NGU Report 96.113
Geology of the Øyungen
intrusion and surrounding rocks:
constraining the setting of
emplacement.

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REPORT

Report no.: 96.113	ISSN 0800-3416	Grading: Open

Title:
Geology of the Øyungen intrusion and surrounding rocks: constraining the setting of emplacement.

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County: Sør Trøndelag	Commune: Ålen
Map-sheet name (M=1:250.000) Røros	Map-sheet no. og -name (M=1:50.000) Dalsbygda, Haltdalen
Deposit name and grid-reference: Øyungen gabbro G.R.070610	Number of pages: 35 Price (NOK): 166,- Map enclosures: One

Fieldwork carried out: August 1996	Date of report: 30/9/96	Project no.: 2693.00	~~Person responsible:~~ [signature]

Summary:
Detailed mapping of a syn-orogenic mafic intrusion and the surrounding rocks provides supporting evidence for a recent re-interpretation of regional stratigraphy (Sturt et al. 1991). The Øyungen intrusion is a monotonous sheeted body of uralitised gabbro sitting in the Åsli formation of the Gula Group (Nilsen & Wolff 1989). The new tectono-stratigraphy places a first-order uncomformity beneath the Åsli formation (Bjerkgård &Bjørlykke 1994), separating rocks which experienced an Ordovician orogenic event (Heidal series) from Ordovician sediments (Sel series). This unconformity has been identified in the Øyungen area, lying to the west of the intrusion. The boundary between the Åsli formation and Fundsjø group in this area is not a thrust (c.f. Nilsen and Wolff 1989) but is primary (as in Bjerkgård & Bjørlykke 1994). The Øyungen intrusion lies within metasediments of the Sel series and has sheeted contact and contains many sheeted xenoliths, all parallel to structures in the country rocks. Evidence from contact metamorphic porphyroblasts and xenoliths suggest the Sel rocks were undeformed sediments prior to emplacement; bedding is preserved in many places. Weak fabrics in xenoliths and contact rocks suggest deformation due to flattening during emplacement. The main foliation in the metasediments is parallel to bedding and wraps contact metamorphic minerals. Locally this fabric appears to have been active at higher temperatures, that is, overlapping with the presence of a thermal aureole near the gabbro. Later folding is seen in the metasediments but not in the gabbro. Variation in the orientation of the gabbro contact is believed to be primary and related to the sheeting mechanism of emplacement. A wide contact metamorphic aureole is recognized: granulitic assemblages (cordierite + orthopyroxene) are seen in a narrow contact zone and in xenoliths. Migmatitic rocks and areas of mobilisate are also seen near the contact. Large areas contain pseudomorphed porphyroblasts, most or all after andalusite. The pattern of the aureole suggests the intrusion continues at depth beyond the area of outcrop. A later regional metamorphism post-dates the main foliation and is associated with pseudomorphing of porphyroblasts and the growth of kyanite, staurolite, white mica and chlorite. This study confirms the work of Birkeland & Nilsen (1974) and Bøe (1972) and confirms the applicablility of the new tectono-stratigraphy to this area and places the intrusion within this new framework.

Keywords: Bedrock geology	Structural geology	Metamorphic petrology
Tectono-stratigraphy	Mafic intrusion	Scientific report

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1 INTRODUCTION

The Øyungen intrusion lies in the vicinity of lake Øyungen to the west of Hessdalen in Ålen kommune, Sør Trøndelag fyllke. The area is generally well exposed and lies above the tree line. Exposure is especially good on the hills surrounding the lake. The intrusion lies within metasediments of the Trondheim nappe complex and consists mainly of uralitised gabbro with some later felsic pegmatites.

This study is based on field work undertaken the author during August 1996. It was made possible by a grant from the European Leonardo da Vinci programme and by logistic and financial support from NGU.

1.1 Previous Work

This study area and its immediate surroundings were investigated in the early 1970's by workers from the University of Oslo. This consisted of a number of doctoral theses. This work was published as Birkeland & Nilsen (1972) and Bøe (1974) who reference the unpublished material. These workers place the rocks surrounding the Øyungen body within the Gula schist group. They present evidence from andalusite porphyroblasts that the contact metamorphism found in this area affected rocks with a fine grainsize and that the area was subsequently affected by regional metamorphism. This later metamorphism led to alteration of the contact aureole minerals and was associated with the main Caledonian orogeny. They therefore place the emplacement event as early in the orogenic cycle. The study area is covered by the NGU 1:250 000 map Røros og Sveg (Nilsen & Wolff 1989) who place the intrusion within rocks of the Åsli formation of the Gula group. The contact between this unit and the Fundsjø volcanics is shown as a thrust. This is shown in figure 1 which shows the position of the study area within the Trondheim Nappe Complex.

1.2 Regional context: recent changes in stratigraphy

Our understanding of the geology of the Trondheim Nappe Complex has recently been greatly enhanced by work started in the Otta area. Papers such as Sturt et al. (1991, 1995) have helped shed new light on the relationship between the Gula group and the rocks lying to its east. The Gula group is now seen to contain a major unconformity separating rocks of different history (Bjerkgård & Bjørlykke 1994). The lower Gula is correlated with the

Hummelfjell group to the east and both with the Heidal series to the south. These rocks were deformed and metamorphosed in an early Ordovician orogenic event associated with ophiolite obduction. Post-orogenic sediments lie above a profound unconformity and make a thick package including much volcanic material. These sediments are correlated with the Sel rocks of the Otta area. This 'Heidal-Sel' unconformity has been mapped in the Folldal area (Bjerkgård & Bjørlykke 1994) and further north (B.A. Sturt & D.M. Ramsay pers. comm. 1996) where it lies beneath the Åsli formation of the Gula group. Therefore the Fundsjø group of Nilsen and Wolff (1989) is now grouped with the upper Åsli formation into the Sel unit (Bjerkgård & Bjørlykke 1994). The thrust contact placed between the Åsli and Fundsjø formations is seen as erroneous, Bjerkgård & Bjørlykke (1994) demonstrated that, in the Folldal area, this contact was primary.

This new stratigraphy has implications for the Øyungen area, particularly since the boundary between the two major units should pass through this general area. The entire tectonostratigraphy has been affected by the Silurian Scandian metamorphism and deformation but the 'Heidal' part of the Gula group may also contain evidence of earlier fabrics and metamorphic minerals. Therefore if, as implied by the work of Birkeland & Nilsen (1972) the Øyungen body was intruded early in the Scandian orogeny the question of whether the body lies within 'Heidal' or 'Sel' is of the greatest importance, since the relationships between the contact metamorphism and fabrics within the country rocks should be dramatically different. Clarification of the relationships, timing and stratigraphy in this area would therefore test the applicability of the new tectono-metamorphic framework to this area.

1.3 Aims of the study

The aims of this study were to clarify the relationships between the intrusion and the surrounding metasediments. The following aspects were seen as most important.

1. To confidently place the emplacement event within the regional tectono-stratigraphic framework, thereby testing this framework (see above).
2. To trace the position of the 'Sel-Heidal' unconformity in the area.
3. To assess the metamorphic effects of heating from the intrusion upon the country rocks.
4. To assess the role the solid intrusion played in any subsequent deformation and to describe any deformation of the intrusion, either magmatic or post-magmatic.

