U–Pb age of the Leirungsmyran gabbroic complex, Jotun Nappe, southern Norway

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The Leirungsmyran gabbroic complex, in the northeastern part of the Jotun Nappe, yields a zircon (and titanite) U–Pb age of 1450 ± 3 Ma, indicating an affinity of this intrusion with anorogenic plutons in the Baltoscandian and Laurentian Shields. The Leirungsmyran gabbroic complex lacks the structural and metamorphic features typical of granulite to amphibolite facies ultramafic to felsic rocks elsewhere in the nappe. Similarly, the U–Pb isotopic systems of zircon and titanite in the Leirungsmyran gabbroic complex were not disturbed during the intense metamorphic and tectonic event at 900 Ma that very strongly affected U–Pb systematics of zircon and titanite in other parts of the nappe. These relationships could reflect a very heterogeneous distribution and intensity of metamorphic and strain features related to a common 900 Ma event. Alternatively, they could be taken to indicate that the Leirungsmyran gabbroic complex is part of a separate thrust-sheet assembled to the other segments of the Jotun Nappe in the late stages of or following the main Sveconorwegian event.

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The Jotun Nappe represents one of the higher allochthons of the Caledonian orogen in southern Norway. It comprises a fragment of Middle to Late Proterozoic crust and its late Precambrian sedimentary cover, inverted and transported to its present position during the Caledonian orogeny (Milnes & Koestler 1985). The evidence suggests that the Jotun Nappe was thrust eastward over a distance of several hundred kilometers (see also Hossack 1978) but many of the questions concerning paleogeographic reconstructions and orogenic processes remain open to some speculation.

Precise geochronology is one of the approaches that can contribute to a better understanding of the internal evolution of the Jotun Nappe and help to establish reliable correlations with other Precambrian terranes to which the nappe may once have been related. Previous geochronology within the Jotun Nappe had revealed a complex Precambrian history characterized by the formation of a monzonite to syenite suite at ca. 1690 Ma, intrusion of gabbro at 1250 Ma, and regional deformation and metamorphism at 900 Ma (Schärer 1980a, b). Exhumation of the complex and deposition of late Precambrian to early Paleozoic sedimentary sequences preceded the Caledonian inversion of the nappe and thrusting. The Caledonian events caused comparatively little deformation and metamorphism in the crystalline outer portions of the nappe. This is reflected by the incomplete resetting of Rb–Sr isotopic systems in biotite and feldspar and by the lack of resetting of U–Pb systems in titanite and zircon in Tyin gneisses (Fig. 1; Schärer 1980a). In contrast, much stronger Caledonian effects are observed in central domains of the nappe. In the Årdal area (Fig. 1) Rb–Sr mineral systems and U–Pb in titanite give Caledonian ages and a granodiorite–trondhjemite complex was emplaced (Schärer 1980b) or metamorphosed (Koestler 1982) during the Caledonian event.

The autochthonous portion of the Baltic Shield, which, together with its autochthonous to parautochthonous cover, was overridden by the Jotun Nappe, experienced high-grade metamorphism and migmatization at around 1520 Ma (Corfu 1980a; Milnes et al. 1988). This corresponds to the final stages of Mid Proterozoic crust formation in central and southern Scandinavia. The Sveconorwegian effects in this basement were relatively mild and restricted to the emplacement of high-level granites at ca. 930 Ma (Priem et al. 1973; Corfu 1980a; Milnes et al. 1988), without high-grade metamorphism or strong regional deformation. The autochthonous basement and the nappe exhibit therefore a quite distinct Precambrian evolution supporting the concept of a distant origin of the nappe.

