A Rb-Sr age study from the Mosjøen unit, Helgeland Nappe Complex, and its bearing on the timing of tectonometamorphic events within the Uppermost Allochthon, Central Scandinavian Caledonides, Norway

B. O. TØRUDBAKKEN & M. MICKELSON

Tørudbakken, B. O. & Mickelson, M.: A Rb-Sr age study from the Mosjøen unit, Helgeland Nappe Complex and its bearing on the timing of tectonometamorphic events within the Uppermost Allochthon, Central Scandinavian Caledonides, Norway. *Norsk Geologisk Tidsskrift*, Vol. 66, pp. 263–270. Oslo 1986. ISSN 0029–196X.

The Mosjøen unit within the Helgeland Nappe Complex is made up of a polydeformed supracrustal sequence consisting mainly of greenschists, greenstones and layers of calcite and dolomite marbles, which have been intruded by large masses of igneous rocks ranging in composition from gabbroic to granitic. The main structural elements and the metamorphic maximum are related to the D_2-deformation. The Mosjøen gabbro, yielding an igneous Rb-Sr mineral isochron age of 420 ± 8 m.y. (I_o = .70412 ± .00003), was emplaced during the D_2 event. A 433 ± 11 m.y. total rock Rb-Sr isochron was obtained for a granitic dyke crosscutting the D_2 structures. The geochronological data are interpreted to indicate a Silurian age for the main tectonometamorphic event (D_2) in the Mosjøen unit. Previous geochronological studies from other parts of the Uppermost Allochthon demonstrate strong early Caledonian (late Cambrian to early Ordovician) metamorphism and deformation prior to Silurian deformation. The present tectonostratigraphic sequence within the Uppermost Allochthon was established during the main Caledonian thrusting event in the late Silurian to early Devonian.

B. O. Tørudbakken & M. Mickelson, Saga Petroleum A/S, Mariesvei 20, Postbox 9, 1322 Høvik, Norway.

The Mosjøen area is situated in the Helgeland Nappe Complex (HNC) (Ramberg 1967, Gustavson 1973) which is a part of the Uppermost Allochthon (Stephens et al. 1985) of the central Scandinavian Caledonides. The northern part of the HNC has been subdivided into a number of geological units which are shown in Fig. 1. These subdivisions were originally based on structural and lithological criteria, and the provinces were interpreted as basement and cover complexes (Riis & Ramberg 1979).

The earliest geological investigations in the Mosjøen – Elsfjord area have been summarized by Nissen (1974). Of special importance for the Mosjøen area are the works by Vogt (1897, 1900, 1910) in which he describes the Mosjøen gabbro (Fig. 2) and the iron ores in the Mosjøen unit. Nissen (1969, 1972, 1974) has contributed mineralogical and petrographical data together with a geological map (scale 1:100,000) covering parts of the Mosjøen, Toven and Leirfjorden units. More recently, petrographical and structural work from the northern part of the Mosjøen unit has been done by Johnsen (1979), and a regional geophysical investigation has been made with discussion of the basic intrusions (Fredsted 1981). The whole region is covered by the geological maps Mosjøen (Gustavson 1981) and Mo i Rana (Gustavson & Gjelle 1978), both at a scale 1:250,000.

One geochronological investigation has previously been published from the HNC. This is a Rb-Sr study from the southern part of the Bindal Massif, where intrusions yielded a Silurian age (Priem et al. 1975). More detailed geochronological data are, however, available from the Rödingsfjället Nappe complex (RNC) (Claesson 1979, Graversen et al. 1981, Brattli et al. 1982), and the Beiarn Nappe Complex (BNC) (Cribb 1981, Styles 1978, Tørudbakken & Brattli 1985), both of which show many similarities to the HNC, with respect to lithology, deformation and metamorphism. The data from the RNC and the BNC indicate that late Precambrian basement rocks (1200–600 m.y.) are present in the Uppermost Allochthon, while Rb-Sr dating of intrusions have yielded a wide range of Caledonian ages.

