

# An occurrence of the Gula Nappe in the Western Gneiss Region, central Scandinavian Caledonides

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At Fosslia (100 km NNE of Trondheim, Western Gneiss Region), a cover sequence of metasedimentary and metavolcanic rocks overlies migmatitic gneisses and subordinate mafic rocks of the Precambrian crystalline basement.

The cover comprises micaceous gneisses, quartz veined gneisses, quartz-feldspar gneisses, quartzites, felsites, amphibolites, graphitic schists, mica schists, and rusty weathering sulphide rich mica schist. These lithologies are similar to those in the Gula Nappe in the Trondheim Nappe complex. The proposed correlation is strengthened by U/Pb dating of zircons from a granodioritic dyke intruding the cover. The dyke is restricted to the cover sequence. The U-Pb zircon upper intercept age is  $430 \pm 12$  Ma. This age is interpreted as the time of dyke crystallization. The age is close to those obtained on trondhjemitic dykes in the Gula Nappe in the Trondheim Complex. The Fosslia occurrence provides additional evidence of the existence of isolated allochthonous Caledonian cover units in the northern part of the Western Gneiss Region, and that such units can be identified despite intense deformation and amphibolite facies metamorphism.

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Vestranden as used in this paper is the northernmost part of the Western Gneiss Region (WGR) in Norway. This Precambrian realm has a critical implication in the interpretation of the Caledonide Orogen because the behaviour of the basement during the Caledonian event can be studied here. Cratonic and miogeoclinal rocks of the Baltoscandian margin occur in several nappes of the Lower, Middle and Upper Allochthons. The source area of these nappe units could have been a westerly continuation of the WGR. The pressure-temperature-time (PTt) evolution of the WGR and the relationship between metamorphism in the WGR and in the overlying Caledonian nappes are critical factors in the reconstruction of the tectonothermal evolution of the Caledonides. Paradoxically, however, the geology of the Vestranden area has been little explored. This concerns in particular the numerous occurrences of supracrustal rocks, of which some are westerly extensions of the Trondheim Nappe Complex (TNC). The TNC comprises the Gula and Stören Nappes, both of which represent outboard terranes that prior to the Caledonian thrusting were situated to the west

of the Baltoscandian margin. Identification of solitary cover units in the WGR and their correlation with units of well-known Caledonian allochthons are important subjects of study since they may constrain the timing of deformation and metamorphism in the basement. Occurrences of Caledonian allochthonous units in WGR also imply that the nappes were thrust across this region. Attempts to trace the allochthon from the Trondheim region into the WGR are few but promising (Krill 1980; Kollung 1984; Schouenborg 1986; Tucker 1986). In the WGR, the cover is generally tightly and often recumbently folded together with the Precambrian gneisses. Basement-cover contacts are concordant and commonly recrystallized. The westwards gradually increasing 'Caledonization' of the basement-cover contacts has been described by Bryhni & Brastad (1980) and Koestler et al. (1984) and others.

The present paper considers an isolated occurrence of supracrustal rocks located in Precambrian gneisses at Fosslia, about 40 km from the Atlantic coast (Fig. 1). The new geological map of Norway (Sigmond et al. 1984) describes

the Fossilia cover unit as mica schists and mica gneisses of Precambrian and/or Cambro-Silurian age.

The identification of the Fossilia cover as a unit of the TNC is based on lithological correlation between the Fossilia occurrence and parts of the Caledonian allochthon in the Snåsa region, previously studied in detail by Andreasson & Johansson (1982). In addition, a U/Pb zircon dating of a concordant granodioritic dyke in the supracrustal rocks has been undertaken.

## Geology

The Fossilia cover succession comprises about 800 metres of essentially supracrustal rocks (Fig. 2). An almost complete section is exposed west of the Fossilia farm along road 724 between Namdalseid and Osen. The UTM coordinate for the Fossilia locality is 32W PS 047 270 on map sheet 1623 I Jössund (1:50000). Other exposures are found in the Öyungsåa river canyon and south of the canyon.

Migmatitic gneisses of mainly granitic composition and subordinate mafic bodies form the Precambrian *basement* surrounding the Fossilia cover unit. Farther west in Osen, a preliminary

U-Pb zircon age of  $1630 \pm 80$  Ma has been obtained for similar migmatitic gneisses (Schouenborg et al., unpublished results).

