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U-Pb dating of a metatrondhjemite from the island of Ytterøy, Trondheimsfjorden, Central Norway

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REPORT

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U-Pb dating of a metatrondhjemite from the island of Ytterøy, Trondheimsfjorden, Central Norway

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Summary:
Zircon fractions extracted from a metatrondhjemite sheet interbanded with mafic volcanites on the island of Ytterøy in the Støren Nappe, Trondheimsfjorden, have yielded a U-Pb age of 495.3 ± 2.5 Ma. This is interpreted as the crystallisation age of this subvolcanic felsic intrusion. Field relationships indicate that the trondhjemite and greenstone volcanites are more or less coeval; both rock-types have participated in all the Scandian deformation phases recorded on the island. A nearby metalimestone with gradational contacts into mafic volcanites is also considered to be roughly the same age as the trondhjemite.

Based on comparisons with other U-Pb dated trondhjemitic sheets associated with metabasalts in this part of Norway, the Ytterøy greenstone pile appears to be one of the oldest volcanite units in the Trondheim Nappe Complex. Both the metabasalts and the metalimestone are probably of latest Cambrian to very earliest Ordovician age.

Keywords: Bedrock geology	Caledonian	Radiometric dating
Zircon		

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1 INTRODUCTION

In the Caledonides of Central Norway, thick units of metamorphosed basaltic lavas, traditionally termed 'greenstones' in the Nordic area, constitute an important element of the geology. In terms of Caledonide tectonostratigraphy, these occur almost exclusively within the higher parts of the Upper Allochthon (Roberts & Gee 1985) in the Koli Nappes. Geochemical studies on many of these greenstone units have indicated their accumulation in a variety of tectonic settings, but by and large they derive from ocean basin or island arc environments (Gale & Roberts 1974, Furnes et al.1985). Some have been shown to form parts of dismembered or fragmented ophiolites.

Associated with the greenstones in some areas are felsic rock-types, either extrusive keratophyres or subvolcanic trondhjemites or plagiogranites. These have provided natural and ideal targets for U-Pb zircon age determinations, some results of which are referred to later in the 'Discussion' chapter. During a regional mapping programme of parts of the northern Trondheimsfjord district in the mid-1980's, one such prominent metatrondhjemite on the island of Ytterøy was sampled with a view to separating zircons for U-Pb dating. The result of this study forms the basis of this short report.

2 GEOLOGY OF YTTERØY

The geology of the island of Ytterøy consists mainly of variably deformed, NE-dipping, schistose greenstones. The succession forms part of the Støren Nappe, which in turn is part of the Trondheim Nappe Complex. Apart from a few comparatively thin quartz keratophyre layers, the monotony of the greenstones is broken only by a 20-30-m thick metalimestone occurring in the southwestern part of the island, and a prominent layer-parallel plagiogranitic sheet in the northwest (Fig.1). Ytterøy is also well known in geological circles for the occurrence of a solitary lamprophyre dyke which cuts the metalimestone (e.g. Carstens 1961, Mitchell & Roberts 1986, Torsvik et al.1994).

Based on regional mapping and suggested lithostratigraphic correlation the greenstones, as well as the limestone and plagiogranite, are generally considered to be of Ordovician age (Carstens 1961, Wolff 1979). The metalimestone is strongly banded and foliated and passes conformably into schistose greenstones, both above and below, via transitional units of phyllite, banded tuff and thin ribs of limestone. The upper contact has evidently been the locus of somewhat higher strain and, in part, is somewhat protomylonitic. Unlike several other carbonates in the Støren Nappe, for example those in the Hølonda and Snåsa areas, no body fossil or microfossil remains have yet been found in the Ytterøy limestone. An upper isotopic constraint on the age of the mafic volcanites, and limestone, is set by the lamprophyre dyke; which is either Devonian or, more likely, Permian in age (cf.Torsvik et al.1994). However, the Ytterøy supracrustal rocks are considered to have been deformed and metamorphosed during the *Scandian* phase of the Caledonian orogeny, in Late Silurian to possibly Early Devonian time.

