Rb–Sr whole-rock and thin-slab dating of mylonites from the Kalak Thrust Zone, near Børselv, Finnmark

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Rb–Sr dating of mylonites from the basal thrust zone of the Kalak Nappe Complex near Børselv, Finnmark, has yielded two distinct isochron ages. One sample series gave an 11-point isochron age of 479 ± 15 Ma. In another series, larger samples taken from nearer the base of the thrust zone, where top-to-the-east shear bands are prolifically developed, were sawn into thin slabs parallel to the mylonitic foliation. Two of these subseries of thin slabs produced separate but near-parallel isochron ages of 385 ± 26 and 380 ± 22 Ma, indicating resetting of the Rb–Sr isotope systems on a local scale. Taken at face value the results may appear, at first sight, to lend support to the notion of a two-stage orogenic development for the Kalak metasediments during the protracted Caledonian cycle involving thrust-related, ductile mylonite generation in Early Ordovician time; and a phase of more brittle, foreland-directed, simple shear close to the base of the Kalak Thrust Zone in the Early to earliest Mid Devonian period. There are, however, certain problems involved in the interpretation of the older (479 Ma) isochron age, in spite of its low MSWD, which call for a measure of reservation.

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The metamorphic allochthon of the Caledonides of Finnmark has been divided into several nappes and nappe complexes, and minor thrust sheets, of which the Gaissa, Laksefjord, Kalak and Magerøy units are the most well known. In recent years, discussion has centred on the tectonothermal histories of these nappe complexes and the time, or times, of their detachment and east- to southeastward transport onto the thin veneer of platformal sediments draping the Baltoscandian margin (Ramsay et al. 1985; Roberts 1985; Dallmeyer 1988a).

Earlier work by Sturt et al. (1967, 1975), employing Rb–Sr and K–Ar data, favoured a two-stage translation of the Kalak and other sandstone-dominated nappes, i.e. with thrusting in both 'Finnmarkian' (latest Cambrian/Early Ordovician) and 'Scandian' (mid Silurian/Early Devonian) time. Field evidence for this notion included the occurrence of early ductile mylonites along the floor thrust zone to the Kalak Nappe Complex (KNC), and later ductile-to-brittle, or brittle. lower grade ultracataclasites at the base of this same zone. The transport vector for the earlier mylonites was directed towards southeast or south-southeast, whereas a more easterly directed transport characterised the later, retrogressive, more brittle movements (Gayer et al. 1987; Townsend 1987). While this structural disparity alone provides no proof of large temporal separation, comparison with the situation in North Troms (Zwaan & Roberts 1978), where the structural grains in the Kalak and higher, Scandian-emplaced Reisa Nappe Complexes (Zwaan 1988) are similarly divergent, does indeed allow for this possibility.

Recent $^{40}Ar/^{39}Ar$ dating work by Dallmeyer (1988a, b) has shown that the KNC has had a polyphase thermal history, with both Early Ordovician and Late Silurian–Early Devonian events represented. In addition, there are nappes or thrust-sheets within the Kalak which carry evidence of an even earlier Caledonian deformation (Pedersen et al. 1989); and, significantly, others with clear indications of possible Grenvillian or Morarian-equivalent (Aitcheson et al. 1989; Daly et al. in press) and earlier Proterozoic orogenic events (Sturt & Austrheim 1985).

Notwithstanding this internal tectonothermal complexity, the question of timing of Caledonian nappe translation remained, and this led one of us (D.R.), in 1987, into collecting several large samples of mylonites from the Kalak Thrust Zone (Townsend 1986) with a view to attempting to