The Fossilia *cover* comprises micaceous gneisses, quartz-veined gneisses, quartz-feldspar gneisses, quartzites, amphibolites, a characteristically mineralized metavolcanic/metasedimentary rock association, and granodioritic dykes. Due to the intense folding and metamorphism it is not possible to establish any stratigraphic order. The sulphide rich metavolcanites/metasediments and the dykes are of particular interest for the correlation with the TNC east of Vestranden. The metavolcanites/metasediments include fine-grained, garnetiferous and sulphide-bearing amphibolite; sulphide-rich garnet-staurolite mica schist, and thin lenses of sulphide ore and garnetiferous ore. Sulphide phases are pyrite (predominating) and pyrrhotite. The garnets of the sulphide ore and sulphide-rich mica schist are almandines with high spessartine contents (c. 20 wt-%). This lithological association is never found in the Vestranden basement. In the micaceous gneisses, fibrolitic sillimanite generally after kyanite is the stable alumina-silicate.

Two granodioritic dykes, 50 and 30 centimetres across, occur in the metavolcanic association (Fig. 3). Due to deformation the dykes are concordant

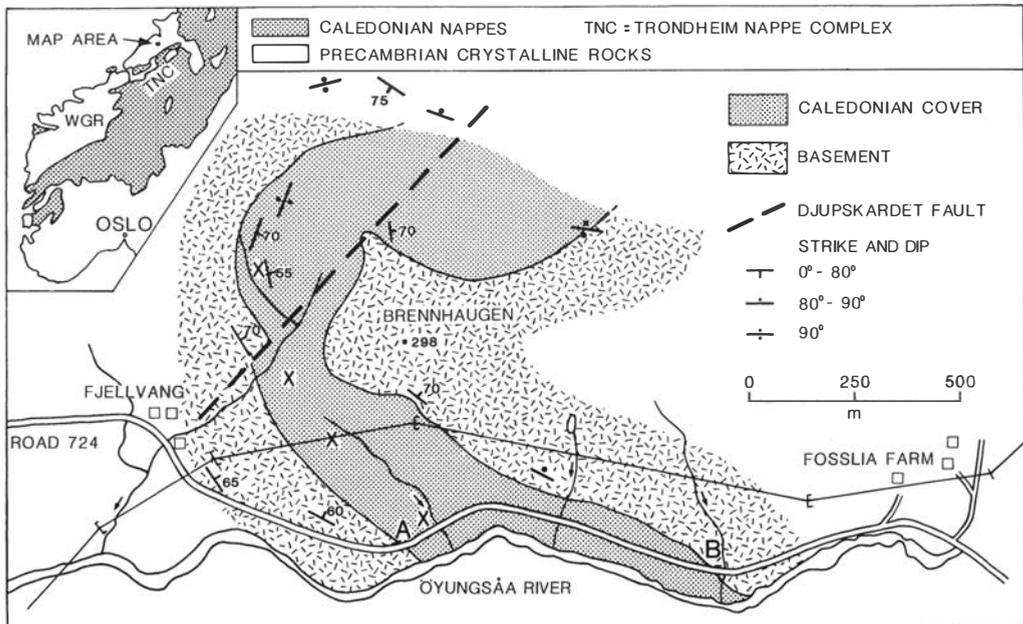


Fig. 1. Basement-cover map of the Fossilia area. X = occurrences of granodioritic-granitic rocks within the cover sequence.

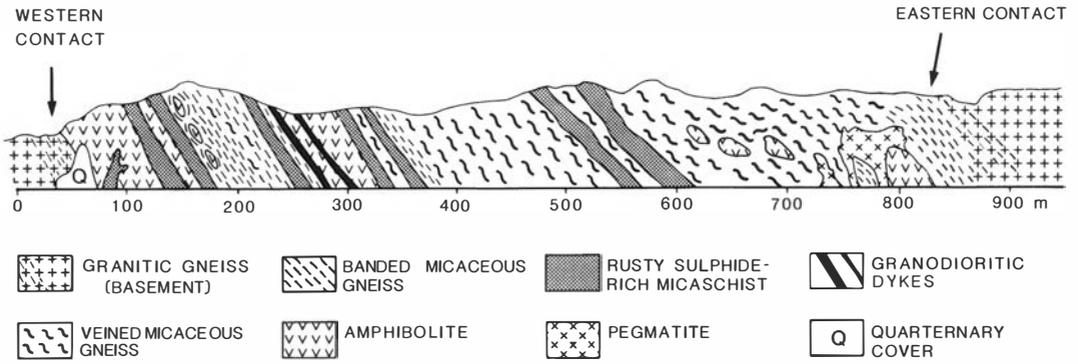


Fig. 2. Cross-section of the Fosslia cover sequence along road 724. The topography is generalized and the height of the section is less than 10 m.

