A U–Pb zircon, Archaean age for granitoid rocks in the Kunes Nappe, Laksefjord Nappe Complex, Finnmark, North Norway

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Nappes in the middle parts of the Caledonian tectonostratigraphy in Finnmark, northern Norway, contain slices of granitoid basement that hitherto have not been reliably dated. Zircons extracted from two, high-K, calc-alkaline granites from the Storfjord Basement Complex of the Kunes Nappe, Laksefjord Nappe Complex, are strongly discordant and display some scatter, but provide evidence indicating that the granites formed in the Archaean (c. 2850 Ma; 2600 Ma minimum age). Mature arc, alkali-rich granites of this type and similar age are known from some of the nearby Archaean terranes in this northernmost part of the Fennoscandian Shield, southeast of the Caledonian front. Most of these NW–SE-trending terranes or cratonic blocks can be followed northwestwards, on geophysical evidence, for some 350 km beneath the Caledonian nappes and far into the southwestern Barents Sea. The granites and related plutonic rocks of the Kunes Nappe are considered to derive from a former highland region (termed the Finnmark Ridge) of Fennoscandian (Baltican) Archaean to Palaeoproterozoic rocks, now largely concealed beneath the SE-transported Caledonian allochthons of northwestern Finnmark and the nearby continental shelf.

Introduction

The tectonostratigraphy of the Caledonides of Finnmark comprises four major nappes or nappe complexes, in ascending order: Gaissa Nappe Complex, Laksefjord Nappe Complex, Kalak Nappe Complex and Magerøy Nappe (Roberts 1985) (Figure 1a). The Gaissa Nappe Complex (GNC), also known as the Gaissa Thrust Belt (Gayer et al. 1987), overlies parautochthonous successions, notably on Varanger Peninsula. The GNC forms part of the orogen-wide Lower Allochthon, which is considered to represent original platformal successions deposited along the Baltoscandian margin of the palaeocontinent Baltica. The Laksefjord and Kalak Nappe Complexes (LNC and KNC, respectively) at higher structural levels are sandstone-dominated thrust units that are generally regarded as having developed as a continental-rise prism just outboard of the

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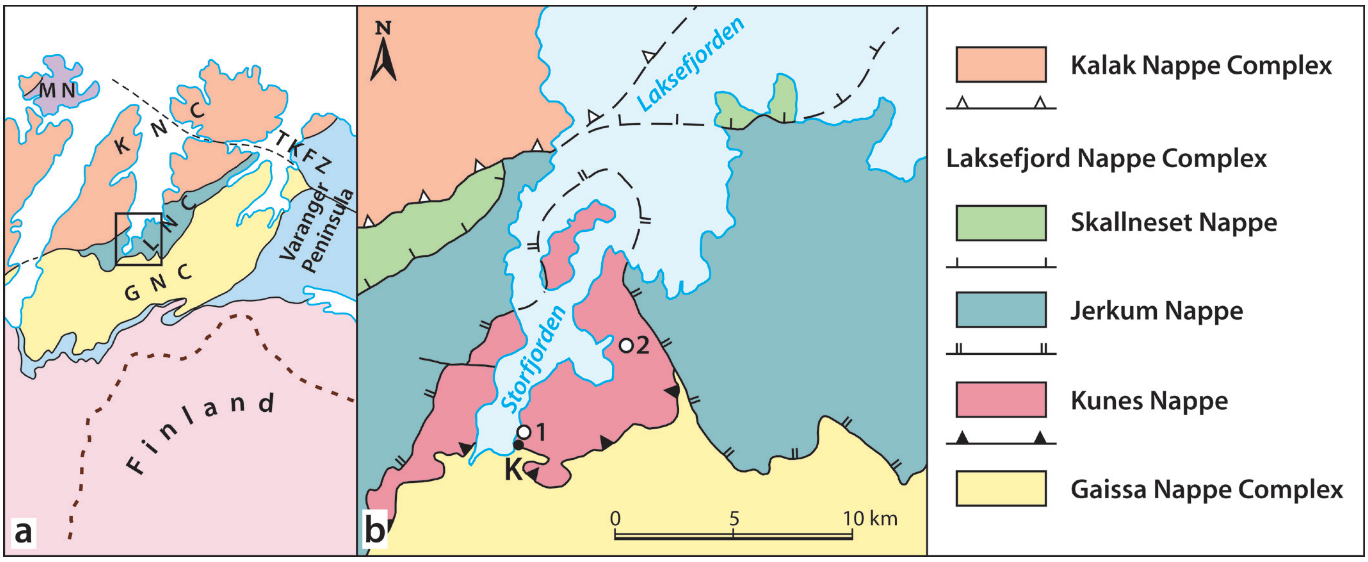