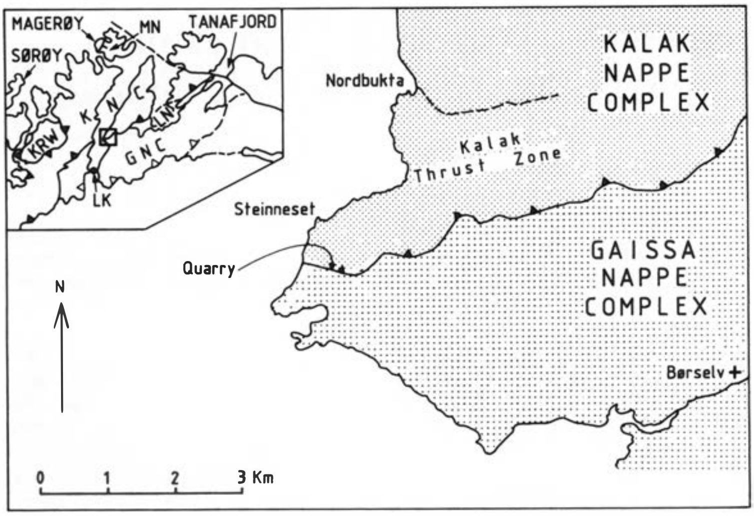

Fig. 1. Location of the quarry, and the mylonite series KM1 and KM2, along the basal part of the Kalak Thrust Zone. The dashed line inland from Nordbukta marks the upper limit of the thrust zone. In the inset map: KNC – Kalak Nappe Complex; LNC – Laksefjord Nappe Complex; GNC – Gaissa Nappe Complex; MN – Magerøy Nappe; KRW – Komagfjord–Repparfjord Window; Lk – Lakselv.

date these tectonites by the Rb–Sr 'thin slab' technique (Claesson 1980, 1986). This short account reports on the results of this dating study.

Sampling and lithologies

Samples of mylonite were collected from a small disused quarry south-southeast of Steinneset, just east of the minor road running along the coast of eastern Porsangerfjord, northwest of Børselv (1:50,000 map-sheet Børselv 2035I, grid-ref. 4015/0390). This quarry occurs close to the very base of the KNC thrust zone above the subjacent Porsanger Dolomite of the Gaissa Nappe Complex (Fig. 1). The thrust-fault contact itself has a prominent topographic expression (Fig. 2), but is not directly exposed in this particular area. Descriptions of the geology and structure of the area are contained in a number of theses (Noake 1975; Townsend 1986; Welbon 1986). Mapping and structural studies in the area have also been carried out by the first author, and map compilatory work at a scale of 1:50,000 is in progress.

Fig. 2. The thrust contact (Kalak Thrust) of the Kalak Nappe Complex and the footwall Porsanger Dolomite (Gaissa Nappe Complex), near Steinneset; looking east. The quarry is actually located just off the field of the photograph, to the left, in the hanging-wall pelitic mylonites.

A feature of the ductile mylonites, which are derived from pelitic to psammitic sediments of assumed Late Proterozoic age (cf. Daly et al. in press), is their marked stretching lineation, at this locality plunging at low angles to the west-northwest within the mylonitic foliation. Sheath folds are also present. The mylonites are variably but fairly extensively affected by a less ductile component of simple-shear deformation in the form of shear bands (the C surfaces of S–C structures; Lister & Snoke 1984) and local ultracataclasites. These structures deform the mylonitic foliation and indicate a top-to-the-east to locally east-northeast sense of shear near the very base of the Kalak Thrust Zone.The mylonites show extensive evidence of retrogressive metamorphism, generally in chlorite grade. Garnets, which are common elsewhere in the KNC, also in intra-Kalak thrust zones (Townsend 1986). are relatively uncommon and largely converted to chlorite in the mylonites of the Kalak Thrust Zone.

Mylonite samples were collected as two separate series, here called KM1 and KM2. The *KM1* series comprised 15 separate 1–1.5 kg samples taken from a zone ca. 4–10 m above the basal, brittle, thrust-fault contact with underlying Porsanger Dolomite. Nine of these (nos. 1–9) were of a pelitic mylonite, three of a paler, silty, pelitic mylonite (nos. 10–12) and three of intensely mylonitised metasiltstone or fine-grained psammite (nos. 13–15). Shear bands were comparatively poorly and sporadically developed in this mylonite series. The *KM2* samples consisted of three large blocks collected from within a zone just 2–4 m above the dolomite. These were sawn parallel to the prominent mylonitic foliation into thin slabs measuring from 1.0 to 1.5 cm in thickness, each block, or subseries, consisting of 6 thin slabs. Two of the subseries. nos. 16 and 17, were of dark grey, compact, pelitic mylonites, whereas the third, no. 18, comprised a paler, rather more silty, tectonically laminated mylonite to ultracataclasite. All KM2 samples, and especially those of the pelitic mylonites, showed well developed and tightly spaced shear bands disrupting the ductile mylonite foliation (Fig. 3).

