The age and origin of the Jutulsessen granitic gneiss, Gjelsvikfjella, Dronning Maud Land

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Rb-Sr and Sm-Nd whole-rock data are presented for the Jutulsessen granitic gneiss, deformed intrusive mafic dykes, and cross-cutting pegmatites and aplites. The data indicate that Nd-isotopic homogenisation last occurred at ≈1 153 Ma, whereas Sr-isotopic homogenisation last occurred at ≈535 Ma. Both ages are significant in that they correspond to widely recognised periods of tectonothermal activity, namely the latest Kibaran orogeny and the late Ross (or Pan-African) orogeny. The age discrepancy is attributed to isotopic decoupling of the Rb-Sr system from the Sm-Nd system during the Late Cambrian. The intrusive age of the Jutulsessen granitic suite is interpreted to be ≈1 153 Ma, and the combined Sr and Nd data suggest that it was derived from a mantle-type source (I-type), or from juvenile sediments with short crustal residence times. The isotopic data also imply that the observed structural D_1 and D_2 events at Jutulsessen are Proterozoic in age, and the D_3 event is Late Cambrian. Comparison of these data with other areas of the East Antarctic craton and elsewhere indicate that the Early Cambrian Ross orogeny extensively reactivated an older Kibaran orogenic belt, but that the effects of this reactivation are variable and difficult to characterise from one area to another.

Rb-Sr- en Sm-Nd-heelrotsdata word aangebied vir die Jutulsessen granietgneis, vervormde intrusiewe mafiese gange en dwarssnydende pegmatiete en apliete. Die data toon dat Nd-isotopiese homogenisasie laas voorgekom het teen ≈1 153 Ma, terwyl Sr-isotopiese homogenisasie laas teen ≈535 Ma voorgekom het. Beide tydperke is besonders daarin dat hulle ooreenkom met erkende periodes van tektonotermiese aktiwiteit, naamlik die laaste Kibariese en die laaste Ross (of Pan-Afrikaanse)-bergvorming. Die ouderdomsteenstrydigheid word toegeskryf aan isotopiese ontkoppeling van die Rb-Sr-stelsel gedurende die Laat-Kambriese tydperk. Die intrusie-ouderdom van die Jutulsessen-graniet word geïnterpreteer om ≈1 153 Ma te wees, en die gekombineerde Sr- en Nd-data suggereer dat dit as gevolg van 'n manteltipe bron (I-tipe) was of van onlangse sedimente met kort korsblywende tye. Die isotopiese data impliseer ook dat die waargenome strukture D_1- en D_2-gebeure by Jutulsessen Protosoïes in ouderdom is, en die D_3-gebeure is Laat-Kambries. Vergelyking van die data met ander gebiede van die Oos-Antarktiese kraton en elders toon dat die Vroeg-Kambriese/Ross-bergvorming grootliks reaktivering van 'n ouer Kibariese bergvormingsgordel is, maar dat die gevolge daarvan varieer en moeilik is om te onderskei tussen verskillende gebiede.