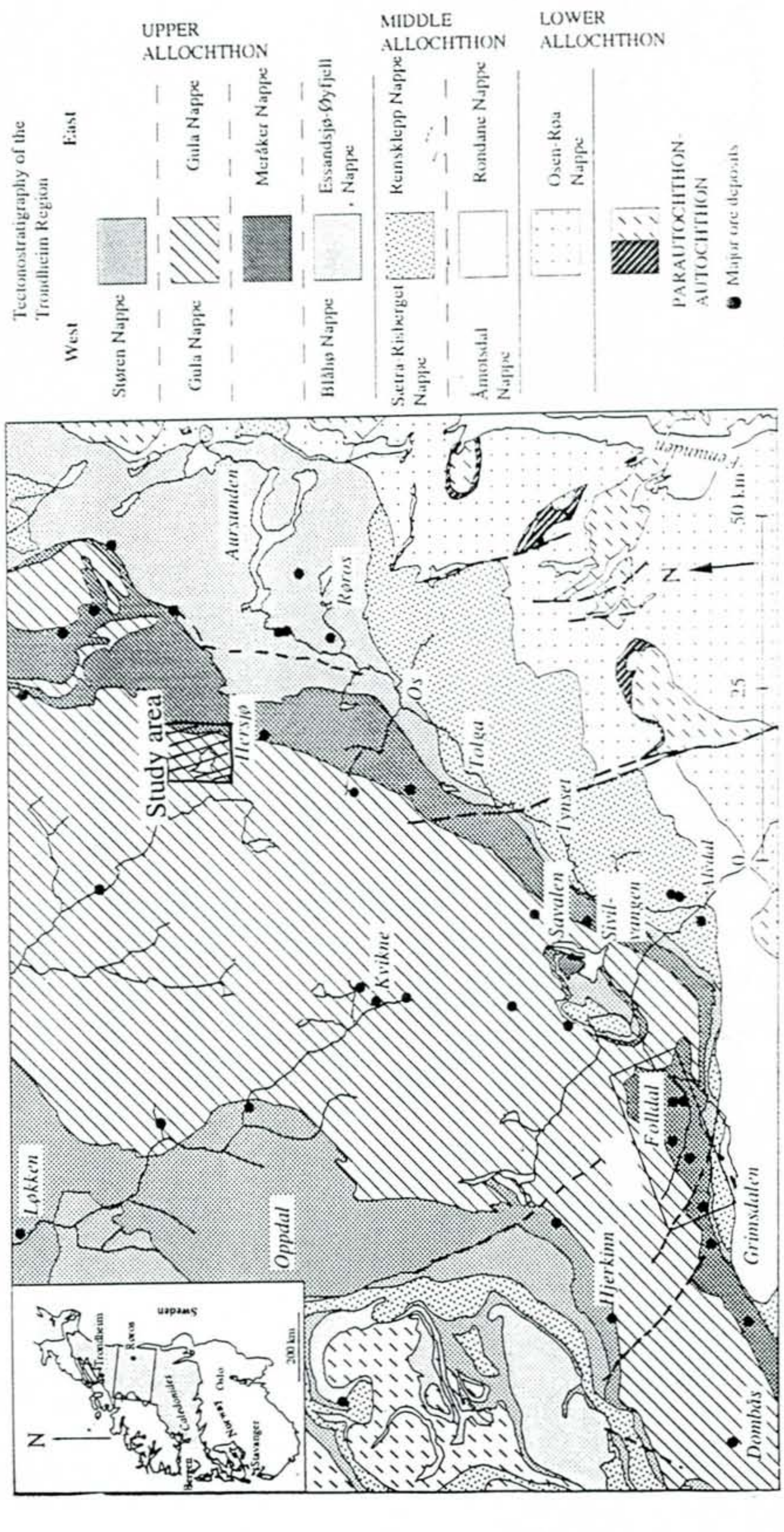


Figure 1. Tectonostratigraphic map of the southern part of the Trondheim region. The study area is indicated. Taken from Bjerkgård & Bjørlykke (1994).

2 THE ØYUNGEN INTRUSION

There is little available information on this body. Birkeland & Nilsen (1974) describe it as consisting of strongly uralitised gabbro and recognized the existence of an intermediate to acid border facies, consisting partly of quartz diorite.

This study has not concentrated on the petrology of the intrusion. In outcrop the rock is monotonous and structureless, being medium grained, isotropic and lacking phenocrysts (figure 2). No significant variation in mineralogy was recognised and no clear magmatic fabrics seen. A few places near the edge of the intrusion show crystal-plastic deformation of the gabbro but the vast majority of outcrops are entirely devoid of any structures. In thin-section one sample of the gabbro (Ø14) was seen to contain plagioclase, clinopyroxene, biotite and minor orthopyroxene. The pyroxenes are commonly partly altered to amphibole. Biotite may be seen mantling pyroxene grains but is also seen as isolated crystals within plagioclase. Biotite grains are aligned in a crude foliation which was not clear in outcrop. Many felsic pegmatites are found in the west of the intrusion. These pegmatites are very coarse and contain prominent feldspars and micas and may also yield garnet. They form sets of veins, usually aligned parallel to the edge of the intrusion (figure 3). A sample of this material was collected for dating from G.R. 048621.

A trondhjemitic body is found on the hill to the north of Elgsjøen (G.R.0157). This has not been looked at in detail.

2.1 Form of the intrusion

The intrusion has a wedge-shape, tapering off to the north. Good exposures of the west, south-east and northern edges show that this wedge is made up of sheets. The western edge is a sharp contact parallel to structures in the country rocks, as is the east. The northern and south eastern edges are formed of numerous sheets which are well displayed in areas of good outcrop. Sheet edges are parallel to structures in the country rocks. The southern edge is less well exposed but appears to cut across the regional strike without sheeting. Some fabrics in the country rocks are parallel to this margin.

Figure 2. Field photo of typical Øyungen gabbro

Figure 3. Field photo of felsic pegmatite sheets cutting Øyungen gabbro. Car keys for scale.
G.R. 068642

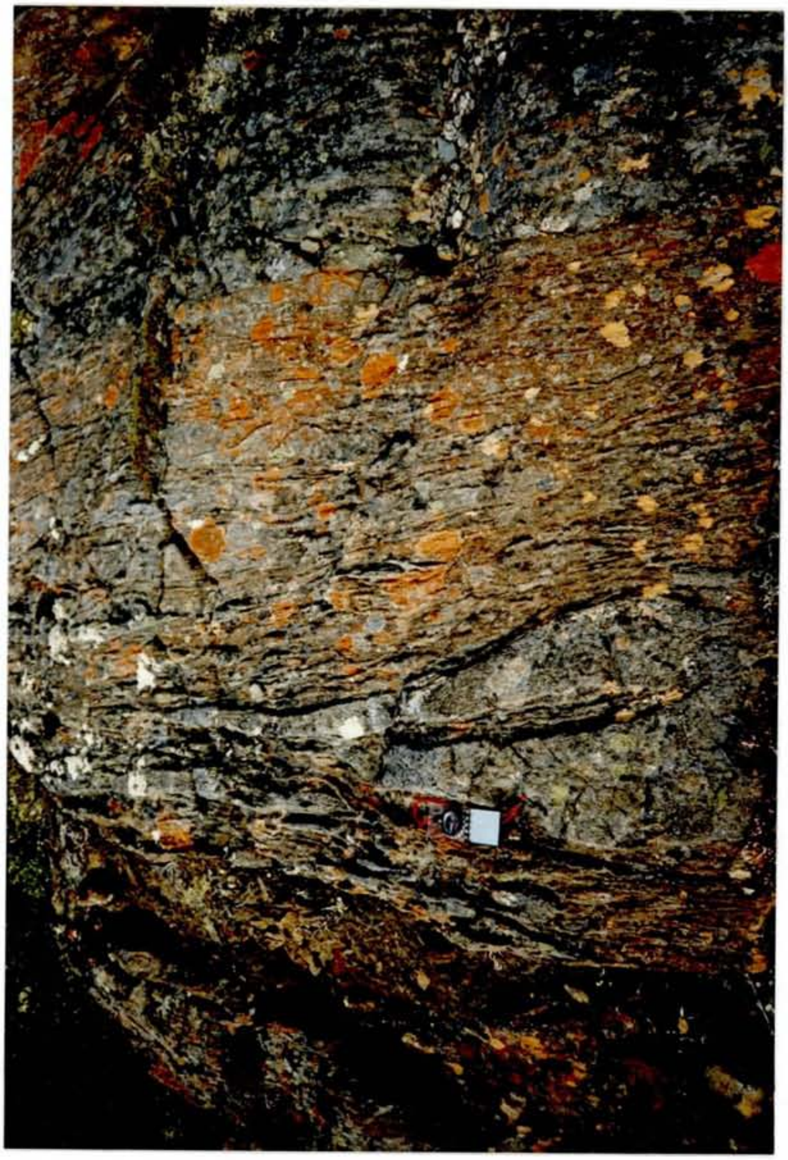


Figure 4. Field photo of banding (bedding) within a metasediment xenolith. G.R.077596

Numerous planar xenoliths provide further evidence for sheeting. These contain lithological banding parallel to their long edges (figure 4). This banding is thought to represent modified bedding, rather than a tectonic fabric. No folds were found and the irregular lensoid nature of this banding interpreted as being caused by metamorphism and deformation during intrusion. In contrast metasediment sheets surrounding the intrusion are foliated and may be folded. These fabrics appear to be post-intrusion in age.