Analytical techniques

Rb–Sr ratios were determined by XRF-spectrometry. The uncertainty of the method is estimated to $\geq 1\%$ (2σ). Errors in the Rb and Sr concentrations are about $\geq 5\%$. Measurements of unspiked $^{87}Sr/^{86}Sr$ were carried out on a VG Isotope 354 mass spectrometer at the Mineralogisk-geologisk Museum, Oslo, following methods similar to those described by Pankhurst & O'Nions (1973). The variable mass discrimination in $^{87}Sr/^{86}Sr$ was corrected by normalising the $^{87}Sr/^{86}Sr$ ratio to 8.3752. The ^{87}Rb decay constant used was $1.42 \times 10^{-11}\ a^{-1}$ and the regression technique employed was that of York (1969). All results are given with a 2σ error margin.

Results

The analytical results are presented in Tables 1 and 2 and as isochron diagrams (Figs. 4, 5).

Series KM1: Taking all 15 samples into the calculation, the best-fit regression line defines an errorchron of 517 ± 31 Ma, with a high MSWD

Fig. 3. Shear bands developed in the mylonites near the base of the Kalak Thrust Zone in the quarry near Steinneset; looking north on the face of a near-vertical joint. The sense of shear is dextral, top-to-the-east. Scale – eraser on pencil measures 1.4 cm across. The samples taken for the thin-slab dating (KM2 series), particularly subseries 16 and 17, were comparable in lithological character and density of shear bands to the mylonite illustrated here.

Table 1. Rb–Sr analytical data, mylonite series KM1.

Sample no.	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
1	150	197	2.221	0.74421 ± 3
2	179	161	3.215	0.74945 ± 3
3	123	196	1.829	0.74050 ± 3
4	127	182	2.016	0.74182 ± 3
5	140	172	2.364	0.74392 ± 3
6	165	165	2.918	0.74820 ± 3
7	162	177	2.651	0.74655 ± 3
8	165	157	3.051	0.74890 ± 3
9	171	149	3.340	0.75060 ± 3
10	142	176	2.345	0.74382 ± 3
11	147	189	2.667	0.74316 ± 3
12	128	181	2.047	0.74191 ± 3
13	83	205	1.182	0.73466 ± 3
14	100	274	1.061	0.73442 ± 3
15	108	271	1.160	0.73616 ± 3

of 19.6 and initial Sr ratio of 0.7268. Considering just the samples of pelitic mylonite, minus the aberrant sample no. 1, this produces an 8-point isochron of 476 ± 26 Ma with a markedly reduced MSWD of 2.6. Adding the three samples of the slightly silty pelitic mylonite, one derives a similar but now 11-point isochron age of 479 ± 15 Ma with the quality of fit number reduced to an acceptable 2.26 (Fig. 4).

Series KM2: The analytical data for the thin-slab subseries 16, 17 and 18 are presented in Table 2 and Fig. 5. Isochron lines are drawn in the case of subseries 16 and 18 (Fig. 5). Each of the subseries shows broadly the same best-fit regression line, although no. 17 has to be disregarded in view of the high MSWD:

Table 2. Rb–Sr analytical data, mylonite series KM22, thin-slab subseries nos. 16, 17 and 18.

Sample no.	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
16A	177	167	3.081	0.74666 ± 3
16B	144	194	2.159	0.74191 ± 3
16C	205	167	3.573	0.74919 ± 3
16D	193	144	3.899	0.75123 ± 3
16E	218	136	4.666	0.75565 ± 3
16F	175	164	3.103	0.74743 ± 3
17A	168	154	3.169	0.74734 ± 3
17B	189	145	3.791	0.74988 ± 3
17C	193	154	3.646	0.74972 ± 3
17D	175	139	3.674	0.74933 ± 3
17E	147	153	2.790	0.74635 ± 3
17F	180	139	3.751	0.75231 ± 3
18A	118	316	1.086	0.73464 ± 3
18B	95	353	0.780	0.73302 ± 3
18C	100	231	1.255	0.73542 ± 3
18D	111	338	0.956	0.73389 ± 3
18F	110	201	1.579	0.73748 ± 3

Subseries no. 16 – 380 ± 22 Ma, MSWD 3.04

Subseries no. 17 – 383 ± 178 Ma, MSWD 36.2

Subseries no. 18 – 385 ± 26 Ma, MSWD 2.51

An interesting feature is that subseries 16 and 18 fall on two, separate, near-parallel regression lines, with Sr initial ratios of 0.7302 ± 10 and 0.7287 ± 4, respectively. For subseries 17 the i.r. is 0.7303 ± 86.

