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The age, petrogenesis and emplacement of the Dalmatian Granite, H.U. Sverdrupfjella, Dronning Maud Land, Antarctica

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Abstract: The ~470 Ma Dalmatian Granite forms sheet-like bodies intruded discordantly into orthogneisses, paragneisses and calcareous rocks belonging to the ~1000 Ma Jutulrora, Sveabreen and Fuglefjellet formations respectively. The Dalmatian Granite is muscovite + biotite bearing. Two varieties are recognized, one that is magnetite-bearing and another that is characterized by tourmaline nodules. At some localities, development of the tourmaline-bearing variety is spatially associated with the presence of carbonates. Physical conditions of emplacement for the Dalmatian Granite are estimated to be approximately 700°C and 6kbar with $pH_2O = P_{load}$. The emplacement of the granite is considered to have occurred syntectonically during D_3 approximately 470 Ma ago. The granites are therefore similar in age to Pan African age granites in Mozambique as well as Ross Orogeny age granites in the Transantarctic Mountains.

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Key words: granite, syn-tectonic, Pan African, Ross Orogeny.

Introduction

The East Antarctic metamorphic shield comprises a number of Archaean cores surrounded by predominantly Proterozoic metamorphic belts, which have suffered a number of relatively well-defined deformational events of various ages, some of which extended into the Phanerozoic (see review in James & Tingey 1983). Although the timing and intensity of these events varies between geographical locations, the youngest episode commonly recognized occurred in the Palaeozoic, and was widespread throughout Gondwana. In East Antarctica, this event is commonly manifested as minor, post-deformational igneous intrusions with widespread mineral isotopic resetting, but it may also have been associated with orogenesis (the Ross Orogeny), such as in the Transantarctic Mountains. In Africa and adjoining areas of Brazil, Arabia and Madagascar, the Pan African event is represented by thermotectonic activity spanning the period 450–550 Ma (Tankard *et al.* 1982).

Western Dronning Maud land is no exception to this general pattern, comprising a cratonic fragment of Archaean granitic basement with relatively undeformed (probable) Mid- to Late-Proterozoic supracrustal sequences, juxtaposed against a Late-Proterozoic or younger metamorphic mobile belt (Wolmarans & Kent 1982, Moyes & Barton 1990). This metamorphic belt has recently been studied in detail in the H.U. Sverdrupfjella area and a number of late, relatively undeformed igneous intrusions have been recognized (Grantham *et al.* 1988). These intrusions have been assumed to represent Pan African activity in this region, and are accompanied by a widespread mineral isotopic resetting (particularly biotite) at approximately 460–480 Ma (Moyes & Barton 1990). This paper reports on a detailed investigation of one such suite of granitic intrusions, the "Dalmatian Granite" (Grantham *et al.* 1988), and presents structural, petrological, geochemical and isotopic data which may be used to elucidate the age and conditions of Pan African activity in this part of Dronning Maud Land.

Field occurrence and relationships

Regional mapping in western and central H.U. Sverdrupfjella, Dronning Maud Land has revealed numerous exposures of apparently undeformed leuco-granite (Fig. 1). These granites,

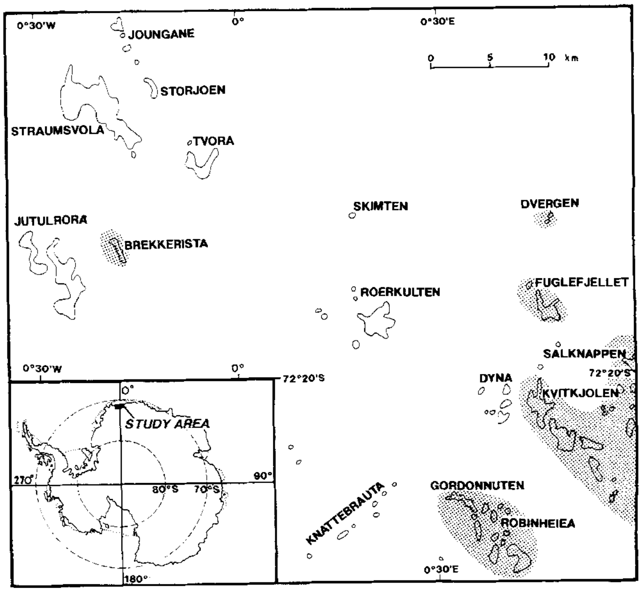

Fig. 1. Locality map and map showing the nunataks (stippled) where the Dalmatian granite is exposed.

