in accordance with the sense of shear recorded in the migmatites at Bremnes (Figs. 1, 2).

On Stord (Fig. 1), well preserved cumulates in the VG are rare. A strong fabric characterized by alternating irregular bands defined by variable contents of light- and dark-coloured minerals dominates the structure. The banding is reminiscent of the original cumulates and, where preserved, primary igneous minerals (cpx, ol, plag, amph) define the banding. Locally, the bands may be traced continuously into areas with low shear strains. In the low-strain areas well preserved cumulate structures with plagioclase and pyroxene-olivine-rich layers may be observed. Because primary minerals define the banding and as the banding demonstrably has been formed by the shearing of cumulates, the deformation probably took place after the cumulates had started to form, but prior to their complete crystallization. The sense of shear can be determined with confidence where cumulates are deflected by increasing shear strain into shear zones. The observed shear zones characterized by the banding show sinistral displacements which is similar to the observations from the less deformed cumulates on Bømlo and the migmatites in the roof at Bremnes.

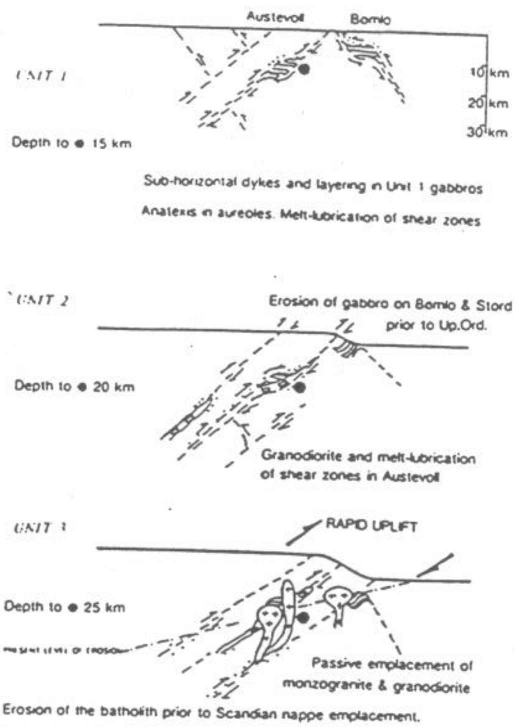

Fig. 2. A model for the emplacement of the Sunnhordland Batholith. The difference in crustal level between the Bømlo and Austevoll areas, and the pressure estimates have not been discussed here. Note that the plutons of Units I and II are located along major shear zones, which are of opposing directions.

The deformation during emplacement of the VG and SG was dominated by rotational strains related to shear zones. The shear zones had profound effect on both the shape of the gabbros and their internal structure. Shear strains were taken up in the migmatites which formed from sedimentary protoliths in the envelope.

Unit II is represented by one major pluton, the Reksteren Granodiorite (RG; Fig. 1). In the north it is cut by the late Sunnhordland Fault. The southern margin preserves the intrusive relationships with Unit I gabbros. On Rekstercn, an approximately 2 km wide zone adjacent to the granodiorite is characterized by anastomosing shear zones of variable shear strain. These provide a number of asymmertical structures at the scale of outcrop, which demonstrate that the deformation was non-coaxial with a sinistral sense of shear. The deformation in the zones was contemporaneous with the intrusion of the granodiorite. This is shown by the large number of dykes, veins and sheets of the granodiorite forming dilational dykes which were folded and boudinaged during the progressive deformation, according to their relative age and orientation in the shear zones. Internally in the main body of the RG a sub-vertical lithological banding striking parallel to the long axis of the pluton was formed.

The zone with high shear strains along the S-margin of the RG is continuous with the shear zones that were active earlier during the emplacement of the SG in Austevoll. Displacements on these zones are consistently sinistral, during the emplacement of both the SG and RG. A post-intrusive, static recrystallization fabric characterizes the microtexture in most of the shear zones adjacent to the RG. Many shear zones are cut by little deformed dykes and veins of granitic rocks. This shows that displacement on the shear zones was negligble after the RG had been emplaced.

In summary major plutons of both the early gabbros and the RG in the SB are located along shear zones which were active during the intrusion of the plutons. The internal structure of the plutons, as shown by the SPO of mineral aggregates, extensional veins in cumulates and the internal banding defined by the igneous minerals, can be assigned to the same deformation as that which affected their high-grade aureoles during the peak of the contact metamorphism. The late granites in the SB pierce through the earlier rocks and structures without appreciable structural effect. Hence they represent permitted plutons. An emplacement model for the SB, of which some of the essential points have been discussed here, is shown in Fig. 2.

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