U-Pb zircon age of 469 ± 5 Ma for a metatonalite from the Kjosen Unit of the Lyngen Magmatic Complex, northern Norway

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Two fractions of zircon from a tectonised tonalite from within metagabbro of the Kjosen Unit of the Lyngen Magmatic Complex give a concordant U-Pb age of 469 ± 5 Ma.
This is interpreted as a minimum age for the Kjosen Unit. This Late Arenig-Llanvirn age is similar to that found in the last stages of magmatic development of the Karmøy Ophiolite Complex of Southwest Norway.

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Introduction

The Lyngen Gabbro Complex of Randall (1971) has been renamed the Lyngen Magmatic Complex by Furnes & Pedersen (1995). The Lyngen Magmatic Complex (LMC) lies within the Lyngsfjell Nappe Complex, which in turn lies on top of the Reisa Nappe Complex (Zwaan 1988) (Fig. 1, this paper). These nappe complexes form part of the Upper Allochthon of the Scandinavian Caledonides (Anderson et al. 1992). According to Furnes & Pedersen (1995) the LMC is composed of the Jiekkevarri, Strupen and Kjosen Units. Furnes et al. (in prep.) now refer to these units, informally, as the Lyngen Gabbro (western type), Lyngen Gabbro (eastern type) and Kjosen Greenschist, respectively. The Jiekkevarri Unit is made up of layered ultramafics and layered gabbro, basalt dykes and pillow lavas of N-MORB affinity. The Strupen Unit is generally separated from the Jiekkevarri Unit by the Ryppdalen Shear Zone, a major, oceanic, high-temperature ductile shear zone (Slagstad 1995). The Strupen Unit consists of dunite, harzburgite, gabbronorite and quartz gabbro intruded by basic dykes and tonalite sheets. The geochemistry provides indications of boninitic characteristics and the Strupen Unit is interpreted as having formed in a fore-arc part of an island arc. The Kjosen Unit is in thrust contact with the Strupen Unit and consists of strongly tectonised metabasalts of MORB to calc-alkaline and alkaline character (Furnes & Pedersen 1995).

By comparison with other radiometrically dated ophiolites in Scandinavia, the LMC is assumed to be Early Ordovician in age, one of the Group I ophiolites of Furnes et al. (1985). Its upper age limit is given by the unconformably overlying Favosites-bearing Late Ordovician to Early Silurian Balsford Group clastics (Minsaas & Sturt 1985). Furnes et al. (1985), Minsaas & Sturt (1985) and Sturt & Roberts (1991) considered that the LMC was obducted, polyphasally deformed and eroded in Early to early-Mid Ordovician time during an orogenic phase which is generally referred to as the Finnmarkian (see also Andresen & Steltenpohl 1994). Until now, none of these LMC units has been radiometrially dated. This short paper presents the results of U-Pb zircon dating of the Kjosen Unit.

The Kjosen Unit

One of the authors (GJHO) has mapped the Kjosen Unit in the area shown in Fig. 1 at a scale of 1:15,000. The Kjosen Unit can be subdivided into several tectonic sub-units