The data reported in this paper show that subdomains with contrasting Precambrian evolution exist in the interior of the nappe itself. The study is focused on the Leirungsmyran gabbroic complex (Emmett 1989). In contrast to many of the dominant lithologies of the Jotun Nappe, this gabbro is essentially undeformed and unmetamorphosed. It lacks, in particular, the coronitic textures that characterize many gabbros and dolerites within other portions of the nappe (Battey et al. 1979; Emmett 1982a). This absence of strong metamorphic overprint led to the hypothesis that the Leirungsmyran gabbroic complex may have been emplaced into the Jotun Nappe during a late Precambrian event, possibly during the initial stages of rifting of Iapetus (Emmett 1989). In this case, the gabbros would have been analogous to late Precambrian mafic dykes observed at the margins of the Baltic and Laurentian cratons (Claesson 1976; Kamo et al. 1989). Our new results show, however, that the gabbro was formed during a considerably older event, at 1450 Ma, and demonstrate that this portion of the Jotun Nappe escaped the Sveconorwegian effects widespread elsewhere in this terrane.

Geology and contact relationships of the Leirungsmyran gabbro

A detailed description of the field relationships, petrography and geochemistry of the Leirungsmyran gabbroic complex is given by Emmett (1989); therefore, only the most relevant observations are summarized here. The Leirungsmyran gabbroic complex is situated in the northeastern part of the Jotun Nappe south of Lake Gjende (Fig. 1). It consists of medium- to coarse-grained biotite and biotite–amphibole gabbro that locally grades into pegmatitic patches and leucocratic vein sets. The gabbro is cut by dolerite dykes (the internal dyke set) that have chilled margins. Neither the gabbro nor the internal dykes have garnet coronas. Geochemically, the stock and the internal dykes are mildly alkalic and have within-plate basalt affinity. The basaltic magmas appear to have lacked olivine on the liquidus which suggests a deep-seated (30–45 km) origin (Emmett 1989).

To the east and north the Leirungsmyran gabbroic complex is truncated by a wide zone of greenschist or epidote–amphibolite facies, locally mylonitic rocks that define a major fault and shear zone. The other margins of the Leirungsmyran gabbroic complex are very poorly exposed. At one locality in the eastern bank of the Leirungsåi (locality A in Fig. 1) veinlets of the acidic border phase of the gabbro invade a slightly amphibolitized (but unsheared) variety of the Svartdalen gneiss, the so-called Knutshø amphibole gneiss. Veinlets of the acid phase invade the Knutshø amphibole gneiss and