with the compositional banding of the host rock, at least on the scale of an outcrop. The dykes occur sporadically along strike up the Djupskardet valley (Fig. 1). On the western slope of the valley, the host rock metavolcanites are cut out against basement. The dykes consist of plagioclase, quartz, K-feldspar (<17%) and minor amounts of garnet, zircon and chlorite. The dykes have suffered amphibolite facies metamorphism.

The basement is characterized, essentially, by a single mature foliation, i.e. a thoroughly recrystallized or migmatitic gneissic banding. In contrast, the mesostructures of the cover include several generations of folds and foliations. Among structures easily observed in the road section are east-west trending folds refolded along west-northwest trending axes. In the hinges of the latter folds, small quartz-feldspar veins define an



Fig. 3. Granodiorite dyke (light grey) in the Fosslia road-cut. Length of hammer is 55 cm.

axial-plane foliation. A late, northeast trending dextral fault (Djupskardet fault) displaced the cover rocks along their western contact. The eastern contact between basement and cover is partly disturbed by a large pegmatite (Fig. 2). Such cross-cutting late Caledonian pegmatites are common in the western part of Vestranden. At two localities zircons from this type of pegmatites have been dated by the U/Pb method. In the Foldereid area in the northernmost part of Vestranden a basement cover contact is intruded by a  $401 \pm 3$  Ma old pegmatite (Schouenborg, pers. comm. 1986), and north of Namsos a  $404 \pm 2$  Ma old pegmatite intrudes migmatitic gneisses in the basement (Schouenborg et al. in prep). The western contact is characterized by marked secondary tectonic conformity between basement and cover (Fig. 2). Here, the structures of both basement and cover have been transposed into a conspicuously straight and tight foliation. However, unlike the basement-cover contacts east of Vestranden (e.g. in the Tømmerås Window and the Grong-Olden Culmination; Andreasson 1978), the Fossilia contacts are recrystallized and lack phyllonites and mylonites.

## Radiometric dating

Zircons from the larger granodioritic dyke, in the Fossilia cover unit, were dated by the U-Pb method in an attempt to determine the intrusive age of the dykes and thereby estimate the maximum age of nappe displacement.

The weight of the sample was approximately 60 kg of rock. The zircons were separated and divided into three non-magnetic size fractions from which zircons of similar habit and clarity

were hand-picked (Table 1). Zircon dissolution and extraction of U and Pb followed the procedure of Krogh (1973) with a further purification of Pb by electrodeposition on a Pt-electrode. The isotopic ratios of lead and uranium were determined on a MAT 261 and an AVCO 901-A mass spectrometer respectively. The common lead correction was made assuming the following composition (Stacey & Kramers 1975):  $^{206}\text{Pb}/^{204}\text{Pb} = 18.0$ ,  $^{207}\text{Pb}/^{204}\text{Pb} = 15.6$ ,  $^{208}\text{Pb}/^{204}\text{Pb} = 37.8$ . The total Pb blank contamination is 2.5 ng. The age calculations followed Ludwig (1980) using the decay constants recommended in Steiger & Jäger (1977). The errors of the concordia ages are given as  $\pm 2$  sigma.

The zircon morphology (Fig. 4), degree of alteration and fracture frequency vary considerably between the different size fractions. All fractions are very rich in uranium (Table 1). The large zircons are often irregularly shaped and aggregates of smaller zircon grains are common.

Table 1. U-Pb isotopic analyses of zircons from the Fossilia granitic dyke. Size-fractions 1 = 45–74  $\mu\text{m}$ , 2 = 74–106  $\mu\text{m}$ , 3 = 106–150  $\mu\text{m}$ .