The geochemistry of the Ytterøy greenstones is the topic of an on-going study. Although the analytical data have not yet been fully assessed, preliminary work has shown that the volcanites carry many of the chemical attributes of ocean-floor basalts (D.Roberts, unpubl.data).

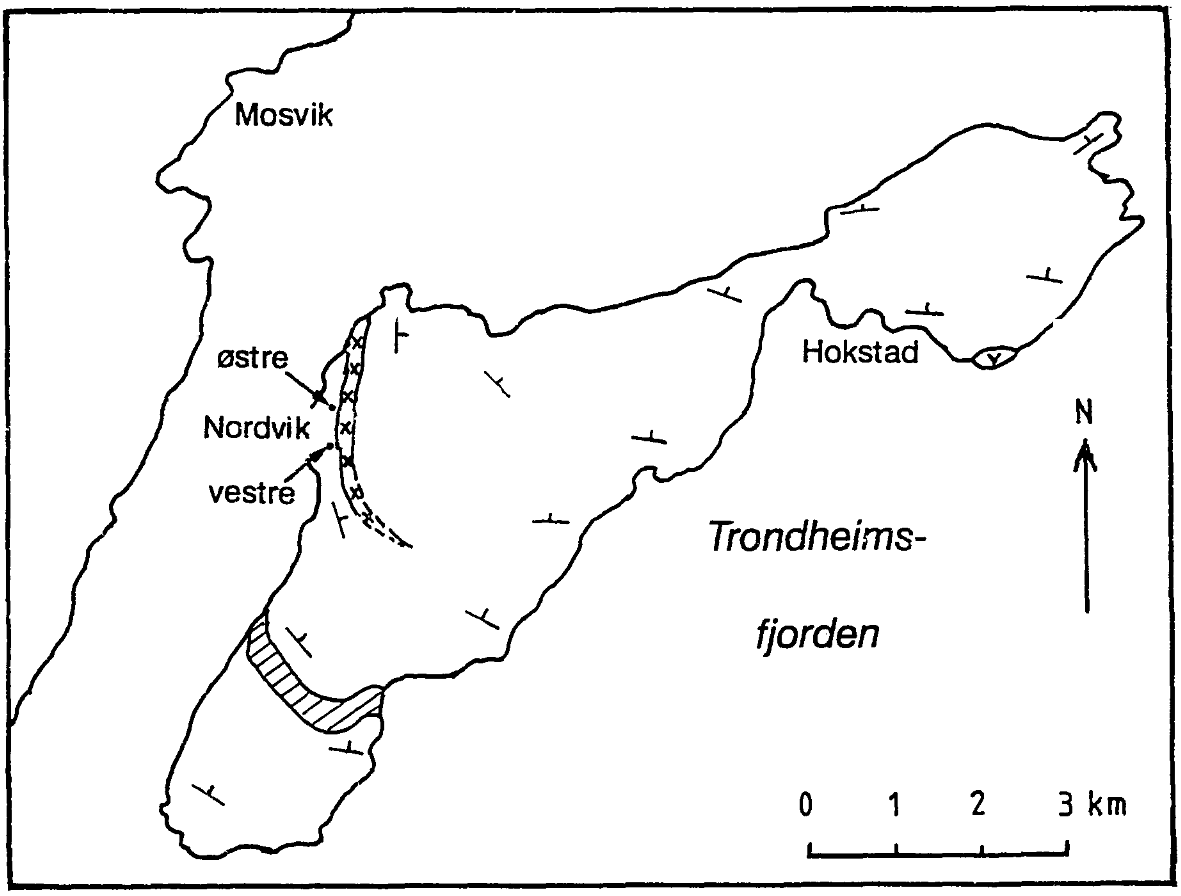


Fig.1. Outline map of Ytterøy showing the location of the metatrondhjemite (cross ornament) near the farms vestre and östre Nordvik. The metalimestone mentioned in the text, c.3 km south of vestre Nordvik, is indicated by the lined ornament. The remainder of Ytterøy (without ornament) is underlain mostly by schistose greenstones with sporadic keratophyres (rhyodacites) and tuffs. The small area on the coast just east of Hokstad (V ornament) is metagabbro.