In this paper we present new Rb-Sr isotope data from the Mosjøen area. The results are then

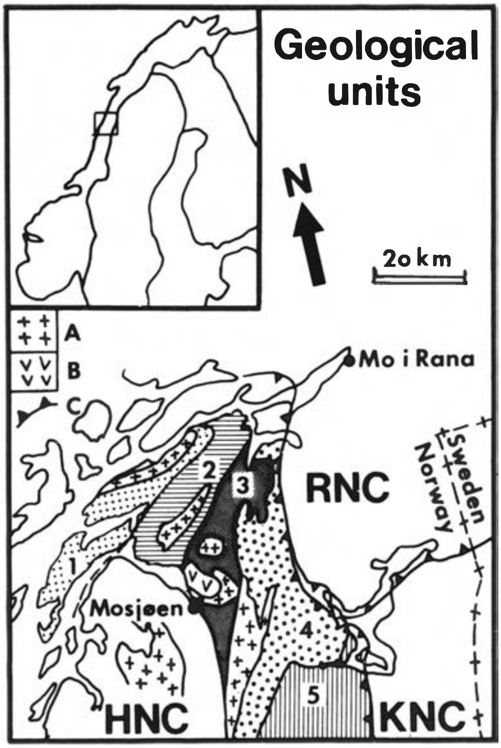

Fig. 1. Principal geological units in the northern part of the Helgeland Nappe Complex (HNC), Nordland. 1-Leirfjorden unit. 2-Toven unit. 3-Mosjøen unit. 4-Geittind unit. 5-Apfjell unit. A-Acid intrusions. B-Basic intrusions. C-Thrust boundary. RNC-Rödingsfjället Nappe Complex. KNC-Köli Nappe Complex.

combined with other available data from the Uppermost Allochthon in order to evaluate their regional importance.

Field relationships

The Mosjøen unit comprises a sequence of supracrustal rocks intruded by numerous igneous rocks of variable composition. The unit has a N-S trending elongate outcrop pattern (Fig. 2). In the north the unit terminates towards the thrust boundary between the HNC and the RNC. To the south the unit thins out between the Reinfjell tonalite and the Bindal Massif.

Metasupracrustal rocks

Due to strong deformation and metamorphism, it has not been possible to establish a stratigraphic sequence in the Mosjøen unit. Instead, the rock descriptions are based on the areal distribution of the main rock types.

The western and the northern areas within the unit are dominated by thick sequences of medium-grained calcite-marbles with frequent dolomite-marbles (Nissen 1974, Johnsen 1979, Mickelson 1986). The marbles are interlayered with a number of micaschist layers, greenschists and iron ore bands. Occurrences of ore and industrial minerals (magnetite, brucite, scheelite) in this part of the unit have been explored for their potential economical value.

The sequence east of the marbles (Fig. 2) is dominated by greenschists of various compositions, mostly hornblende-bearing (Mg-rich), though actinolite and other amphiboles have also been detected. Thin layers of calcite- and dolomite-marbles alternate with the greenschists, garnet-mica schists (sometimes with staurolite or andalusite), graphite-schists, grey phyllites and greenstones/amphibolites. Several zones contain irregularly shaped flattened fragments of basic composition with amygdaloidal structures, which may indicate a volcanic origin. Some of the massive greenstones contain well preserved plagioclase-phenocrysts and trachytic textures probably reflecting their origin as lavas (Fig. 3a, b; see also Mickelson 1986).

Intrusions

A wide range of intrusions are found in the Mosjøen unit, ranging in composition from ultramafic via gabbroic and tonalitic to granitic (Fig. 2). Ultramafic and several minor gabbroic bodies are found within the greenschists. These intrusions are interpreted as pre-tectonic relative to the main deformation and metamorphism (D_2 deformation, see below).

The next group of intrusions include larger bodies, e.g. the Mosjøen and Luktvann gabbros, and the Helfjell granite. These intrusions are interpreted as syntectonic relative to the D_2 event. The large gabbroic intrusions are undeformed in their central parts, where primary mineralogy and igneous textures have been preserved. However, the marginal parts of the same gabbros were metamorphosed during the D_2 episode and locally a foliation has developed. During metamorphism, the igneous minerals plagioclase, clinopyroxene, orthopyroxene, biotite, magnetite/ilmenite (and hornblende) were transformed to a metamorphic assemblage with hornblende, sec-