Figure 1. (a) Simplified tectonostratigraphy of northern Finnmark. The boxed area is shown in Figure 1b. GNC–Gaissa Nappe Complex; LNC–Laksefjord Nappe Complex; KNC–Kalak Nappe Complex; MN–Magerøy Nappe; TKFZ–Trollfjorden-Komagelva Fault Zone. The pink-coloured area is Archaean to Palaeoproterozoic crystalline basement. (b) Location map for the granite samples KU1 (1) and KU2 (2). K–Kunes.

Baltoscandian platform, and constitute parts of the Middle Allochthon. Rocks of the Magerøy Nappe form part of the Upper Allochthon and are considered to have a more exotic, Iapetan or even Laurentian origin (Kirkland et al. 2005, Corfu et al. 2006, 2007). In very simple terms, these various nappes were transported roughly southeastwards onto the Baltoscandian margin of Baltica during the protracted Caledonian orogeny.

Several of the many thrust sheets that compose the LNC and KNC contain basal plinths or slices of crystalline rocks derived from the Precambrian basement, which are overlain by variably thick successions of metasedimentary rocks. Whilst some of these basement slices can be linked quite readily to autochthonous rock complexes exposed in inner Finnmark today (i.e., southeast of the Caledonian front), others are of unknown age or uncertain affinity.

In this short contribution, we report the first U–Pb zircon age results for granitoid rocks from the base of the Laksefjord Nappe Complex. Earlier attempts to date similar orthogneisses incorporated in higher thrust sheets of the KNC have relied on Rb–Sr whole-rock isochrons (Ramsay and Sturt 1977, 1469 ± 70 Ma, Sturt and Austrheim 1985; 3044 ± 50 Ma), which often provide less robust age constraints than with U–Pb dating. More recently, Kirkland et al. (2008) have reported a U–Pb zircon age of 1796 ± 3 Ma for a foliated granite in a thrust slice of basement gneissic rocks of Baltican affinity on the island of Seiland in western Finnmark.

Regional setting

The LNC comprises three separate thrust sheets that were referred to informally as Lower, Middle and Upper Laksefjord nappes by Føyn et al. (1983). Exposed mainly in the inner parts of Laksefjorden, in Storfjorden (Figure 1b), crystalline basement rocks dominate the Lower nappe but are also found farther inland in one area at the base of the Middle nappe. The Middle and Upper nappes of Føyn et al. (1983) comprise mostly low-grade metasedimentary rocks of the 8 km-thick Laksefjord Group, of unknown but suspected Meso- to Neoproterozoic age. In a study of allochthonous 'window basement' rocks in Norway, Rice (2001) introduced a more formal name, *Kunes Nappe*, for the Lower Laksefjord nappe. In a similar vein, and as an aid in ongoing map compilations and revisions of map-sheets, Roberts et al. (in prep.) have assigned the Middle and Upper nappes to the *Jerkum Nappe* and *Skallneset Nappe*, respectively (Figure 1b).

In a palaeogeographical perspective, the basement rocks of the Kunes and Jerkum nappes have been considered to derive from a mountainous ridge (the 'Finnmark Ridge' of Gayer and Roberts 1973), c. 100–150 km in width, situated to the northwest of a fairly shallow-marine 'Gaissa Basin' marginal to the Archaean complexes of the northern Fennoscandian Shield (Gayer et al. 1987, Townsend 1987, Gayer and Rice 1989). Conglomerates and sandstones of the Laksefjord Group are interpreted as alluvial-fan to proximal flood-plain deposits shed off a major syn-sedimentary fault, with palaeocurrent data indicating a clear NW-directed dispersal pattern. The sedimentary succession is inferred to have been sourced in the highlands of the Finnmark Ridge (Chapman 1980, Føyn et al. 1983, Roberts 2007), and clasts in conglomerates of the basal Ifjord Formation can be matched with many of the rock types in the basement complex of the Kunes Nappe (Chapman 1980, Føyn et al. 1983). In terms of structure, initial Caledonian ductile thrusting of the LNC was directed southeast, and superseded by out-of-sequence brittle thrusting towards east-southeast (Townsend 1987). For further structural details and interpretations, the reader is referred to the papers of Chapman (1980), Gayer et al. (1987), Townsend (1987) and Rice (2001).