3 METASEDIMENTS

Nilsen & Wolff (1989) place the metasediments surrounding the Øyungen intrusion within the Gula group. The new tectonostratigraphy developed by Sturt et al. (1991, 1995) and Bjerkgård & Bjørlykke (1994) would remove the thrust contact between the Gula Group and the Fundsjø group but place a new boundary somewhere within the Gula Group. This mapping has confirmed the new tectonostratigraphy. No thrust exists at the base of the Fundsjø group, good exposures to the west of Hessjøen (G.R 083566) show a primary contact between the lowest greenstones and the metasediments. The change in rock type occurs parallel to bedding and foliations and shows no evidence of unusually high strains. The contact was taken as the base of massive greenstones, which lie in immediate contact with banded tuffs.

The contact between the 'Sel' and the 'Heidal' has been found to lie to the west of the main intrusion (see map), but has not been mapped in detail. Except in the highest grade contact rocks, sedimentary features are common in rocks east of this contact, and no evidence of polyphase deformation was found. All metasediments lying within the main mapped area are therefore placed within the Sel unit. Rocks lying between the Fundsjø group and the 'Heidal' (lower Gula Group) are here informally called 'lower Sel'.

A variety of rock-types may be seen within the lower Sel unit, but it was not possible to erect an internal stratigraphy. The majority of this unit is formed from semi-pelitic to psammitic rocks often with fine scale layering (see figure 5). Calc-silicate areas may be found, either as layers or as pods / boudins. Other rock-types include banded tuffs and mud-flake conglomerates which have been found close to the Fundsjø group. A discontinuous unit of white quartzite conglomerate (figure 6) is shown in the main map. It is thought unlikely that this unit represents only one stratigraphic horizon. This conglomerate is very similar in appearance to the Skardshøi conglomerate, described by Bøe et al. (1993) from equivalent rocks in the Otta area. One way-up structure was found at G.R. 079565 which gave younging towards the east.

The field appearance of the lower Sel is very dependent upon its position with respect to the intrusion. Meta-sediment xenoliths are sheet-like (see above) and are thought to contain relict bedding. The rocks are now hornfelsic, often with prominent biotites in a granular quartz-rich matrix. Rocks close to the intrusion are totally recrystallised hornfelsic rocks with a migmatitic appearance. These are described more fully below. Further out are found migmatitic rocks which may preserve bedding in places (figure 7). Rocks with small patches or 'sweats' of melt and containing prominent andalusite porphyroblasts grade into grey andalusite schists. Rocks without porphyroblasts are only found on the eastern edges of the mapped area. These lowest grade rocks are granular in appearance and have not experienced significant metamorphic recrystallisation.

4 STRUCTURE

The structure of the Øyungen area is simple. No samples contain evidence for more than two phases of deformation, a foliation forming event, related to an lineation, and a later folding event recognised in the field and in thin-sections. This is agreement with the conclusions of earlier workers (Birkeland & Nilsen 1972, Bøe 1974). Workers in similar rocks to the south recognise an older weak bedding parallel foliation (Bjerkgård & Bjørlykke 1994, B.A. Sturt pers. comm. 1996). Two distinct fabrics have not been seen in this area however the main foliation might be a composite fabric. The foliation is always seen to be parallel to bedding and always wraps any porphyroblasts or resulting pseudomorphs (figure 14).

Figure 5. Field photo of bedding preserved in lower Sel andalusite schist. Small spots are weathered out andalusites. G.R. 043568

Figure 6. Field photo of quartzite conglomerate within lower Sel. G.R. 050569

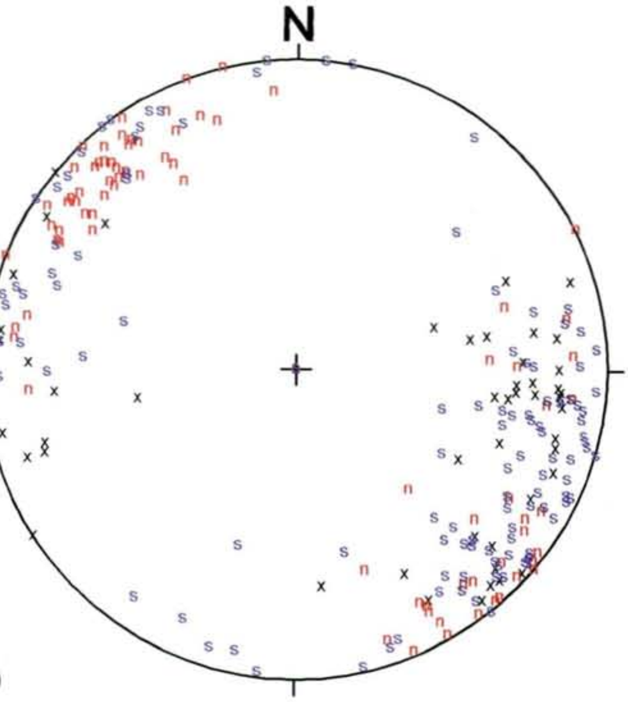
Figure 7. Field photo of folded foliation affecting migmatitc lower Sel. G.R. 072575

4.1 Form and emplacement of the intrusion

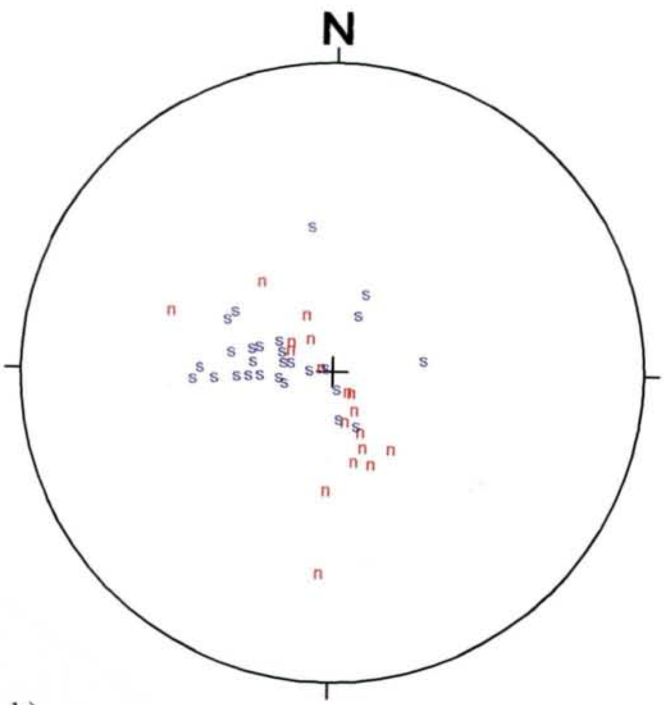
Figure 8 plots structural data from this area, divided up into geographical areas. These plots reveal no clear pattern. Figure 9 is a cross-section across the gabbro and shows a marked change in dip across the gabbro. Broader considerations constrain the Sel to lie between the Heidal / lower Gula and the Fundsjø volcanics. This fact, and the lack of deformation fabrics within the gabbro and its xenoliths suggest the cross-section shows the original shape of the intrusion rather than the results of folding. Abundant sheets and xenoliths (section 2.1) as well as the uniform appearance of the gabbro, suggest the intrusion was formed by the amalgamation of a great many sheets of magma. The sheets of acid pegmatite (figure 3) therefore provide an analogy for the emplacement of the entire body. In order to make space for these sheets, the magma must push aside the surrounding rocks. This might be driven by magma overpressure and would cause a weak flattening fabric to be formed in metasediments near the contact. Fabrics formed at extremely high temperatures (e.g during emplacement), partly defined by the alignment of undeformed orthopyroxene, are found in contact / xenolithic rocks such as Ø2 and Ø15. The anomalously large distance between the upper and lower boundaries of the lower Sel (e.g. between Heidal and Fundsjø) in figure 9 as compared with areas to the north (B.A. Sturt pers. comm. 1996) is explained by the presence of the gabbro. At the edges of the intrusion the intrusion walls must come together as the intrusion thins. This would explain the form of the gabbro in figure 9. Pushing aside of the surrounding metasediments might also explain the form of the southern contact which cross-cuts the regional strike but is parallel to fabrics in the contact rocks. The pattern of metamorphism (figure 11) suggests that the intrusion continues southwards at shallow depths, at least in the area around G.R. 0858.