Discussion

There are certain complications related to the Rb–Sr isotope systems in these samples that render interpretation of the isochron ages difficult. This especially concerns the age obtained on sample series KM1:

(1) There are detectable, though poor, linear correlations in the Rb versus Sr relationship in both the KM1 and the KM2 series. For KM1, samples 14 and 15 appear to be exceptions to this linear correlation. Such linear correlation would indicate a two-component mixing in the samples that would perturb any time-dependent variation of $^{87}Sr/^{86}Sr$ versus Rb/Sr (Claesson 1986).

(2) The calculated mean $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ values for the KM2 subseries plot considerably to the right of the isochron obtained for KM1, which would suggest either that the Rb–Sr systems in the two series are not related, or that the isochron obtained for series KM1 is in some way misleading. Because of the close spatial and lithological relationship of the samples, the last suggestion seems to be the more likely. Another explanation may be that the resetting of the KM2 samples was not a thermal event, but due to isotopic exchange with large volumes of fluids passing through the rocks. To explain the observed effect, such a fluid must have had a low $^{87}Sr/^{86}Sr$ ratio.

Thus, in spite of the acceptably low MSWD value on the 11-point isochron from KM1, the calculated age may be difficult to accept as a true or valid age, e.g. of deformation. Of other possible interpretations, the strongest contender for producing a partial isotopic equilibration at this time is conceivably that of regional meta-

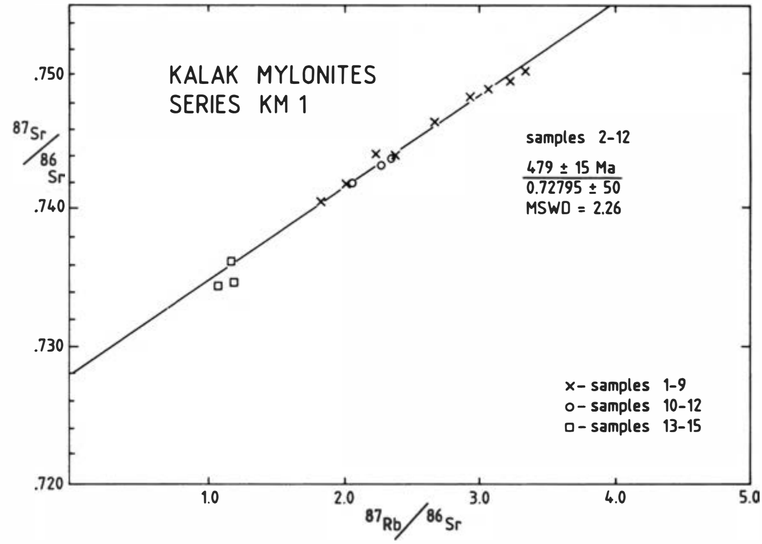

Fig. 4. Rb–Sr isochron diagram, mylonites, series KM1.

morphism. Another alternative might be that of complex mixing relations, and Rb–Sr systematics, within the original sediments.

The results of the Rb–Sr dating show that the thin-slab series KM2 yielded isochron ages in the range ca. 385–380 Ma, and the KM1 series an isochron age of ca. 480 Ma. Small-scale isotope systems seem to have been involved in the case of KM2, at a level close to the floor of the thrust zone. These particular mylonites, KM2, carry profuse and prominent shear bands, the development of which may have facilitated the opening of the isotope systems. We interpret the mylonites as having had their isotopic clocks reset at around or just prior to 385 Ma.