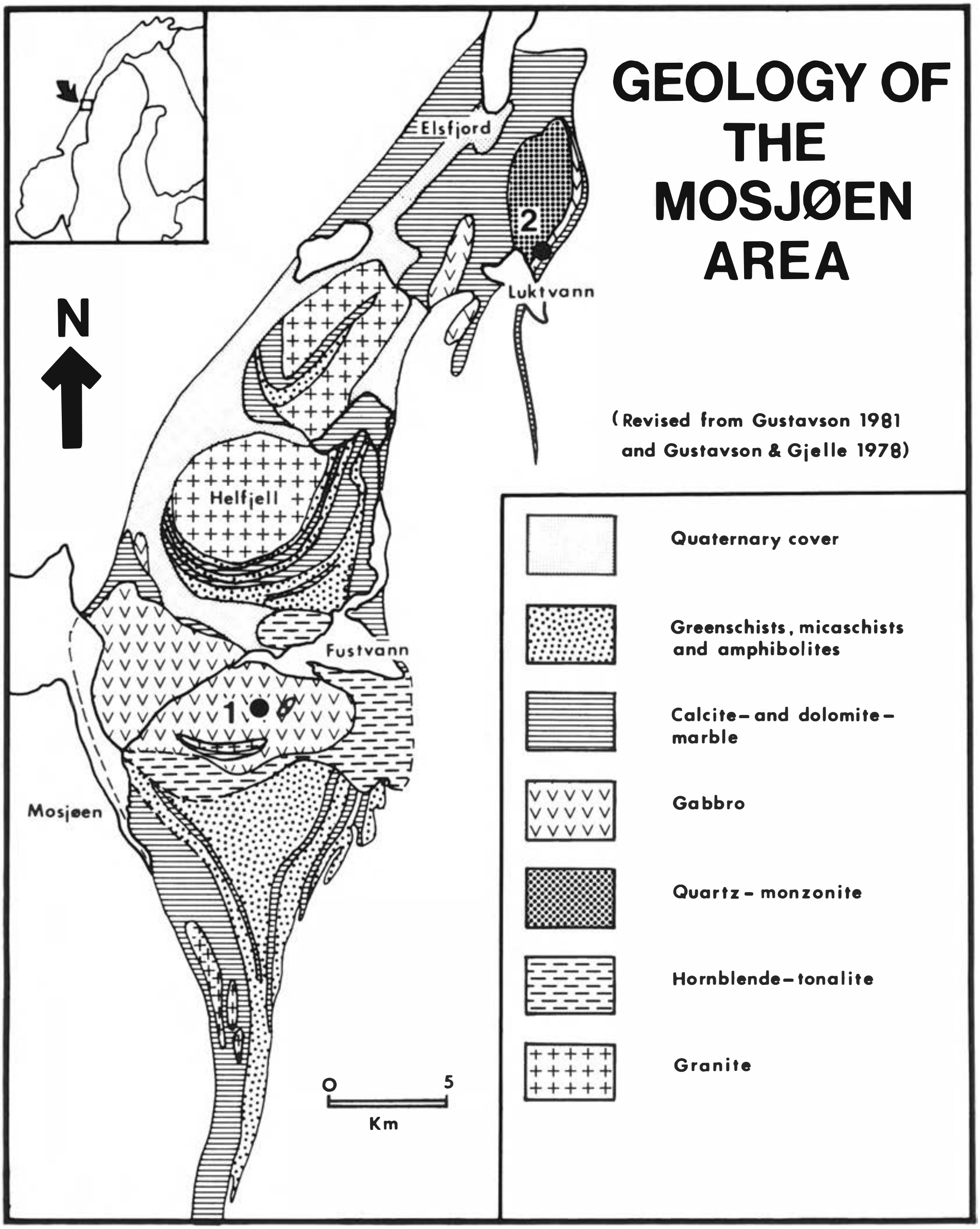

Fig. 2. Geology of the Mosjøen area. Black dots indicate sampling localities for isotope investigations: 1-Mosjøen gabbro (Sample BT-0036), 2-Luktvann granitic dyke (Samples L1-L6).

