GEOLOGICAL NOTE

Early Ordovician ages of zircons from felsic rocks and a conglomerate clast, Frosta peninsula, Central Norwegian Caledonides

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Zircons extracted from a felsic sheet in the bimodal, magmatic, Fånes complex of the Støren Nappe on Frosta peninsula yielded a U–Pb age of 488 ± 5 Ma, interpreted as the age of crystallisation. A large clast of geochemically similar felsite in an overlying polymict conglomerate provided a U–Pb zircon age of 482 ± 3 Ma. The presented crystallisation ages are thus mutually indistinguishable and indicate that the conglomerate was sourced, at least in part, from the Fånes complex. The age results constrain the accumulation of the Fånes complex to a Late Cambrian (Furongian) to earliest Ordovician (Tremadocian) time span, similar to the ages of other felsic extrusive or intrusive rocks in fragmented ophiolites or suprajacent, primitive, island-arc trondhjemites in the Trondheim Region.

Introduction

In a companion paper in this Bulletin volume, Lippard and Roberts (2010) present the results of a geochemical study of two volcanic rock complexes occurring in the Støren Nappe on the Frosta peninsula, situated roughly 25 km northeast of Trondheim. They also include analyses of clasts of felsic and mafic volcanic rocks occurring in two, separate, conglomerate formations in this same area. During the fieldwork, extra samples were taken from a felsite sheet interlayered with metabasaltic greenstones, and also from a large clast of felsite in one of the overlying conglomerates, with the aim of retrieving zircons for U–Pb dating.

A sufficient number of zircon grains were obtained from these samples and duly analysed, and in this short contribution we present the results and interpretation of the data.

General geology

The geological setting of the rocks exposed in the Småland area of the Frosta peninsula has been described in some detail by Lippard and Roberts (2010). Accordingly, we present only a summary here, together with a map (Figure 1) showing where the samples were taken.

The volcanosedimentary succession on Frosta peninsula forms a part of a Cambro-Ordovician assemblage assigned to the Støren Nappe, which is one of several thrust sheets under the collective name Köli Nappes. In terms of Caledonide tectonostratigraphy, the Köli Nappes represent the more exotic, oceanic terranes that derived from outboard of the Baltoscandian margin of the palaeocontinent Baltica during the main Caledonian, *Scandian* orogeny, and form the bulk of the Upper Allochthon (Roberts and Gee 1985, Stephens and Gee 1989). The

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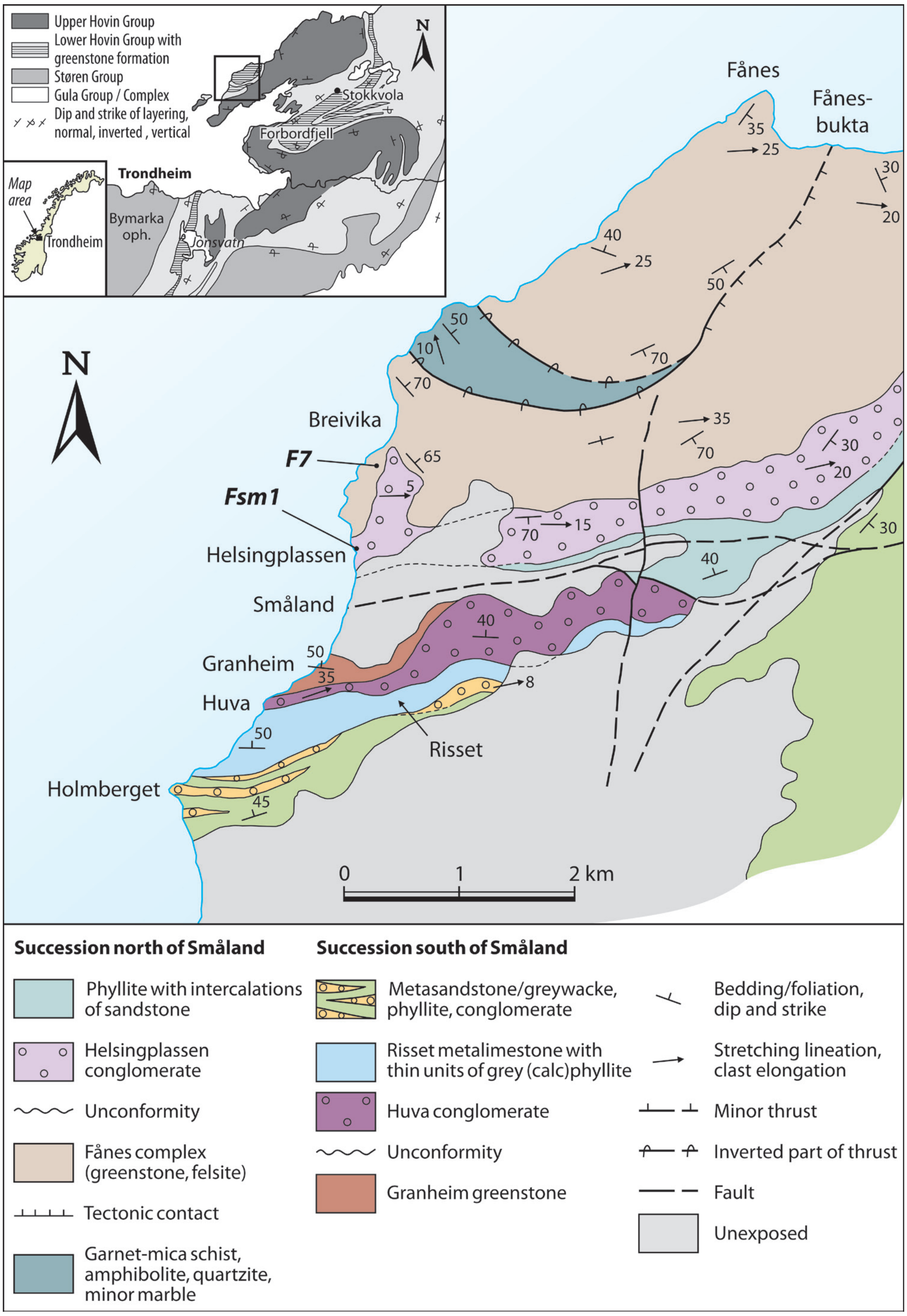