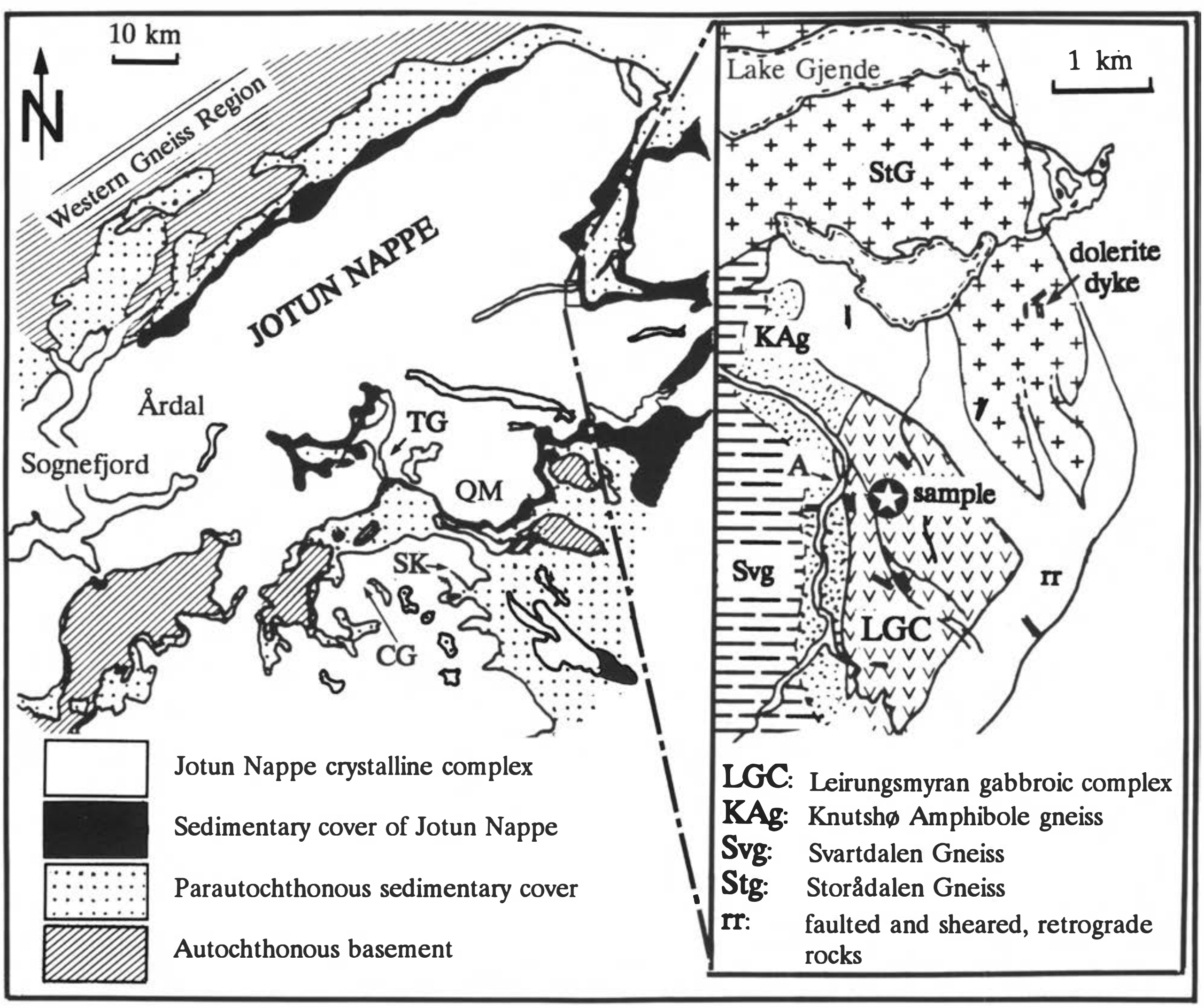

Fig. 1. Left-hand side: geological map of the central–northeastern part of the Jotun Nappe, southern Norway. TG, QM, SK and CG are previous sample locations discussed in the text. Inset on right-hand side: geological map of the Leirungsmyran gabbroic complex with sample location (simplified from Emmett 1989). A is a site mentioned in the text.

nearby, e.g. in streams draining northwards from Steinflyi, this amphibole gneiss is clearly transitional into the fresh Svartdalen gneiss. Although there is some mylonitization of the acidic rock the bulk of the evidence supports, therefore, an intrusive relationship of the gabbro into Svartdalen gneiss.

The Svartdalen gneiss is a two-pyroxene, two-feldspar monzonitic gneiss metamorphosed to low-pressure granulite facies (Emmett 1982b) and is intruded by a set of dolerite dykes (the external dyke set) that crosscut the foliation. The external dykes differ from the internal dyke set in that they lack chilled margins, contain clouded plagioclase, garnets and garnet coronas, and have distinctly lower abundances of large-ion lithophile elements, Zr and Nb but higher Y. The tholeiitic affinity and disequilibrium mineralogy and textures suggest a close similarity of the external dykes with mafic dykes described elsewhere in the Jotun Nappe (Emmett 1982a; Battey et al. 1979). These dykes have coexisting igneous olivine and plagioclase that indicate crystallization at relatively low pressure (< 7 kb; Emmett 1982a).