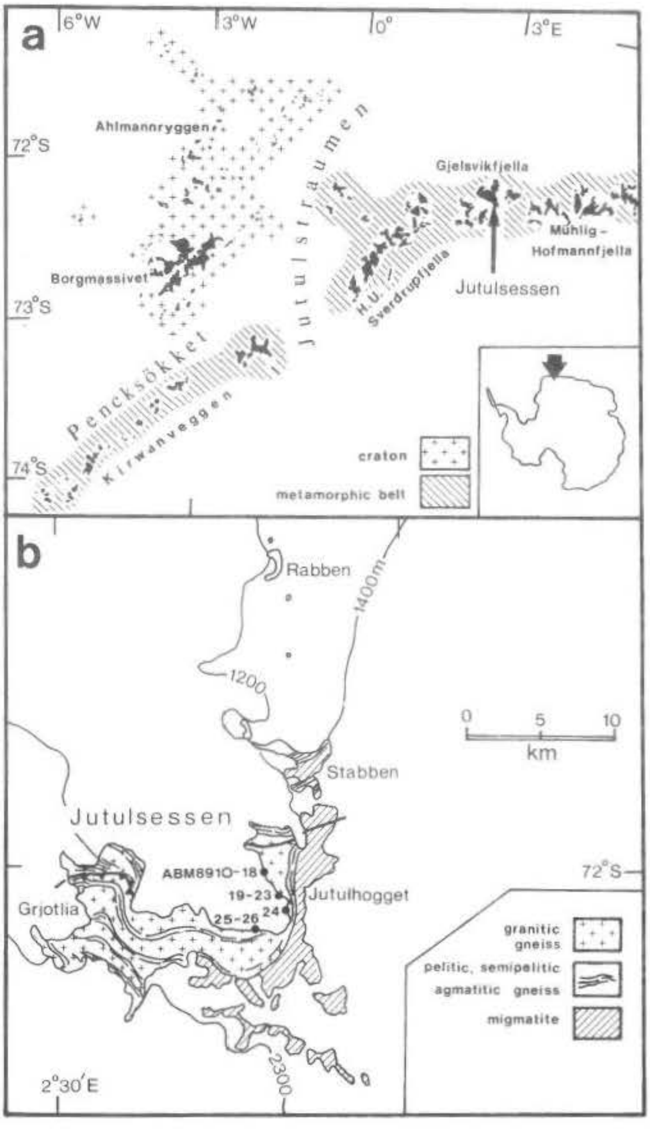
Introduction

South African earth sciences research in Antarctica has focused recently on the tectonic evolution of the metamorphic belt, known as the Maudheim Province (Groenewald *et al* 1991), which can be traced across Dronning Maud Land from the Heimefrontfjella in the west, through the Kirwanveggan, HU Sverdrupfjella and Gjelsvikfjella eastwards (Figure 1a). The evolution and origin of this metamorphic belt is significant since it provides direct correlation with similar belts in southern Africa, and hence provides constraints on the formation and fragmentation of Gondwana. Isotopic investigations have been aimed primarily at providing both absolute age data and constraints on the origin of the major lithostratigraphical units in the metamorphic belt. Unequivocal data have proved elusive, due in part to alteration, but mainly to the complex structural and tectonic evolution of the rocks, which makes interpretation difficult (see review in Wolmarans & Kent 1982, Moyes & Barton 1990). However, it has been well established that the metamorphic suite of the HU Sverdrupfjella and Kirwanveggen (collectively termed the Sverdrupfjella Group) provide isotopic evidence for two major thermotectonic events - during the Proterozoic at 1 200-1 100 Ma (the Bunger orogeny of Angio & Turner (1964), and equivalent to the late Kibaran and Grenville orogenies), and during the Late Cambrian at 500-450 Ma (the Ross orogeny of Angio & Turner (1964) and equivalent to the late Pan-African event). The nature and timing of this Late Cambrian event have recently become significant since it has been proposed that Gondwana amalgamation was complete by this time (Dalziel 1992). Moyes *et al* (1993a) have reviewed the available isotopic data from western Dronning Maud Land in this context; they recognised that the Proterozoic event was a major orogenic period involving high-grade (granulite-grade) metamorphism, but in contrast, the data suggest that the Late Cambrian event was much less intense in character and probably reflected a period of regional uplift. Furthermore, it is concluded that the data are more compatible with a model of large-scale magmatic underplating for large areas of the East Antarctic craton during this event, as proposed by Stüwe & Sandiford (1993), and in direct contrast to the coeval subduction-related orogenesis seen in the Transantarctic Mountains. It is apparent, therefore, that the evolution of western Dronning Maud Land during the Late Proterozoic to Late Cambrian is of paramount significance in understanding Gondwana amalgamation in a wider perspective.

An initial comparative investigation of similar metamorphic suites outside the geographical region of the HU Sverdrupfjella was undertaken during the 1989/90 austral summer field season, when Jutulsessen was visited for a period of approximately ten days, just prior to the establishment of the Norwegian base Troll in the

Figure 1

(a) Western Dronning Maud Land, showing principal geographic areas and geology. (b) Location map for Jutulsessen. Based on Ohta et al (1990)



area (Figure 1b). This paper presents Rb-Sr whole-rock and mineral data, and Sm-Nd whole-rock data from the granitic gneiss, intrusive mafic dykes and cross-cutting pegmatites and aplite dykes, which form the main buttress of Jutulhogget. These data are significant because they place constraints on the nature and timing of the Late Cambrian event in Dronning Maud Land, and have significant implications for the interpretation of isotopic data from the high-grade metamorphic suites in this part of Antarctica.