4.2 Fold structures

Minor folds are seen in outcrop (e.g. figure 7), but are not common and are not found within xenoliths or within rocks enclosed by gabbro sheets. They have fold axes dipping steeply to the north and always fold the foliation. Hundred metre scale folds can sometimes be traced out within the metasediments. They are defined by folding of lithological boundaries in the sediments and also changes in orientation of the bedding / foliation fabric. However the tightness of this folding and the lack of traceable units means that fold structures cannot be traced for long distances. They are also not believed to affect the intrusion (see above).



a)



b)

Figure 8. Equal area stereoplot of structural data from country rocks. a) Poles to planar fabrics (foliations / bedding) b) lineations. x - data from xenoliths, s - data from southern area, n - data from north.

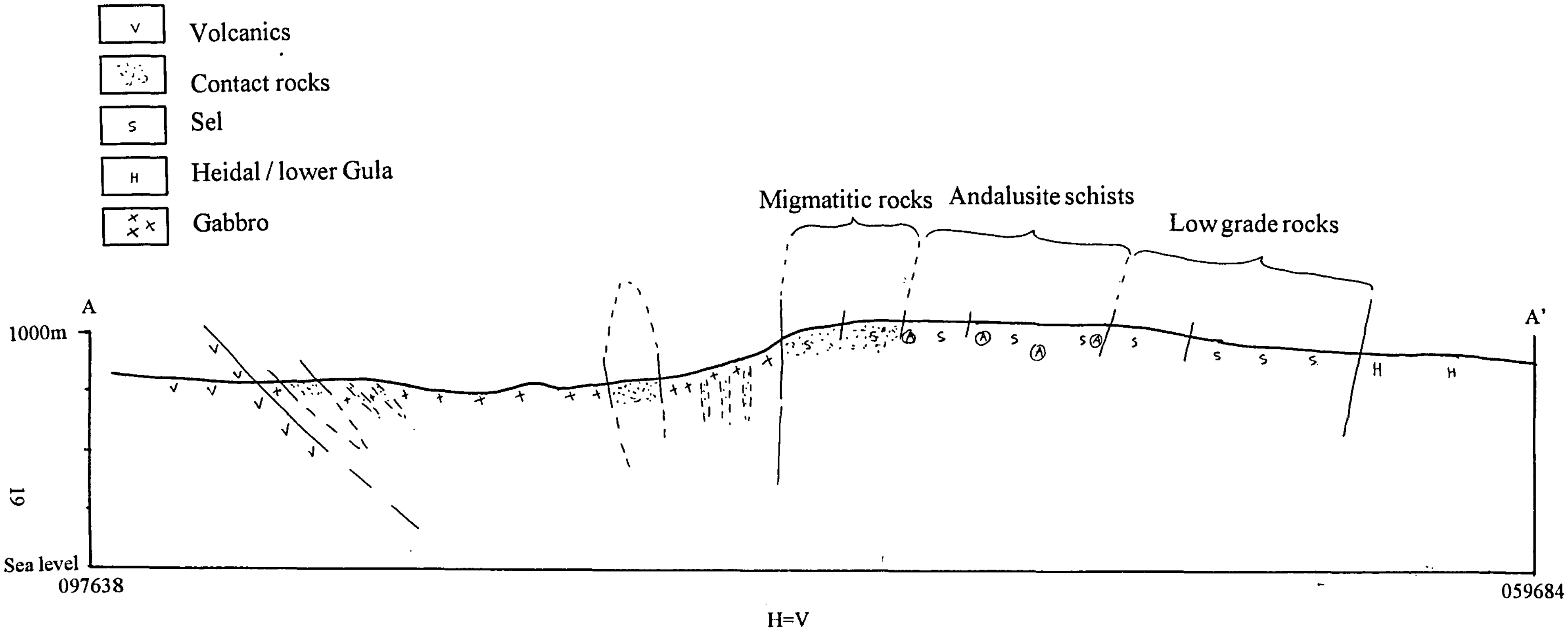


Figure 9. Structural cross-section across northern edge of gabbro. See figure 10 for location.

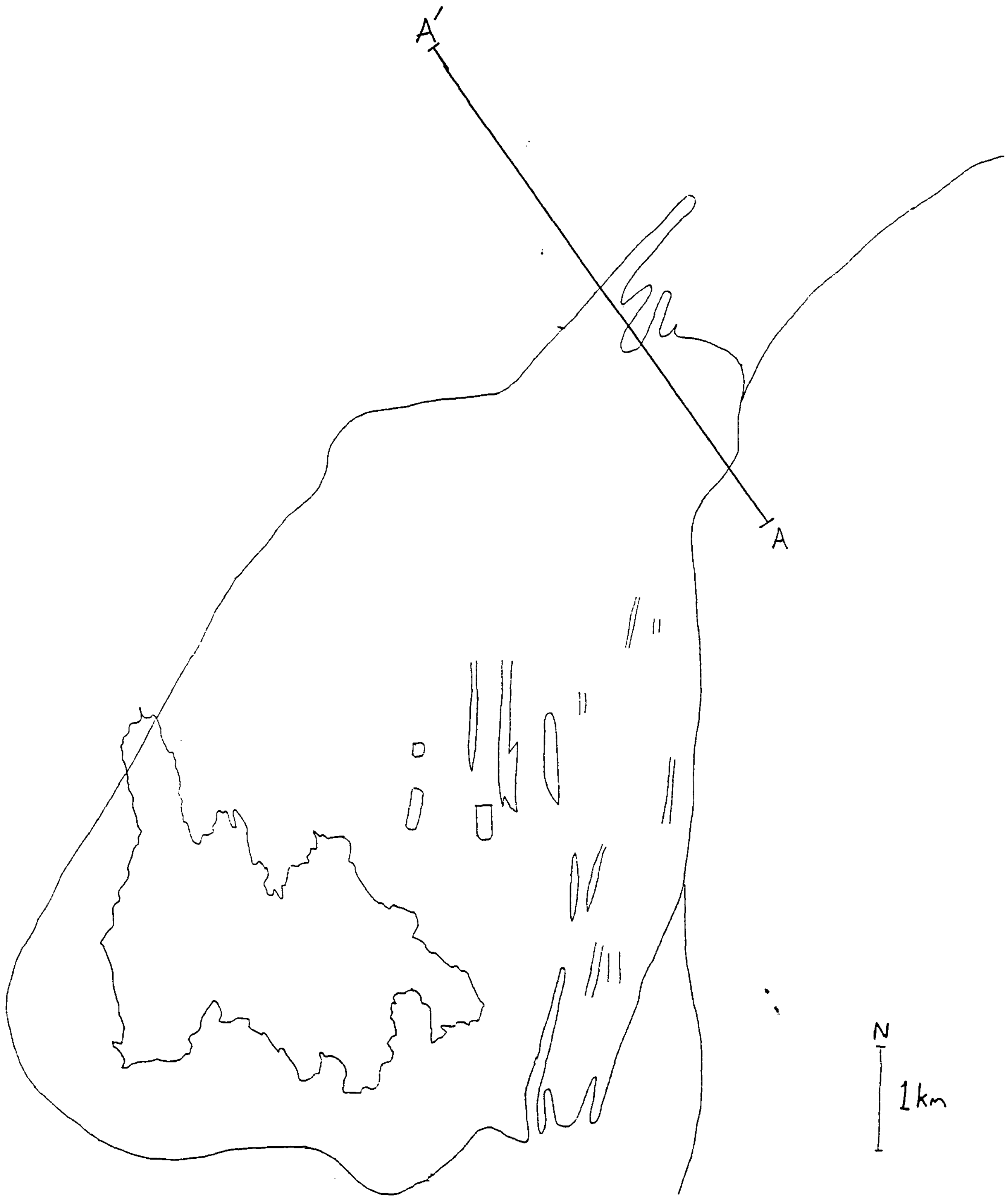


Figure 10. Map showing location of cross-section in figure 9.