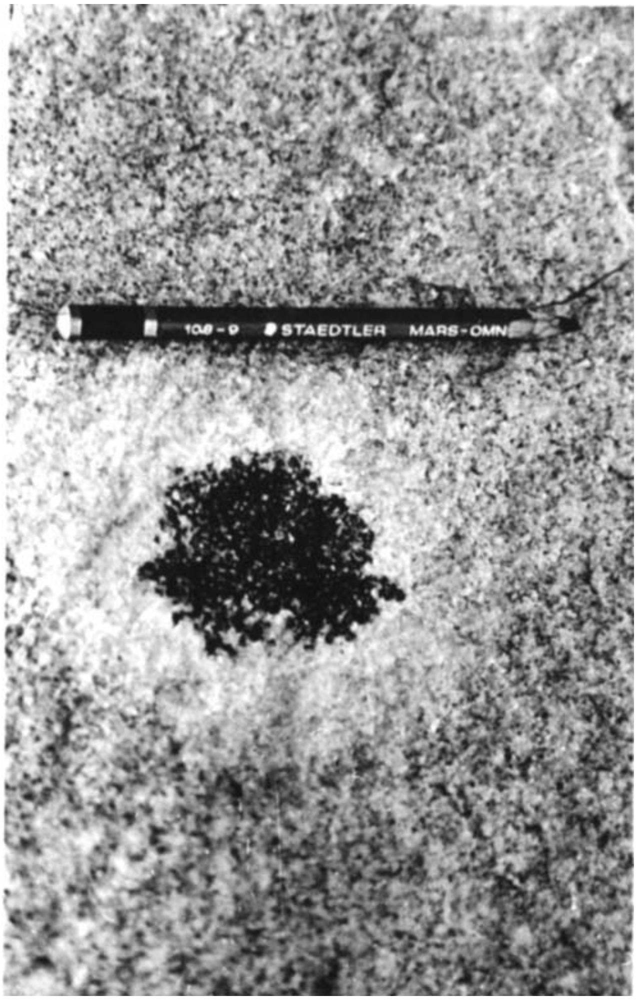

Fig. 2. Nodular structure in the Dalmatian Granite.

exposed at Brekkerista, Dvergen, Salknappen, Kvitkjolen, Gordonnuten, Robinheiea and Fuglefjellet (Fig. 1) occur as sheet-like bodies, up to 10 m thick, with varying orientations.

The granites intrude the Jutulrora Formation at Brekkerista, the Fuglefjellet Formation at Fuglefjellet, Dvergen and Kvitkjolen, and the Sveabreen Formation at Salknappen, Kvitkjolen, Gordonutten and Robinheiea (Fig. 1). Grantham *et al.* (1988) described the stratigraphy of the H.U. Sverdrupfjella.

The Dalmatian Granite is typically medium-grained, leucocratic and characterized by the presence of both muscovite and biotite. Two varieties of the granite have been recognized, namely one with tourmaline-bearing nodules and another that is tourmaline-free. The nodule-bearing granites are exposed at Brekkerista, Kvitkjolen, Fuglefjellet, Robinheiea and Dvergen (Fig. 1). The nodules have a melanocratic (tourmaline-bearing) core and a leucocratic rim, and are up to 10 cm in diameter (Fig. 2). The leucocratic rim is characterized by muscovite.

Locally, where the nodules are numerous, the leucocratic rims coalesce to form bands enclosing adjacent melanocratic cores. The tourmaline-free variety, exposed at Fuglefjellet, Dvergen, Robinheiea, Kvitkjolen and Salknappen (Fig. 1), is characteristically medium-grained, pinkish in colour and contains phenocrysts of magnetite which are usually 1–2 mm in diameter but rarely up to 1 cm in diameter.

The two varieties of granite are clearly part of the same intrusive phase because, at Dvergen, a granite sheet displaying both varieties intrudes discordantly across quartzofeldspathic gneisses interlayered with marbles. Where the granite intrudes the quartzofeldspathic gneisses it is characterized by magnetite phenocrysts but where it intrudes the marble layers, tourmaline nodules occur. Similar relationships are seen at Kvitkjolen and Fuglefjellet where a spatial relationship between tourmaline-bearing granite and the presence of carbonate rocks in the vicinity is recognized.

Petrography

The granite is uniformly medium grained and is composed of quartz (33%), microcline (32%), plagioclase of composition An_{20} (28%) (determined using the Michel-Levy method on albite twins in plagioclase), muscovite (4%) and biotite (2%). Accessory phases include apatite, magnetite and zircon. Some of the muscovite is clearly an alteration product of plagioclase in which it occurs as small patches. The remaining muscovite is considered to be primary because it has the same habit as biotite and conforms to the textural criteria for primary muscovite from Miller *et al.* (1981). These criteria are that the mica must "(1) have relatively coarse grain size, comparable to obviously primary phases, (2) be cleanly terminated, ideally with subhedral to euhedral form, (3) not be enclosed by, or raggedly enclose, a mineral from which the muscovite may have formed by alteration; (4) be in a rock with clean, unaltered, igneous texture" (Fig. 3).