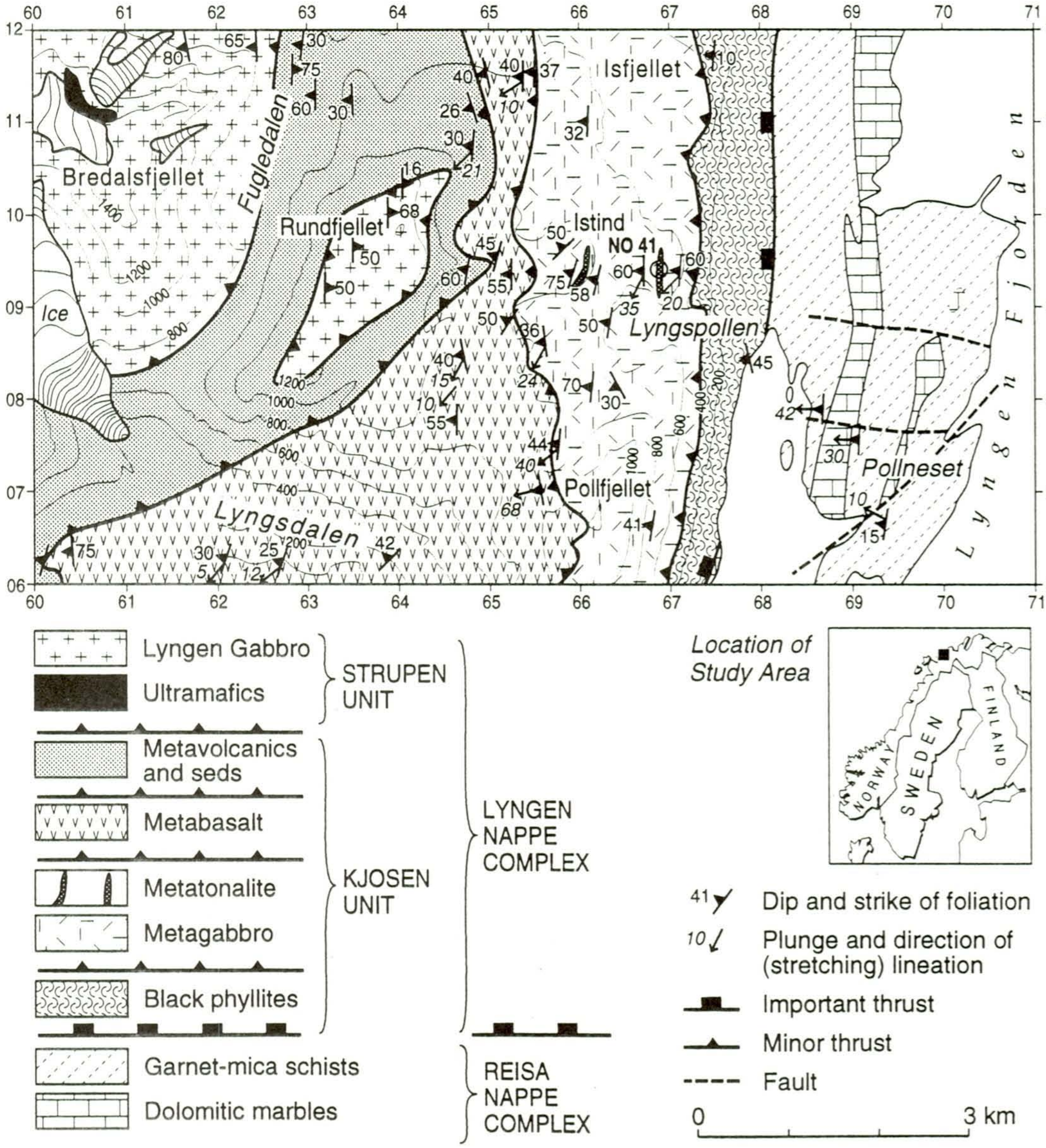

Fig. 1. Geological map of part of the Kjosen Unit on the west side of Lyngenfjord, Troms, with the sample locality indicated. Grid lines and base map taken from map-sheet 1633 IV Storfjord, Series M711, 1:50,000. Area originally mapped at 1:15,000 scale by GJHO.

based on contrasting lithology. In the east, c.550 m of black phyllite (the Koppangen Formation of Randall (1971)) is in thrust contact with garnet-mica schists and dolomitic marbles of the Reisa Nappe Complex. The main cliffs along the side of Lyngenfjord are composed of c.1100 m of green metagabbro tectonically overlying the phyllite. Around Pollfjellet (Fig. 1) the gabbro is hardly deformed and despite metamorphic recrystallisation, rhythmic compositional layering is visible. Traversing away from Pollfjellet in any direction leads to more and more intensely tectonised metagabbro as it grades into a greenschist composed of albite, actinolite, biotite, epidote and opaques. In places, the metagabbro is in contact with sheets of tectonised leucogranite (see below). The boundaries of the metagabbro unit are strongly tectonised and characterised by the development of mylonite. This interpretation is at odds with that shown on Zwaan's (1988) 1:250,000 map-sheet 'Nordreisa', where the Pollfjellet outcrops are drawn as a klippe of the Lyngen Gabbro.