Although it might be tempting to ascribe this resetting to late-orogenic uplift, in contrast to the situation obtaining along many Scandian mylonite

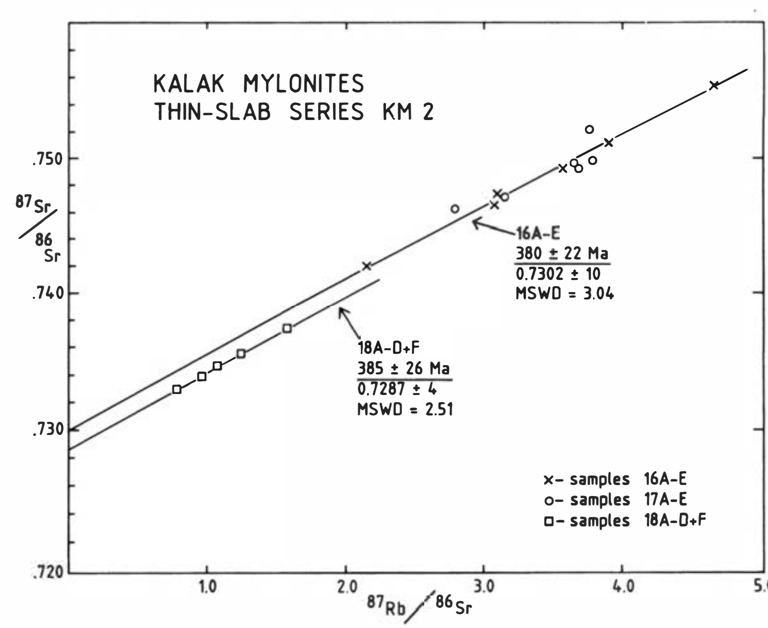

Fig. 5. Rb–Sr isochron diagrams, shear-banded mylonites, thin-slab subseries 16, 17 and 18; series KM2.

zones in the Central and southern Scandinavian Caledonides wherein late extensional structures are common, the shear bands in the Kalak Thrust Zone show a consistent, contractional, top-to-the-east sense of shear. This in itself is interesting, with the Early to Mid Devonian contractional shear in this northern area broadly simultaneous with extensional shear in the southern and inner parts of the already uplifted mountain belt. This feature is here interpreted as resulting from diachronous, Scandian, scissor-like oblique collision, with an extensional to transtensional regime ascribed to gravitational collapse of the nappe pile taking over in the uplifted and eroding orogenic hinterland (Roberts 1983). In the nappes of Finnmark, there is little minor-structural evidence to be seen of a comparable, widespread, late-Caledonian extensional shear.

The thin-slab technique has been employed elsewhere in the Scandinavian Caledonides (Claesson 1980, 1986) and the results appear to indicate that local isotope systems in comparatively dense, porphyroclast-free mylonites are capable of generating meaningful isochron dates, i. e. dates which place an age on the deformation and the formation of mylonites. In this context, the difference in the initial Sr ratio between the two series of samples is also of interest, with the thin-slab mylonite subseries showing the highest values. This accords with an interpretation involving resetting of the isotope system, at this scale, during Early Devonian time.

In terms of the Caledonian tectonometamorphic evolution of the Kalak Nappe Complex, a polyphase development was initially proposed by Sturt et al. (1967, 1975), with suggestions that distinctive Late Cambrian/Early Ordovician (Finnmarkian) and Mid Silurian/Early Devonian (Scandian) events were represented. Before 1967, all major Caledonian deformation in Finnmark was assumed to be of Silurian age. Recently, Krill & Zwaan (1987) and Krill et al. (1988) have revived this concept, maintaining that (1988, p. 183) "the Scandian and Finnmarkian orogenic phases in Finnmark represent a single phase . . .", i.e. Scandian.

In contrast, Dallmeyer et al. (1987) and Dallmeyer (1988a, b) have presented $^{40}Ar/^{39}Ar$ mineral and whole-rock dating results from the KNC which clearly point to distinct Early Ordovician and Mid to Late Silurian, tectonothermal events. Significant orogenic activity, which correlates in time with high-P eclogite metamorphism in Norrbotten, northern Sweden (Dallmeyer & Gee 1986), occurred during and/or just before the Arenig (Dallmeyer 1988a). A separate, later metamorphic overprint rejuvenated argon systems in muscovite and nepheline, and even locally in hornblende, with post-metamorphic cooling through ca. 500–350°C between ca. 425 and 415 Ma. Within and marginal to the Komagfjord–Repparfjord window, cooling ages of 425–400 Ma have been recorded in white micas defining the main cleavage in 'autochthonous' cover sediments just below the Kalak Thrust (Dallmeyer et al. 1988).