3 THE METATRONDHJEMITE

3.1 Field relationships

The trondhjemite is exposed along the western slope of the ridge Dølåskammen east of the farms vestre and østre Nordvik, and is most readily accessible along and adjacent to road-cuts where the samples were collected (see below). In the road-cuts and steep ridge slope it occurs as sheets or sills varying from 30 cm to 4 m in thickness, lying within or subparallel to the banding in the greenstone (Fig.2). Higher up, sheets of up to 10 m in thickness are encountered.

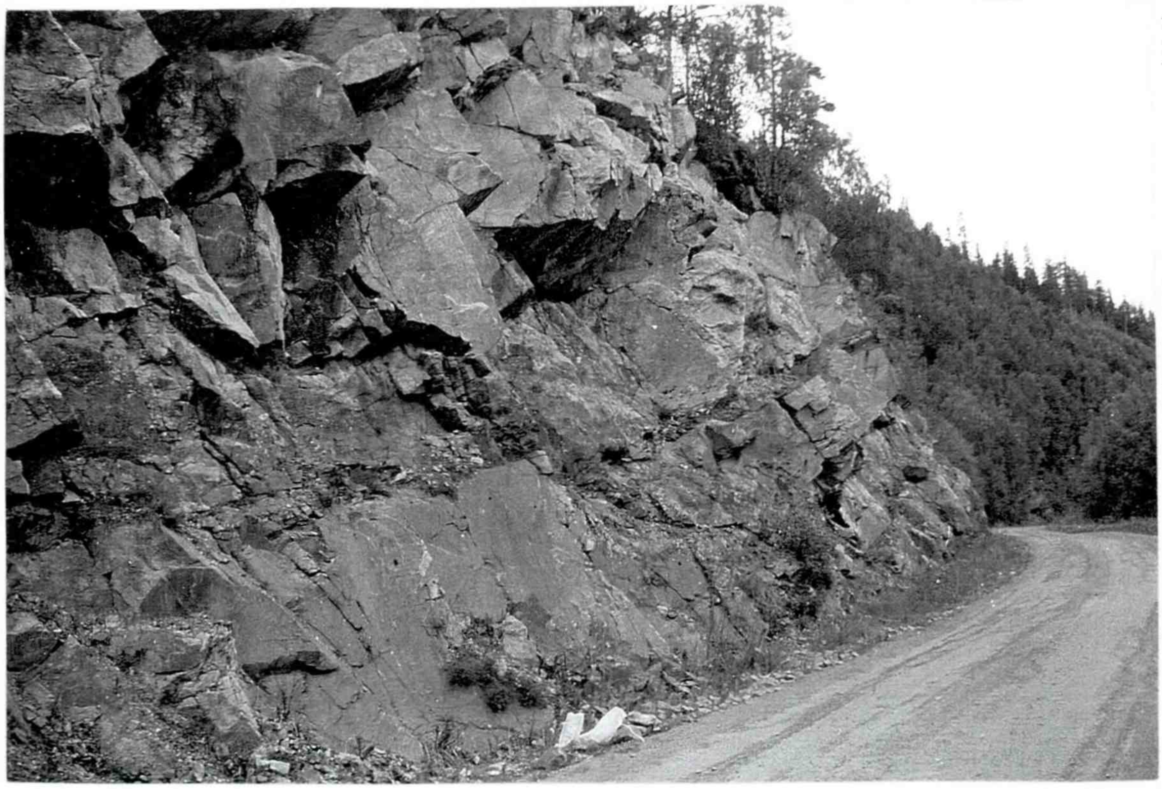
The NE- to E-dipping, medium- to coarse-grained trondhjemite is quite strongly foliated. The repetitious sheet-like nature of the rock, alternating with schistose greenstone, is a characteristic feature. Almost all of the individual sheets or sills contain thin layers, lenses or stringers of greenstone (Fig.2). The impression, therefore, is that we are probably dealing with a felsic, subvolcanic, sheeted sill type of emplacement, broadly coeval with, or just slightly later than the effusion of the basaltic lavas. On the coast c.500 m north of the farm østre Nordvik, the greenstone carries intercalations of a white, banded to laminated, fine-grained quartz keratophyre. This could be the effusive counterpart of the metatrondhjemite.