Some biotite grains show incipient alteration to pale green chlorite. Plagioclase commonly shows zoning. In the

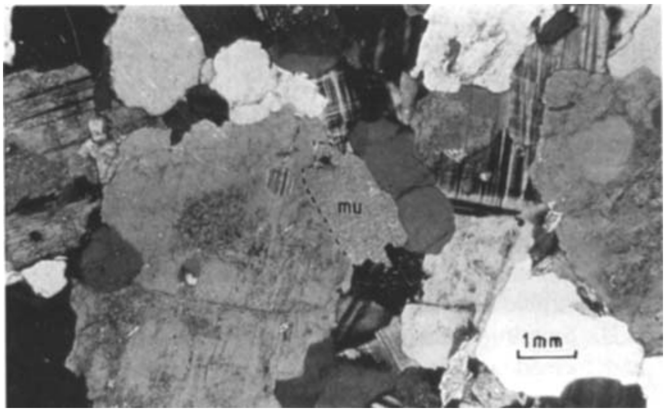

Fig. 3. Photomicrograph showing the textural nature of muscovite in the granite. The muscovite is shown with the symbol mu.

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granites containing tourmaline nodules, contacts between the leucocratic zones of the nodules and the host granite are diffuse as are the contacts between the melanocratic cores and the leucocratic rims.

Geochemistry

Major and trace element contents were measured by XRF techniques, using fused beads and pressed powder pellets on a Philips 1404 spectrometer at the University of Natal, Pietermaritzburg. In addition, two samples were analysed for the rare earth elements (REE) using an ICP method at Stellenbosch University. Representative analyses of 10 samples of the granite, Table I.

These data indicate that the major element chemistry of the granite does not vary significantly, having a mean normative (C.I.P.W.) composition of quartz (31%), orthoclase (29%), plagioclase (36%), corundum (1%), and hypersthene (1%). The normative plagioclase composition is An_{13} and the granites are iron-rich with an $\Sigma Fe/\Sigma Fe+Mg$ ratio of 0.85.

Trace elements show somewhat greater variation than the major elements, but these appear to be related mainly to different geographical locations. Thus samples from Brekkerista (BK, Table I) have lower contents of Th, Zr, Y, Nb and La compared to samples from Dvergen (DVG, Table I). Trace element discrimination diagrams have been used on samples of Phanerozoic granites in order to distinguish tectonic environment (Pearce *et al*, 1984), and it is assumed that these general models may also be applied here. The low Ce, Zr and Sm contents of these samples compared to orogenic granites is suggestive of a syncollisional environment; a plot of Rb versus Nb+Y also indicates the same environment (Fig.4).

Rare earth element (REE) values for samples BK59 and BK60 are given in Table I, and chondrite-normalized plots given in Fig. 5. It is evident from these data that the samples

Table I. Whole rock analyses of the Dalmatian Granite

	DVG2	BK56	BK57	BK58	BK59	BK6O	BK61	BK62	DVGD	BK4
SiO_2	74.63	74.35	74.84	74.95	74.47	75.02	74.31	74.41	74.63	73.98
Al_2O_3	14.08	14.40	14.10	14.64	14.17	13.77	14.98	14.50	13.65	14.79
Fe_2O_3	0.28	0.2	0.2	0.19	0.18	0.20	0.19	0.23	0.23	0.21
FeO	0.65	0.51	0.51	0.49	0.46	0.50	0.47	0.57	0.59	0.53
MnO	0.06	0.0	0.01	0.01	0.01	0.01	0.0	0.01	0.05	0.01
MgO	0.17	0.25	0.24	0.36	0.23	0.24	0.15	0.3	0.09	0.14
CaO	1.02	0.97	0.92	0.89	0.94	0.83	1.16	1.08	1.03	1.05
Na_2O	3.69	3.36	3.29	3.44	3.31	3.39	3.95	3.47	3.43	3.68
K_2O	5.74	5.22	5.22	5.29	5.05	5.23	5.07	5.47	5.32	4.94
TiO_2	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.13
P_2O_5	0.03	0.06	0.05	0.07	0.06	0.05	0.06	0.07	0.05	0.06
Total	100.43	99.41	99.47	100.42	98.97	99.33	100.43	100.20	99.15	99.52
Rb	184	207	222	220	200	201	180	200	231	212
Sr	236	224	217	185	190	187	209	220	244	209
Th	18.7	8.6	9.7	6.1	8.4	9.5	9.3	8.1	23	4.7
Zr	82	67	63	53	64	65	72	71	85	47
Y	7	3.8	4.4	4.9	3.7	4.4	4.1	4	4.8	2.6
Nb	7	5.9	6.2	7.1	4.8	6.8	4.6	4.8	12.9	4.6
Ba	1127	1203	1125	1001	1121	1129	925	1133	1097	1164
Sc	2.9	1.2	2	1.6	.8	2.1	2.4	ND	2.6	1.1
Zn	28	32	27	23	31	35	25	32	48	24
La				18.85	19.87					
Ce				29.95	31.12					
Pr				3.4	3.59					
Nd				11.98	12.81					
Sm				2.19	2.41					
Eu				0.7	0.74					
Gd				1.54	1.78					
Dy				0.94	1.2					
Ho				0.19	0.25					
Er				0.51	0.63					
Yb				0.45	0.59					

The REE analyses were conducted at Stellenbosch University by the ICP method of analysis. Fe_2O_3 contents are estimated after le Maitre (1976). ND=not detected. Detection limits for Th, Y, Nb and Sc are estimated at 0.5, 0.3, 0.1 and 0.3 ppm respectively and analytical accuracy for these elements are estimated at 20%, 3%, 3% and 10% respectively.

