Rb–Sr dating of a syn-tectonic granite within the Lyngen Nappe Complex and its implications for late orogenic evolution of the Troms Caledonides

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A syn-tectonic metagranite, intruding the structurally uppermost part of the Upper Ordovician/Lower Silurian Balsfjord Group, Lyngen Nappe Complex, on Reinøy, Troms, has been dated by the Rb–Sr method. The obtained isochron age of 432 ± 7 Ma (I.R. 0.71108 ± 0.00025) is interpreted to represent the magmatic crystallization age of the granite, suggesting that deformation and metamorphism of the Balsfjord Group started shortly after deposition. The syn/post-D1 and pre-D2 age for the granite suggests that juxtaposition of the Balsfjord Group and structurally underlying Nordmannvik Nappe and overlying Tromsø Nappe Complex took place during the early Silurian, possibly representing initiation of the Scandian orogenic event in the north Norwegian Caledonides. Such an interpretation is consistent with recently obtained $^{40}Ar/^{39}Ar$ mineral ages (amphibole and white mica) from the Balsfjord Group and Nordmannvik Nappe which have yielded cooling ages related to uplift of around 425–420 Ma.

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The Caledonides of northern Norway are composed of a series of nappes emplaced eastward onto the Baltoscandian Platform at a late state during the Scandian (Late Silurian/Early Devonian) continental collisional event (Roberts & Gee 1985). The various nappes are generally grouped into four nappe complexes: the Lower, Middle, Upper and Uppermost Allochthons. The Lower and Middle Allochthons are composed of Late Precambrian and Early Paleozoic sediments derived from the rifted margin that bordered the Baltoscandian Platform to the west. Large volumes of Proterozoic crystalline rocks, representing the depositional basement to these sediments, are common within the Middle Allochthon. The exotic terranes of the structurally overlying Upper Allochthon show evidence of Early Paleozoic Caledonian igneous activity, and contain island-arc complexes, associated basin-related volcano-sedimentary sequences and fragmented ophiolite assemblages. The Uppermost Allochthon is composed of migmatitic gneisses, psammites, marbles and schists, with zones of lower grade supracrustal rocks. Synorogenic granitoids characterize the Uppermost Allochthon, and are most likely associated with a destructive plate margin (Roberts & Gee 1985).

The Scandian orogenic event is thought to have been responsible for the main part of the deformation and metamorphism within the nappe pile, as a result of the final emplacement of the nappe complexes to their present tectonostratigraphic positions. However, evidence of pre-Scandian tectonothermal activity is recorded from different segments of the Caledonides, including an extensive Early Ordovician event which involved high-grade metamorphism (Dallmeyer & Gee 1986; Mørk et al. 1988), and the later obduction of ophiolite assemblages (Dunning & Pedersen 1988).

Within the Upper Allochthon in central Troms (Fig. 1), a regional unconformity separates an older ophiolite fragment (the Lyngen Ophiolite) from the overlying metasedimentary succession (e.g. Minsaas & Sturt 1985; Andresen 1988). A depositional age for parts of the metasedimentary sequence is given by Upper Ordovician to Lower Silurian fossils (Bjørlykke & Olaussen 1981; Binns & Matthews 1981). A fossil-bearing sequence of similar age is found in the tectonostratigraphically lower Vaddas Nappe (Binns & Gayer 1980), relating the main nappe translation in this region to the Scandian orogenic phase. However, the presence of an ophiolite fragment, and the interleaving of low- and high-grade metamorphic nappes within the Upper Allochthon in Troms, led Binns (1978) and Andresen et al. (1985) to propose that the nappe stack was composed of nappes with a pre-Scandian as well as a Scandian tectonometamorphic fabric. In an attempt to constrain the tectonometamorphic evolution in the Troms and Ofoten Caledonides, isotopic age dating, using a variety of methods ($^{40}Ar/^{39}Ar$, Rb/Sr and U/Pb), was undertaken (Lindstrøm & Andresen 1992; Dallmeyer & Andresen 1992). This work, being a part of that project, presents a Rb/Sr dating of a granite intrusive within a metasedimentary unit in the uppermost part of the Upper Allochthon in Troms.