Figure 1. Simplified geological map of southwestern Frosta peninsula showing the locations of the samples F7 and Fsm1. Locality F7 is a roadside outcrop at 584730 7054350 on 1:50,000 map-sheet Leksvik 1622 III. Locality Fsm1 is a wave-washed shore outcrop at 584600 7053650, also on the map-sheet Leksvik. Coordinates apply to UTM Zone 32, WGS84.

Köli rocks also incorporate most of the fragmented ophiolites and island arcs that have been described from the Norwegian Caledonides (e.g., Gale and Roberts 1974, Furnes et al. 1985, Dunning and Pedersen 1988; other references are cited in the companion paper).

In the Småland area (Figure 1), two different successions each consisting mainly of oceanic extrusive rocks overlain by a sedimentary cover sequence have been mapped and described by Lippard and Roberts (2010). North of Småland there is a bimodal succession of mainly mafic volcanites (traditionally termed greenstones) and shallow felsic intrusions (termed felsites) which together constitute the *Fånes complex*. This is overlain unconformably by the polymict *Helsingplassen conglomerate* (Figure 1), the clasts of which consist mainly of greenstones and felsites derived from the subjacent Fånes complex. South of Småland, a formation of metabasaltic greenstones, including pillow lavas, is termed the *Granheim greenstone*. This is structurally inverted and is stratigraphically overlain by the *Huva conglomerate*, consisting mostly of greenstone pebbles with subordinate felsite, which is in turn overlain by a metalimestone, conglomerates, and interbedded phyllites and turbiditic greywackes. Conodonts in the metalimestone provide an

Early to Mid Katian (Late Caradocian) age for this formation (Tolmacheva and Roberts 2007).

The Granheim and Fånes greenstones are geochemically distinct, the former showing flat REE patterns whereas the Fånes mafic rocks are depleted in LREE. Whilst an initial interpretation would suggest their extrusion as E-type (Granheim) and N-type (Fånes) MORB lavas, other geochemical criteria point to generation in a subduction-related, primitive-arc setting. The felsites also show an arc-type geochemical signature. Clasts of felsite in the Helsingplassen conglomerate are petrographically and geochemically indistinguishable from the felsite sheets in the Fånes complex.

Although several of the ophiolitic and magmatic arc assemblages in the Central Norwegian Caledonides have been dated, with zircon ages ranging from 497 ± 2 to 480 ± 4 Ma (see Figure 7 in Roberts et al. 2002), no isotopic dating has hitherto been reported from the Frosta region. Moreover, the volcanic successions on Frosta are constrained biostratigraphically only to be older than Late Caradocian. The data reported here thus help to fill a gap in our overall knowledge of timing of Early Palaeozoic magmatism in this part of the Caledonide orogen.