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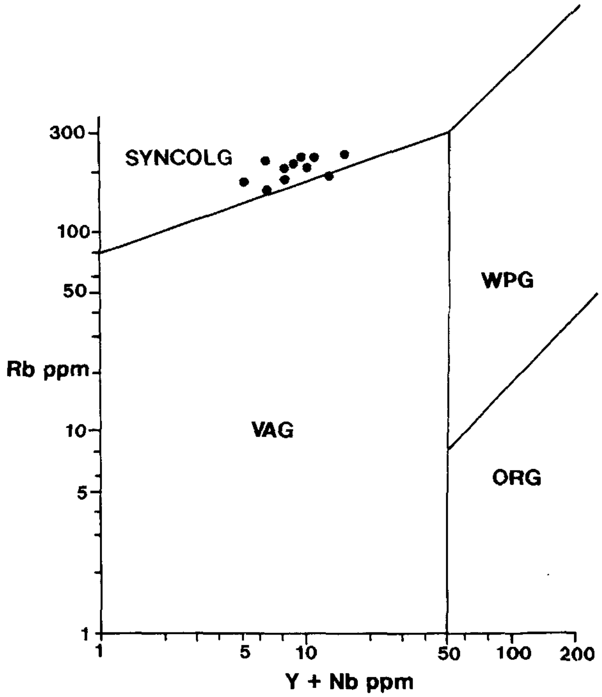

Fig. 4. Discrimination diagram (after Pearce *et al.* 1984) for the Dalmatian Granite.

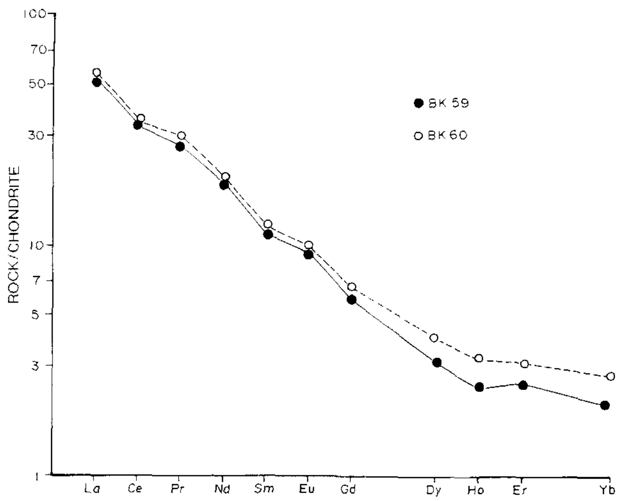

Fig. 5. Chondrite-normalized REE variation diagrams for two samples of Dalmatian Granite.

contain low overall total REE contents, a moderately steep overall slope (Ce_{cn}/Yb_{cn} ratios of 12.75 and 16.09), heavy REE with relatively flat patterns, and a small Eu enrichment (Eu^* values of 1.11 and 1.05 respectively).

The degree of Eu enrichment in these samples is small, but is not a common feature in granitic rocks and implies a derivation by partial melting rather than fractional crystallization processes. However, the ultimate source for such rocks is contentious. For example, Cullers & Graf (1984) suggested that the absence of Eu depletion and high Ce_{cn}/Yb_{cn} ratios indicated that garnet and/or amphibole was retained during partial melting without much feldspar, thus implying silicic granulites or eclogites as sources for these rocks. Conversely, Pride & Muecke (1980) suggested that these patterns may be due to partial melting of a plagioclase-rich restite or cumulate, and a similar suggestion of plagioclase-rich restite inclusions has been made by Chappel *et al.* (1987). With regard to this latter model, there is no petrographic data to support excess or xenocrystic plagioclase in the Dalmatian Granite. An alternative explanation for the near-compatible behaviour of Eu might be that the oxygen fugacity was sufficiently high to ensure that little or no Eu^{2+} was present in the melt, a condition that is partly verified by the presence of magnetite phenocrysts.

Rb-Sr isotopic data

Rb-Sr isotopic data for sixteen whole rock and ten mineral separate samples are given in Table II. Regression data were produced using the GEODATE programme (Eglington & Harmer, 1989), assuming errors of 1.0% for the $^{87}Rb/^{86}Sr$ ratio, 0.0001% (whole rock) and 0.001% (minerals) for the $^{87}Sr/^{86}Sr$ ratio, with a correlation coefficient of 0.0 for whole rocks and 0.99 for the mineral separates.