The basement rocks of the Kunes Nappe

The Kunes Nappe consists largely of the *Storfjord Basement Complex* (Findlay and Elverson 1977, Rice 2001) and a thin (c. 145 m) cover succession, the Adamsfjord Formation (Rice et al. 1989, Rice 2001). The *Adamsfjord Formation* comprises mainly very low-grade dolostones, limestones and siltstones, and reportedly (Føyn et al. 1983) lies unconformably upon the basement complex in one area. The age of this formation is unknown.

Rocks and structures of the Storfjord Basement Complex have been described in some detail by Noake (1974), Findlay and Elverson (1977), Chapman (1980), Føyn et al. (1983) and Rice (2001). A variety of plutonic and hypabyssal rocks are represented, principally alkali granite, adamellite, granodiorite, diorite, amphibolitic gabbro and mafic dykes, many of which are variably foliated. Most of the above authors have regarded this assemblage as comparable to parts of the Archaean to Early Palaeoproterozoic basement exposed farther to the southeast in East Finnmark, northern Finland and NW Russia, but until now there has been no indication of the definite age of any of these rocks.

In this study, we sampled granitoids of very similar character from two localities (Figure 1b): (1) in a small cliff close to an old, overgrown, forested track c. 1.8 km north of the Kunes/E6 road junction, in eastern Storfjorden; and (2) from a long road-cut on the west side of the main E6 highway (Figure 2) c. 1.6 km north of the bridge over the waterfall at Adamsfjord. The first locality, sample KU1–07, is located c. 200 m above the base of the Kunes Nappe at **482105 7805850**. The second, sample KU2–07 (Figure 2), is situated at **486610 7810010**. Both sets of coordinates are UTM zone 35, WGS84. Both localities are on the 1:50,000 mapsheet Adamsfjord 2135–I.

Sample KU1–07 is a grey to slightly pinkish-grey, variably foliated granite which in thin-section shows a general hypidiomorphic-granular texture disturbed by anastomosing foliation surfaces lined by microcrystalline sericite or illite. Perthitic orthoclase is the dominant feldspar (c. 60% of the mode) with minor microcline and plagioclase. Quartz (c. 25%) is strongly undulose with ribbon structure and rare recrystallised subgrains along its margins. Large feldspar crysts are partly fractured and degraded at their margins. Accessory minerals are epidote, apatite and rare titanite, zircon and opaques.

Sample KU2–07 is pinkish-grey to pale pink in colour, less foliated and slightly coarser grained than KU1, but otherwise has similar textural and mineralogical characteristics.

Geochemistry

Major and trace element analyses of the two samples are quite similar (Table 1) and on a total alkali vs. SiO_2 diagram (Figure 3a) they both fall in the field of alkali granites. On a K_2O vs. SiO_2 plot (not shown) they rank as high-K, calc-alkaline granites. A trivariate Hf–Rb/30–3xTa discriminant plot places the samples firmly in the field for volcanic-arc granites (Figure

Figure 2. The sampling locality for granite KU2–07, road-cut on the western side of the E6 highway (see text for details).

Table 1. Major, trace element, REE and Hf, Ta, Th and U analyses of the two granites from the Storfjord Basement Complex. Major elements in wt.%, trace and other elements in ppm.