The results reported in this present study, from just one part of the basal thrust zone of the KNC, may on first sight appear to fall in line with this notion of a two-phase, Caledonian, tectonothermal evolution and transport. Reservations have been expressed, however, on the validity and significance of the KM1 ca. 479 Ma isochron age. If meaningful at all, in relation to the field criteria for the mylonites described earlier this ca. 479 Ma age would apply to the comparatively high-T ductile mylonites, representing the principal stage of mylonite generation in the Kalak Thrust Zone. The 385/380 Ma thin-slab isochrons, on the other hand, are readily ascribed to the shear-banded S–C mylonites, representing the later, relatively brittle, easterly directed component of nappe transport.

In the underlying, lower grade Gaissa Nappe Complex, the thrusting vector is notably eastward directed (Townsend et al. 1987). No trace of ductile mylonites or southeastward transport has been detected. There is evidence in the Gaissa for thrust-related metamorphic inversion, with high-anchizone/low-epizone conditions developed just beneath the basal Kalak Thrust; resulting from Scandian emplacement of the hot KNC rocks (Rice et al. 1989). K–Ar and $^{40}Ar/^{39}Ar$ dating (Dallmeyer et al. 1989) from the Gaissa has not yielded any definitive age for the regionally penetrative slaty cleavage, other than a K–Ar apparent age of ca. 440 ± 9 Ma, interpreted as a maximum date. Field evidence shows that thrusting at the base of the Gaissa Nappe postdated the time of cleavage generation. Just one K–Ar whole-rock analysis has so far been carried out on the ultracataclasite of the sole thrust, from Handelsbukt ca. 12 km east-northeast of Lakselv: 391 ± 9 Ma (2σ) (J. G. Mitchell, unpubl. data, pers. comm. 1989; $K_2O = 4.62 \pm 0.10$, radiogenic $Ar^{40} = (6.50 \pm 0.04)10^{-2}$, atmospheric contamination = 1.4%). This falls in line with the Rb–Sr thin-slab isochron ages reported here, for the similar, east-directed, late-stage movements at the base of the Kalak.

Employing a time-scale adopted by Caledonian–Appalachian IGCP projects (McKerrow et al. 1985), the younger movements recorded in the thin-slab isochrons would be of early Middle Devonian (Eifelian) age. Cooling ages reported by Dallmeyer and co-workers for cleavage-parallel micas extend up into the late Early Devonian (Emsian). In the Magerøy Nappe, on Magerøya, the synkinematic Finnvik Granite has yielded a Rb–Sr whole-rock isochron intrusion age of 411 ± 7 Ma (Andersen et al. 1982), which is basal Early Devonian (Gedinnian). Migmatites in the KNC below the amphibolite-facies ductile mylonites forming the basal thrust zone of the Magerøy Nappe have yielded a reset age of 410 ± 28 Ma. This various evidence indicates that, in Finnmark, considerable Scandian orogenic activity extended up into Devonian time. In higher parts of the Caledonian allochthon in this region, amphibolite-facies conditions with ductile thrust-faulting persisted into the Early Devonian. Lower down, nearer the foreland, at the base of the KNC and in the subjacent Gaissa Nappe Complex, later, more brittle, east-directed movements appear to have extended into lowermost Mid Devonian time.

Conclusions

Rb–Sr whole-rock dating of mylonites from the basal thrust zone of the Kalak Nappe Complex, near Børselv, Finnmark, has yielded two distinct isochron ages. One sample series produced an 11-point isochron age of 479 ± 15 Ma. The age obtained on this series is burdened with interpretative problems despite its low MSWD, but it does correspond broadly with similar ages obtained by the ^{40}Ar–^{39}Ar method in higher parts of the KNC. In another series, taken from close to the base of the thrust zone where contractional, top-to-the-east shear bands are prolific, two subseries of thin slabs produced near-parallel isochron lines with ages of 385 ± 26 and 380 ± 22 Ma, indicating resetting of the Rb–Sr isotope systems on a local scale during a thrust-deformation event.