Geochronology

The rocks sampled for this study are a felsite sheet from the Fånes complex (sample no. F7) and a large clast of geochemically similar felsite from the Helsingplassen conglomerate (sample no. Fsm1) (Figure 1; grid coordinates are given in the figure caption). Zircon concentrates for both samples were prepared at NGU, and zircon grains were hand picked from these materials at Brown University for U–Pb isotopic analysis. The F7 felsite yielded relatively few zircons, and they are characteristically small stubby prisms and prism fragments (<100 μm in longest dimension), exhibited some cloudiness, and contained some inclusions and cracks. Six fractions were prepared for analysis, each consisting of 10 to 12 grains. The Fsm1 felsite clast yielded zircons with similar qualities but of slightly larger size, from which four fractions were prepared.

The fractions were processed through HF dissolution and chemical separation, largely following analytical procedures given by Krogh (1973). Pb and U were analysed on a Finnigan MAT 261 mass spectrometer, using either combined Faraday-SEM multicollection or peak hopping into the SEM, according to signal intensity. Results are reported in Table 1 and plotted on a concordia diagram in Figure 2.

All zircon fractions analysed have low U contents and therefore developed relatively low amounts of radiogenic Pb since their crystallisation. Three of the six fractions of F7 (fractions z2, z3, and z6) show very low $^{206}Pb/^{204}Pb$ ratios (<500) even after correction for blank and fractionation, leading to larger errors in their calculated ages, especially the $^{207}Pb/^{235}U$ ages. One additional fraction from F7 (z1) has large errors due to low signal

Table 1. Zircon analyses from samples F7 and Fsm1.

Sample	U (ppm)	Pb (ppm)	$^{206}Pb/^{204}Pb$ measured[1]	corrected	$^{206}Pb/^{238}U$ err abs[2]	$^{207}Pb/^{235}U$ err abs[2]	ρ (rho) err corr[3]	$^{206}Pb/^{238}U$ age (Ma)	$^{207}Pb/^{235}U$ age (Ma)	$^{207}Pb/^{206}Pb$ age (Ma)
F7 zir 1	10.541	0.856	299.9	1027	0.07926 ± 202	0.5876 ± 348	0.502	492 ± 13	469 ± 28	361 ± 116
F7 zir 2	13.222	1.0924	231.9	385.8	0.08081 ± 157	0.6193 ± 289	0.496	501 ± 10	489 ± 23	436 ± 91
F7 zir 3	25.668	2.0432	330.2	490.3	0.07750 ± 98	0.5930 ± 173	0.506	481 ± 6	473 ± 14	432 ± 56
F7 zir 4	26.311	2.123	661.9	877.5	0.07883 ± 47	0.6158 ± 97	0.457	489 ± 3	487 ± 8	478 ± 31
F7 zir 5	13.334	1.068	437.9	745.8	0.07784 ± 83	0.6130 ± 142	0.530	483 ± 5	486 ± 11	496 ± 43
F7 zir 6	12.245	0.997	195.2	301.1	0.07925 ± 167	0.6097 ± 312	0.494	492 ± 10	483 ± 25	444 ± 99
Fsm1 zir 1	31.819	2.4775	1450	4217	0.07736 ± 40	0.6114 ± 66	0.549	480 ± 3	484 ± 5	504 ± 20
Fsm1 zir 2	28.553	2.2421	749.0	1179	0.07754 ± 45	0.6108 ± 72	0.561	481 ± 3	484 ± 6	497 ± 22
Fsm1 zir 3	43.760	3.4642	1445	2733	0.07799 ± 37	0.6156 ± 50	0.628	484 ± 2	487 ± 4	501 ± 14
Fsm1 zir 4	23.779	1.8631	699.9	1180	0.07758 ± 77	0.6009 ± 102	0.634	482 ± 5	477 ± 8	459 ± 29

All zircon fractions were dissolved in the presence of a mixed ^{205}Pb–^{235}U spike calibrated against NBS and NBL metal standards. All Pb/U ratios are corrected for total blanks of 10 ± 5 pg Pb, 2 ± 1 pg U, mass fractionation of 0.08 ± 0.06%/amu, and initial Pb (age-appropriate values from Stacey and Kramers 1975). Pb/U ratio and age errors are reported at 2σ level. Concentrations are approximate because they are based on estimated sample weights (too small to measure).