Field evidence, from several localities, indicates that the entire greenstone-trondhjemite package or association has clearly participated in all the Caledonian deformation phases recognised in this area. Examples are to be seen along the coast of flattened, isoclinal, SE-plunging folds deforming thinner bands or sheets of trondhjemite (Fig.3). These folds carry the pervasive regional schistosity as an axial planar fabric, and this is itself deformed, in some localities, by upright second-phase or flat-lying third-phase folds.

3.2 Petrography and geochemistry

The greyish-white metatrondhjemite carries a pronounced foliation. Quartz and plagioclase (c.An_{14}) are the principal minerals, with minor amounts of K-feldspar, muscovite, biotite and clinozoisite, and accessory apatite, zircon, sphene and chlorite. The texture is, in general, characterised by lensoid clusters of fine-grained, recrystallised, highly strained quartz, and of coarser grained plagioclase which is partly saussuritised and carries aggregates of clinozoisite. In some thin-sections a vermicular and graphic texture is displayed by intergrowths of quartz and feldspar. The lensoid mineral clusters which, together with the micas, define the foliation are up to 2 cm in length.

A double-fist size sample taken from exactly the same outcrop as the material collected for the U-Pb zircon study was analysed for major and minor elements at NGU, Trondheim. Care was taken to break the sample into small pieces on the outcrop in order to check for the possible presence of xenoliths. The analytical data and CIPW norms are presented in Table 1. On a plot of normative An-Ab-Or (Fig.4) the Nordvik metatrondhjemite falls almost in the centre of the trondhjemite field