The metagabbro is structurally superseded by c. 400 m of dark green to black metabasalt, darker than the green metagabbro. Black chert layers are not uncommon. Deformed pillow lava stuctures can be seen 400 m west of Istind (Fig. 1, grid reference 654104 on Sheet 1633 IV, Storfjord, Series M711, 1:50,000). Way-up criteria (i.e., v-shapes at the bottom of pillows) show that the pillows are right way up, and dipping parallel to a metamorphic foliation striking 167° and dipping 35° to the west. The strain state of the metabasalt is variable; textures vary from those of greenstone pillow lava to greenschist to mylonite (L-S tectonites with the lineation generally plunging at 15° to the SW; see Fig.1). Mylonites are especially common at the margins of the metagabbro unit. In thin-section , the mineralogy of the metabasalt is similar to that of the metagabbro, i.e. albite, actinolite, biotite, epidote and opaques. XRF major and trace element analysis of 30 samples and the use of various discrimination diagrams and 'spidergrams' show that they are mid-ocean ridge basalt (MORB) type (Oliver, unpubl. data).

A unit of striped greenschists lies above the metabasalts, with the striping on the millimetre and centimetre scale. Although no relict lava structures were found, there is a close similarity to some outcrops of the metabasalt unit below. The paler layers are relatively richer in quartz and feldspar. In places (e.g., grid reference 645180 on Sheet 1633 IV, to the north of Fig. 1), the striped greenschists show gradations into metaquartzites. It is therefore probable that this unit is a metamorphosed sequence of volcanic and sedimentary rocks. Striping (bedding?) and foliation strike generally 185° and dip 45° west. There were no field criteria available to judge whether or not there were volcanoclastic components in this unit. The chemistry of the mafic varieties of this unit is much more variable than that of the metabasalts of the unit below, varying from N-MORB to calk-alkaline (unpublished XRF results). Again, the strain state is highly variable with the highest strain seen at the boundaries with neighbouring units where mylonites occur.

The most westerly unit exposed in the area is the Strupen Unit of the Lyngen Gabbro. In this area it is composed of layered gabbronorites, quartz gabbros and minor dunite. The bulk rock and isotope chemistry is of island arc tholeiitic affinity (IAT) to boninitic composition (Furnes & Pederson 1995). Apart from the base of the unit, where there is a 20 m band of strong mylonitisation striking generally north-south and dipping 45° to the west, there is a conspicuous lack of a metamorphic foliation. This distinguishes the Strupen Unit from the other units described above. The peak of Rundfjellet is an outlying klippe of the Strupen Unit (see Fig. 1). Magmatic layering here strikes N-S and varies in dip from to 50° to 60° to the east, obviously being unrelated to the orientation of the underlying thrust which dips gently west.

Wherever kinematic indicators were observed and measured, i.e. asymmetric augens, quartz vein offsets, etc., the sense of movement in all the mapped Kjosen sub-units was consistent with the hangingwall moving up to the E or NE.

Kjosen Unit as a dismembered MORB ophiolite

The Kjosen Unit can be mapped as four thrust slices lying beneath the Strupen Unit of the LMC. One possibility is that the Kjosen black phyllite thrust slice represents metamorphosed and tectonised deep-water black shales. This, together with the presence of a thick MORB lava thrust slice and a thicker gabbro slice, would suggest that a piece of MORB ophiolite has been dismembered during Scandian terrane accretion (see Anderson et al. 1992). Its MORB chemistry distinguishes it from the IAT to boninitic Strupen Unit. Because the contact between the two is a thrust (a medium-angle reverse fault), there is no evidence for their relative ages. No evidence for a sheeted dolerite dyke complex was observed but this is not considered surprising in view of the strain state which has produced abundant mylonites and greenschists of basalt-dolerite composition.

Age dating

Sample description

Sample NO41 was collected between Istind and Lyngspollen, (grid reference 669094 on Sheet 1633 IV, Storfjord, Series M711, 1:50,000) from within the mass of metagabbro. In the field it is a coarse-grained foliated leucocratic sheet, at least 10 m thick, which can be traced for 150 m along strike. The sheet is one of two and lies parallel to the regional foliation striking at 185^{o} and dipping 60^{o} to the west. Its western contact is unexposed but the eastern boundary has a sharp contact with metagabbro. This may have been an original igneous contact but now it is highly strained. It is assumed that because the sheet is surrounded by metagabbro it was intruded into the gabbro. However, the possibility that the sheet represents a tectonised inclusion in the gabbro cannot be totally excluded. A prominent extension or stretching lineation plunges at 35^{o} towards 197^{o}. The rocks are L-S tectonites.