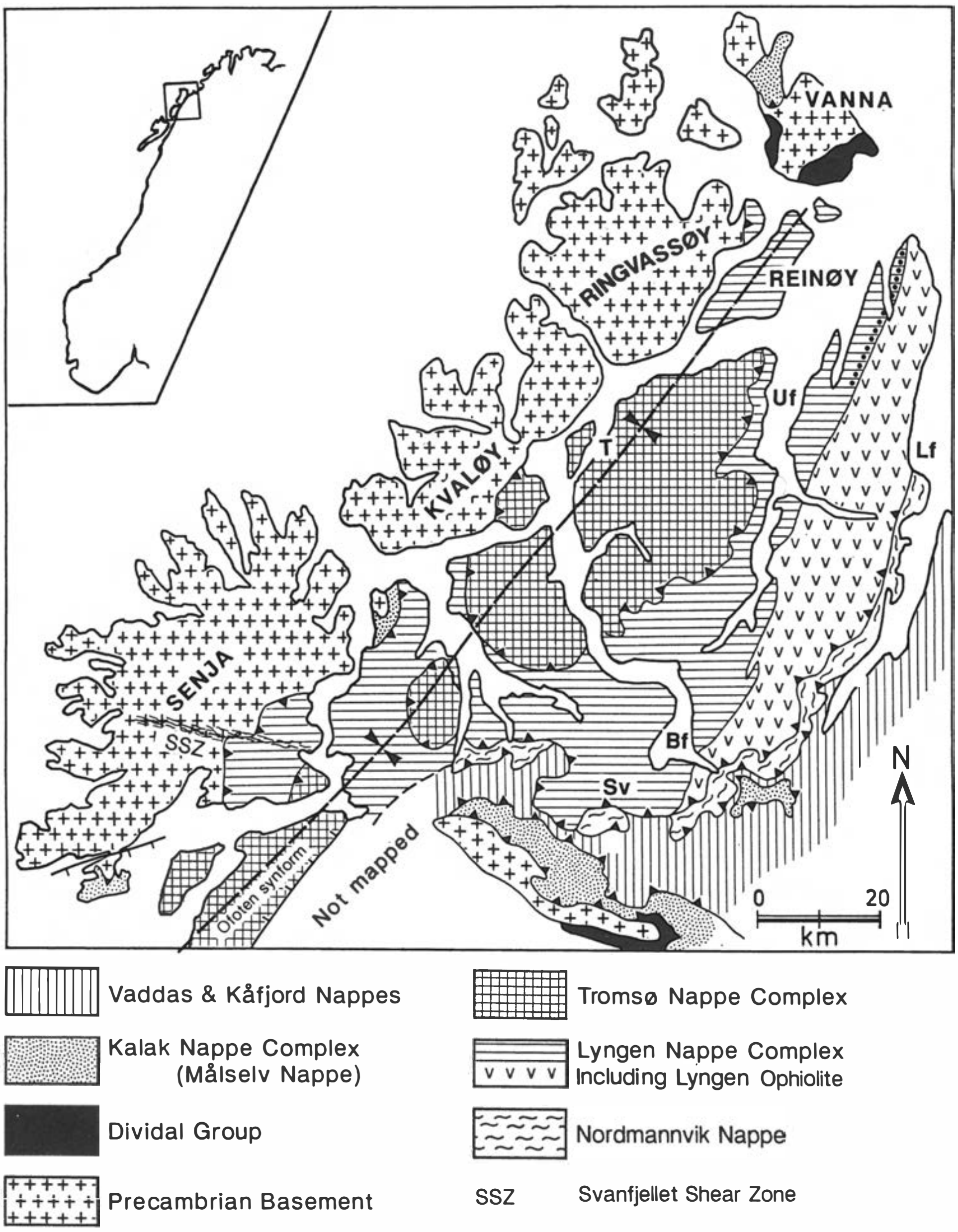

Fig. 1. Tectonostratigraphic map of the north Troms Caledonides. Modified from Andresen et al. (1985). Uf = Ullsfjord, Lf = Lyngenfjord, Bf = Balsfjord, Sv = Sagelvvatn, T = Tromsø.