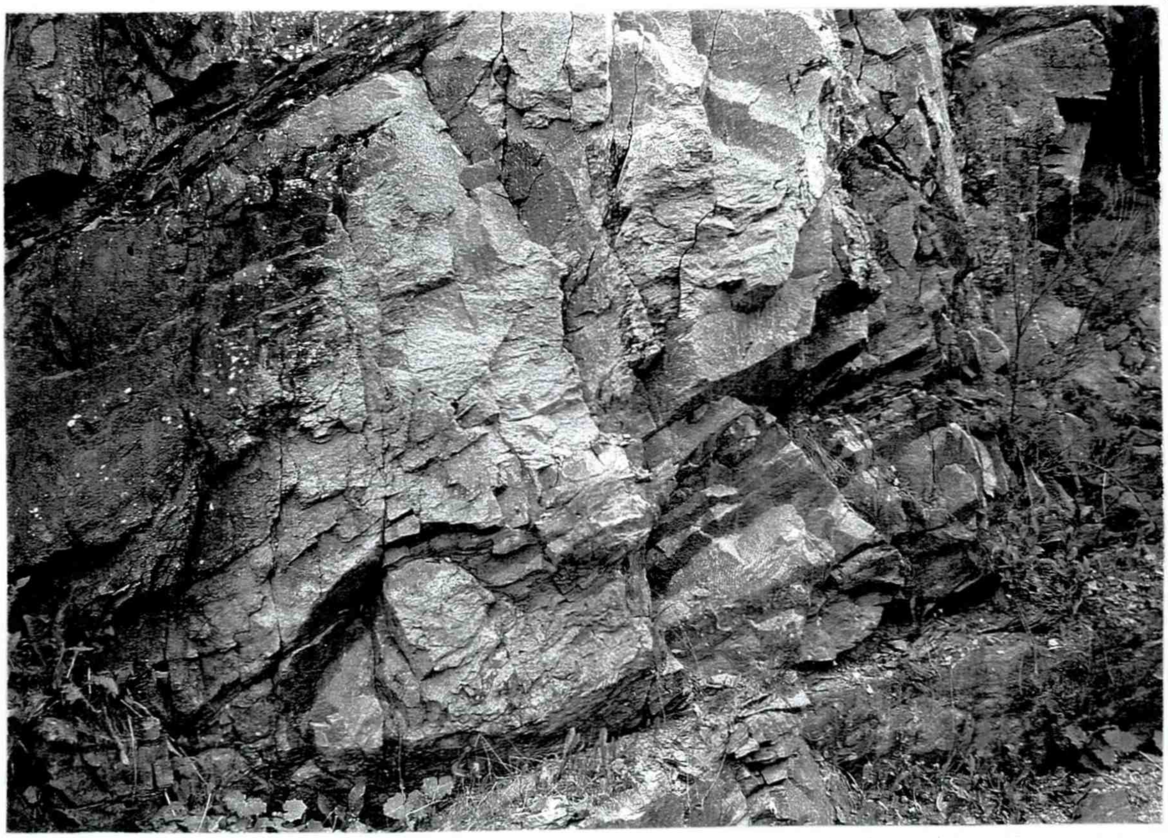


*Fig.2. **(a)** The sample locality along the road near vestre Nordvik farm; metatrondhjemite sheets with intercalated schistose greenstone (metabasalt). **(b)** A close-up of part of the same road-cut outcrop.*

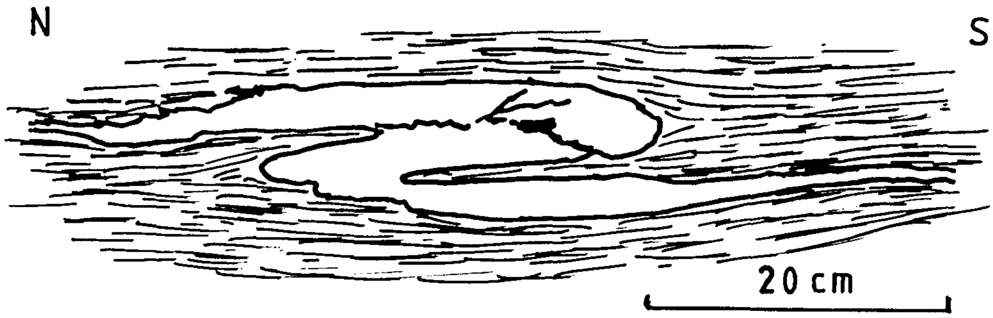


Fig.3. Field sketch showing a thin sheet of metatrondhjemite within schistose greenstone, deformed by an early (F1), flattened subisoclinal fold. The regional schistosity (S1) lies parallel to the axial plane of this fold. The fold axis plunges at 10° towards 121°.