	KU–1	KU–2
SiO_2	71.50	70.20
Al_2O_3	14.90	15.20
Fe_2O_3	1.22	1.27
TiO_2	0.16	0.13
MgO	0.90	0.51
CaO	0.84	1.40
Na_2O	4.92	5.02
K_2O	3.44	3.45
MnO	0.01	0.01
P_2O_5	0.04	0.05
LOI	1.63	1.24
Total	**99.56**	**98.48**
Zr	136	122
Y	3.9	2.4
Sr	128	240
Rb	68.5	67.7
Zn	12	8.5
Cu	<2	4.6
Ni	<2	2.8
Cr	7.1	7.8
Ba	809	899
Nb	2.1	1.4
V	17.1	10.9
Ga	16.9	18.7
La	49	15
Ce	90	23
Pr	8.6	2.3
Nd	30	8.2
Sm	3.9	1.3
Eu	0.86	0.55
Gd	--	--
Tb	0.22	0.10
Dy	0.84	0.60
Er	0.42	0.21
Yb	0.31	0.27
Lu	0.05	0.03
Hf	3.8	3.5
Ta	0.15	<0.10
Th	26	1.2
U	0.95	<0.30

3b). The REE analytical data indicate quite marked but variable FigLREE enrichment for both samples (Figure 3c) and a concave-upwards shape through the HREE, with La_n/Lu_n ratios of 102 and 49. Eu anomalies vary from slightly negative (KU1) to slightly positive (KU2).

In summary, the geochemical signatures are indicative of high-K, calc-alkaline rocks characteristic of a mature magmatic arc, reflecting magmatism during the terminal stages of a subduction cycle.

Geochronology

Samples KU1 and KU2 both yielded modest amounts of zircon of rather small size (<100 μm in longest dimension). Zircon grains are pink to reddish-pink and most are cloudy to opaque, features indicating significant radiation damage. Zircons in KU1 were stubby to equant with aspect ratios of 2:1 or less, whereas those in KU2 were c. 3:1. Analysed grains in both samples were the clearest grains available in the zircon concentrate, but all grains contained at least some internal cloudiness. No internal interfaces were observed optically within any of the sampled grains or the population from which they were drawn. Optical examination did not reveal any other features indicating the presence of either core-overgrowth structure or, more generally, concentric zoning. Given the very small yields and poor quality of the grains, the analysed fractions were not subjected to air abrasion.

Two fractions from KU1 and four fractions from KU2 were analysed, each consisting of several grains. Analytical techniques largely followed those given by Krogh (1973). The results are reported in Table 2 and plotted on a concordia diagram (Figure 4). The data show considerable scatter, which precludes obtaining a meaningful age by regression. For example, the four fractions from KU2 are not colinear, and would regress to form intercepts of 2824 ± 270 Ma and 1444 ± 360 Ma with a MSWD of 211. The large uncertainties in the intercept ages and poor MSWD indicate that the zircons in this rock do not have a simple history, and must reflect a variably aged inheritance, multiple episodes of discordance, or both. More generally, we observe that the fractions scatter along an approximate discordia line between 2850 Ma and 1450 Ma, which is shown simply as a reference line for the following discussion.

The possible significance of the discordant and scattered data is best considered in the context of the characteristics and geological setting of the samples. The c. 2850 Ma upper intercept age corresponds to either the approximate age of these intrusions or to the approximate age of inheritance contained within a younger Proterozoic magma. As discussed further below, plutons with ages of 2900 to 2480 Ma are known from nearby areas in Norway, Finland and NW Russia in the crystalline basement of the Fennoscandian Shield just 50 to 150 km southeast of inner Laksefjorden (Levchenkov et al. 1995, Nordgulen et al. 1995,

Figure 3. Geochemical plots of the two granites. Open circle–KU1; filled circle–KU2. (a) SiO_2 versus total alkali diagram. (b) Hf–Rb/30–3xTa plot. (c) Chrondrite-normalised REE profiles for the two granites.