Fraction	1	2	3
U (ppm)	5540	10630	3630
Pb <sub>rad</sub> (ppm)	339	352	399
$^{206}\text{Pb}/^{204}\text{Pb}$ $\Delta$	8980	5130	3250
$^{207}\text{Pb}/^{206}\text{Pb}$ $\diamond$	0.05564	0.05547	0.05533
$^{208}\text{Pb}/^{206}\text{Pb}$ $\diamond$	0.00158	0.00147	0.00162
Age in Ma:			
$^{206}\text{Pb}/^{238}\text{U}$	420	231	737
$^{207}\text{Pb}/^{235}\text{U}$	423	250	664
$^{207}\text{Pb}/^{206}\text{Pb}$	438	431	426

$\Delta$  = Corrected for blank lead.

$\diamond$  = Corrected for blank lead and common lead

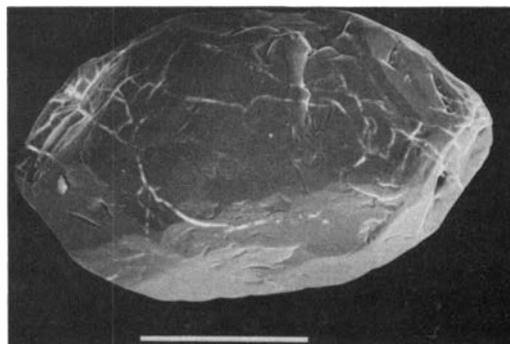
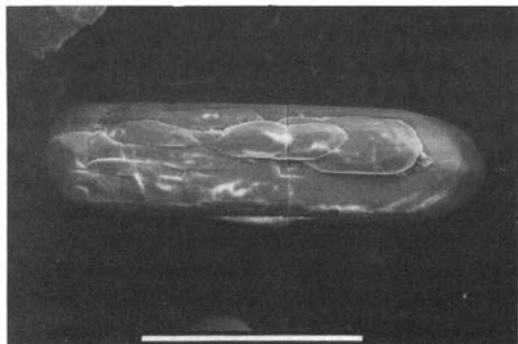


Fig. 4. Zircons from the Fossilia granitic dyke. The length of the scale bars is 100  $\mu\text{m}$ .

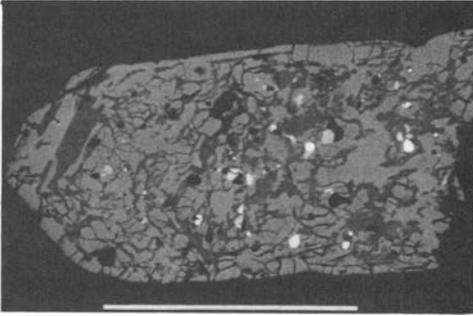


Fig. 5. Backscatter electron image of an altered zircon grain. Dark grey areas consist of altered, impure zircon; the light grey areas are unaltered pure zircon. Uraninite appears as white rounded dots. The length of the scale bar is 100  $\mu\text{m}$ .

Inclusions of plagioclase and K-feldspar occur. Fractures are present in all zircons, but are more frequent in the large grains. Sometimes they are seen as networks on the grain surface. The medium- and small-size zircons have fewer fractures and often better developed crystal forms with pyramidal terminations. A thin, clear and inclusion-free rim is often found. The very high uranium contents are partly explained by inclusions of uraninite ( $\text{UO}_2$  Fig. 5). Energy-dispersive microprobe analyses also indicate the presence of  $\text{ThO}_2$  in the inclusions. The inner parts of many zircons are severely altered. This alteration often follows fractures and certain crystal growth surfaces (Fig. 5). Analyses of the dark grey areas in Fig. 5 indicate increased contents of calcium and iron and also a fluid phase, most likely water. The altered areas protrude into unaltered zircon where they form lobate contacts between unaltered and altered zircon. It is worth noting that the degree of alteration is not related to the presence of uraninite inclusions. Entirely unaltered zircon without any sign of metamictization is commonly found around the uraninite inclusions.