Geological setting

The thin, flat-lying nappes in central Troms are situated in a broad, asymmetric depression (half-graben), bordered to the east by a thin veneer of autochthonous sediments above a crystalline Precambrian basement (Andresen et al. 1985; Krogh et al. 1990). An east-dipping, post-Caledonian, brittle normal fault separates the Caledonian nappes from the Precambrian basement rocks along the west coast of Troms (Forslund 1988). The tectonostratigraphy currently in use for the area is summarized in Fig. 1. The lowermost allochthonous unit, the Kalak Nappe Complex (Målselv Nappe), corresponds to parts of the Middle Allochthon further north. The structurally higher Vaddas, Kåfjord and Nordmannvik Nappes and the Lyngen Nappe Complex are generally incorporated in the Upper Allochthon in Troms. The Tromsø Nappe Complex is correlated with the Uppermost Allochthon (Andresen 1988). Major nappe boundaries are characterized in most places by a marked change in lithology and metamorphic grade. The Reinøy granite, the subject of this study, is located in the upper part of the Lyngen Nappe Complex (Figs. 1 and 3).

The Lyngen Nappe Complex is characterized by middle to upper greenschist facies rocks, dominantly of sedimentary origin, and is structurally overlain and underlain by nappes of considerably higher metamorphic grade. The underlying Nordmannvik Nappe has undergone high amphibolite to granulite facies metamorphism (Bergh & Andresen 1985; Elvevold 1988), and Krogh et al. (1990) have recently described the high-grade metamorphic evolution of the Tromsø Nappe Complex, which locally carries relict eclogite-facies mineral assemblages. The lower part of the Lyngen Nappe Complex is dominated by a mafic to ultramafic layered complex (the

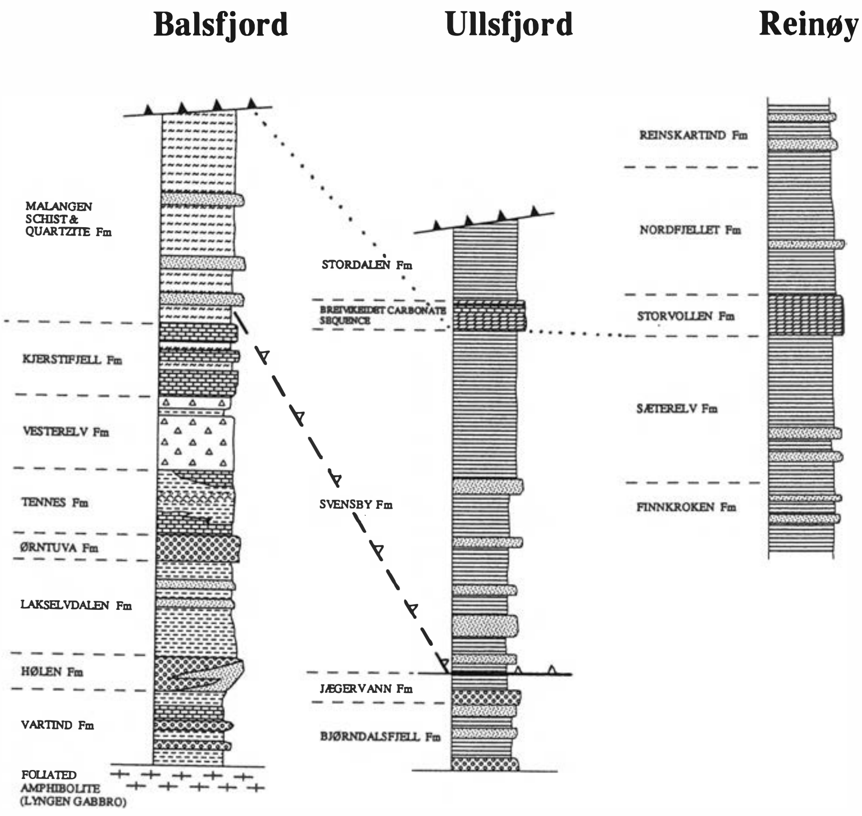

Fig. 2. Lithostratigraphy of the Balsfjord Group, Lyngen Nappe Complex (from Andresen & Steltenpohl 1990), showing the location of the Reinøy sequence relative to the sedimentry sequences further south. Notice the pre/syn-metamorphic (D1) thrust above the Kjerstifjellet Marble, which northward cuts down-section and removes the fossiliferous carbonate rocks from the stratigraphy in the Ullsfjord area. The Reinøy granite intrudes the Nordfjellet formation on Reinøy.