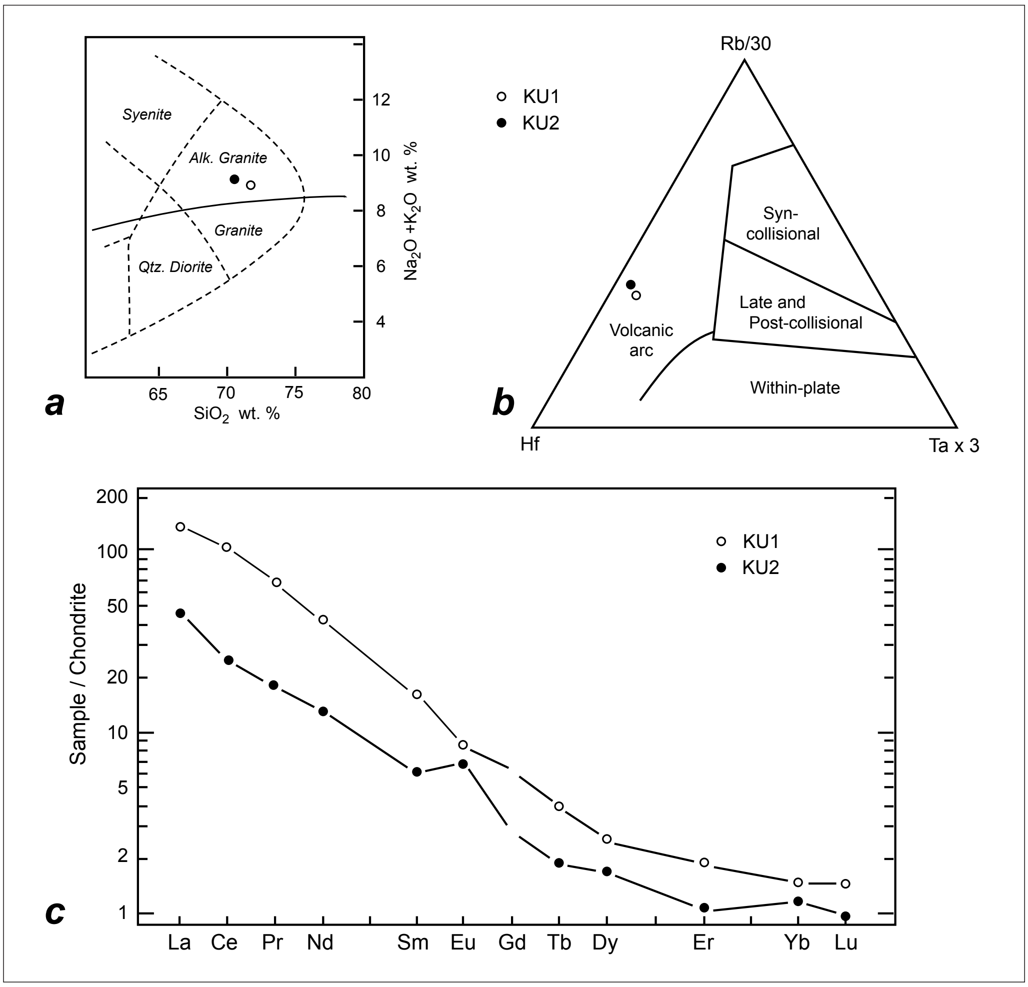

Table 2. Zircon analyses from KU1–07 and KU2–07.

Sample	U (ppm)	Pb (ppm)	$^{206}Pb/^{204}Pb$ measured[1]	$^{206}Pb/^{238}U$ ±err abs[2]	$^{207}Pb/^{235}U$ ±err abs[2]	ρ (rho) err corr[3]	$^{206}Pb/^{238}U$ age in Ma	$^{207}Pb/^{235}U$ age in Ma	$^{207}Pb/^{206}Pb$ age in Ma
KU1–07 zir 1.1	231.0	105.3	1979	0.4177±16	9.113±36	0.992	2249.8 ± 8.7	2349.4 ± 9.2	2437.1 ± 0.8
KU1–07 zir 1.2	387.8	174.1	2600	0.3895±22	8.577±48	0.996	2120.5 ± 11.9	2294.2 ± 12.9	2452.6 ± 0.8
KU2–07 zir 2.1	583.1	239.5	2336	0.3930±10	8.709±22	0.976	2136.9 ± 5.2	2308.0 ± 5.7	2463.0 ± 0.9
KU2–07 zir 2.2	670.0	263.3	1927	0.3772±15	8.168±32	0.986	2063.1 ± 8	2249.8 ± 8.8	2424.3 ± 1.1
KU2–07 zir 2.3	355.9	157.3	2375	0.4152±19	9.928±45	0.996	2238.8 ± 10.2	2428.1 ± 11.1	2590.7 ± 0.7
KU2–07 zir 2.4	564.3	197.7	1407	0.3401±8	6.844±16	0.973	1887.3 ± 4.2	2091.4 ± 4.7	2298.8 ± 0.9

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±.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 fo r fractionation and blank.