Geological summary

The essential character of the metamorphic rock suite of the Gjelsvikfjella was noted during early reconnaissance mapping by Roots (1953), and later by Ravich & Soloviev (1969). Detailed work was not undertaken until recently, however, when Ohta *et al* (1990) and Dallmann *et al* (1990) published accounts of the structure, petrography, geochemistry and preliminary isotopic geochemistry of the major rocks units in this area. A number of different lithologies have been recognised in the Gjelsvikfjella, although granitic gneisses are most common, and form the bulk of the outcrop at Jutulsessen (Figure 1b). Details of petrography and structure are given in Ohta *et al* (1990) and Dallmann *et al* (1990). They distinguished older, transposed and interfingering gneiss lithologies with a well-defined gneissosity, and a sequence of cross-cutting aplitic and pegmatitic veins, dykes and networks (Figure 2). Dyke intrusion has often been accompanied by partial melting and neosome formation, and transition to migmatite is common. Lithological variations in the gneisses result from a number of varying processes, namely compositional banding, degree of migmatisation, and transposition of cross-cutting veins and dykes. Dallmann *et al* (1990) considered the gneisses as orthogneisses, and more specifically, as a "strongly deformed granitic intrusive complex". The gneisses are dominantly granitic (*sensu lato*) to tonalitic in composition, and comprise essentially plagioclase, microcline, quartz, amphibole and biotite; garnet occurs in biotite-rich units, and in some biotite-rich samples granular clinopyroxene may be present - in one sample studied here (ABM89-13) green-coloured, subhedral crystals were separated for analysis. An opaque oxide is frequently surrounded by sphene, and accessory phases include abundant apatite, with lesser quantities of zircon, allanite, monazite, rutile and ilmenite (Dallmann *et al* 1990). Metamorphic conditions in pelitic rocks were estimated by Ohta *et al* (1990) to be ≈750 °C and 8 ±1 kb, or upper amphibolite facies. However, orthopyroxene in some silica-undersaturated rocks suggested a transition to lower granulite grade. Subsequent regression to middle to lower-amphibolite facies was indicated by cordierite and hercynite in some rocks

(Ohta *et al* 1990). Deformed mafic dykes (post-D_1) are dominated by amphibole and plagioclase, and frequently biotite, with accessory apatite, zircon and sphene. Structurally younger cross-cutting aplitic and pegmatitic veins and dykes (post-D_2, pre-D_3) form significant volumes at some outcrops. The pegmatites comprise roughly equal proportions of plagioclase and alkali feldspar, with lesser proportions of quartz and biotite; alteration of the pegmatites is common. The pink aplite dykes are composed of a similar mineralogy, although alteration is more frequent.

Structural data indicate that the gneisses have been deformed by at least three events, of which D_1 and D_2 are the most intense. The first event was characterised by complex composite gneissose banding (S_1) which transposed earlier structures (Dallman *et al* 1990). The second was characterised commonly by asymmetric shear folds (F_2). These main fabric-forming events were principally pure-shear type, which suggests that considerable flattening had occurred, with the preferred shear sense within folds of both generations to the north-east, although insufficient data are available to characterise this implicitly (Dallmann *et al* 1990). The third deformation event was much less intense, with regional folding about a gently-dipping south-east fold axis. Ohta *et al* (1990) and Dallmann *et al* (1990) correlated the D_1 event with the Proterozoic Kibaran orogeny, and D_2 with the Late Cambrian Ross or Pan-African event.

Figure 2

Typical exposure of Jutulsessen granitic gneiss, locality ABM89-23. Note complex field relationships between granitic gneiss, deformed mafic dykes and cross-cutting pegmatites. Ice-axe shaft approximately 85 cm long