In thin-section, sample NO41 is composed of streaks of quartz and plagioclase aggregates with minor hornblende and accessory rutile. These aggregates are interpreted to be the relics of igneous grains which have experienced grain-size reduction during shearing. There was not enough of sample NO41 for representative XRF analysis, but a very similar, tectonised, 2 m-thick, tonalite sheet within greenschist of the Kjosen Unit (sample KJ104 from map-reference 697283, map-sheet 1634III) gave the following XRF results (major elements, wt%): *SiO_2 70.26, Al_2O_3 13.64, TiO_2 0.32, Fe_2O_3 (total) 4.90, MgO 1.13, CaO 4.90, Na_2O 3.85, K_2O 0.07, MnO 0.05, P_2O_5 0.13, LOI 0.01, Sum 99.26:* (trace elements, ppm): *Nb 1, Zr 110, Y 48, Sr 196, Rb not detected, Zn 13, Cu 5, Ni 8, Cr 1, V 50, Ba not detected, Th 2, Pb 4, Hf 4, Ce 4, La not detected.* Samples KJ104 and NO41 are classified as metamorphosed and tectonised tonalites.

On the basis of these field relationships it was concluded that the tonalite sample NO41 represents a metamorphised plagiogranite which intruded the gabbro. This could have been in the vicinity of the original spreading ridge that formed the ophiolitic part of the LMC. However, there is a clear possibility that the plagiogranite may represent a later intrusive phase in the protracted development of the complex.

Radiometric age determination

A one kilogram sample was processed for heavy mineral separation. Abundant rutile but only nine zircon grains from a magnetically graded 7^{o} tilt, at 1.7 Amps on a Frantz Isodynamic Separator) heavy mineral fraction were hand-picked under a binocular microscope. Sample 1 (NO41/1) was made up of rather brown and cloudy fragments. Sample 2 (NO41/2) consisted of brown, cloudy, well formed equant prisms, one of which was a twinned crystal. It is probable that sample 1 is made up of broken examples of prisms such as those in sample 2. Normally, these coloured zircons would not be a first choice for geochronology. However, all samples were vigorously abraded until crystal edges became rounded (Krogh 1982). This was to remove the outer skin, which from experience commonly suffers Pb-loss by diffusion. Zircon was analysed for U and Pb isotopes according to the methods described by Krogh (1973), Corfu

Table 1. Results of the U-Pb isotope analyses of the metatonalite (NO41) from the Kjosen Unit.

	Concentration				Atomic ratios				Apparent Ages		
Fraction	Wt (mg)	U (ppm)	Pb (rad)	$^{206}Pb/^{204}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
1	0.010	1366	96	3356	0.0248	0.0753±3	0.5874±31	0.05655±10	468	469	474
2	0.004	5034	374	4413	0.0864	0.0755±5	0.5911±37	0.05677±18	469	472	483

& Gunsky (1987) and Corfu & Muir (1989). Results are given in Table 1. The confidence level of errors is quoted at 2σ. An attempt tc analyse U-Pb isotopes in rutile failed.

Both samples gave concordant data (see Fig. 2) that yield an age of 469 ± 5 Ma using the most reliable $^{206}Pb/^{238}U$ chronometer. This age falls within the interval Late Arenig-Llanvirn in the recently refined time scale of Tucker & McKerrow (1995).

Discussion

The 469 ± 5 Ma U-Pb zircon age for the tectonised and metamorphosed tonalite is considered to represent the minimum age of formation of the Kjosen Unit MORB ophiolite. Most of the earliest stages of ophiolite development in the Norwegian Caledonides which have been isotopically dated fall in the range 485-500 Ma (Dunning & Pedersen 1988, Pedersen & Furnes 1991). Field criteria do not allow us to distinguish between the possibility that the tonalite was intruded in the region of the spreading ridge, or the alternative interpretation of a much later emplacement and further away from the ridge setting. The Strupen and Jiekkevarri Units, which form by far the largest outcrop area of the Lyngen Magmatic Complex, need not be the same age as the Kjosen Unit. Their interpreted magmatic character (Furnes & Pedersen 1995) also allows for intrusion over an as yet undetermined period of time.