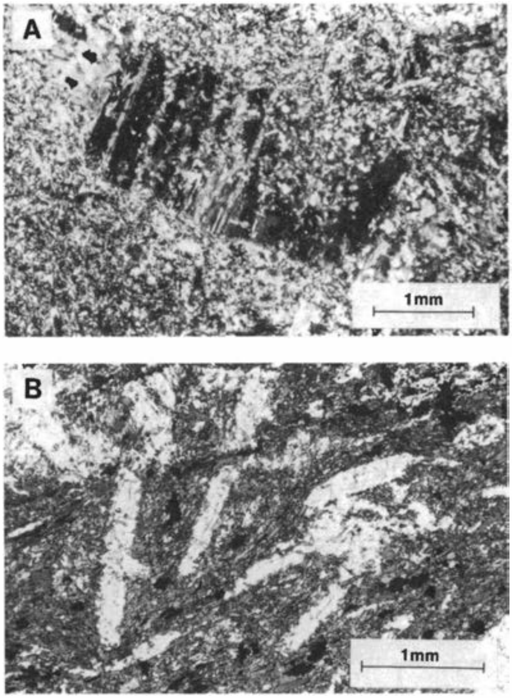

Fig. 3. A. partially preserved plagioclase phenochrystal in greenstone. B. Trachytic texture in greenstone. In both samples the matrix is made up of fine-grained amphibole, plagioclase and opaques.

ondary plagioclase, quartz and sphene. The Helfjell granite also shows marginal deformation. The inner parts of the intrusion are undeformed and no preferred mineral orientations have been observed. In the outermost 50–100 m broad rimzone a weak mica foliation has developed. This foliation has been mapped all around the almost circular-shaped granite. The foliation is parallel to the main foliation in the country rocks. Xenoliths found in the granite show evidence of assimilation.

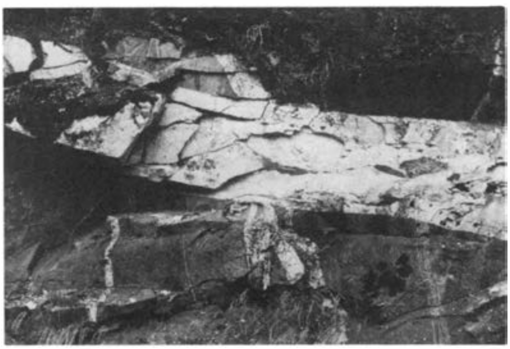

Fig. 4. Luktvann granitic dyke at the sampling site for isotope investigation. The dyke is about 1 m thick, and crosscuts the D_2 fabric of the Luktvann meta-gabbro.

Fig. 5. Hornblende-tonalite aplite crosscutting the metasediments to the west of Fustvann (Fig. 2).

Large masses of intermediate to acid intrusions which show evidence of post D_2 emplacement occur in the Mosjøen unit (Fig. 2). In this study, we consider only the hornblende tonalite and granite dykes occurring in the vicinity of the Mosjøen gabbro (Fig. 2). The hornblende tonalite has intrusive contacts cross-cutting the main foliation, and contains rotated xenoliths of the country rocks (Fig. 5). Also, in places, contact-metamorphism is found to overprint the earlier D_2 fabric, transforming the country rock into hornfels.

Porphyric granite occurs as dykes. These dykes cut the Mosjøen gabbro. A post-D_2 granitic dyke near Luktvann was selected for Rb-Sr dating. The dyke is shown at the sampling site in Fig. 4. There, the granite dyke cuts the metamorphic fabric in the marginal zone of the Luktvann gabbro and thus clearly post-dates the D_2 deformation and metamorphism.

Deformation and metamorphism

The rocks in the Mosjøen unit have been affected by several episodes of deformation. The descriptions given here are mainly based on field studies in the southern part of the unit (Fig. 2). The northern parts of the unit have been described by Johnson (1979).

The main deformation episode in the Mosjøen units is D_2, comprising tight to isoclinal folding (F_2) and transposition developing into a penetrative foliation. The main S_2 foliation is defined by parallel orientation of chlorite, biotite, amphibole, opaques, white mica, and aggregates of plagioclase and quartz. Locally, an earlier foliation (S_1) can be identified, in which case the S_2 foliation is developed as a crenulation cleavage.

The S_1 foliation is probably also of metamorphic origin, and is defined by oriented micas.

Geological mapping has shown that the S_2 foliation wraps around the larger intrusions (e.g. Mosjøen gabbro, Helfjell granite). The metamorphic fabric in the marginal parts of these intrusions seems to be concordant to the surrounding S_2 structures, although it has been observed that apophyses from the Mosjøen gabbro cut the main foliation in the country rocks, and folds are preserved in xenoliths within the gabbro. To the south of the Mosjøen gabbro, a 'foliation triple point' (Brun & Pons 1981) has developed. This may have been caused by interference between the regional stress field and a local stress field due to intrusion of the gabbro. It should also be mentioned at this point that sillimanite and andalusite occur in some schists south of the Mosjøen gabbro, where they are apparently syntectonic (D_2) and of contact metamorphic origin. Viewed together, the available data suggest syn-D_2 emplacement for the Mosjøen gabbro, other similar gabbroic intrusions, and the Helfjell granite.