Sample characteristics and U–Pb results

The sample (Fig. 1) was collected from a pegmatite pod that forms veinlets within and locally also grades into the gabbro. The pegmatite contains simple, shortprismatic, euhedral zircons with face combinations that correspond to intermediate to high A and T indices of Pupin (1980). The zircons were abraded (Krogh 1982) and analyzed following standard isotope dilution procedures (Krogh 1973) and yield essentially concordant data points (Table 1; Fig. 2a). One analysis was also done on an abraded fragment of titanite. This is a rather unusual variety of titanite: the ca. 3 mm long mineral is opaque, black to white and metamict and contains over 1.8% Th (estimated from ^{208}Pb) in addition to about 160 ppm U and 16 ppm common Pb. Although the Th and common Pb abundances are more characteristic of allanite, an electron microprobe test identified the mineral as titanite. The titanite was dissolved in a Savillex vial and chemically separated using an HBr procedure. The U–Pb analysis is 17% discordant and plots on a discordia line drawn through the three concordant zircon analyses and ca. 400 Ma indicating that the titanite was disturbed during the Caledonian event but not during the 900 Ma event recorded by titanite elsewhere in the Jotun Nappe (see below). The upper intercept at 1450 ± 3 Ma is strongly controlled by the zircon data and defines the time of intrusion of the Leirungsmyran gabbroic complex.

Comparison with U–Pb systematics in other parts of the Jotun Nappe

Fig. 2b shows the contrasting features between the U–Pb data for the Leirungsmyran gabbroic complex (LGC) and U–Pb data reported by Schärer (1980a) for the monzonitic to syenitic Tyin gneisses (TG), for a quartz–monzonite (QM) and for a coronitic gabbro (CG). Also plotted are U–Pb data for a paragneiss of the Jotun Nappe (SK; Corfu 1980b).

The metagabbro (CG; Fig. 1) is essentially undeformed and retains its magmatic, ophitic texture, but it was strongly affected by metamorphic reactions that formed, among others, garnet coronas and clouded feldspars. The zircons analyzed by Schärer (1980a) are composed of two morphologically distinct types and yield highly discordant data that define a line between 1252^{+28}_{-25} Ma, the age of igneous crystallization of the gabbro, and ca. 900 Ma, which corresponds to the time of regional metamorphism (Fig. 2b). Schärer (1980a) discussed two alternative interpretations for the discordia pattern: (1) the line reflects simple Pb loss at 900 Ma; (2) the line reflects mixing of a primary generation of long-prismatic, relatively U-rich zircons and a secondary generation of equant and granular, U-poor zircons of metamorphic origin. The second interpretation would suggest a similarity with recently documented cases of metamorphic zircon growth in coronitic gabbros and dolerites of the Grenville Province in Canada (Davidson & van Breemen 1988) and of the Western Gneiss Region (Tucker et al. 1990), although in these cases metamorphic zircon was formed from a reaction involving badde-

Table 1. U–Pb data.

Analysis No.	Weight[1] [μg]	U[1] [ppm]	Pb comm[2] [pg]	Th/U[3]	^{206}Pb/^{204}Pb[4]	^{206}Pb/^{238}U[5]	^{207}Pb/^{235}U[5]	^{207}Pb/^{206}Pb[5]	^{207}Pb/^{206}Pb[5] [Ma]
736 -pegmatite, differentiated gabbro; grid reference 32VMP891137 (NGO 1/50000 sheet 1617IV Gjende)									
1 single zircon	22	401	5.8	0.48	23,970	0.2521 ± 12	3.168 ± 15	0.09115 ± 09	1450
2 single zircon	5	497	1.8	0.32	21,250	0.2499 ± 12	3.140 ± 17	0.09114 ± 14	1449
3 single zircon	9	244	2.2	0.57	15,940	0.2501 ± 11	3.135 ± 16	0.09091 ± 14	1445
4 single titanite	48	161	871	115	139	0.2209 ± 18	2.730 ± 41	0.08963 ± 99	1418

[1] Weight and U concentrations known to about 10–20%.
[2] Total common Pb, including blank; corrected for fractionation and spike [pg = picogram].
[3] Model Th/U ratio inferred from ^{208}Pb/^{206}Pb ratio.
[4] Corrected for fractionation and spike.
[5] Corrected for fractionation, spike blank and initial common Pb; titanite corrected using an initial Pb composition of 6/4 = 15.8, 7/4 = 15.25, 8/4 = 35.8; Uncertainty (2σ) takes into account measurement errors, blank uncertainties and reproducibility of Pb and U standards.