The results may, at first glance, be taken to support the notion of a two-stage Caledonian orogenic development of the Kalak, in this case perhaps with thrust-related, ductile mylonite generation in Arenig time; and a late Scandian phase of more brittle, foreland-directed translation in the Early to earliest Mid Devonian period. However, the problems associated with the actual interpretation of the age of the isochron line for the KM1 series are such that it would be premature at this stage to reach any definitive conclusion.

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References

Aitcheson, S. J., Daly, J. S. & Cliff, R. A. 1989: A Late Proterozoic orogen in the North Norwegian Caledonides. Abstract. *Terra Abstracts 1*, 15.

Andersen, T. B., Austrheim, H., Sturt, B. A., Pedersen, S. & Kjærsrud, K. 1982: Rb–Sr whole rock ages from Magerøy, North Norwegian Caledonides. *Norsk Geologisk Tidsskrift 62*, 79–85.

Claesson, S. 1980: A Rb–Sr isotope study of granitoids and related mylonites in the Tännäs Augen Gneiss Nappe, southern Swedish Caledonides. *Geologiska Föreningens i Stockholm Förhandlingar 102*, 403–420.

Claesson, S. 1986: Direct dating of thrusts in the Swedish Caledonides with the Rb–Sr thin slab technique. *Geologiska Föreningens i Stockholm Förhandlingar 108*, 277.

Dallmeyer, R. D. 1988a: Polyorogenic $^{40}Ar/^{39}Ar$ mineral age record within the Kalak Nappe Complex, northern Scandinavian Caledonides. *Journal of the Geological Society, London 145*, 705–716.

Dallmeyer, R. D. 1988b: Polyphase tectonothermal evolution of the Scandinavian Caledonides. *Geological Society Special Publication 38*, 365–379.

Dallmeyer, R. D. & Gee, D. G. 1986: Polyphase Caledonian orogenesis within the Baltoscandian miogeocline: evidence from $^{40}Ar/^{39}Ar$ mineral dates from retrogressed eclogites. *Geological Society of America Bulletin 97*, 26–34.

Dallmeyer, R. D., Reuter, A. & Clauer, N. 1987: Scandian vs. Finnmarkian terrane accretion in the northernmost Norwegian Caledonides (extended abstract). *IGCP 233 Symposium, Nouakchott, Mauritania*, 77–81.

Dallmeyer, R. D., Mitchell, J. G., Pharaoh, T. C., Reuter, A. & Andresen, A. 1988: K–Ar and $^{40}Ar/^{39}Ar$ whole-rock ages of slate/phyllite from allochthonous basement and cover in the tectonic windows of Finnmark, Norway: evaluating the extent and timing of Caledonian tectonothermal activity. *Geological Society of America Bulletin 100*, 1493–1501.

Dallmeyer, R. D., Reuter, A., Clauer, N. & Liewig, N. 1989: Chronology of Caledonian tectonothermal activity within the Gaissa and Laksefjord Nappe Complexes (Lower Allochthon), Finnmark, Norway: evidence from K–Ar and $^{40}Ar/^{39}Ar$ ages. *In* Gayer, R. A. (ed.): *Caledonian Geology of Scandinavia*. Graham & Trotman, London, 9–26.

Daly, J. S., Aitcheson, S. J., Cliff, R. A., Gayer, R. A. &

Rice, A. H. N. in press: Geochronological evidence from discordant plutons for a Late Proterozoic orogen in the Caledonides of Finnmark, northern Norway. *Journal of the Geological Society, London.*

Gayer, R. A., Rice, A. H. N., Roberts, D., Townsend, C. & Welbon, A. 1987: Restoration of the Caledonian Baltoscandian margin from balanced cross-sections: the problem of excess continental crust. *Transactions of the Royal Society of Edinburgh: Earth Sciences 78*. 197–217.

Krill, A. G. & Zwaan, K. B. 1987: Reinterpretation of Finnmarkian deformation on Western Sørøy, northern Norway. *Norsk Geologisk Tidskrift 67*, 15–24.

Krill, A. G., Rodgers, J. & Sundvoll, B. 1988: Alternative to the Finnmarkian–Scandian interpretation on Magerøya, northern Norway. *Norsk Geologisk Tidsskrift 68*, 171–185.