The Late Arenig-Llanvirn age for the Kjosen Unit tonalite is similar to the age obtained for the Feøy gabbro which formed in the last stages of the magmatic arc history of the Karmøy Ophiolite Complex of SW Norway (Dunning & Pedersen 1988, Pedersen & Hertogen 1990). This ophiolite complex has had a protracted magmatic history of some 25-30 Ma. In view of the variable petrological and geochemical character of other units in the LMC it is quite conceivable that this, too, has had a similar long history of magmatic development.

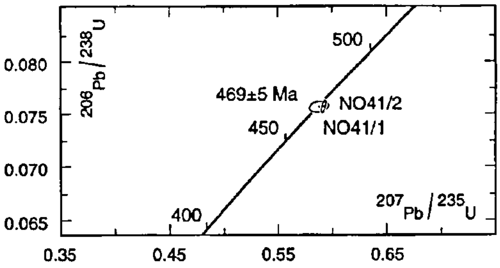

Fig. 2. U-Pb concordia diagram of zircon analyses (1 and 2, Table 1) from the sampled metatonalite in the Kjosen Unit of the Lyngen Magmatic Complex.

Conclusion

A metatonalite in the Kjosen Unit MORB ophiolite, part of the Lyngen Magmatic Complex, has yielded a U-Pb zircon age of 469 ± 5 Ma. This is interpreted as a minimum age for the Kjosen Unit.

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References

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

Andresen, A. & Steltenpohl, M.G. 1994: Evidence for ophiolite obduction, terrane accretion and polyorogenic evolution of the north Scandinavian Caledonides. *Tectonophysics 231*, 59-70.

Corfu, F. & Grunsky, E.C. 1987: Igneous and tectonic evolution of the Batchawana greenstone belt, Superior Province: a U-Pb zircon and titanite study. *J. Geol. 95*, 87-105.

Corfu, F & Muir, T.L. 1989: The Hemlo-Heron Bay greenstone belt and Hamlo Au-Mo deposit, Superior Province, Ontario, Canada. 1. sequence of igneous activity determined by zircon U-Pb geochronology. *Chem. Geol. (Isotope Geoscience Section), 79*, 183-200.

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. *Contr. Min. Pet. 98*, 13-23.

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.* J. Wiley & Sons, Chichester, 657-670.

Furnes, H. & Pedersen, R.B. 1995: The Lyngen Magmatic Complex: Geology and Geochemistry. *Geonytt 22*, 2.

Krogh, T.E. 1973: A low-contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determinations. *Geochem. Cosmochim. Acta 37*, 485-494.

Krogh, T.E. 1982: Improved accuracy of U-Pb zircon ages by the creation of more concordant systems using air abrasion technique. *Geochem. Cosmochim. Acta 46*, 637-649.

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*. J. Wiley & Sons, Chichester, 379-393.

Pedersen, R.B. & Furnes, H. 1991: Geology, magmatic affinity and geotectonic environment of some Caledonian ophiolites in Norway. *J. Geodynamics 13*, 183-203.

Pedersen, R.B. & Hertogen, J. 1990: Magmatic evolution of the Karmøy Ophiolite Complex, SW Norway: relationships between MORB-IAT-boninitic - calc-alkaline and alkaline magmatism. *Contr. Min. Pet. 104*, 277-293.

Randall, B.A.O. 1971: An outline of the geology of the Lyngen Peninsula, Troms, Norway. *Nor. geol. unders. 269*, 68-71.

Slagstad, D. 1995: Lyngen Magmatic Complex Rypdalen Shear Zone: magmatic and structural evolution.(Abstract). *Geonytt 22*, 3.

Sturt. B. A. & Roberts. D. 1991: Tectonostratigraphic relationships and the obduction histories of Scandinavian ophiolite terranes. *In* Peters Tj. et al. (eds.). *Ophiolite genesis and evolution of the oceanic lithosphere*. Min. of Petrol. and Mins. Sultanate of Oman, 745-769.

Tucker, R.D. & McKerrow, W.S. 1995: Early Palaeozoic chronology: a review in light of new U-Pb zircon ages from Newfoundland and Britain. *Can. Jour. Earth Sci. 32*, 368-379.

Zwaan, K.B. 1988: Nordreisa, berggrunnsgeologisk kart - M 1:250 000. *Nor. geol. unders.*

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