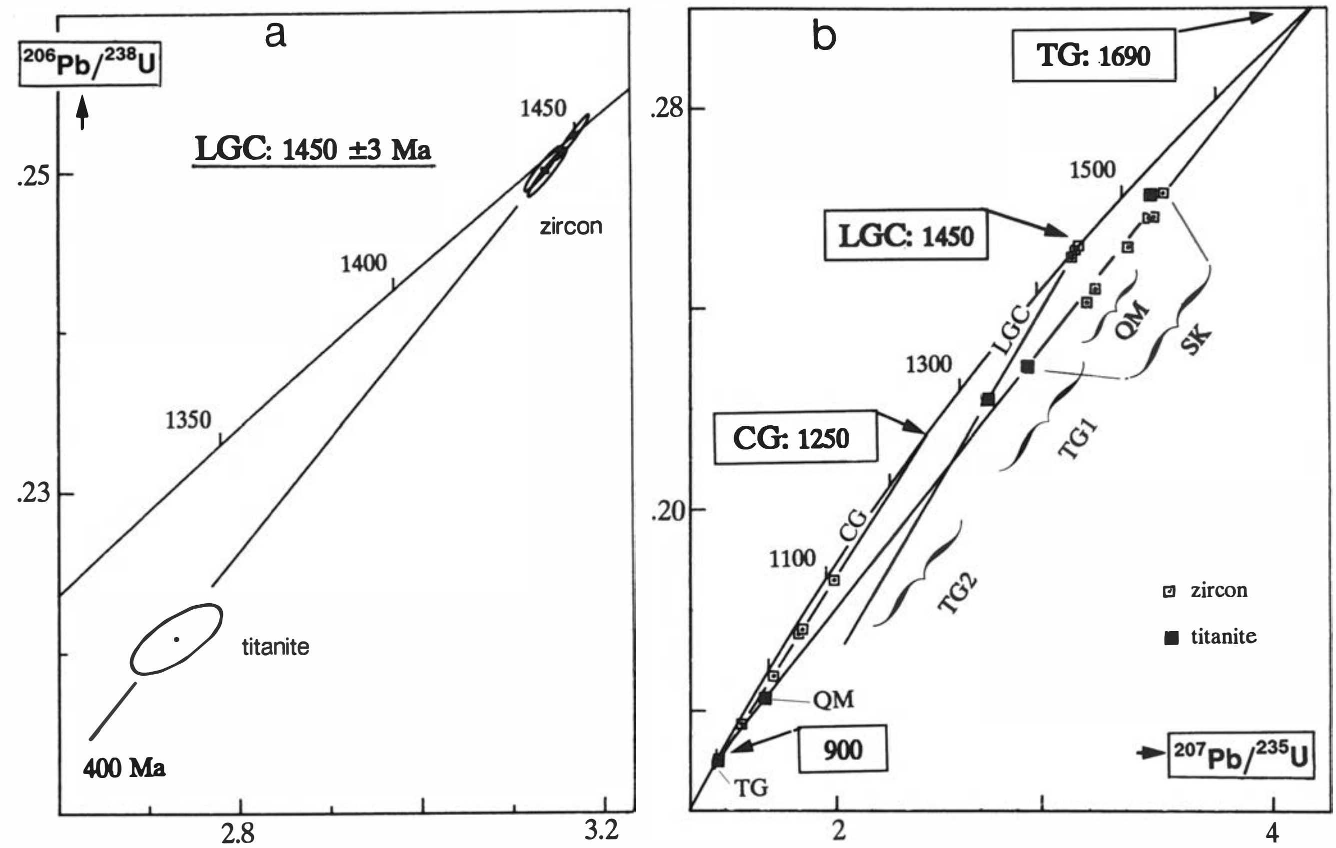

Fig. 2. (a) Concordia diagram with U–Pb data for zircon and titanite from the Leirungsmyran gabbroic complex (LGC). Error ellipses reflect 95% confidence level. (b) Concordia diagram summarizing published U–Pb data for the Jotun Nappe. CG are data for a coronitic gabbro (Schärer 1980a). TG1, TG2 and QM show the range defined by discordant zircons from Tyin gneisses and a quartz monzonite, respectively, along a line between the age of crystallization at ca. 1690 Ma and the age of metamorphism and deformation at 900 Ma (Schärer 1980a) (the data points for TG1, TG2 and QM are omitted for clarity). SK are data for a paragneiss of the Skakadalen Group (Corfu 1980b).

leyite rather than from primary zircon. Regardless of its exact significance, it is therefore reasonable to conclude that the strong discordance of the metagabbro zircons and the 900 Ma lower intercept age directly reflect the metamorphic event (Schärer 1980a). These relationships contrast strongly with those observed in the Leirungsmyran gabbroic complex where the zircons are morphologically uniform and have undisturbed U–Pb systems supporting the geological and mineralogical evidence that the complex completely escaped the medium- to high-grade Sveconorwegian metamorphism (Emmett 1989).

The above distinction is further supported by the lack of Sveconorwegian influence in titanite in the Leirungsmyran gabbroic complex. In contrast, titanite in the Tyin gneisses (TG; Fig. 1) has been totally reconstituted during the 900 Ma event and the coexisting zircons exhibit a very strong discordance (Fig. 2b; Schärer 1980a) defining an upper intercept at 1694 ± 