When plotted in the concordia diagram, the Fossilia zircons yield an age of  $430 \pm 12 \text{ Ma}$  (Fig. 6). This age is interpreted as a minimum estimate for the intrusion age of the dykes. One size fraction (106–150  $\mu\text{m}$ ) plots above the concordia and has probably lost uranium, while the two remaining fractions plot below the concordia suggesting lead loss. If the latter two size fractions are regressed alone, they yield an upper intercept age of  $438 \pm 25 \text{ Ma}$  and a lower intercept age of  $8 \pm 25 \text{ Ma}$ . The seemingly disparate behaviour

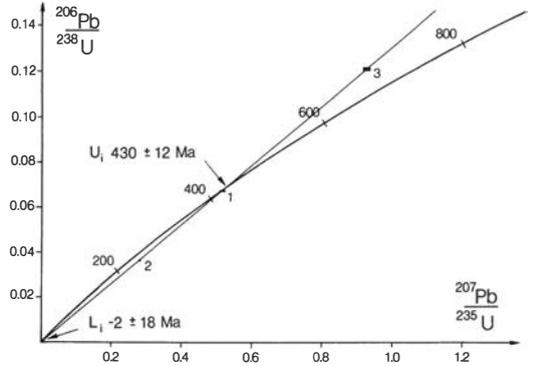


Fig. 6. Concordia diagram for the zircons of the Fossilia dyke. Symbol sizes correspond to an error of  $\pm 2$  sigma. MSWD = 0.5.

of different size fractions can be explained by differences in degree of alteration, fracture frequency and numbers of inclusions. The loss of uranium is in accordance with the observed severe alteration of many large-size zircons. Thin, clear rims on many zircons either represent a late-stage magmatic growth of younger zircon or crystal enlargement during later metamorphism. The only major phase of intense metamorphism after 430 Ma is the mid-Silurian–early Devonian (Scandian) metamorphism. This metamorphism may have caused the growth of the thin rims. However, the very small volume of the rims excludes a significant Scandian influence on the obtained age. However, it is reasonable to interpret the age as a minimum estimate; the true age of intrusion may be somewhat older.

## Discussion

The occurrence of rootless Palaeozoic dykes in the supracrustals at Fossilia clearly indicates the presence of an isolated Caledonian allochthonous cover sequence. The allochthonous cover can be identified by comparison with well-preserved rocks in the eastern nappe terrains. Rock units identical to those at Fossilia occur in the Gula Nappe of the TNC in the Snåsa area (Table 2), immediately to the east of Vestranden, where they have been described in detail by Andreasson & Johansson (1982). The reader is also referred to Nilsen (1971, 1978), Nilsen & Mukherjee (1972), and Guezou (1978) for descriptions of Gula rocks in the Trondheim region.

In the Gula Nappe of the Snåsa Area (e.g. at

Table 2. List of some key localities for the trondhjemite/granodiorite and other rock types typical of the Gula Nappe in the Snåsa synform. All coordinates refer to UTM grid zone and 100 km square 33W UM.

Locality	UTM-coordinates	Host-rocks
Grisbakkfjellet	9545 3725	pyrrhotite mineralization
Grisbakkfjellet	9565 3720	rusty garnet-rich micaschist
Lurudal	7840 4270	garnet-amphibolite, garnet-micaschist, sulphide mineralization
Hammerheia	5570 2600	garnet-mica schist, sulphide-rich amphibolite
Kongslia	7865 2535	wheat rust schist, black schist, pyrrhotite mineralization
Storåselva	8830 2985	garnet-mica schist, amphibolite, sulphide-rich sericite-schist
Storåselva	9140 3060	large trondhjemite dyke with xenoliths of garnet-hornblende-mica schist

Andorfjell; Andreasson & Johansson 1982), a feature of correlative significance is the rich variety and rapid alternation of rock types: mica schist, quartz-veined mica schist, amphibolites, hornblende gneisses, calc-silicate gneisses, magnesian marbles, graphitic schists and quartzites, felsites, small lenses of sulphide ore and garnetiferous sulphide ore, and trondhjemitic to granodioritic dykes. These dykes are normally less than two metres across and are almost invariably associated with small sulphide lenses or mineralized amphibolites and schists, as is the case in the Fossilia occurrence. Some trondhjemite-granodiorite key localities in the Gula Nappe of the Snåsa Area are listed in Table 2.