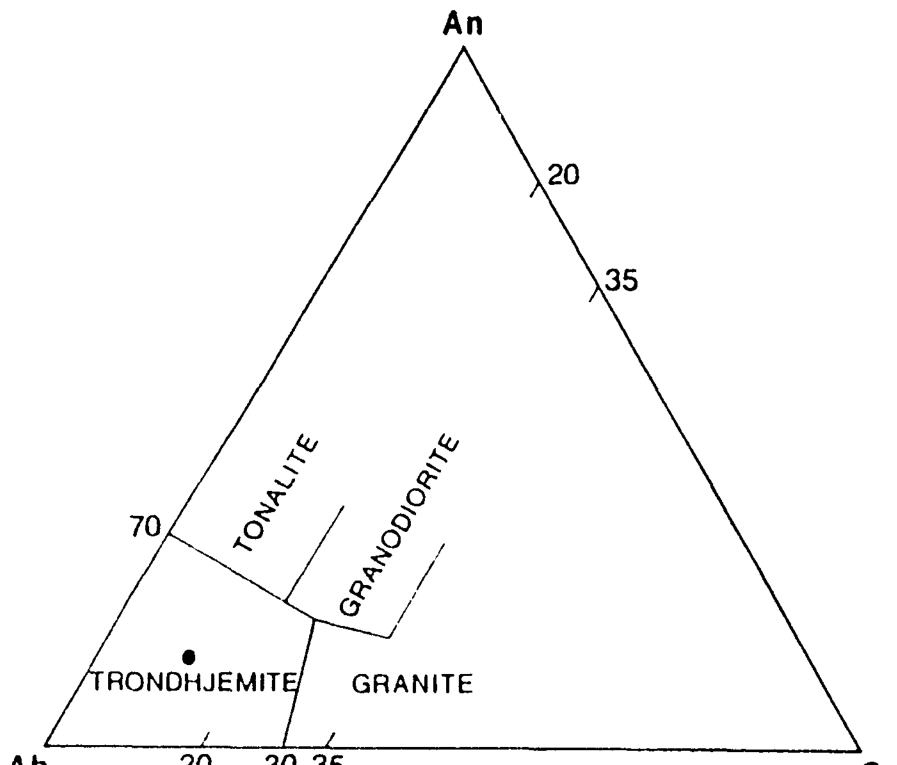


Fig.4. Normative An-Ab-Or diagram showing the composition of the Nordvik metatrondhjemite. Diagram from Barker (1979).

Table 1. Major and trace element contents (wt.% and ppm, respectively) and CIPW norms for the trondhjemite from the road-cut close to vestre Nordvik farm.

SiO_2	74.59	Zr	123	q	37..9
AL_2O_3	12.82	Y	27	c	1.1
TiO_2	.21	Sr	175	or	6.3
FeO	.97	Rb	16	ab	41.5
Fe_2O_3	.92	Zn	11	an	6.9
MgO	.50	Cu	6	di	—
CaO	2.44	Ni	5	hy	1.9
Na_2O	4.91	Cr	5	mt	1.3
K_2O	1.06	Ba	150	hm	—
MnO	.03	Nb	5	il	.4
P_2O_5	.05	V	20	ap	.1
CO_2	.77				
H_2O+	1.09				
H_2O-	.01				

Table 2. U-Pb Zircon Analyses, Metatrondhjemite at Ytterøy.

FRACTIONS		CONCENTRATIONS					ATOMIC RATIOS							AGE [Ma]
No.	Properties (1)	Wt. [µg] (2)	Pb rad [ppm] (2)	U [ppm] (2)	Pb com [pg] (3)	Th/U (4)	$^{207}Pb/^{204}Pb$ (5)	$^{207}Pb/^{206}Pb$ (6)	±	$^{206}Pb/^{238}U$ (6)	±	$^{207}Pb/^{235}U$ (6)	±	$^{207}Pb/^{206}Pb$ (6)
1	+100-150,c,cl,sp,A	35	11.9	141	4	0.525	342	0.05711	9	0.08022	32	0.63168	27	495.7
2	+100-150,c,cl,cr,p,A	41	15.1	176	4	0.556	478	0.05709	10	0.08029	28	0.63197	24	494.8

Notes:

(1) 1 gr denotes number of zircon grains analyzed (*e.g.* 1) all other analyses are multigrain fractions selected from non-paramagnetic separates at 0° tilt at full magnetic field in Frantz Magnetic Separator; 100, 150 = size in mesh (150 mesh = 70µm); c = colorless; cl= clear; cr = cracked; sp = short prismatic; p = prismatic; A = grains air-abraded following Krogh (1982).
(2) Concentrations are known to ± 30% for sample weights of about 20 µg and ± 50% for samples ≤ 5 µg.
(3) Corrected for 0.0215 mole fraction common-Pb in the ^{205}Pb-^{235}U spike.
(4) Calculated Th/U ratio assuming that all ^{208}Pb in excess of blank, common-Pb, and spike is radiogenic (λ $^{232}Th = 4.9475 \times 10^{-11}$ y^{-1}).
(5) Measured, uncorrected ratio.
(6) Ratio corrected for fractionation, spike, blank, and initial common-Pb (at the determined age from Stacey and Kramers (1975)). Pb and U fractionation correction = 0.1%/amu (± 0.14%); U blank = 0.5 pg, Pb blank ≤ 10 pg. Absolute uncertainties (2σ) in the Pb/U and $^{207}Pb/^{206}Pb$ ratios calculated following Ludwig (1980). U and Pb half-lives and isotopic abundance ratios from Jaffey *et al.* (1971).