20 Ma that dates igneous crystallization, and a lower intercept age at 900 Ma that reflects the same metamorphic event recorded by the coronitic gabbro (CG). The zircon data for the weakly deformed quartz monzonite (QM; Fig. 1; Schärer 1980a) exhibit a more moderate degree of discordance and the coexisting titanite also retains small amounts of 1.7 Ga Pb (Fig. 2b).

The least discordant zircon and titanite data set (SK, Fig. 2b) was obtained from a greenschist-facies paragneiss from an assemblage of heterogeneous gneisses (Skakadalen Group: Corfu 1980b) that include supracrustal rocks and mylonitic gneisses. The latter grade locally into less deformed monzonitic to syenitic units. The zircon and, most significantly, the titanite data exhibit only moderate degrees of discordance, although the influence of the 900 Ma event is unmistakable.

The variation in the intensity of the Sveconorwegian event recorded by the U–Pb isotopic systems of zircon and titanite in the Jotun Nappe can be correlated with the observed petrographic evidence regarding the degree of metamorphic recrystallization and deformation. This is exemplified by the correlation between the degree of discordance of zircon and titanite in the compositionally similar Tyin gneisses (TG) and the quartz monzonite (QM). The paragneiss unit (SK) was deformed but appears to have escaped amphibolite grade metamorphism, which is consistent with the preservation of a significant 1.7 Ga Pb component in titanite and zircon. The distinction between coronitic gabbro (CG) and Leirungsmyran gabbro complex (LGC) reveals a pronounced correlation between degree of metamorphism and degree of 900 Ma discordance.