Lyngen Ophiolite), sitting structurally above a sequence of strongly sheared amphibolites and greenschists, which grade downward into graphitic schists and thin conglomerate layers, all considered part of the Lyngen Nappe Complex. The mafic layered complex was interpreted by Minsaas & Sturt (1985) and Furnes et al. (1985) to represent a fragmented ophiolite, an interpretation supported by recent geochemical work (Fuller 1986; Furnes & Pedersen pers. comm. 1992).

The Lyngen Ophiolite is unconformably overlain by the Upper Ordovician/Silurian Balsfjord Group (Bjørlykke & Olaussen 1981; Minsaas & Sturt 1985). The Balsfjord Group is dominated by schists and carbonates (marble and dolomite), but also contains polymict conglomerates, diamictites, meta-psammites and minor volcanics (Fig. 2). There is a distinct change in lithostratigraphy from carbonate-dominated deposits (with fossils) in the Sagelvvatn/Balsfjord area to dominantly schists and meta-psammites in the Ullsfjord area. This north–south, along-strike lithostratigraphic change was discussed by Andresen & Bergh (1985), who suggested it was either due to a dramatic facies change or caused by a post-depositional fault. More recent work in the inner part of Ullsfjorden supports the latter interpretation (Andresen & Steltenpohl 1991). A pre- to syn-metamorphic thrust, cutting upsection southwestward, appears to be localized just above the Hølen conglomerate in the Ullsfjord area. This new interpretation implies that the depositional ages of the units structurally above the Kjerstifjellet Marble, including those on Reinøy, relative to the fossiliferous units, are uncertain. All units within the Balsfjord Group, however, have undergone three episodes of deformation (D1–D3), although of variable intensity, mainly under middle to upper greenschist facies metamorphic conditions (Andresen & Bergh 1985). The metamorphism locally reaches amphibolite facies towards the contact to the overlying, higher grade Tromsø Nappe Complex (Kristensen 1983; Andresen & Bergh 1985; Krogh et al. 1990). Steltenpohl et al. (1990) and Andresen & Steltenpohl (1991) suggested that both sequences, and the correlative Salangen Group in the Ofoten area, formed part of the same Ordovician basin prior to Scandian deformation. The dominant foliation throughout the sequence is an S1 axial plane schistosity. Major D2 folds in the region affect the thrust contacts confining the Lyngen Nappe Complex, indicating that the D1 structures are related to assembly of the nappes (Bergh & Andresen 1985).

Field relations and petrography of the Reinøy granite

The correlation between the metasediments on the island of Reinøy with the Ullsfjord sequence on the mainland (Fig. 2) is primarily based on lithological similarities, especially the continuation of the Breivikeidet carbonate sequence to the carbonaceous Storvollen formation on Reinøy (Fig. 3). In addition, the metasedimentary rocks in the two areas have undergone the same grade of metamorphism and type of deformation (Velvin 1985;