4 U-PB ZIRCON DATING

Approximately 50 kilograms of fresh sample material were collected for this isotopic study, from a comparatively newly blasted road outcrop close to the farm vestre Nordvik (UTM 0075 7485, 1:50,000 map-sheet 'Verran' 1622I). The sample of metatrondhjemite was pulverised and sieved to a fine powder (<70 microns) and separated into mineral constituents by standard techniques of heavy-liquid and magnetic mineral purification.

Two fractions of high-quality prismatic zircon, of probable igneous origin, were selected and analysed by the isotopic dilution method following techniques developed by Krogh (1973, 1982) and outlined in Tucker et al.(1990) using a ^{205}Pb-^{235}U enriched tracer solution purified by Parrish & Krogh (1987). Both fractions of zircon are concordant within analytical uncertainty (Fig.5, Table 2), and the weighted average ^{207}Pb/^{206}Pb age of 495.3 $\pm$ 2.5 is taken as the time of crystallisation of the trondhjemite protolith.

5 DISCUSSION

Bearing in mind the probable consanguineity of the trondhjemite sheet and its host metabasalt, the 495 $\pm$ 2.5 Ma crystallisation age of the metatrondhjemite (Fig.5) can also be taken as the approximate age of the mafic volcanic pile, as well as of the metalimestone. In the recently revised subdivision of the Cambrian and Ordovician systems (Tucker & McKerrow 1995), this age would correspond exactly with the Cambrian-Ordovician boundary; in the revised chronology of these authors the base of the Ordovician (Tremadoc) is put at 495 Ma.

In the Central Norwegian Caledonides, several U-Pb zircon dates have been reported either in the literature or as 'personal communications'. Within the Støren Nappe, zircon ages of 493 $\pm$ 10 and 487 $\pm$ 5 Ma have been obtained from plagiogranite dykes in the Løkken Ophiolite, and 480 $\pm$ 4 Ma for similar dykes in the Vassfjell Ophiolite (Dunning 1987 and pers. comm.1990; in Sturt & Roberts 1991). The Folldal trondhjemite in the SE Trondheim Region has yielded a U-Pb zircon age of 488 $\pm$ 2 Ma (Bjerkgård & Bjørlykke 1994), while an albite-trondhjemite in the Gjersvik Nappe in the Grong district has a reported age of 483 $\pm$ 4 Ma (Kullerud et al.1988). Both these bodies are intimately associated with mafic volcanite sequences.

The 495 $\pm$ 2.5 Ma date from Ytterøy is thus, with one exception (the 493 date from Løkken), just slightly older than other reported plagiogranites/trondhjemites cutting consanguineous metabasalts. This could mean that the Ytterøy mafic volcanites (+ trondhjemite) are genuinely slightly older than most other Early Ordovician mafic volcanites in this region; or it is perhaps more likely that we have fortuitously dated just a slightly older part of a thick, volcanic/subvolcanic accumulation of wide-ranging extent which also covered a wide span in time, i.e. some 10-15 million years. Volcanism spanning such a time range is known from e.g. the Karmøy-Bømlo region of SW Norway (Pedersen 1992) as well as from the Gjersvik Nappe (Roberts & Tucker 1991).

Another U-Pb zircon date which is of interest here is that from a minor felsic intrusion in the gabbro/dolerite dyke unit of the Leka Ophiolite Complex; 497 $\pm$ 2 Ma (Dunning & Pedersen 1988). In terms of actual age this is identical, within error, to the age reported here from the Ytterøy metatrondhjemite. However, the Leka zircon age relates to the lower and presumed earlier, subvolcanic part of the Leka ophiolite, i.e. the higher, pillowed basalt member of the ophiolite complex should (or may presumably) have an age younger than 497 Ma.