[2] 2σ absolute errors, referring to digits in last decimal places.

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

Daly et al. 2006). Whilst this observation can support either of the two, above-mentioned possibilities, it is significant because it argues that the upper intercept age corresponds to an actual event within the basement granitoids rather than a fortuitous or spurious result.

Further discrimination between the two possibilities outlined above is afforded by the character of the rocks and their zircons. If the discordia array represents a c. 2850 Ma inheritance in a younger Proterozoic magma, the implied amount of inheritance is quite large (e.g., exceeding 50% in one of the fractions). However, the zircons from these rocks are simple in their optical characteristics and do not display any features (e.g., core-overgrowth relationships) that would indicate such a large degree of inheritance. Furthermore, the rocks themselves

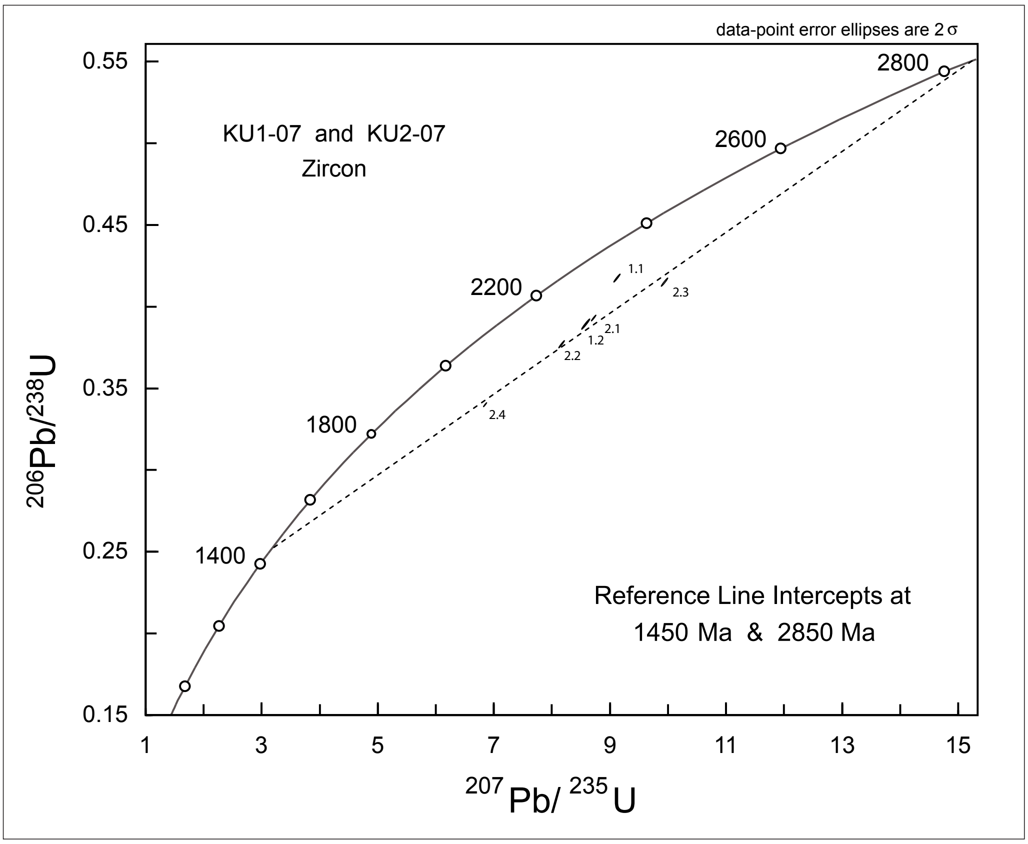

Figure 4. Concordia diagram for the zircon fractions from granites KU1 and KU2.

are fairly typical, high-K, calc-alkaline granitoids that do not normally form by assimilating large amounts of upper crustal rocks (e.g., contrast with S-type granites). The presence of relatively minor amounts of inherited grains in these rocks is certainly possible and may explain some of the scatter, but the above considerations suggest to us that the upper intercept age is unlikely to fundamentally originate from inheritance. This possibility, however, cannot be ruled out without further information from detailed imaging studies.