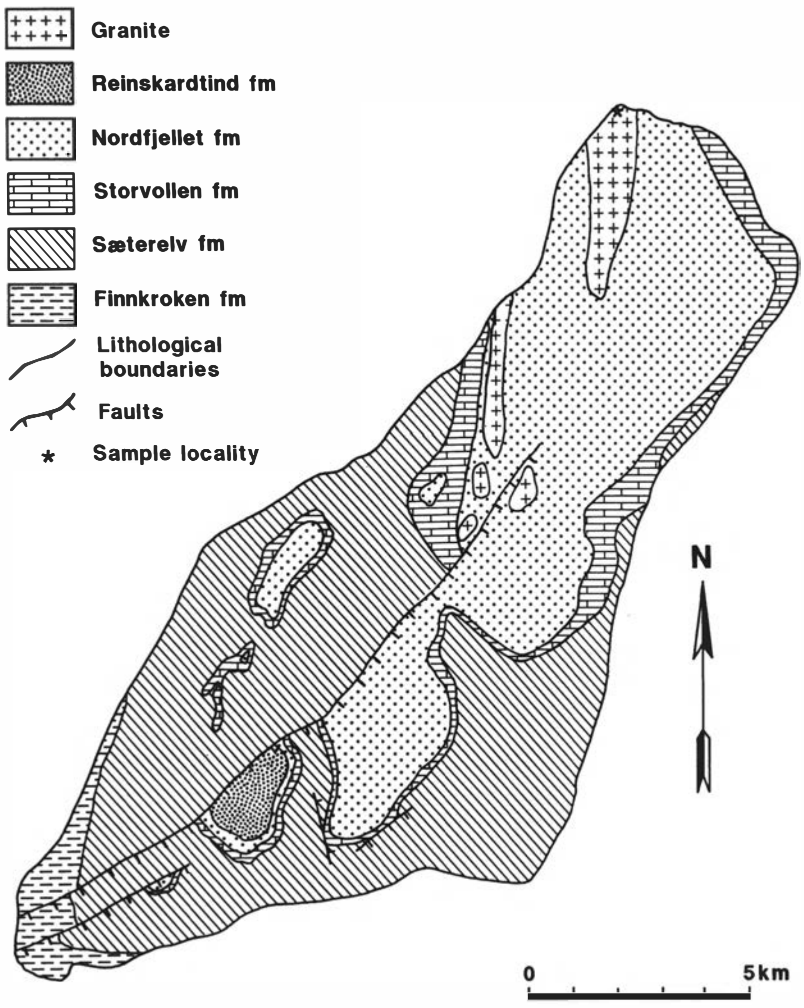

Fig. 3. Geologic map of Reinøy showing the distribution of the main outcrop areas of the Reinøy granite. Modified from Velvin (1985).

Bergh & Andresen 1985). Velvin (1985) divided the metasediments on Reinøy into five lithostratigraphic formations, all with sharp and conformable depositional contacts (Fig. 3). The formations were given the local names, from the base up; the Finnkroken, Sæterelv, Storvollen, Nordfjellet and Reinskardtind formations. Most intrusive rocks on Reinøy, including granites and at least two generations of metadolerites, are found within the Nordfjellet formation. This formation is dominated by garnet–quartz–mica schist with some quartzitic layers. Small mafic bodies also occur within other formations, whereas granites exclusively occur within the Nordfjellet formation, as relatively larger bodies or as thin, randomly oriented dikes limited to smaller areas. Only the larger granite bodies are shown on the map (Fig. 3).

The investigated granite extends for about 4 km southward from the northernmost point of Reinøy, and is the largest intrusive body on the island. It has a sharp contact to the surrounding schist, which is coarse grained, with large garnet porphyroblasts, and an almost gneissic texture next to the granite. Xenoliths of schist are found several places within the granite. Granite dikes cut across the metamorphic foliation (S1) but are themselves folded by F2-folds. A weak foliation, defined by parallel oriented micas, is commonly observed in the granite bodies and coincides with the S1 foliation in the surrounding schist.

The granite is fine to medium grained, with subgranoblastic texture. It is composed of plagioclase (30–35%), quartz (30–35%), alkali-feldspar (20–30%), biotite (3–5%), white mica (3–5%) and epidote (2–3%). Garnet, sphene, chlorite and opaques are found as accessories. Most minerals are recrystallized, but primary (?) magmatic grains of feldspar and biotite are seen in thin-section. Saussuritization and sericitization of plagioclase grains and secondary growth of chlorite from biotite indicate low-grade metamorphism of the granite. The foliation is defined by parallel oriented secondary biotite and white mica. Garnets have core and rims indicating a two-stage growth that occurred prior to D2.