[1] *Uncorrected for fractionation and blank.*

[2] *err abs refers to 2σ absolute errors in last decimal places.*

[3] *Error correlation (rho) of ^{206}Pb–^{238}U and ^{207}Pb–^{235}U ratios.*

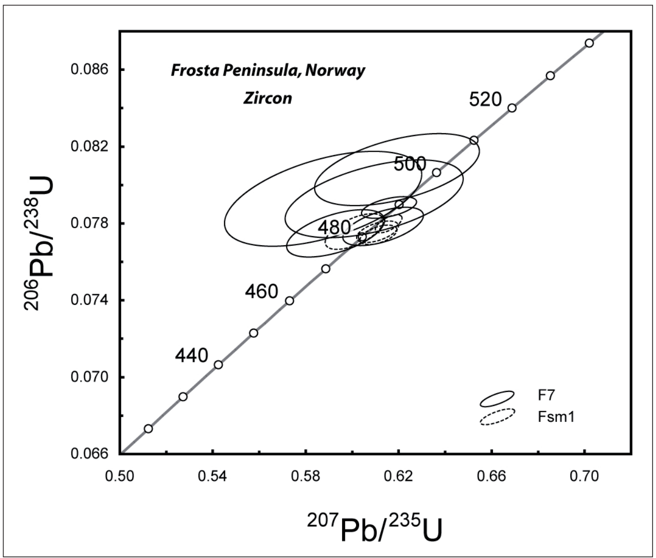

Figure 2. Concordia diagram for the zircon fractions from samples F7 and Fsm1.

intensity during mass spectrometer analysis. The four fractions from Fsm1 all yielded larger corrected $^{206}Pb/^{204}Pb$ ratios (>1000) and low uncertainties in their calculated ages.

On the concordia diagram, error ellipses for all analyses cluster between 480 and 500 Ma and overlie the concordia curve, and are therefore considered concordant. The larger errors for 4 of the 6 fractions from the F7 felsite provide little additional constraint beyond that provided by the two more precise and overlapping ages from fractions z4 and z5 in this sample, but they serve to indicate the absence of both inheritance and discordance. Inheritance is not expected in these primitive, oceanic volcanic rocks, and discordance due to radiation damage is not anticipated given the low U contents of the zircon. Considering only the more precise z4 and z5 fractions from F7 along with the four fractions from the Fsm1 felsite clast, the $^{206}Pb/^{238}U$ ages cluster tightly between 480 and 490 Ma.

Given the relatively low $^{206}Pb/^{204}Pb$ ratios and the sensitivity of $^{207}Pb/^{235}U$ ages to the common Pb correction, and the concordant nature of the ages, the most appropriate estimate of error for these ages is considered to be that based on the $^{206}Pb/^{238}U$ ages. The weighted average of z4 and z5 of sample F7 is 487 ± 9 Ma (95% c.l.), with an MSWD of 4.2, which provides an identical but less precise age than that given by the weighted average of all 6 fractions: 488 ± 5 Ma (95% c.l.) with an MSWD of 3.5. The 488 ± 5 Ma age based on all 6 analysed fractions is accepted as the best estimate of the age of crystallisation of sample F7. The weighted average of all 4 fractions of sample Fsm1 is 482 ± 3 Ma (95% c.l.) with an MSWD of 1.7.

Based on these considerations, the crystallisation ages of the two samples are at the limits of resolvability. The felsite clast in Fsm1 may be marginally younger than the felsite in the stratigraphically subjacent volcanic rocks, but the ages of these two samples cannot be confidently distinguished.

Discussion

The U–Pb zircon ages reported here point to a likely Tremadocian or latest Furongian age for the bimodal Fånes complex. In the Köli Nappes of the Trondheim Region, several felsic rocks in ophiolites or primitive island-arc intrusions invading oceanic metabasalts have provided U–Pb zircon dates ranging from Late Cambrian (Furongian) to Early Ordovician (Tremadocian) age (see summary in Roberts et al. 2002). The age of the arc-type, Fånes felsite thus falls within this restricted time slice.

The mutually indistinguishable ages of the felsite of the Fånes complex and the felsic clast in the overlying Helsingplassen conglomerate, in conjunction with their geochemical similarities, argue strongly that the provenance of the conglomerate included the felsic rocks of the Fånes complex. There is good evidence from elsewhere in the Trondheim Region that the ophiolites and primitive, magmatic arc rocks were obducted and weakly metamorphosed in Early Arenig (Floian) time—termed the *Trondheim event*—just prior to rapid uplift and erosion which led to deposition of the Mid/Late Arenig (Dapingian) to Late Caradoc (Katian), Hovin and Horg groups (Roberts 2003, Lippard and Roberts, 2010). The actual age of the Helsingplassen conglomerate, containing the clasts of felsite, is unknown, but based on our knowledge of the geology and biostratigraphy of the Støren Nappe it is inferred to be of Late Arenig-Llanvirn (Dapingian to Darriwilian) age.

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