Our preferred interpretation of the discordia array is that it reflects c. 2850 Ma crystallisation of granitoid intrusions that were disturbed strongly once or more in Proterozoic and possibly younger times. The large degree of discordance is consistent with the observations of a pink to reddish-pink colour of the zircons and their cloudiness, indicating that these zircons contain sufficient U to have developed significant radiation damage at various points in their history.

We emphasise that the uncertainty in the c. 2850 Ma age is large, and the true age of these rocks could lie anywhere in the range of 2600 Ma to 3000 Ma. 2600 Ma is considered a minimum age because the $^{207}Pb/^{206}Pb$ ages extend up to nearly this age (from 2299 ± 1 to 2591 ± 1 Ma, and all but one exceed 2424 Ma; Table 2). The $^{207}Pb/^{206}Pb$ ages indicate that zircon of at least the indicated age is present in each fraction. Whilst we do not attribute any specific age information to the lower intercept age of c. 1450 Ma—due to the scatter and our inability to resolve the potential effects of multiple, discordance-producing events—a significant amount of the discordance must have occurred in Mesoproterozoic time.

Discussion

The interpreted Archaean age of intrusion of these granites (c. 2850 Ma, and a 2600 Ma minimum age), coupled with their geochemical character indicative of a mature-arc affiliation, begs the question as to whether similar plutonic rocks are known from this northern part of the Fennoscandian Shield. A feature of the shield in this part of NW Russia and northernmost areas of Norway and Finland is its subdivision into roughly NW–SE-trending, crustal provinces or terranes, dominated by Archaean complexes ranging in age from 3.5 to 2.5 Ga (Slabunov et al. 2006). From northeast to southwest, these embrace the Murmansk Craton, Lapland–Kola orogen and Karelian Craton, each of which is a fault-bounded composite terrane with distinctive mobile belts (Daly et al. 2006, and references therein).

In brief, during the time of Archaean crustal evolution alone, no fewer than three subduction-related, arc-generation events have been recognised, at c. 3.1–3.0, 2.95–2.85 and 2.82–2.75 Ga (Gaal and Gorbatschev 1987, Slabunov et al. 2006, Hölttä et al. 2008); the second and third mature arcs involving calc-alkaline and, in part, K-rich granitoid rocks, i.e., from c. 2.90 to

c. 2.75 Ga. Thus, without going into detail, granitic rocks akin in age and chemistry to the Kunes granitoids do occur in this extensive region.

The many exotic terranes within these Murmansk and Karelian cratons, and Lapland–Kola orogen (itself a collage of terranes), some of which have lensoid form, extend northwestwards beneath the Caledonides. On aeromagnetic data, such terranes can be traced for up to c. 100 km, striking toward NW to NNW, beneath the thin-skinned Caledonian thrust sheets and nappes (Olesen et al. 1990). Furthermore, in integrated deep-geophysical studies, Ritzmann and Faleide (2007) and Barrère et al. (2009) have shown that this Fennoscandian (Baltican) crust can be followed for a further 200–250 km into the southwestern Barents Sea, before encountering a suture zone juxtaposing Laurentian crust. Thus, accepting a broad continuity of strike over the c. 350 km of concealed, Archaean, Baltican basement terranes, there is every likelihood that the alkali granites of the Kunes Nappe have derived from one of these subjacent, concealed terranes.

The bimodal magmatic rocks of the Storfjord Basement Complex are today situated just 50 km northwest of the Caledonian front and, as noted above, have been considered to derive from a hinterland part of the Finnmark Ridge. Their thrust emplacement during the Caledonian orogeny is reported to have occurred mainly during an early phase of SE-directed ductile deformation, followed by an episode of ESE-directed, brittle, out-of-sequence thrusting (Williams et al. 1984, Townsend 1987, Rice 1998), with a minimum displacement along the basal thrust to the Kunes Nappe of c. 105 km (Townsend 1987). Whatever the true distances involved in cumulative nappe transport, embracing both the early ductile and the later brittle movements, the granitic rocks which we have now dated from the Storfjord Basement Complex were almost certainly a part of one of the concealed terranes of the Fennoscandian Shield before their accretion into the Caledonian orogenic wedge and subsequent uplift along a footwall short-cut thrust fault (Rice 2001).

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