4.3 Timing of deformation

Evidence from thin-sections of thermally metamorphosed rocks and from xenoliths suggest that all deformation is post-intrusion in age. No evidence for pre-metamorphism fabrics was found within any porphyroblastic rocks. Many Sel rocks are only weakly deformed by a single fabric which is seen to wrap porphyroblasts. Fabrics preserved in xenoliths appear to relict sedimentary bedding, albeit slightly modified by the intrusion process. The D1 event recognised within the Sel further south (e.g. Bjerkgård & Bjørlykke 1994) has not been identified and so the timing of this event (if present) cannot be commented on. Birkeland & Nilsen (1972) described andalusite porphyroblasts with rims overgrowing a foliation, which they used as evidence for an early syn-tectonic age of emplacement. This conclusion is backed up by samples Ø6, Ø11 and Ø12 which contain fibrolitic sillimanite apparently deformed by or growing along a foliation. This sillimanite is not altered and appears to have been stable during deformation. This suggests the area was still at elevated temperatures during at least the onset of the main fabric forming event. No solid evidence of syn-tectonic emplacement was found; weak flattening fabrics within xenoliths and contact rocks may be explained by normal magmatic processes.

5 METAMORPHISM

At least two distinct phases of metamorphism are recognized in the Øyungen area, an early contact metamorphism and a later higher pressure regional event. Previous work in the area (Birkeland & Nilsen 1972, Bøe 1974) described the metamorphism of an area from Øyungen north up to the Hyllingen intrusion. They recognised the early growth of andalusite porphyroblasts over a wide area. This they interpreted as a contact metmorphism, inferring the presence of sub-surface intrusions to explain the large area containing these porphyroblasts. They also recognised sillimanite grade hornfelsing immediately surrounding outcropping gabbro intrusions. They described a later higher pressure regional event which converted many porphyroblasts into pseudomorphs of white mica and kyanite. This event was associated with porpyroblastic growth of kyanite, staurolite and garnet.

The new interpretation of the regional stratigraphy and the recognition of a major boundary within the upper Gula suggests this work should be read with care. This possibility exists that assemblages described in these papers may come from the lower Gula and so contain minerals which formed pre-Sel and survived as relics. However this report shows that this problem is not a serious one and future work mapping north of Øyungen should fully settle these questions.

5.1 Contact metamorphism

Figure 11 shows the distribution of contact metamorphic facies around the intrusion. Unshaded areas correspond to areas of poor exposure.

High grade rocks: Rocks close to the intrusion show abundant evidence of high temperatures, including partial melting, whole-scale recrystallisation and the growth of high-temperature minerals.

Melting Migmatitic rocks are well developed in this area, (figure 7). Moving towards the intrusion the first sign of melting is the presence of melt sweats within andalusite schists. As the proportion of melt increases the rock takes on a streaky appearance caused by flattened melt patches inter-layered with relict bedding. Finally the rock is almost completely recrystallised into a mobilisate. This is a gneissic rock with a featureless matrix, rich in quartz and biotite, which contains blocks and boudins of quartzite or calc-silicate. This material is interpreted as a rock which contained sufficient melt to allow disaggregation of bedding and whole-scale recrystallisation. Evidence that the matrix contained a melt phase is found by looking at the boudins (figure 12). Boudinage of rigid refractory layers created 'pressure shadows' in boudin necks, these are filled with undeformed melt, suggesting that a melt phase was present during boudinage.

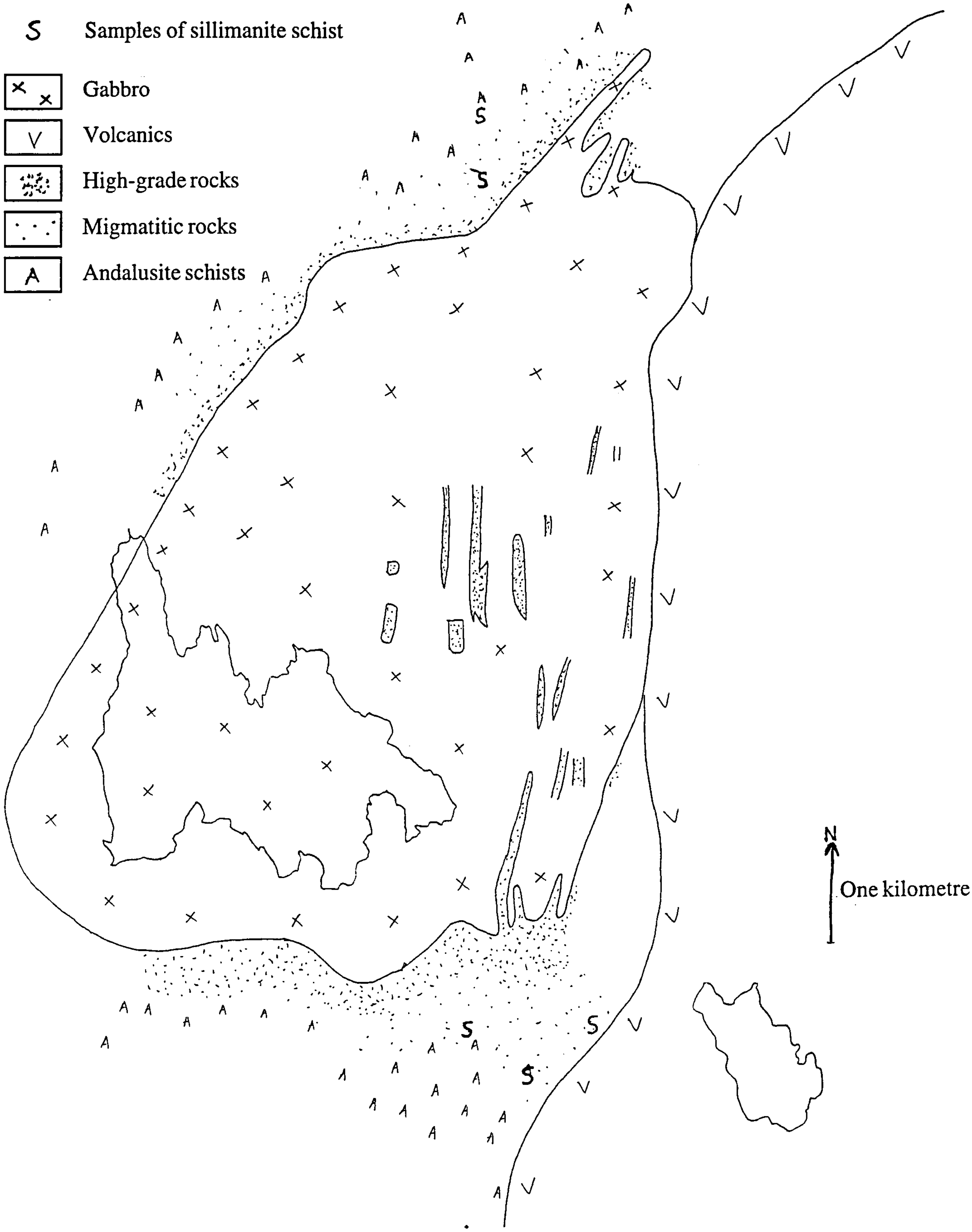


Figure 11. Map showing contact metamorphic facies around the intrusion. Unshaded areas represent unexposed or unmapped areas.