From Fig. 6 it can be seen that the whole rock samples scatter widely, but fall into two distinct geographical groups: those from Brekkerista (BK) and those from elsewhere (DVG, KK & SF). The Brekkerista samples scatter widely (MSWD = 79) about a line equivalent to 750 ± 428 Ma, with an initial $^{87}Sr/^{86}Sr$ ratio (hereafter R_0) of 0.7238. Clearly these data are too scattered for interpretation. However, the mineral separates from three of these samples yield more consistent data. For example, sample BK61 whole rock-biotite-feldspar give an isochron (MSWD = 0.3) of 470 ± 9 Ma, with an R_0 = 0.7354 (equivalent to an εSr = 444 where εSr represents the difference between the sample and bulk earth values at that time). Similarly, sample BK57 whole rock-biotite-feldspar scatter (MSWD = 6.5) about a line of 459 ± 12 Ma, with an R_0 = 0.7351 (εSr = 440), and sample BK56 whole rock-muscovite-biotite-feldspar scatter more widely (MSWD = 29) about a line of 457 ± 17 Ma, with an R_0 = 0.7349 (εSr = 437). The consistency of these ten data points allows them to be combined, resulting in a scatter (MSWD = 15) about a line of 461 ± 11 Ma (R_0 = 7353, εSr = 442); most of this scatter is due to three samples namely BK56 biotite and feldspar and BK57 feldspar which give lower whole rock-mineral ages of 438, 394 and 388 Ma respectively. Omission of these points results in a seven point isochron (MSWD = 1.5) of 469 ± 5 Ma, with an R_0 = 0.7353 and εSr = 443 (Fig. 6). The two chlorite separates from BK58 and BK59 give younger whole rock-mineral ages of 348 and 307 Ma respectively.

The whole rock data from the Kvitkjolen (KK series) scatter widely (MSWD = 35) about a line equivalent to

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Table II. Rb/Sr Isotopic data from the whole rock and mineral separates from the Dalmatian granite at Brekkerista

No.	Rb(ppm)	Sr(ppm)	$^{87/86}$Sr	±(2r)	At.^{87}Rb/^{86}Sr
BK4	198.4	233.2	0.75315	1	2.47
BK56	202.7	228.7	0.75236	1	2.58
musc	605.8	23.8	1.25983	5	77.7
biot	856.8	15.5	1.84937	7	178.3
feld	493.6	394.1	0.75831	5	3.64
BK57	223.7	214.5	0.75541	1	3.03
biot	924.9	24.1	1.52051	3	119.8
feld	428.1	340.1	0.75886	3	3.66
chlo	30.7	22.2	0.78549	3	3.97
BK58	219.5	192.2	0.75908	3	3.32
chlo	255.3	31.8	0.85960	10	23.3
BK59	214.1	196.4	0.75310	1	3.17
chlo	129.2	24.1	0.80823	3	15.7
BK60	202.2	191.7	0.75391	1	3.07
BK61	184.0	212.2	0.75235	1	2.52
biot	952.0	15.4	2.10210	14	203.3
feld	397.5	342.7	0.75792	5	3.37
BK62	199.2	235.4	0.75331	1	2.46
Lrim	172.6	187.0	0.75036	1	2.68
Melano	152.7	160.7	0.75078	1	2.76
KK5	208.9	249.0	0.73010	1	2.44
KK6	185.1	244.5	0.72718	15	2.19
KK7	202.8	389.4	0.72386	1	1.51
DVG-DAL	231.4	271.4	0.73173	1	2.48
DVG-2	182.3	273.4	0.72942	1	1.94
SF 869	145.1	921.6	0.71433	1	0.46

All concentrations and isotopic ratios measured by isotope dilution on a Micromass VG354 mass spectrometer. Duplicate analyses on spiked samples indicate a reproducibility of better than 0.002% on the Sr isotopic ratios. Standard SRM987 gave a mean value of 0.71023 ± 3 (33 analyses) during the course of this analytical work.

447 ± 95 Ma, with an R_o = 0.7140 (εSr = 140). The two samples from Dvergen (DVG samples) give an apparent age of 301±51 Ma, with R_o = 0.7211 (εSr = 238). Clearly these two sets of data cannot be interpreted implicitly, but do correspond to some degree with the ages obtained from the Brekkerista samples.

The preferred age of intrusion for these granitic sheets is taken here to be 469 ± 5 Ma, as defined by the Brekkerista samples. It should be noted, however, that although the Brekkerista and Kvitkjolen sheets appear to be of similar age, their R_o varies from 0.7353 to 0.7140, respectively.

Emplacement of the granite sheets.

At Salknappen sheets of tourmaline-free granite up to 2 m thick intrude the gneisses of the Sveabreen Formation, and are generally concordant with the gneissic layering. Numerous small reverse faults in the pelitic gneisses dipping to the NW were observed. These small faults displace the margin of the granite sheet but do not deform the granite. Thin veins of granite linking the sheets are oriented parallel to these reverse faults. At Kvitkjolen, similar undeformed sheets intrude gneisses, but where they intrude carbonates of the Fuglefjellet Formation, they are weakly folded and boudinaged. This indicates that the carbonates behaved less competently during deformation. Application of the strain analysis method of Talbot (1970) to the deformed veins in the carbonates indicates that the deformation causing folding and boudinage resulted from a weak flattening strain, since the Φ_{zy} and Φ_{zx} angles are 34° and 33° respectively (Fig. 7).