Samples and analytical techniques

Rb-Sr and Sm-Nd whole-rock data have been obtained from seven representative samples of the granitic gneiss, from five samples of various deformed mafic dykes within the gneiss, and from four samples of pegmatite and/or aplite dykes (Figure 2). The samples of the gneiss analysed here have a medium-grained equigranular texture, are relatively homogeneous on hand-specimen scale, and all have a well-defined foliation. They are considered representative of the gneiss as a whole. Rb-Sr data have also been obtained from a biotite, amphibole and pyroxene mineral separate from sample ABM89-13 of the granitic gneiss. Whole-rock powders were prepared using standard rock-crushing techniques, and mineral separates through magnetic separation and hand-picking under a binocular microscope. Chemical dissolution of ≈0.1 g whole-rock samples and ≈0.05 g - 0.03 g mineral separates was achieved through standard HF + HNO_3 mineral acid dissolution in clean, open Teflon beakers. Separation of Rb, Sr and the rare-earth element group was attained using standard cation-exchange techniques in an HCl medium. Nd and Sm were separated individually using solvent extraction in an HCl medium. All reagents were purified and prepared in-house. Measured total method blank levels were <2 ng for Rb and Sr and <0.5 ng for Nd and Sm. All Nd natural and Sr natural ratios and concentrations were measured on a VG354 mass spectrometer, and Rb, Nd and Sm concentrations were obtained on a Micromass MM30 mass spectro-meter. The radiogenic isotope data have been regressed using the GEODATE programme (Eglington & Harmer 1991). Duplicate analyses of selected samples indicates that precision for the $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios is better than 0.002% (2σ) and better than 0.5% (2σ) for all concentrations. It should be noted that throughout the text all ages, initial ratios and errors are quoted at the 2σ (95% confidence) levels. Nd isotopic ratios were corrected using a $^{146}Nd/^{144}Nd$ ratio of 0.7219; model age data for Sm-Nd and Rb-Sr compared to depleted mantle are based on the equations of Ben Othman *et al* (1984), and bulk earth comparisons on the following constants - $^{87}Rb/^{86}Sr$=0.0847 and $^{87}Sr/^{86}Sr$=0.7047; $^{147}Sm/^{144}Nd$=0.1967 and $^{143}Nd/^{144}Nd$=0.51264. Decay constants are $^{87}Rb = 1.42 \times 10^{-11} y^{-1}$, $^{147}Sm = 6.54 \times 10^{-12} y^{-1}$.

Rb-Sr results

Rb-Sr data are given in Table 1 and are shown in Figure 3. The whole-rock data from the granitic gneisses scatter (MSWD=82) about a line equivalent to an age of 578 ±170 Ma with R_0=0.7062. This scatter is due primarily to one sample, ABM89-17, and exclusion of this reduces the scatter (MSWD=31) about a line equivalent to an age of 673 ±117 Ma with an initial $^{87}Sr/^{86}Sr$ ratio (R_0) of 0.7055. Epsilon (ε) Sr values at this time have a mean value of +22, with a mean bulk earth model age (SrT_{chur}) of 1 453 Ma and mean depleted mantle model age (SrT_{dm}) of 1 663 Ma. The mafic dykes scatter closely (MSWD=9.3) about a line equivalent to an age of 546

±28 Ma with R_0=0.7062; the mean εSr value at this time is +30.9, with mean SrT_{chur} of 1 152 Ma and mean SrT_{dm} of 1 299 Ma. The pegmatites also scatter widely, but with the exclusion of sample ABM89-20 (which contains secondary calcite), scatter closely (MSWD=9.1) about a line equivalent to an age of 531 ±19 Ma, with R_0=0.7063. The mean εSr value at this time is +41, and mean SrT_{chur} of 1 010 Ma and mean SrT_{dm} of 1 135 Ma. It is highly significant that, given the range of rock types analysed, all the whole-rock data plot along an essentially similar linear trend with nearly identical R_0 values; regression of all the data combined yields significant scatter (MSWD=67) about a line equivalent to an age of 535 ±52 Ma, with an R_0=0.7065. This regression line is plotted in Figure 3 for clarity only, although the data strongly imply that the gneisses, mafic dykes, pegmatites and aplites had very similar Sr isotopic characteristics at approximately 535 Ma. It is interesting to note that the two whole-rock samples of the granitic gneiss reported by Ohta *et al* (1990) have somewhat different Sr isotopic characteristics, and do not supplement this data set. The data for biotite, amphibole and pyroxene separates from sample ABM89-13 (granitic gneiss) are also given in Table 1 and are plotted in Figure 3. From these it can be seen that the data scatter closely (MSWD=7.4) about a line equivalent to an age of 478 ±13 Ma with R_0=0.7074. Although this age is just within error of the whole-rock data, it does appear to reflect a slightly younger age on the mineralogical scale.