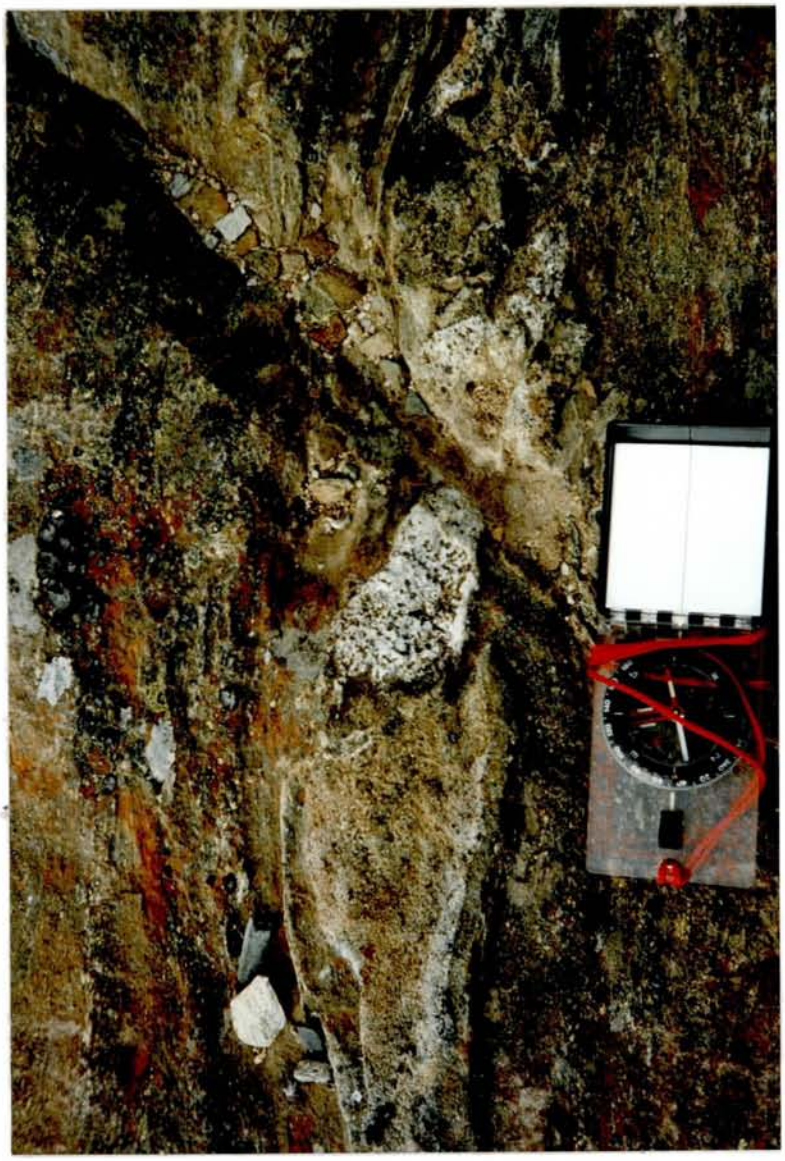


Figure 12. Boudin neck from mobilisate containing undeformed felsic melt. Evidence for the presence of intergranular melt within the rock during boudinage.G.R. 082573

5.2 Petrology

A total of 14 thin-sections taken from aureole rocks have been studied. They may be conveniently divided into three groups (figure 11):

1) High-grade rocks (hornfels). Samples taken from xenoliths or within a hundred metres of the contact (Ø2, Ø3, Ø7, Ø15) have been completely recrystallised under granulite facies conditions. No trace of pre-intrusion structures remains on a thin-section scale but lithological banding, representing modified sedimentary bedding, is preserved in most xenoliths, as may be seen on the main map. Thin-sections may show (Ø2, Ø15) a crude alignment of high-temperature phases but deformational fabrics are otherwise absent. These rocks were protected from the post-intrusion deformation by their proximity to the rigid intrusion, as may be seen in the random orientation of even the latest phase of mineral growth. Three phases of mineral growth are may be distinguished within these samples:

a) High-grade assemblages. Recrystallisation under granulite facies conditions typically destroys earlier minerals and structures. The earliest phase of mineral growth recognised corresponds to the highest-grade contact metamorphism, close to or during emplacement. Minerals associated with this phase in the four samples are cordierite, orthopyroxene, hercynitic spinel, garnet and possibly sillimanite and biotite. The best preserved examples of this assemblage are found in Ø2 and Ø15 which both yield cordierite and orthopyroxene.

b) Retrograde assemblages. Granulite facies rocks often show mineral growth due to retrograde reactions during cooling. This phase of mineral growth does not imply a new phase of metamorphism but merely reflects the difficulty of preserving granulite facies mineral assemblages at lower, but still elevated temperatures. Evidence for this phase is found best in Ø3 which contains pseudomorphs formed of biotite-quartz intergrowths and garnets containing vermicular intergrowths with opaques. These features are evidence of retrograde breakdown of ?cordierite in the absence of a fluid-phase and have been recorded from similar rocks in Ireland (Wellings 1996). Growth of fibrolitic sillimanite along grain boundaries (especially cordierite) in Ø15 is a further example of this process. Minerals inferred to have grown during this cooling phase include garnet, sillimanite and biotite.

c) Regional assemblages. Two samples contain evidence of a further metamorphic event superimposed upon the previous two. Ø3 contains abundant staurolite and kyanite. These minerals are found as random aggregates and appear to be separate from and later than the biotite-quartz intergrowths described above. Late staurolite is also seen in Ø7. Minerals ascribed to this event include kyanite, staurolite, chlorite and white mica.

2) Sillimanite schists. This group of rocks is not defined geographically but simply includes non-contact rocks which include sillimanite. Samples Ø5, Ø6, Ø8, Ø11 and Ø12 are all schistose rocks which contain fibrolitic sillimanite. In sample Ø5 fibrolite is found in between porphyroclastic grains of plagioclase and is not found in the main schistose matrix. Ø8 is contains no foliation and sillimanite lies along grain boundaries as in Ø5. In Ø12 fibrolite is found in large wrapped pseudomorphic domains or intergrown with biotite along the foliation. Fibrolite in Ø11 is found mats lying within the foliation, individual fibres are themselves aligned, often intergrown with quartz. Ø6 contains fibrolite within small areas along the foliation. Pseudomorphs similar to those from the andalusite schists (only with coarser grainsize) and not associated with sillimanite are also found in both rocks. These are described in the next section.

Three samples contain late staurolite, as large grains in Ø11 but as small grains in Ø12 and Ø6. Ø12 and Ø11 both contain large grains of kyanite statically replacing sillimanite.

Samples Ø6, Ø11 and Ø12 provide intriguing evidence as to the timing of deformation and metamorphism. Fibrolite sheaves found along the main foliation in Ø11 and Ø6 imply that this foliation (which wraps the pseudomorphs) was formed whilst this area was at elevated temperatures (within the stability field of sillimanite). This is the only foliation in this rock and so may be correlated with the main foliation in all the metasediment samples. This evidence agrees with the observation of Birkeland & Nilsen (1972) that andalusite porphyroblastesis overlapped with formation of the foliation and so suggests an early syn-tectonic age of emplacement. Of further interest is the presence of pseudomorphs after porphyroblasts within samples Ø6, Ø11 and Ø12. These unknown porphyroblasts were formed before the growth of the fibrolite, since they were either directly replaced by fibrolite (Ø12) or wrapped by foliations containing fibrolite (Ø6, Ø11). The growth of the porphyroblasts and their replacement may have taken place during the normal course of thermal metamorphism, the samples growing andalusite during heating and then finally achieving sillimanite-grade temperatures during deformation. This cannot be assumed however, and these samples are a reminder that not all porphyroblasts need be andalusite and that andalusite porphyroblastesis may not be the result of one single large thermal metamorphic event.