If it is assumed that this deformation is the same as that causing the reverse faulting, then the orientation of this flattening strain is Z plunging 30° toward 240°, Y plunging

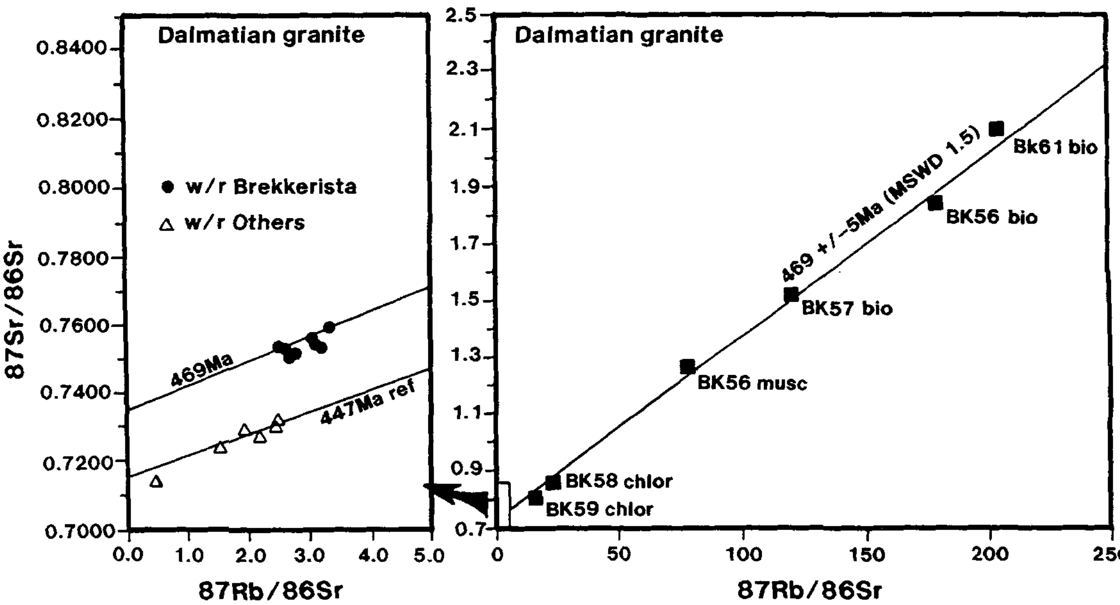

Fig. 6. Whole rock Rb/Sr isotopic data for all whole rock samples analysed (left) and mineral data (right) for samples BK56, BK61 and BK57 yielding a 7 point isochron (MSUM = 2.5) of 469 ± 5 Ma (R_o = 0.7353 and εSr = 443) as discussed in the text. The chlorite points (BK58 chlor and BK59 chlor) in this figure do not form part of the isochron.

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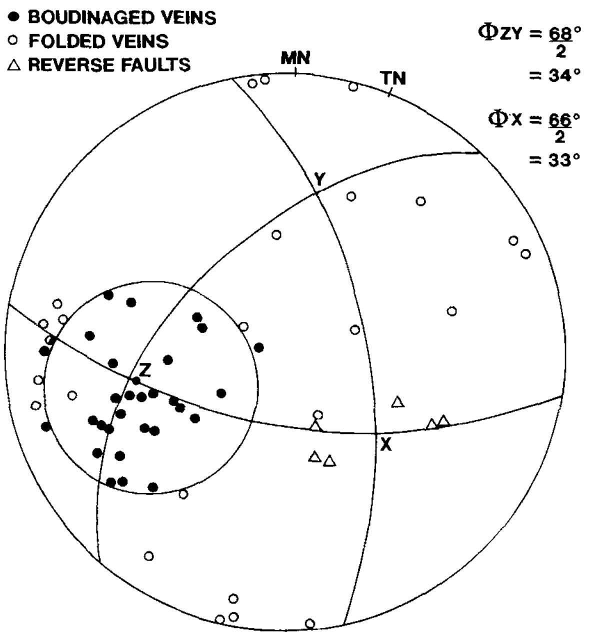

Fig. 7. Stereographic projection of folded and boudinaged veins of Dalmatian Granite intruded into the Dalmatian Granite.

28° toward 350° and X plunging 40° towards 110°. The method developed by Talbot (1970) uses poles to the orientations of the veins and thus Z plunging 30° toward 240° translates into extension approximately perpendicular to the E-dipping S_o, S_1 and S_2 planar structural elements. This extension thus permitted intrusion of the granite approximately parallel to these planar structural elements. An estimate of the increased thickening resulting from emplacement of these granitic sheets is approximately 10% at Robinheiea.

The orientations of the reverse faults at Salknappen are similar to the NW-dipping axial planes of D_3 folds at Jutulrora and Brekkerista, and which commonly have axial planar foliation defined by biotite. Most of the biotite from rocks in this part of the western Sverdrupfjella appears to be post D_{1-2}, since it transgresses S_{1-2} and or replaces mineral assemblages defining S_{1-2}. The thrust faults displacing the margins of the granitic sheets, the weakly developed folds and the boudins, and the tabular nature of the intrusions are interpreted here to indicate that the granites were emplaced syntectonically during D_3. The age of this event is taken to be approximately 460–480 Ma, as discussed in the preceding section.