Analytical methods

The analysed samples were collected from road cuts through the largest granite body at the northernmost part of the island (Fig. 3), the UTM localization is given in Table 1. Concentrations of Rb and Sr were determined on the Phillips PW 1400 X-ray fluorescence spectrometer at the University of Tromsø. Measurements of the iso-

Table 1. Whole rock isotopic data for the Reinøy granite.

	ppm Rb	ppm Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	SE
REIN 3	94.6	148.1	1.8508	0.72278	±6
REIN 5	112.7	136.4	2.3931	0.72566	±7
REIN 6	108.4	75.9	4.1461	0.73637	±6
REIN 7	104.3	142.9	2.1139	0.72400	±6
REIN 8	85.9	87.8	2.8363	0.72802	±9
REIN 9	103.9	87.4	3.4486	0.73239	±6

Map reference: 1535 II Helgøy (1:50,000) UTM 633 675.

topic ratios were made on the VG Micromass MS 30 at the Mineralogical Museum in Oslo. Variable mass discrimination in the Sr-isotopic ratios was corrected by normalizing the $^{86}Sr/^{88}Sr$ ratio to 0.1194. The ^{87}Rb decay constant used was 1.42×10^{-11}/years (Steiger & Jäger 1977), and the data were regressed by the technique of York (1969). The analytical data are given in Table 1, all errors quoted are 2 σ errors.

Results

Regression of the analytical data from the six whole rock samples of the Reinøy granite yields an isochron age of 432 ± 7 Ma, with an initial Sr-isotopic ratio of 0.71108 ± 0.00025 and a MSWD of 3.55 (Fig. 4). The MSWD value indicates some geological disturbance of the isotope system. The scatter may be due to a part opening of the whole rock system associated with the post-emplacement recrystallization, involving growth of garnet, and the partial alteration of plagioclase and biotite. The relatively low degree of deformation of the granite suggests that the mobility of the elements was too limited to result in a near complete equilibration of the isotope system. An interpretation of the isochron age as reflecting the age of emplacement and crystallization of the granite is therefore preferred. The Sr-initial ratio indicates derivation of the granite from continental crustal material.

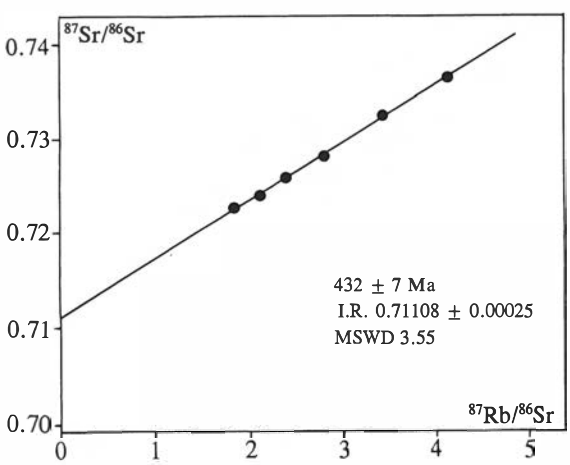

Fig. 4. Isochron plot of the analysed samples from the Reinøy granite.

Discussion

Field relationships indicate that the Reinøy granite was emplaced prior to the D2 deformation, and most likely synchronous with the local D1 deformational event (Velvin 1985). Its age links the deformation and magmatism in this part of the Lyngen Nappe Complex to an early deformational phase of the (Late Caledonian) Scandian orogenic event, as suggested by Steltenpohl et al. (1990) and Andresen & Steltenpohl (1991). The Early Silurian age implies that the depositional age of the Nordfjellet formation cannot be much younger than the fossiliferous (Upper Ordovician to Early Silurian) Sagelvvatn rocks structurally below. It can, however, be older than the Sagelvvatn sequence. As both units are characterized by a considerably lower grade of metamorphism than overlying and underlying supracrustal nappe sequences, it suggests that they were originally deposited in the same sedimentary basin ('Balsfjord Basin'), postdating the early Ordovician ophiolite obducting event. The age of the Reinøy granite furthermore supports the interpretation that collapse of the basin and initiation of the Scandian orogenic event in this part of the Caledonides is of Early Silurian age and that it started just after deposition of the fossiliferous Sagelvvatn unit.