Lister, G. S. & Snoke, A. W. 1984: S–C mylonites. *Journal of Structural Geology 6*, 617–638.

McKerrow, W. S., Lambert, R. St. J. & Cocks, L. M. R. 1985: *In* Snelling, N. J. (ed.): *The Chronology of the Geological Record*. Geological Society of London Memoir 10, 73–80.

Noake, J. S. 1975: The geology of Inner Sværholthalvøya, Finnmark, North Norway. Unpubl. PhD thesis, University of Wales, Cardiff.

Parkhurst, R. J. & O'Nions, R. K. 1973: Determination of Rb–Sr and $^{87}Sr/^{86}Sr$ ratios and some standard rocks and evaluation of X-ray fluorescence spectrometry in Rb–Sr geochemistry. *Chemical Geology 12*, 127–136.

Pedersen, R. B., Dunning, G. R. & Robins, B. 1989: U–Pb ages of nepheline syenite pegmatites from the Seiland Magmatic Province, N. Norway. *In* Gayer, R. A. (ed.): *The Caledonide Geology of Scandinavia*. Graham & Trotman, London, 3–8.

Ramsay, D. M., Sturt, B. A., Zwaan, K. B. & Roberts, D. 1985: Caledonides of northern Norway. *In* Gee, D. G. & Sturt, B. A. (eds): *The Caledonide Orogen – Scandinavia and Related Areas.* John Wiley & Sons, Chichester, 163–184.

Rice, A. H. N., Bevins, R. E., Robinson, D. & Roberts, D. 1989: Thrust-related metamorphic inversion in the Caledonides of Finnmark, north Norway. *In* Daly, J. S., Cliff, R. A. & Yardley. B. W. D. (eds.): Evolution of metamorphic rocks. *Geological Society Special Publication 43*, 413–421.

Roberts, D. 1983: Devonian tectonic deformation in the Norwegian Caledonides and its regional perspectives. *Norges geologiske undersøkelse 380*, 85–96.

Roberts, D. 1985: The Caledonian fold belt in Finnmark: a synopsis. *Norges geologiske undersøkelse Bulletin 403*, 161–177.

Roberts, D. 1988: Reinterpretation of Finnmarkian deformation on western Sørøy, northern Norway: some comments. *Norsk Geologisk Tidsskrift 68*, 309–312.

Sturt, B. A. & Austrheim, H. 1985: Age of gneissic rocks in the Caledonian nappes of the Alta district, northern Norway. *Norges geologiske undersøkelse Bulletin 403*, 179–181.

Sturt, B. A., Miller, J. A. & Fitch, F. J. 1967: The age of alkaline rocks from west Finnmark, northern Norway, and their bearing on the dating of the Caledonian orogeny. *Norsk Geologisk Tidsskrift 44*, 255–273.

Sturt, B. A., Pringle, I. R. & Roberts, D. 1975: Caledonian nappe sequence of Finnmark, northern Norway, and the timing of orogenic deformation and metamorphism. *Geological Society of America Bulletin 86*, 710–718.

Townsend, C. 1986: Thrust tectonics within the Caledonides of northern Norway. Unpubl. PhD thesis, University of Wales, Cardiff. 137 pp.

Townsend, C. 1987: Thrust transport directions and thrust-sheet restoration in the Caledonides of Finnmark. *Journal of Structural Geology 9*, 345–352.

Townsend, C., Roberts, D., Rice, A. H. N. & Gayer, R. A. 1986: The Gaissa Nappe, Finnmark, North Norway: an example of a deeply eroded external imbricate zone within the Scandinavian Caledonides. *Journal of Structural Geology 8*, 431–440.

Welbon, A. I. 1986: The Børselv duplex, in the inner portion of the Gaissa Nappe. Unpubl. MSc thesis, University of Wales, Cardiff.

York, D. 1969: Least squares fitting of a straight line with correlated errors. *Earth and Planetary Science Letters 5*, 320–324.

Zwaan, K. B. 1988: Nordreisa, berggrunnsgeologisk kart – M 1:250,000. *Norges geologiske undersøkelse*.

Zwaan, K. B. & Roberts, D. 1978: Tectonostratigraphic successions and development of the Finnmarkian nappe sequence, North Norway. *Norges geologiske undersøkelse 343*, 53–71.