There are two possible interpretations for the divergent overprints of the Sveconorwegian tectonothermal event in different domains of the nappe: (1) the high-grade conditions affected equally the whole body of the nappe, but it was a shortlived event and the metamorphic relations occurred only in those domains subjected to intense strain or those domains where fluids were present and able to promote extensive metamorphic reactions (e.g. Robinson 1991); (2) the different domains of the nappe were physically separate entities during the metamorphism and were only brought into juxtaposition in the late stages of or after the main event. Based on the present knowledge, it is difficult to convincingly argue for or against either one of these hypotheses. The fact that the paragneisses of the Jotun Nappe (SK, Fig. 1) have escaped widespread Sveconorwegian isotopic resetting, in spite of being as wet and locally as deformed as the Tyin gneisses, however, led Corfu (1980b) to favor the concept of a $\leqslant$900 Ma thrust juxtaposition of distinct domains within the nappe.

The 1450 Ma age of the Leirungsmyran gabbroic complex also presents another complication with respect to the age of the Svartdalen gneiss. As previously mentioned, the gabbroic complex has been interpreted to intrude the gneiss (Emmett 1989). This implies that the gneissic fabric and the metamorphic assemblage had been formed during a pre-1450 Ma event distinct from the 900 Ma event that shaped the Tyin gneisses (Schärer 1980b). This would appear to conflict with other evidence suggesting that Tyin and Svartdalen gneisses shared a common metamorphic and deformational history. The presence of some unrecognized thrust contact between the Leirungsmyran gabbroic complex and the Svartdalen gneiss would provide a possible solution to this dilemma.

It is obvious that these contradictions can only be properly resolved by more extensive geological and geochronological work. The new U–Pb age and the contrasting U–Pb systematics in different domains of the nappe, however, provide a more focused definition of some of the questions that have to be addressed in order to properly understand the Precambrian evolution of the Jotun Nappe.

Regional significance of 1450 Ma mafic magmatism

Whereas the magmatic episode that developed the syenite and monzonite suite of the Jotun Nappe at around 1690 Ma (Schärer 1980a) corresponds to one of the major crust generation events in Scandinavia and Labrador (e.g. Gaàl & Gorbatchev 1987; Tucker et al. 1990; Wardle et al. 1990), the 1450 Ma Leirungsmyran gabbroic complex reflects more sporadic episodes of anorogenic magmatism recorded throughout these regions. The earliest pulses of anorogenic mafic magmatism include the emplacement of the Värmland dolerites in Sweden (ca. 1470 Ma; E. Welin, quoted in Johansson & Johansson 1990), The Selnes coronitic metagabbro in the Western Gneiss Region (1462 $\pm$ 2 Ma; Tucker et al. 1990) and the Michael and Shabogamo gabbros in Labrador (1430–1450 Ma; Schärer et al. 1986; Connelly & Heaman in press). Anorthosite–granite complexes such as Michikamau and Harp Lake in Labrador also formed during this period (ca. 1460 Ma; Krogh & Davis 1973; Hill & Miller 1990). In contrast, the 1250 Ma coronitic gabbro of the Jotun Nappe (Schärer 1980a) correlated with one of the youngest episodes of pre- and early-Grenvillian anorogenic magmatism in Labrador (Gower et al. 1990) and Scandinavia (Gorbachev et al. 1987) and also with the formation of the large Mackenzie dike swarm of North America (LeCheminant & Heaman 1989).

Conclusions

Zircon (and titanite) yields an age of 1450 $\pm$ 3 Ma for the emplacement of the Leirungsmyran gabbroic complex in the Jotun Nappe, indicating a temporal correlation with anorogenic intrusions in southern Scandinavia and Labrador. No substantial Sveconorwegian (900 Ma) metamorphism and deformation overprinted the Leirungsmyran gabbroic complex, in contrast to the intense Sveconorwegian metamorphism and deformation recorded in other domains of the Jotun Nappe. This heterogeneity correlates with distinct U–Pb patterns for zircon and titanite in different domains of the nappe. The heterogeneity may indicate that the 900 Ma event affected the nappe as a whole but was shortlived and only locally produced a mineralogical (and isotopic) record. Alternatively, it may result from separate metamorphic evolutions of different parts of the nappe that may have been tectonically juxtaposed in the late stages of or after the 900 Ma event.

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