Physico-chemical conditions of genesis.

Recent experimental work on the solubilities of Zr and P in granitic magmas has indicated that they are dependent on temperature and bulk composition of the magmas (Watson 1979, Watson & Harrison 1983). Comparison of the temperatures provided by Zr solubility with those obtained by opaque mineralogy thermometry have yielded similar values (Nash & Crecraft 1985), and Zr solubility temperatures are thus considered reliable (Ellison & Hess 1986, Bohlen & Lindsley 1987). However, interpretation of the temperatures provided by these thermometers is inherently reliant on the nature of zircon and apatite, since rocks which are not saturated with regard to either Zr or P will yield anomalously low values, and xenocrystic zircon or apatite will result in anomalously high values. Application of the saturation surface thermometers of Watson & Harrison (1983) and Harrison & Watson (1984) to granitic rocks assumes that the granites represent liquid compositions and that they have not undergone extensive fractional crystallization and therefore do not represent cumulate rocks. Application of the saturation surface thermometers of Watson & Harrison (1983) and Harrison & Watson (1984) to the granitic sheets studied here results in average temperatures of 704°C for Zr and 894°C for P. The disparity between the two systems is probably due to excess P, since the primary assemblage of muscovite and quartz would not be stable at these higher temperatures (see discussion below). Part of the apatite content of these granitic sheets is therefore possibly xenocrystic in origin.

The presence of primary muscovite + quartz is significant for barometry, as shown in Fig. 8. From this, it may be seen that muscovite + quartz (line 1, from Powell 1978) would be expected on the solidus (line 2, from Johannes 1985) and would be stable above the solidus at pressures exceeding 4kbar in the granite system (Qz-Ab-Or-H_2O). Further, in this system with the plagioclase of composition An_{20} (line 3, Johannes 1985), this assemblage would be stable at pressures in excess of 5.5 kbar. Pressures lower than this would be characterized by K-feldspar + sillimanite. It is noteworthy that comparison of the C.I.P.W. normative compositions of the granitic sheets with minimum-melt compositions derived from experimental work confirms the pressure estimate above and suggests pressures of generation of approximately 6 kbar (Fig. 9).

The samples analysed here have an average normative Ab/An ratio of 6.9 with normative quartz, plagioclase and orthoclase constituting an average of 96.3% of the normative minerals. From Fig. 9, it may also be concluded that the X_{H2O} in the magma approached unity, since lower values would result in a shift of the stability field of muscovite + quartz to lower temperatures (line 4, from Powell 1978), whereas the granite solidus is shifted to higher temperatures (line 5, from Johannes 1985). Thus the temperature of approximately 700°C suggested from the Zr thermometry is consistent with a water-saturated granite with plagioclase of composition An_{20} at approximately 6kbar. However, it should be noted that if $P_{load} = pH_2O$, then the granites cannot have ascended very far from their source, since crystallization would occur rapidly due to decreasing pressure. There is no visible evidence for local or large-scale melting at the various exposures of these granite sheets, thus implying that they must have risen only a short distance from source, probably assisted by syntectonic emplacement.

Discussion

During the Late Cambrian-Early Ordovician, Gondwana was subjected to a widespread tectonothermal event, although the timing, style and intensity of this event varied from region to region. This event has been called by a number of different terms, such as the Pan African (Africa), the Ross Orogeny (East Antarctica), the Pampa Orogeny (South America), the Delamerian Orogeny (Australia) and the Haupiri Disturbance (New Zealand)(see reviews in Miller 1983, Tankard *et al* 1982, and Cahen & Snelling, 1984). In East Antarctica, there appear to be significant differences between geographical areas with regard to the intensity of this event. For example, the term 'Ross Orogeny' has been applied to the Transantarctic Mountains where significant deformation is accompanied by a number of important intrusive granitoid suites (such as the Granite Harbour Intrusives, see Kreuzer *et al.* 1987). Elsewhere in East Antarctica (e.g. western Dronning Maud Land), this event is commonly manifested by a widespread mineral isotopic resetting, in addition to relatively minor intrusive phases (e.g. Dalmatian Grantite), implying a dominantly thermal event rather than a tectono-thermal one as seen in the Transantarctic Mountains. The intensity of this event in areas along the Pacific-Weddell sea margin of East Antarctica may be related to subduction processes (Elliot 1975) however, in western Dronning Maud Land the event appears unrelated to any such processes. In Dronning Maud Land an event of Pan African age has long been recognized, mainly from K-Ar data from whole-rock and mineral samples, but more recently from Rb-Sr work (see compilation of isotopic data in Stuiver & Braziunas 1985). It is apparent from these isotopic data that many mineral species, particularly biotite, were reset between 480–460 Ma, and that a large number of relatively minor intrusive phases (dolerite and granitoid dykes and veins) were also intruded at this time. However, a number of larger intrusions have recently yielded slightly older ages of 550–500 Ma, such as the Brattskarvet granitoid suite in the H.U. Sverdrupfjella (519 ± 17 Ma, Moyes & Barton, 1990) and charnockitic rocks in the Muhlig-Hoffmann Mountains (500 ± 25 Ma, Ohta & Tordbakken, 1989). It is not clear at present whether these intrusions represent equivalents of the Granite Harbour-type batholithic intrusions. The Dalmatian granite sheets studied were clearly intruded during the last recognized phase of the Pan African event, since the preferred age of intrusion of 469 Ma falls well within the 480–460 Ma reset age obtained from numerous mica samples in Dronning Maud Land. The granites have high R_o and εSr values compared to bulk earth values, and would suggest a crustal source. The deduced physical conditions of generation, approximately 700$^{\circ C}$, $pH_2O = P_{load}$ and 6kbar (see above), preclude significant movement of the