The post-D_2 deformation includes tight to open folding, generally with N-S trending fold axes (F_3), and open large-scale buckling with E-W trending fold axes (F_4).

The main metamorphism in the Mosjøen unit is related to the D_2 deformation. The mineral assemblage in the greenschists is characterized by hornblende, chlorite, plagioclase (An_{30}), biotite, opaques, ± actinolite, ±quartz. The mica schists consist of white mica, biotite, quartz, plagioclase, ± garnet, ± staurolite or andalusite. In some thin-sections the isograd *staurolite in – chlorite and white mica out* (Winkler 1976) has been observed. According to these observations it is suggested that the metamorphism is of upper low grade to lower medium grade and of low to medium pressure (Winkler 1976). Preliminary garnet-biotite geothermometry from some of the schists indicate a temperature of about 550°C supporting this suggestion.

Luktvann granite dyke

Six total rock samples were collected from the dyke (Fig. 4). No deformation was obvious in the field, but thin-section examination showed presence of undulating extinction and the development of sub-grains in quartz. In the most deformed sample, recrystallization has produced small unstrained quartz and microcline crystals along the boundaries of larger grains. The original grain-size of the rock is about 1 mm and the mineralogy is quartz, microcline, plagioclase and white mica.

Each total rock sample weighed about 5 kg.

Analytical techniques

Rb-Sr ratios were determined by X-ray fluorescence spectrometry. Measurements of unspiked $^{87}Sr/^{86}Sr$ were made on a VG Micromass 30 at the Mineralogical-Geological Museum, Oslo, using procedures similar to those described by Pankhurst & O'Nions (1973). Variable mass discrimination in $^{87}Sr/^{86}Sr$ was corrected by normalising $^{87}Sr/^{86}Sr$ to 8.3752. The ^{87}Rb decay constant used was 1.42×10^{-11} y^{-1} and the regression technique that of York (1969). Age and intercept errors are quoted at the 2 σ level.

Results and discussion

The Rb-Sr analytical results for the Mosjøen gabbro and the Luktvann granite dyke are shown in Table 1, and data are plotted in the isotope diagrams Figs. 6 and 7.

Granitic dyke, Luktvann

The granite dyke at Luktvann yields a total rock isochron age of 433 ± 11 m.y. (MSWD = 1.22) with an initial ratio of .7075 ± .0002. The total rock date, interpreted to be the age of dyke intrusion, represents a younger time limit of the D_2 deformation and metamorphism in the Mosjøen unit. The initial ratio suggests a deep crust source region or crustal contamination of a mantle-derived magma.

The Mosjøen gabbro

The regression analyses of the minerals separated from the Mosjøen gabbro and the corresponding total rock sample yield an isochron age of 420 ± 8 m.y. (MSWD = 1.25). The initial ratio of the mineral isochron is .70412 ± .00003, which is within the range of values typical for mantle-derived rocks about 400 m.y. old (Faure & Powell 1972).

The date may be interpreted as the cooling age

Table 1. Analytical data

Sample	Rb[a]	Sr[a]	$^{87}Rb/^{86}Sr$[b]	$^{87}Sr/^{86}Sr$[c]
Luktvann granitic dyke, total rocks				
L 1	128	227	1.63	.71735±.00009
L 2	153	198	2.24	.72139±.00009
L 3	132	198	1.92	.71952±.00006
L 4	125	238	1.52	.71689±.00006
L 5	226	104	6.30	.74627±.00005
L 6	178	178	2.89	.72525±.00008
Mosjøen gabbro, sample BT-0036				
Total rock	30	394	0.23	.70552±.00006
Clinopyroxene	1.8	35	0.15	.70505±.00004
Orthopyroxene	5.5	31	0.51	.70710±.00005
Plagioclase	1.1	543	0.01	.70412±.00006
Biotite	143	76	5.46	.73696±.00003

a) By X-ray fluorescence for the Luktvann granitic dyke and by isotope dilution for the Mosjøen gabbro.
b) Precision ± 1%.
c) Precision for $^{87}Sr/^{86}Sr$ quoted as 1 σ standard error of mean.