Figure 3

Rb-Sr whole-rock and mineral data

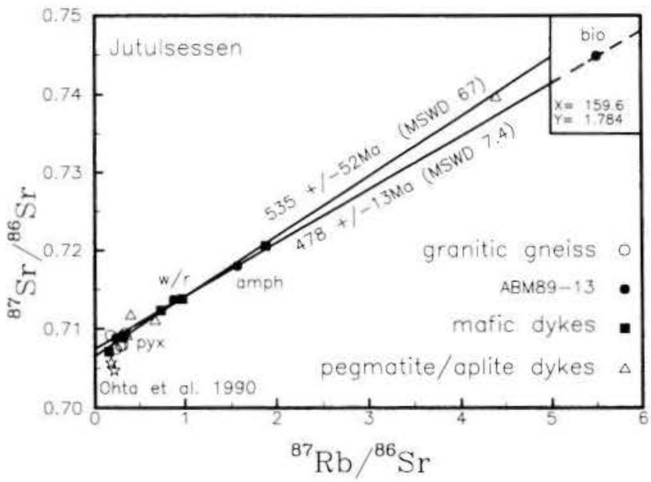


Table 1

Rb-Sr whole-rock and mineral data

Sample No	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	±2σ
Granitic gneisses					
ABM 89–10	100	937	0.309	0.70794	1
ABM 89–13 ω/ρ	160	531	0.875	0.71369	1
pyroxene	3.9	48	0.234	0.70880	3
amphibole	26	48	1.568	0.71800	3
biotite	853	17	159.6	1.78427	5
ABM 89–17	45	748	0.176	0.70915	4
ABM 89–18	89	895	0.287	0.70782	1
ABM 89–19	87	807	0.310	0.70908	2
ABM 89–24	87	745	0.339	0.70938	1
ABM 89–25	78	965	0.234	0.70744	1
Mafic dykes					
ABM 89–11	48	894	0.157	0.70711	3
ABM 89–12	121	477	0.735	0.71230	2
ABM 89–21	298	889	0.970	0.71378	2
ABM 89–22	91	840	0.312	0.70888	4
ABM 89–23	299	461	1.879	0.72054	2
Pegmatite/Aplite dykes					
ABM 89–15	232	153	4.397	0.73975	5
ABM 89–16	100	798	0.362	0.70923	1
ABM 89–20	89	644	0.402	0.71181	2
ABM 89–26	155	665	0.673	0.71113	3

Sm-Nd results

Sm-Nd data are given in Table 2 and are plotted in Figure 4, from which it can be seen that there is only a small spread in the $^{147}Sm/^{144}Nd$ ratios, resulting in large regression errors. The granitic gneisses scatter closely (MSWD=4.4) about a line equivalent to an age of 1 285 ±137 Ma, with an initial $^{143}Nd/^{144}Nd$ ratio (R_0) of 0.51108 and εNd=1.96. The mafic dyke samples also scatter closely (MSWD=7.2) about a line equivalent to an age of 913 ±211 Ma, with R_0=0.51136 and εNd=-1.99. The pegmatite and/or aplite dykes scatter widely (MSWD=22) about a line equivalent to an age of 1 128 Ma (but with an exceedingly large error of ±1 472 Ma due to the small range of $^{147}Sm/^{144}Nd$ ratios in these samples), with R_0=0.51112 and εNd=-1.17. Exclusion of sample ABM89-15 results in closer scatter (MSWD=7.4) about a line equivalent to an age of 918 ±757 Ma with R_0=0.51129 and εNd=-3.23. All three ages are within error of each other, and the different rock types display essentially similar Sm-Nd characteristics, as observed for the Rb-Sr data, namely that all the data scatter along an essentially similar linear trend with similar R_0 values. This results in the combined data set (with the exception of sample ABM89-15 as noted above) scattering closely (MSWD=5.8) about a line equivalent to an age of 1 153 ±125 Ma, with R_0=0.51117 and εNd=0.37. This is the regression line plotted on Figure 4; as with the Rb-Sr data, there is a strong implication that the Sm-Nd characteristics of all the rock types were essentially similar at 1 153 Ma. Mean epsilon (ε) Nd values at this age for the granitic gneisses are +0.6 ±1.02, for the mafic dykes +0.2 ±1.15, and for the pegmatite/aplite dykes -0.8 ±0.95. Mean Nd bulk earth model (NdT_{chur}) ages are 1 042 Ma, 1 158 Ma and 1 211 Ma respectively; mean Nd depleted mantle model (NdT_{dm}) ages are 1 565 Ma, 1 673 Ma and 1 547 Ma respectively.