The driving force for the collapse and basin shortening may be related to emplacement of the Tromsø Nappe Complex. Krogh et al. (1990) have recently argued that the upward increase in metamorphism in the Lyngen Nappe Complex is related to emplacement of the higher grade Tromsø Nappe Complex on top. A metamorphic K/Ar date of *c.* 437 Ma from hornblende within a retrogressed eclogite in the upper part of the Tromsø Nappe Complex (Krogh et al. 1990) indicates that the Tromsø Nappe Complex maintained its high grade metamorphic temperature throughout its emplacement with the Lyngen Nappe Complex. A subsequent step in this compressional event may have been emplacement of the Lyngen Nappe Complex on top of the Nordmannvik Nappe. An Early- to Mid-Silurian juxtaposition of the Lyngen Nappe Complex and Nordmannvik Nappe is supported by recently obtained $^{40}Ar/^{39}Ar$ mineral ages from the two units (Dallmeyer & Andresen 1992). Argon release spectra of amphiboles from the two nappes indicate that uplift and cooling below *c.* 500 °C took place between 425 and 420 Ma. Spectra from white mica indicate cooling below *c.* 375 °C at around 420 Ma. $^{40}Ar/^{39}Ar$ cooling ages on amphibole and muscovite reported from the Gratangen area, just south of the map area in Fig. 1, suggest a more protracted tectonothermal history (Anderson et al. 1992). Data from a high-grade unit correlative to the Nordmannvik Nappe indicate an early period of rapid uplift and post-metamorphic cooling (425–420 Ma). The nappes at the same tectonostratigraphic level as the Lyngen Nappe Complex (Balsfjord Group), however, give cooling ages on muscovite which are consistently younger (395–373 Ma), indicating that the two areas may have undergone different uplift histories following the initial phase of Scandian deformation as suggested by Coker et al. (1992).

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References

Anderson, M. W., Barker, A. J., Bennett, D. G. & Dallmeyer, R. D. 1992: A tectonic model for the Scandian terrane accretion in the northern Scandinavian Caledonides. *Journal of the Geological Society, London 149*, 727–741.

Andresen, A. 1988: Caledonian terranes of northern Norway and their characteristics. *Trabajas de Geologia, University of Oviedo 17*, 103–117.

Andresen, A. & Bergh, S. G. 1985: Stratigraphy and tectonometamorphic evolution of the Ordovician–Silurian Balsfjord Group, Lyngen Nappe, north Norwegian Caledonides. *In* Gee, D. G. & Sturt, B. A. (eds.): *The Caledonide Orogen – Scandinavia and related areas*, 579–591. Wiley, New York.

Andresen, A., Fareth, E., Bergh, S., Kristensen, S. E. & Krogh, E. 1985: A Review of Caledonian lithotectonic units in Troms. *In* Gee, D. G. & Sturt, B. A. (eds.): *The Caledonide Orogen – Scandinavia and related areas*, 569–578. Wiley, New York.

Andresen, A. & Steltenpohl, M. G. 1991: Tectonostratigraphy of the North Troms Caledonides with emphasis on the Lyngen Nappe Complex: a summary. *In* Andresen, A. & Steltenpohl, M. G. (eds.): *A geotraverse excursion through the Scandinavian Caledonides: Torneträsk–Ofoten–Tromsø*. Fieldguide to 'Terranes in the Arctic Caledonides'. IGCP 233 Conference, Tromsø 1991.

Bergh, S. G. & Andresen, A. 1985: Tectonometamorphic evolution of the allochthonous Caledonian rocks between Malangen and Balsfjord, Troms, north Norway. *Norges geologiske undersøkelse 401*, 1–34.

Binns, R. E. 1978: Caledonian nappe correlation and orogenic history in Scandinavia north of lat. 67°N. *Geological Society of America Bulletin 89*, 1475–1490.

Binns, R. E. & Gayer, R. A. 1980: Silurian or Upper Ordovician fossils at Guolasjavri, Troms, Norway. *Nature 284*, 53–55.

Binns, R. E. & Matthews, D. W. 1981: Stratigraphy and structure of the Ordovician–Silurian Balsfjord Supergroup, Troms, North Norway. *Norges geologiske undersøkelse 365*, 39–54.

Bjørlykke, A. & Olaussen, S. 1981: Silurian sediments, volcanics and mineral deposits in the Sagelvvatn area, Troms, northern Norway. *Norges geologiske undersøkelse 365*, 1–38.

Coker, J. E., Steltenpohl, M. G., Andresen, A., Gromet, P. & Kunk, M. J. 1992: U-Pb and $^{40}Ar/^{39}Ar$ thermochronology and tectonic evolution of the Ofoten–Troms Region, North Norwegian Caledonides. *Geological Society of America, Abstracts with Programs 24*(7), 235–236.