Most of the rock types in the Gula Nappe of the Snåsa region occur at Fossilia, but carbonates have not been found so far. The metavolcanic/metasedimentary ore associations at Andorfjell and Fossilia have high Mn/Fe ratios in their silicate minerals and are very similar to the Gula 'iron-formations' (Nilsen 1971). Trondhjemites occur also in the Støren Nappe but their main occurrence is found in the Gula Nappe. According to Klingspor & Gee (1981), Peterman & Barker (1976) and Size (1979, 1985) several generations of trondhjemites with different relationships to deformation and metamorphism can be found in the Gula Nappe. Dykes of granitic compositions also occur (Stephens et al. 1985). The trondhjemites of the type area (Size 1979, 1985) are tonalites with <45% modal quartz; subordinate granodiorites and monzodiorites also occur. Klingspor & Gee (1981) obtained a zircon age of  $477 \pm 7$  Ma and Rb-Sr ages of  $478 \pm 37$ ;  $474 \pm 23$ ;  $465 \pm 13$  and  $447 \pm 47$  Ma on trondhjemites from the Gula Nappe in the central Trondheim Region. These ages are within the error of the Fossilia dating or somewhat older than the one obtained for the Fossilia dykes. However, due to thin zircon

overgrowths, the latter age is interpreted as a minimum age and the actual intrusion age of the Fossilia dykes may be in good agreement with the ages from central Trondheim region.

Further north in the Scandinavian Caledonides trondhjemite and granite occur within the Krutfjellet and Gasak Nappes and the Skibotn Nappe Complex, i.e. in tectonic units thought to be equivalent to the Gula Nappe in the TNC (Table 3; Binns 1978; Sandvall 1981; Stephens et al. 1985). Granite in the Krutfjellet Nappe was dated with the Rb/Sr method and an age of  $438 \pm 6$  Ma obtained (Gee & Wilson 1974). Granitic rocks intruding the Gasak Nappe yield Rb/Sr ages of  $424 \pm 11$  Ma,  $422 \pm 8$  Ma and  $418 \pm 14$  Ma.

## Conclusions

1. The lithological, and radiometric characteristics of the Fossilia cover rocks suggest that they can be correlated with rocks of the Gula Nappe of the Trondheim Region.
2. The Gula Nappe belongs to the Upper Allochthon of the Scandinavian Caledonides (Roberts & Gee 1985). In terms of terranes, the Gula rocks are of outboard affinity (Stephens & Gee 1985) and thus clearly exotic in their present setting which is 'inboard' the Baltoscandian cratonic margin.
3. Amphibolite facies metamorphism and major deformation occurred after the intrusion of the dykes at c.430 Ma, i.e. Scandian time.
4. Our study shows that the allochthonous nature of the Fossilia cover can be demonstrated despite tight isoclinal and recumbent folding and metamorphism of at least amphibolite facies conditions (sillimanite grade). Thus, with regard to terrane analysis, it appears possible to identify terranes

Table 3. Summary of some published age data of trondhjemite–granite intrusions in the Gula Nappe or in nappe units that have been suggested to be equivalents of the Gula Nappe in the TNC. Ref.: 1: Wilson (1981); 2: this paper; 3: Gee & Wilson (1974); 4: Klingspor & Gee (1981), 5: Dangla et al. (1978).

Age in Ma.	Locality	Rock type/name	Method	Ref.
418 ± 14	Gasak Nappe	Duoldagoup dyke	Rb/Sr	1
422 ± 8	Gasak Nappe	Baldoaivve dyke	Rb/Sr	1
424 ± 11	Gasak Nappe	Furulund granite	Rb/Sr	1
430 ± 12	Fosslia	Granodioritic dyke	U/Pb	2
438 ± 6	Krutfjellet Nappe.	Vilasund granite	Rb/Sr	3
447 ± 47	Gula Nappe (TNC)	Trondhjemite	Rb/Sr	4
452 ± 13	Skibotn	Trollvik granite	Rb/Sr	5
465 ± 13	Gula Nappe (TNC)	Trondhjemite	Rb/Sr	4
474 ± 23	Gula Nappe (TNC)	Trondhjemite	Rb/Sr	4
477 ± 7	Gula Nappe (TNC)	Trondhjemite	Rb/Sr	4
478 ± 37	Gula Nappe (TNC)	Trondhjemite	Rb/Sr	4
509 ± 4	Gula Nappe (TNC)	Trondhjemite	U/Pb	4

and terrane boundaries also in areas where there was intense post-accretionary deformation and metamorphism.

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