(Dodson 1973) of the igneous minerals. In this case the mineral isochron marks the time when the gabbro minerals reached their blocking temperatures. Biotite, which controls the slope of the mineral isochron, has a blocking temperature of about 300°C (Dodson 1979). The blocking temperatures for the other gabbro minerals are probably somewhat higher. Based on the radiometric data alone, the Mosjøen gabbro may therefore have intruded at 420 ± 8 m.y. or earlier. However, the blocking-temperatures are lower than the estimated regional-metamorphic temperatures in the country rocks. Since the gabbro was emplaced during the main D_2 event, it may therefore have remained at temperatures above the blocking temperatures until the metamorphism diminished.

Together, the radiometric data and the other geological data presented in this account indicate that the main deformational and metamorphic event D_2 had ended by 433 ± 11 m.y., but the metamorphic temperatures did not decrease be-

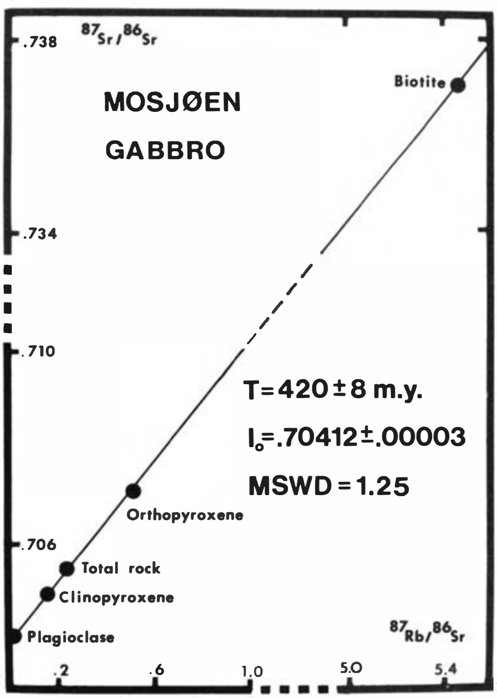

Fig. 6. Rb-Sr isotope diagram for the Mosjøen gabbro (Sample BT-00-36).

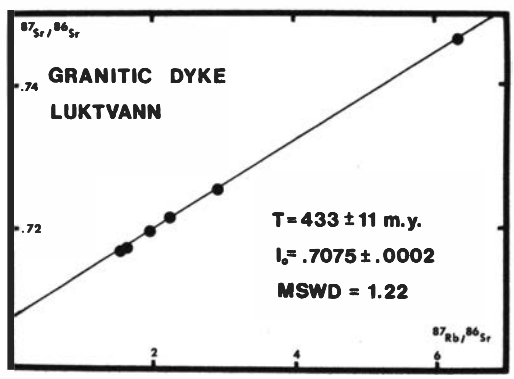

Fig. 7. Rb-Sr isotope diagram for the Luktvann granitic dyke.

low about 300°C before 420 ± 8 m.y. The available data are therefore in favour of a Silurian age for the main D_2 event in the Mosjøen unit.

Previous geochronological studies from the Uppermost Allochthon

In order to evaluate the possible influence of Silurian deformation in the Uppermost Allochthon, Fig. 8 shows the relevant published data and the present results plotted according to the geological time-scale of Palmer (1983) together with the proposed extent in time of the Scandian orogeny.

Priem et al. (1975) reported a Rb-Sr total rock date of 415 ± 25 m.y. (recalculated to λ ^{87}Rb = 1.42 × $10^{-11}y^{-1}$) for the latest intrusions (aplitic dykes and coarsely porphyritic granite) in the Bindal Massif in the HNC, which was interpreted as the intrusive age. The massif was interpreted as having been emplaced during the later stages of F_2 folding in the area (Myrland 1972), shortly after the climax of the Caledonian folding. Further Rb-Sr dating of the igneous rocks in the Bindal Massif have revealed late Cambrian emplacement ages (Nissen 1986). These data together with field investigations (A. Nissen) suggest that the date obtained by Priem et al. (1975) may refer to the latest igneous activity (late dyke intrusions) rather than to the peak of intrusive activity in the Bindal Massif. Post-emplacement cooling of the Bindal intrusions is recorded by three Rb-Sr and four K-Ar biotite dates between 414 m.y. and 386 m.y. (Priem et al. 1975, ages recalculated to λ ^{87}Rb = 1.42 × $10^{-11}y^{-1}$).