3) Pseudomorph schists. These rocks represent the lowest grade rocks within the mapped area. They contain abundant sedimentary structures and are often only weakly foliatied. Figure 5 shows the outcrop from which Ø16 was taken, showing well-preserved bedding and weathered out pseudomorph areas. Working on this rock-type Birkeland and Nilsen (1972) and Bøe (1974) described large areas of andalusite bearing schist, with the andalusite variably retrograded to other minerals and only seen as pseudomorphs. Notwithstanding the reservations expressed above, the pseudomorphs seen in this group of schists are probably all andalusite. Figure 13 shows a hand specimen collected as a loose block from G.R. 054573. The large porpyroblasts are definitely andalusite, having a square morphology and a pinkish colour. These pseudomorph schists all contain a foliation which wraps the pseudomorphs (figure 14). These are often slightly flattened in the foliation, having an ovoid shape; rectangular shapes are also found. Minerals within the pseudomorphs are usually randomly orientated but may be slightly aligned along the foliation within flattened pseudomorphs. The matrix is of quartz, biotite and plagioclase. Pseudomorph areas contain quartz, biotite, staurolite ± white mica ± kyanite. Staurolite is found as small, sometimes altered, prismatic grains, elongated along the z-axis. These grains are often concentrated at the edge of pseudomorphs or along internal linear zones (figure 14). Ø16 contains one relict grain of andalusite. Pseudomorphs in this sample consist largely of white mica, sometimes with coarser grains along the outside. In one corner the relict grain is partially altered to a higher relief, slightly higher birefringence mineral, probably kyanite.

Lower grade rocks. Reconnaisance mapping to the west of the main area reveals the extent of the andalusite schists. As shown in figure 9, rocks lying more than c.1.5km west of the contact do not contain visible andalusite crystals. This area and others far west of the intrusion (G.R. 005575 and 009593) contain Sel rocks which are granular and contain no metamorphic porphyroblasts in hand-specimen. These rocks appear to have been unaffected by the contact metamorphism and have only been affected by ?greenschist facies regional metamorphism.

Figure 13. Photo of hand-specimen of schist with large andalusite porphyroblasts. Loose block from G.R. 054573.

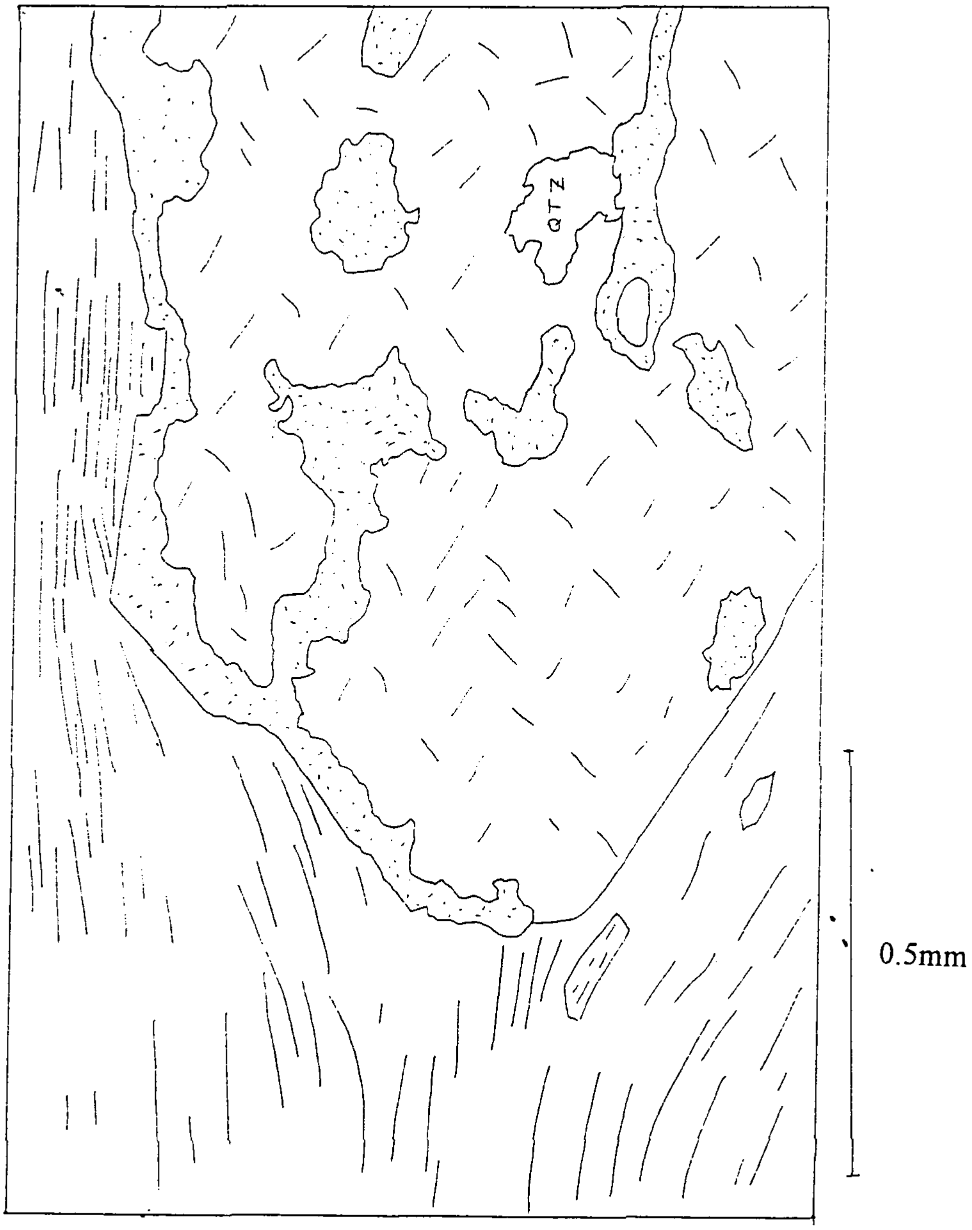


Figure 14. Sketch of microscope image showing pseudomorph after ?andalusite wrapped by main foliation. Cross hatch - area of pseudomorph rich in randomly oriented micas. Dotted - area of staurolite. Lines - quartz-rich matrix with foliation defined by biotite, trend of foliation shown. From sample Ø1.

6 CONCLUSIONS

The Øyungen intrusion consists of monotonous structureless gabbro, strongly uralitised and containing biotite. More intermediate facies are present near the intrusion edge and felsic pegmatites are seen. The intrusion was formed by a sheeting mechanism and has sheeted margins at its northern and south-eastern contacts. It contains many sheet-like metasediment xenoliths.

The rocks surrounding the intrusion are all placed within the lowermost part of the Sel (after Sturt et al. 1991). The contact with the Fundsjø volcanics is a primary one, in agreement with the observations of Bjerkgård & Bjørlykke (1994) further south. The contact between Sel and Heidal has not been mapped in detail, but is placed to the west of the Øyungen intrusion.

No pre-intrusion fabrics have been recognised. A bedding parallel foliation is seen to largely postdate but slightly overlap with the contact metamorphism and is overprinted by the peak regional metamorphism. Folding in the country rocks cannot be traced into the intrusion, whose irregular shape is thought to be primary.

Two metamorphic events are recognised from the study area.

a) Contact metamorphism.

This reached granulite facies in xenoliths and contact rocks, with the development of orthopyroxene-cordierite bearing assemblages. Large areas underwent migmatisation and fibrolite has been found over a kilometre away from the gabbro outcrop. Pseudomorphed porphyroblasts, mostly or all after andalusite, were found up to 2 kilometres away from the contact. Sillimanite is found in rocks containing porphyroblasts, where it post-dates them. All porphyroblasts are wrapped by the main foliation whereas sillimanite was apparently stable during this deformation. This evidence supports previous work which inferred pre- to early syn-tectonic emplacement. It also supports the suggestion that the Øyungen intrusion alone cannot explain the pattern of metamorphism and that large sub-surface gabbro bodies are present in this area.

b) Regional metamorphism.