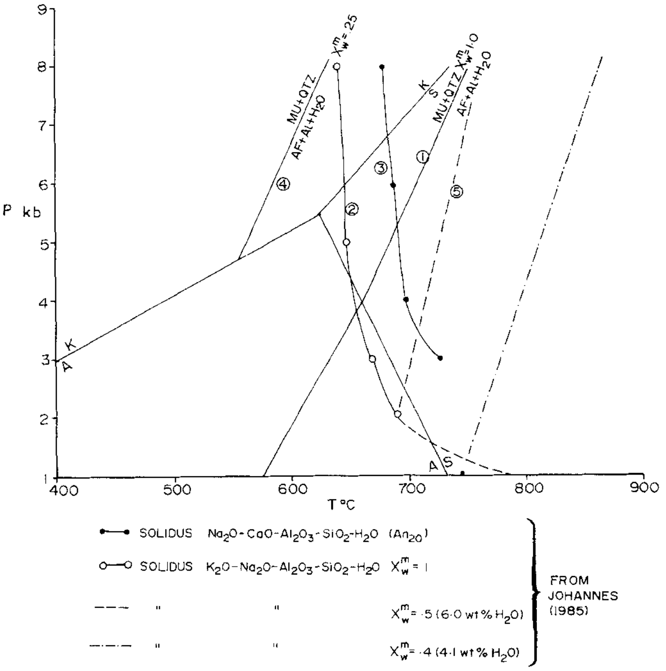

Fig. 8. Physico-chemical conditions pertaining to the petrogenesis of the Dalmatian Granite. The reference sources of the various curves are discussed in the text.

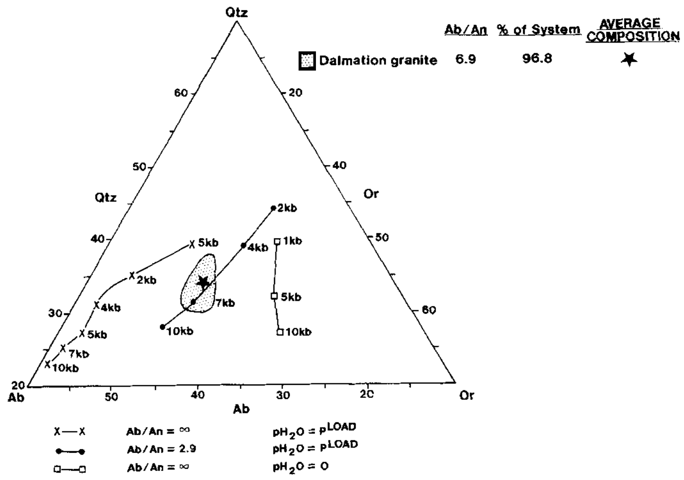

Fig. 9. The composition of Dalmatian Granite in comparison with minimum melt experiment compositions. Data for the various points are from Tuttle & Bowen (1958), Luth (1969), Winkler (1976, p.290).

granite since melting took place, again suggesting source rocks not too distant from the gneissic host rocks.

The younger ages of between 390–300 Ma obtained from chlorites from some of the samples analysed here are difficult to interpret implicitly, and may result from open system behaviour or may reflect lower closure temperatures. It is interesting to note, however, that ages of 380–300 Ma have

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been obtained from a suite of intrusive granitoids (the Admiralty Intrusives) in the Transantarctic Mountains (Elliot 1975, Kreuzer *et al.* 1987). These intrusions are thought to represent igneous activity during a Mid-Palaeozoic event termed the Borchgrevink Orogeny (Elliot 1975). Furthermore, an unconformity in the Kirwanveggan area of Dronning Maud Land has also been interpreted as having a similar age (Wolmarans & Kent 1982). Thus, the lower ages obtained here may correspond to either renewed thermal activity or uplift and cooling during an event younger than the Pan African.

In conclusion, the granite sheets studied here provide good constraints on the P-T-time conditions prevailing during a tectonothermal episode correlated with the Pan African event in this part of Dronning Maud Land. Aspects of the data may also reflect a somewhat younger event, although this is very contentious at present. How widely the data obtained here can be applied to other samples in the same area, and different areas, awaits further investigations.

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