Together, the data suggest a contemporaneity between igneous activity in the Mosjøen unit and the youngest intrusions in the Bindal massif. The main igneous activity in the Bindal area, however, seems to predate the main igneous activity in the Mosjøen unit.

The age referred to in Fig. 8 from the RNC is a total rock Rb-Sr age on late tectonic dykes in the Lake Överuman area (Claesson 1979). The Ordovician age (447 ± 7 m.y.) was interpreted to give a lower limit for the timing of the regional metamorphism and the main deformation in the area. The dykes had, however, in places been subjected to minor post-intrusive deformation. These data demonstrate a pre-Scandian main deformation in this part of the Uppermost Allochthon.

In the BNC, a total rock Rb-Sr age of 440 ± 30 m.y. has been obtained for the Høytind granite (Tørudbakken & Brattli 1985), which clearly

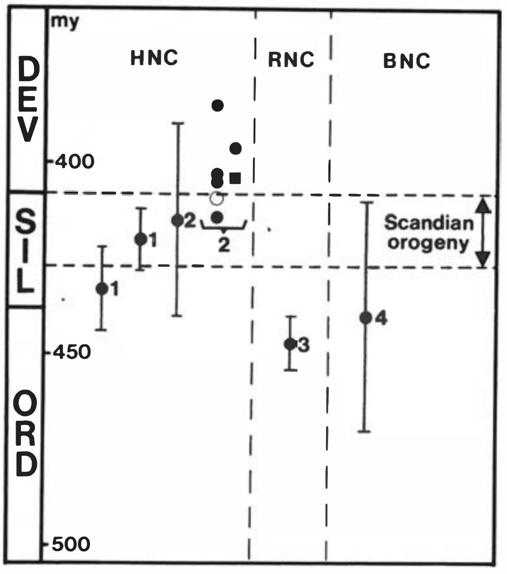

Fig. 8. Radiometric ages and the proposed duration of the Scandian orogeny (Roberts & Sturt 1980, Gee & Roberts 1983) plotted in a geological time-scale (Palmer 1983). 1-This account. 2-Priem et al. 1975. 3-Claesson 1979. 4-Tørudbakken & Brattli 1985. Black dot with error – total rock Rb-Sr. Open circle – Biotite Rb-Sr. Black dot – Biotite K-Ar. Black Square – Muscovite K-Ar.

crosscuts the regional structures (F_1 and F_2) as well as the internal thrust contacts in the upper part of the BNC. Post-intrusional deformation effects in the Høytind granite are minor. In the country rocks the main structures were formed during the F_1, interpreted to have occurred in late Cambrian to early Ordovician time on the basis of radiometric dating of syntectonic (F_1) intrusions (Cribb 1981). The available evidence therefore supports a pre-Silurian main deformational event for the BNC, older than 440 ± 30 m.y.

Conclusions

It is evident from the present work that the main deformation, metamorphism and igneous activity in the Mosjøen unit (within the HNC), may be consistent with the timing of the Scandian orogeny. In other parts of the Uppermost Allochthon radiometric data indicate only minor Scandian deformation following a stronger early Caledonian orogenic event. This variable influence of Scandian deformation suggests that the different tectonostratigraphic units or provinces now constituting the Uppermost Allochthon had different tectonic and metamorphic evolutions prior to their imbrication and nappe translation. These tectonometamorphic events occurred in early Caledonian time and in Scandian time, and have involved late Precambrian basement rocks. The present tectonostratigraphic sequence within the Uppermost Allochthon was formed during the thrusting and translation onto the Baltic Shield in the late Silurian. The Scandian event was over by the late Silurian to early Devonian as shown by the mineral ages.

Acknowledgements. – The field and laboratory research were supported by Norges Almenvitenskapelige Forskningsråd and Sydvaranger Prospektering A/S. We thank Ivar B. Ramberg, Håkon Austrheim (Oslo) and Craig Smally (IFE, Kjeller) and two anonymous referees for helpful advice and criticism. Special thanks go to Craig Smally who kindly improved the English Text, and to Rønnaug Harnes who typed the manuscript.

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