Figure 4

Sm-Nd whole-rock data

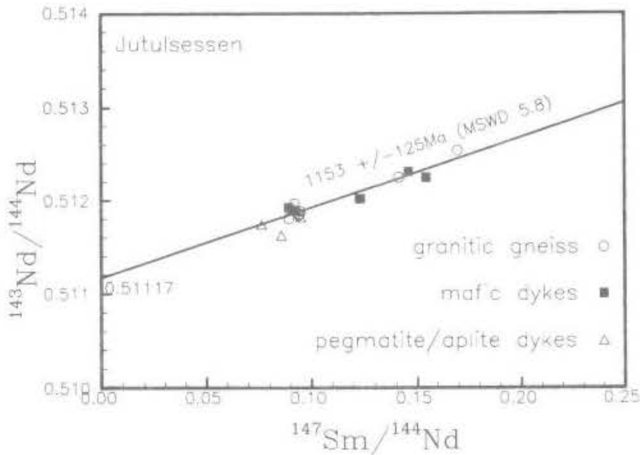


Table 2

Sm-Nd whole-rock data

Sample No	Sm ppm	Nd ppm	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	±2 σ
Granitic gneisses					
ABM 89–10	3.7	23.9	0.095	0.51186	2
ABM 89–13	2.6	11.3	0.141	0.51225	3
ABM 89–17	4.9	17.4	0.170	0.51254	2
ABM 89–18	3.3	21.3	0.094	0.51184	5
ABM 89–19	3.0	20.1	0.089	0.51181	3
ABM 89–24	2.0	12.7	0.095	0.51189	3
ABM 89–25	2.8	18.6	0.092	0.51196	2
Mafic dykes					
ABM 89–11	5.7	22.3	0.155	0.51225	1
ABM 89–12	3.6	14.9	0.146	0.51231	2
ABM 89–21	12.3	80.7	0.092	0.51190	1
ABM 89–22	4.7	23.1	0.123	0.51202	1
ABM 89–23	3.9	26.2	0.089	0.51193	2
Pegmatite/Aplite dykes					
ABM 89–15	18.8	132.3	0.086	0.51162	1
ABM 89–16	3.3	21.4	0.092	0.51190	2
ABM 89–20	3.1	24.4	0.076	0.51174	2
ABM 89–26	0.6	4.0	0.095	0.51182	4

Discussion

The isotopic data presented here are highly significant in the sense that, regardless of rock type, the Sm-Nd and Rb-Sr whole-rock data imply that all the samples had essentially similar isotopic characteristics, but at significantly different times, *viz* ≈1 153 Ma for the Sm-Nd system and ≈535 Ma for the Rb-Sr system. In addition, the εSr values at 535 Ma are relatively low at +20 to +40, and the εNd values at 1 153 Ma are also relatively low at +0.2 to -0.8.