This study recognises a later higher-pressure phase of metamorphism which post-dates formation of the main foliation. This metamorphism is seen in the presence of pseudomorphs and in the common static growth of kyanite, staurolite, white mica and chlorite. This event may be correlated with the metamorphic peak of the Scandian orogeny and was at amphibolite facies. Of interest is the presence of lower grade rocks in the Sel away from the intrusion. These have yet to be studied in detail but appear to have never attained amphibolite grade facies. The more regionally developed Sel assemblages appear to be dominantly greenschist facies. This would imply that the peak regional metamorphism event at Øyungen, occured whilst the aureole was still at elevated temperatures. The increase in pressure implied by the transition of andalusite to kyanite might then be related to burial during deformation (development of main foliation).

This study confirms that the new tectono-stratigraphy of Sturt et al. (1991) can be succesfully applied to this study area, c.130 km from the Otta region. The gabbro was emplaced into the Sel sediments during the early stages of the Scandian orogeny, probably at appreciable depths.

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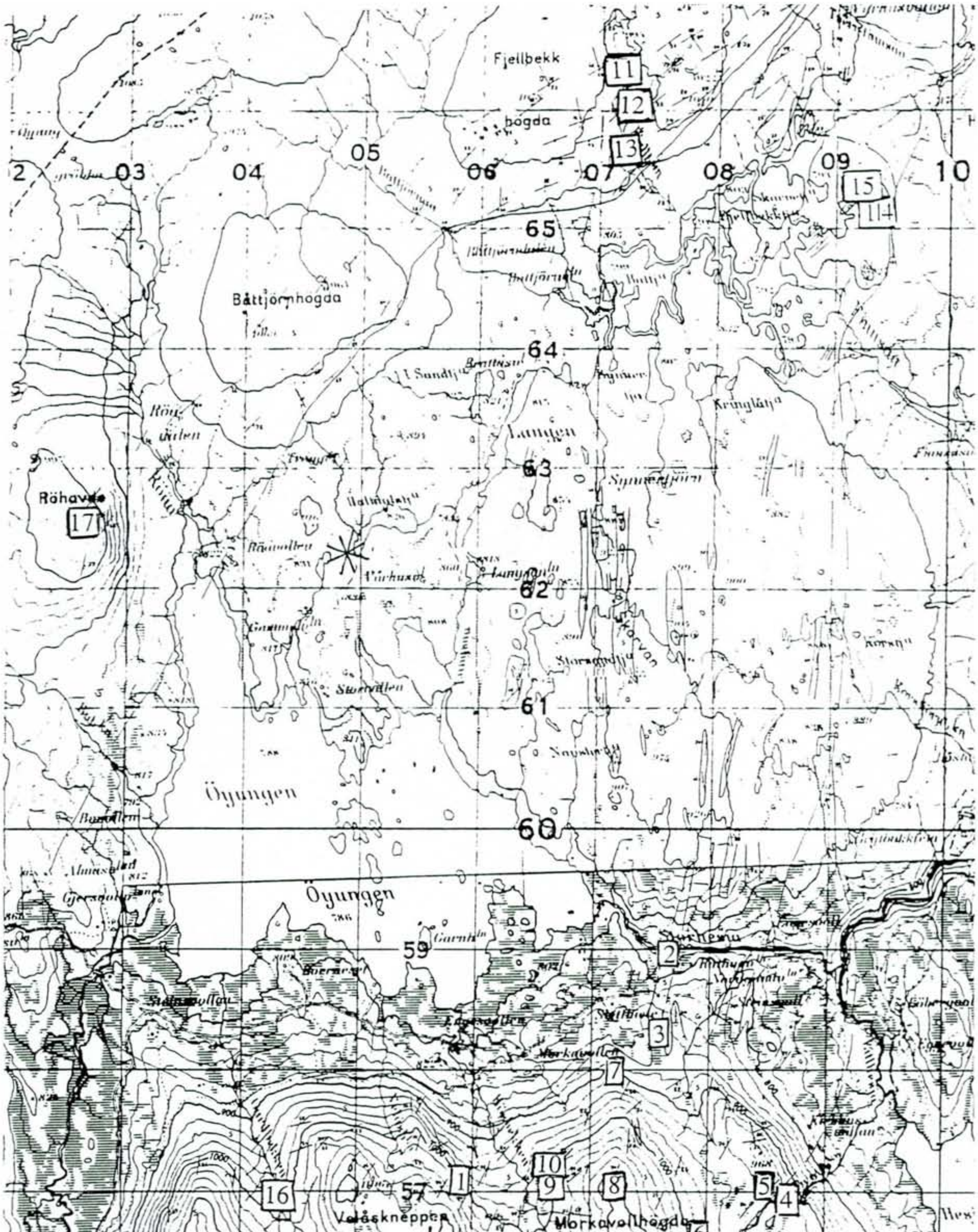
Sample	Rock Type	G.R.	Main minerals	Comments
Ø1	Pseudomorph schist	058,569	Qtz, Pl, Bt, St	Oriented
Ø2	High grade gneiss	075,588	Qtz, Pl, Crd, Opx, Bt, Amp	High temperature foliation
Ø3	Contact metasediment	074,581	Qtz, Bt, w.m. Chl, St, Grt, Ky, Sil	Varied pseudomorphs
Ø4	Meta-tuff	085,568	Qtz, Pl, Amp	Oriented
Ø5	Metasediment	084,568	Qtz, Pl, Bt, Sil, St	Retrograde foliation
Ø6	Pseudomorph schist	078,565	Qtz, Bt, Sil, w.m. St	
Ø7	High grade gneiss	071,578	Qtz, Bt, Sil, grt, w.m. Tor, Spl, Crd	Altered high-grade contact rock
Ø8	Pseudomorph schist	072,568	Qtz, Pl, Bt, Ky, St, w.m. Chl, Sil	
Ø9	Pseudomorph schist	066,569	Qtz, Bt, Pl, Chl, Ky, St, w.m.	
Ø10	Pseudomorph schist	066,569	Qtz, Bt, Pl, Chl, St, w.m.	
Ø11	Pseudomorph schist	071,662	Qtz, Bt, Pl, St, Ky, Sil, Chl	Oriented
Ø12	Pseudomorph schist	072,658	Qtz, Pl, Bt, Sil, Ky, w.m. Tor	
Ø13	Hybrid contact rock	072,656	Qtz, Pl, Amp, Bt, Czo, Cpx	Mixed calc-silicate and melt
Ø14	Gabbro	093,651	Pl, Cpx, Opx, Amp, Bt	Crude alignment of biotite
Ø15	Xenolith	092,652	Grt, Crd, Bt, Sil, Opx	Granulite facies, crude foliation
Ø16	Andalusite schist	042,568	Qtz, Pl, Bt, w.m. And, Ky	Relicit andalusite, bedding
Ø17	Metasediment	025,624		No T / S, contains ore minerals
Ø18	Pseudomorph schist	059,561	Qtz, Pl, Bt, St, w.m.	
Qtz - quartz. Pl - plagioclase. Bt - biotite. St - staurolite. Crd - cordierite. Opx - orthopyroxene. Cpx - clinopyroxene.				
Chl - chlorite. Ky - kyanite. Sil - sillimanite. And - andalusite. Amp - amphibole. Czo - clinozoisite. w.m. - white mica.				
Tor - tourmaline. Spl - spinel. Grt - garnet.				

Appendix 1. Table of thin-sections



Appendix 2. Map showing location of samples Ø1 to Ø18. Location of sample of felsic pegmatite collected for dating show by a star.

Øyungen intrusion

G	Gabbroic rock
	Trondhjemitic rock
S	Lower Sel
	Lower Sel with conglomerate
F	Fundsjø greenstones
H	'Heidal group' = lower Gula

	Geological boundary
	Lithological banding / bedding
	Foliation
	Lineation

Appendix 3. Key to main map.
Grid lines are old form (ED50). All grid references given in text are given in new form (WGS84).
Grid references may be converted from text to enclosure one by adding 81m to eastings and 207m to northings. E.g. G.R.(500500) in text plots at c. 501502 on main map.
Base map taken from 1:50 000 maps Alvdal and Tylldalen.