Dallmeyer, R. D. & Andresen, A. 1992: Polyphase tectonothermal evolution of exotic Caledonian nappes in Troms, Norway: evidence from $^{40}Ar/^{39}Ar$ mineral ages. *Lithos 29*, 19–42.

Dallmeyer, R. D. & Gee, D. G. 1986: $^{40}Ar/^{39}Ar$ mineral dates from retrogressed eclogites within the Baltoscandian miogeocline: implications for a polyphase Caledonian orogenic evolution. *Geological Society of America Bulletin 97*, 26–34.

Dunning, G. R. & Pedersen, R. B. 1988: U/Pb ages of ophiolites and arc-related plutons of the Norwegian Caledonides: implications for the development of Iapetus. *Contributions to Mineralogy and Petrology 98*, 13–23.

Elvevold, S. 1988: Petrologiske undersøkelser av kaledonske bergarter i Takvatnområdet, Troms. Unpublished cand.scient. thesis, University of Tromsø. 149 pp.

Forslund, T. 1988: Post-kaledonske forkastninger i vest-Troms, med vekt på Strømsbukta – Kvaløysletta forkastningen, Kvaløya. Unpublished cand.scient. thesis, University of Tromsø. 160 pp.

Fuller, B. A. 1986: Geochemistry of the Kjosen Formation, Arctic Norway. Unpublished BA thesis, Middlebury College, Vermont, USA. 56 pp.

Furnes, H., Ryan, P. D., Grenne, T., Roberts, D., Sturt, B.A. & Prestvik, T. 1985: Geological and geochemical classification of the ophiolite fragments in the Scandinavian Caledonides. *In* Gee, D. G. & Sturt, B. A. (eds.): *The Caledonide Orogen – Scandinavia and related areas*, 657–670. Wiley, New York.

Kristensen, S. E. 1983: Strukturgeologiske og petrologiske undersøkelser av de øverste tektonostratigrafiske enheter på Malangshalvøya, Troms. Unpublished cand.real. thesis, University of Tromsø. 270 pp.

Krogh, E. J., Andresen, A., Brynhi, I., Broks, T. M. & Kristensen, S. E. 1990: Eclogites and polyphase P-T cycling in the Caledonian Uppermost Allochthon in Troms, northern Norway. *Journal of Metamorphic Geology 8*, 289–309.

Lindstrøm, M. & Andresen, A. 1992: Early Caledonian high-grade metamorphism within exotic terranes of the Troms Caledonides? *Norsk Geologisk Tidsskrift 72*, 375–379.

Minsaas, O. & Sturt, B. A. 1985: The Ordovician–Silurian clastic sequence overlying the Lyngen Gabbro Complex and its environmental significance. *In* Gee, D. G. & Sturt, B. A. (eds.): *The Caledonide Orogen – Scandinavia and related areas*, 379–394. Wiley, New York.

Mørk, M. B. E., Kullerud, K. & Stabel, A. 1988: Sm–Nd dating of Seve eclogites, Norrbotten, Sweden – evidence for early Caledonian (505 M.a.) subduction. *Contributions to Mineralogy and Petrology 99*, 344–351.

Roberts, D. & Gee, D. G. 1985: An introduction to the structure of the Scandinavian Caledonides. *In* Gee, D. G. & Sturt, B. A. (eds.): *The Caledonide Orogen – Scandinavia and related areas*, 485–497. Wiley, New York.

Steiger, R. H. & Jäger, E. 1977: Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology. *Earth and Planetary Science Letters 36*, 359–362.

Steltenpohl, M. G., Andresen, A. & Tull, J. F. 1990: Lithostratigraphic correlation of the Salangen (Ofoten) and Balsfjord (Troms) Groups: evidence for post-Finnmarkian unconformity, north Norwegian Caledonides. *Norges geologiske undersøkelse 418*, 61–77.

Velvin, M. 1985: Berggrunnsgeologiske undersøkelser av Reinøy, Troms, med vekt på den strukturelle utvikling. Unpublished cand.real thesis, University of Tromsø. 160 pp.

York, D. 1969: Least squares fitting of a straight line with correlated errors. *Earth and Planetary Science Letters 5*, 320–324.