It would be difficult to reconcile the essential similarity in the Sm-Nd and Rb-Sr isotopic data if the variety of rock types sampled were derived from either widely differing sources and/or at different times, even assuming that both isotopic systems reflected a similar age. This contrasts with the obvious intrusive and cross-cutting relationships seen between the different rock types (Figure 2). Given that the two isotopic systems reflect widely differing ages compounds this complexity and strongly suggests that in all the samples analysed here, the Sm-Nd isotopic system was last completely homogenised at ≈1 153 Ma, and the Rb-Sr isotopic system at ≈535 Ma. These ages are geologically significant since they correspond to the high-grade Kibaran event of the Proterozoic and the Pan-African (or Ross) event in the Late Cambrian. The most plausible explanation for the disparity in ages is that isotopic decoupling of the Nd and Sr systems occurred during the Late Cambrian at ≈535 Ma; both systems appear to have been homogeneous during the Kibaran orogeny, but only the Sr system was re-equilibrated during the Late Cambrian. Such an isotopic decoupling is entirely consistent with work by Black (1988) in high-grade metamorphic terrains from Enderby Land, Antarctica. It was demonstrated that the Rb-Sr, Sm-Nd and U-Pb systems could behave in an independent manner, regardless of the metamorphic grade to which the rocks were subjected. The development of a penetrative fabric was advocated as being the critical factor in facilitating isotopic homogenisation, in contrast to a more conventional temperature-dependent model for this phenomenon (i e different blocking temperatures for the different systems). Under conditions of penetrative fabric development the Rb-Sr system would be most easily reset, as observed here. The Rb-Sr mineralogical age of 478 ±13 Ma from sample ABM89-13 is governed primarily by the biotite data, and thus the slightly younger age might be ascribed to the time of biotite closure at lower temperature some time after re-equilibration in the whole-rock Rb-Sr system. The growth of biotite along a new penetrative fabric, and subsequent isotopic closure following cooling would be consistent with the data. However, pyroxene and amphibole also lie on this younger isochron, and it is therefore difficult to reconcile this with a simple cooling/closure temperature model. Since these minerals are not obviously associated with a new penetrative fabric, the slightly younger age from the mineralogical data is interpreted here as suggesting that Sr-isotopic re-equilibration continued on a mineralogical scale for ≈60Ma after it had closed on an outcrop scale. It should also be noted that isotopic decoupling occurred in all the rock types analysed here, implying that the Sm-Nd system in the mafic dykes, pegmatites and aplites were last homogenised during the Kibaran orogeny at ≈1 153 Ma. More importantly, the data imply that the youngest rocks sampled here, the post-D_2, pre-D_3 pegmatites and aplites (terminology after Dallmann *et al* 1990) were reset at ≈1 153 Ma, and thus provide a minimum age for the D_1 and D_2 events. It follows, therefore, that D_3 must represent the Late Cambrian Pan-African event at ≈535 Ma. Such an interpretation would be consistent with the open, gentle folding at this time, resulting in Sr-isotopic resetting but Nd-isotopic durability. If this is correct, then the structural interpretation presented by Dallmann *et al* (1990) requires modification, since they correlate the D_2 event with the Late Cambrian episode at 500-450 Ma. It is interesting to note that a Late Proterozoic (or Kibaran) age for D_1 and D_2 is compatible with the widely accepted structural history of the HU Sverdrupfjella and Kirwanveggen (Allen 1991; Groenewald *et al* 1991). In summary, decoupling of the Rb-Sr and Sm-Nd systems in the whole-rock systems is interpreted here as resulting from Late Cambrian tectonothermal activity.

It is interesting to note that isotopic decoupling prevents combination of the Nd and Sr data in a straightforward manner, since ε values for each system will converge only at the respective time of last homogenisation, that is ≈1 153 Ma for Nd and ≈535 Ma for Sr. This places considerable restraints on the information yielded by the ε values and the model ages. However, some interesting points do arise from the data presented above. For example, the low εNd values of +0.2 to -0.8 at 1 153 Ma implies that the source material for all the rock types was close to bulk earth composition. This is supported by the relatively low εSr values at 535 Ma, which would be even lower at 1 153 Ma since isotopic resetting normally results in an increased R_0. Thus both the Nd and Sr data indicate that the source material for all the rock types was either close to bulk earth in composition (i e primitive mantle) or was a crustal source with very little residence time. The similarity in the isochron ages and the NdT_{chur} ages (1 153 Ma and 1 138 Ma respectively) would imply that in a primitive mantle-type model, the source material was extracted and metamorphosed almost instantaneously in a geological sense. For a depleted mantle-type model, the minimum age for the source material is given by the NdT_{dm} ages of 1 600 Ma-1 500 Ma, thus allowing a period of