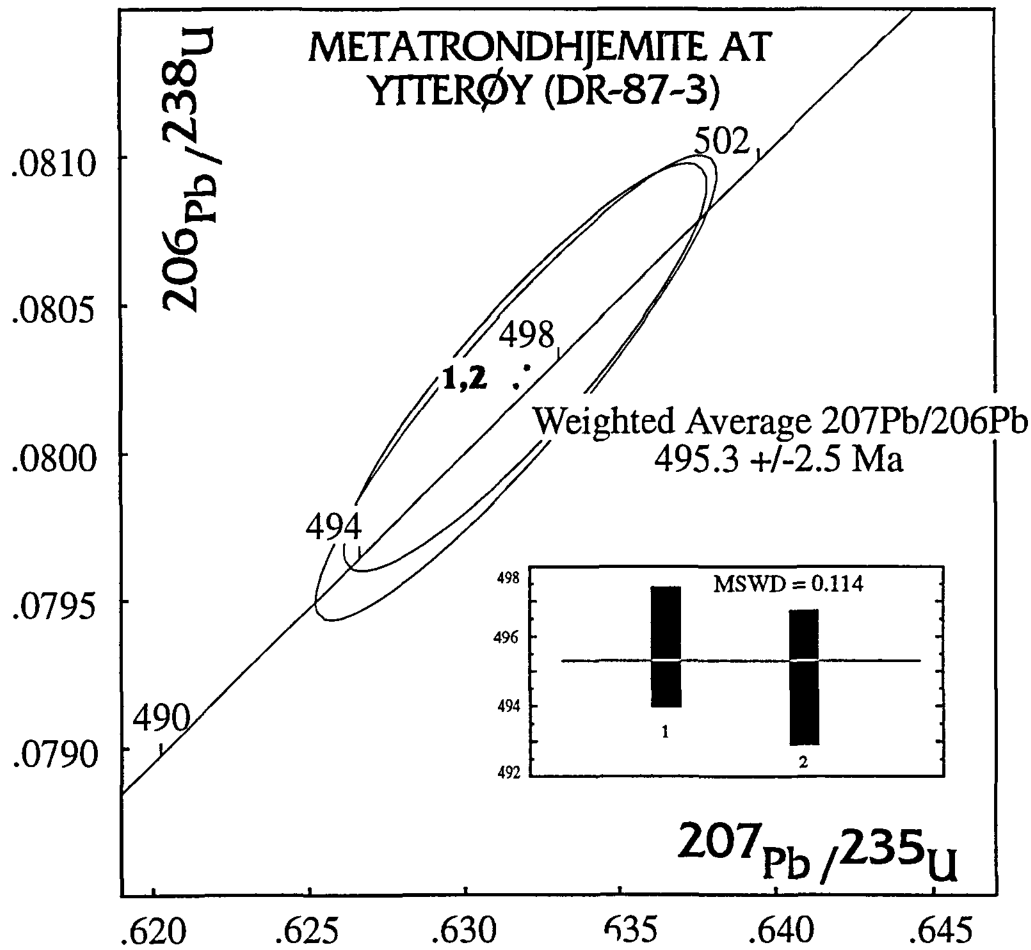


Fig.5. U-Pb concordia diagram of zircon analyses (1,2; Table 2) from the Nordvik metatrondhjemite on Ytterøy.

That the barren metalimestone on Ytterøy must also be of approximately the same (495 Ma) age is an interesting new piece of information in our geological knowledge of the Trondheim Region. The oldest limestone known from faunal evidence, according to Neuman & Bruton (1989), is the Hølonda Limestone; Late Arenig/Early Llanvirn. On the revised timetable of Tucker & McKerrow (1995) the base of the Llanvirn is placed at 470 Ma.

6 CONCLUSIONS

Two fractions of zircon extracted from a metatrondhjemite sheet interbanded with mafic volcanites on the island of Ytterøy in the Støren nappe have yielded a U-Pb age of 495.3 $\pm$ 2.5 Ma; interpreted as the crystallisation age of the subvolcanic felsic intrusion. The host greenstones, and also an interlayered metalimestone, are also considered to be of approximately the same age.

By comparison with other plagiogranitic sheets and dykes associated with metabasalts from this region which have been dated by the U-Pb method, the Ytterøy greenstone pile appears to be one of the oldest volcanite units in the Trondheim Nappe Complex. With the base of the Ordovician now placed at 495 Ma, this also means that the Ytterøy metalimestone is probably also of this same age, and some 20-25 million years older than the oldest known fossiliferous limestone in the Upper Allochthon of the Central Norwegian Caledonides.

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