≈500-400 Ma for extraction to subsequent metamorphism. The isotopic data cannot differentiate between these two models, but DePaolo (1988, p 130) argues that new crustal material is more commonly derived from a depleted mantle source. With regard to the source of the different rock types, the mafic dykes might reasonably be assumed to be mantle-derived. For the granitic gneisses however, the isotopic data cannot differentiate between a mantle-type source (i e an I-type granite), or a juvenile sedimentary source (i e one with extremely limited crustal residence time). Ohta *et al* (1990) suggest that the granitic gneisses were derived from an acidic volcanic unit inter-layering with less abundant argillaceous to sandy sediments; the combined Nd and Sr data presented here would imply that such igneous precursors would be essentially mantle-derived. The pegmatites and aplites must also have been derived from a similar source to the granitic gneisses, and a plausible origin for these rocks would be the granitic gneisses themselves; field relationships indicate that melting of the gneisses under high-grade conditions (during the Kibaran event) was responsible for the observed migmatite development (Ohta *et al* 1990).

Comparison of the Jutulsessen granitic gneiss at Gjelsvikfjella with similar gneisses from the HU Sverdrupfjella reveals some interesting contrasts. In the HU Sverdrupfjella, for example, the metamorphic suites consistently display a Rb-Sr Kibaran metamorphic age (Moyes & Barton 1990), and there is little evidence to suggest isotopic decoupling with the Sm-Nd system during the younger Late Cambrian event. However, Moyes *et al* (1993b) did report a disparity in the Sr and Nd isotopic characteristics in two hornfels samples collected from within the ≈519 Ma Brattskarvet intrusive suite, despite the country rock and larger xenoliths retaining a Kibaran Rb-Sr age. These data appear consistent with a decoupling process, but on a more restricted scale than that seen at Jutulsessen. However, it should be noted that the HU Sverdrupfjella suites also contain textural evidence, particularly in biotites, for a new fabric development at ≈500 Ma (Allen 1991). This is compatible with the Gjelsvikfjella data, and suggests that the development of a penetrative fabric alone cannot account for decoupling in the Gjelsvikfjella but not the HU Sverdrupfjella. Additional factors, such as the intensity of deformation, or associated fluid movement, must also play a significant role. For example, Shiraishi *et al* (1992) reported zircon growth at ≈500 Ma in metasedimentary and meta-igneous rocks from the Lützow-Holm complex, and suggested that the metamorphic grade increased westwards, that is towards the Gjelsvikfjella. They correlated this region of Antarctica with Sri Lanka on the basis of similar isotopic age data. Furthermore, Kinny *et al* (1993) reported new zircon growth and partial overgrowths at ≈500 Ma from the Rauer Islands on the Prydz Bay coast, and recognised widespread retrogression and rehydration of an old granulite terrain at this time. In other words, new zircon growth cannot necessarily be correlated with high-grade metamorphism. Other evidence which suggests that the Gjelsvikfjella suffered either more intense deformation, or deformation of a different character to that seen in the HU Sverdrupfjella during the Early Cambrian, is given by the data of Ohta *et al* (1990), who reported a Rb-Sr whole-rock intrusive age of 500 ±24 Ma for a charnockite from Svarthamaren, east of Jutulsessen. Such an age is again consistent with reported Sm-Nd and Rb-Sr ages of ≈558 Ma from charnockites from India (Choudhary *et al* 1992), but contrasts with U-Pb zircon ages of ≈1 070 Ma from similar rock types in the Heimefrontfjella (Arndt *et al* 1991) and preliminary Rb-Sr whole-rock results from the Kirwanveggen region (PD Harris, personal communication 1993). Thus there is evidence that the Early Cambrian event has reactivated much of an older Proterozoic metamorphic belt, but that the effects of this younger event are not consistent between different areas. The isotopic decoupling observed at Jutulsessen but not in the HU Sverdrupfjella may be a reflection of the waning influence of this Early Cambrian event westwards. Moyes *et al* (1993a) have suggested that such a difference in tectonic intensity may be related to the location of a Late Cambrian suture to the east of the HU Sverdrupfjella.

In summary, therefore, the Rb-Sr and Sm-Nd data from Jutulsessen demonstrate isotopic decoupling of the Rb-Sr and Sm-Nd systems during Late Cambrian times; a revised structural history for Jutulsessen is proposed, in which the D_1 and D_2 events are essentially Late Proterozoic (Kibaran) in age, and D_3 is Late Cambrian (Ross) in age. The data also clearly demonstrate that a considerable amount of work remains to be carried out with regard to Late Cambrian tectonothermal activity in this region.

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