are of bavenite occurrences from pegmatitic vugs within granitic rocks. Secondly, the material from Doi Mok occurs as remarkably large crystals, many times the size of those described previously. It is quite possible that other similar occurrences of bavenite may be found, as it is relatively easy on cursory examination to confuse the large crystals of bavenite with, for example, wollastonite. Furthermore, the reported association of bavenite with beryl and other beryllium minerals suggests that these may also occur at Doi Mok; however, they have not yet been recorded.

The origin of the bavenite at Doi Mok lies in the evidently extensive, possibly multistage, chemical exchange between the granite and the calcareous country rocks during the formation of the skarn. Some of this exchange may post-date the consolidation of both the biotite granite and the tourmaline leucogranite as both are altered in a complementary fashion. The chemical changes probably involve: addition of Ca to the granite (to give calcite, fluorite, sphene); addition of Be (at least) to the country rock (bavenite); and addition of F and W, along the contact zone in particular (fluorite, scheelite). This alteration may be related to the continued crystallization of granite magma, with exsolution of a hydrous fluid phase as the transporting agent, at deeper levels than those exposed in the vicinity of the mine, in addition to subsequent hydrothermal activity.

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REFERENCES

Claringbull, G. F. (1940) *Mineral. Mag.* **25**, 495–7.

Fleischer, M., and Switzer, G. (1953) *Am. Mineral.* **38**, 988–93.

Neumann, H., and Sverdrup, T. L. (1959) *Norsk. Geol. Tidsskr.* **39**, 339–42.

Raade, G. (1968) Ibid. **48**, 259.

Schaller, W. T., and Fairchild, J. G. (1932) *Am. Mineral.* **17**, 409–22.

Suensilpong, S., and Jungyusuk, N. (1981) Some aspects of scheelite-related granites. *J. Geol. Soc. Thailand* (in press).

Switzer, G., and Reichen, L. E. (1960) *Am. Mineral.* **45**, 757–62.

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Primary scapolite from the Forland complex of Prins Karls Forland, Svalbard

PRINS KARLS FORLAND, Svalbard, consists largely of pre-Carboniferous rocks forming the Forland complex (Harland *et al.*, 1979) which have been subjected to Caledonian (S_1) deformation and metamorphism. Detailed accounts of the stratigraphy, structure, and metamorphism of the Forland complex are given by Harland *et al.* (1979), Manby (1978), and Morris (1979). This paper describes for the first time the occurrence of scapolite in the Pinkie Group of the Forland complex. Based on textural and mineralogical evidence Manby (1978) and Morris (1979) show that metamorphism was initiated prior to, and continued with the main penetrative D_1 deformation. Metamorphism was of greenschist-facies grade and D_1 deformation produced a large scale SW-verging

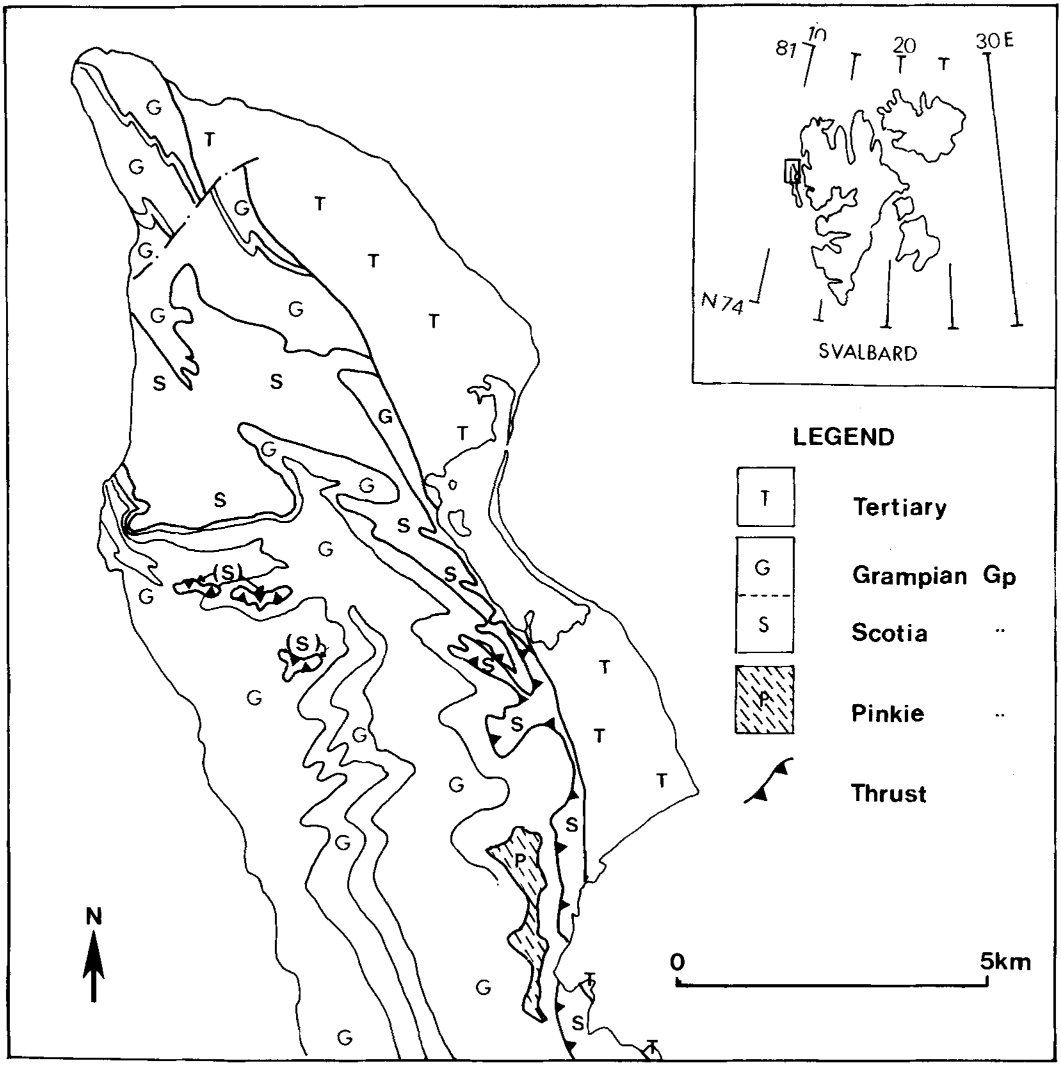

FIG. 1. Sketch geological map of northern Prins Karls Forland.

imbricate fold nappe. The penetrative axial planar foliation of the fold nappe dominates the fabric of these rocks, although bedding is always recognizable. A later D_2 deformation refolds and thrusts these rocks and has imposed a second (S_2) spaced foliation axial planar to the D_2-F_2 crenulation folds. The scapolite-bearing Pinkie Group occurs in a D_1 isocline refolded in a D_2 antiform on the eastern slopes of Vestlefingern.

The Pinkie Group consists of thinly bedded flyschoid pebble beds, sandstones, silts, and slates often with a high carbonate content. Occasionally interbedded dolomitic and calcitic limestone are found as are siliceous dolomites. Volcanogenic rocks and stratiform quartz-magnetite schist also occur. Mineral assemblages found in the Pinkie Group rocks include: scapolite + calcite and, or, dolomite + biotite ± quartz; scapolite + muscovite and, or, biotite + calcite and, or, dolomite + graphite; dolomite + calcite + quartz ± tremolite ± muscovite, all of which are found in the banded limestones and pelites; actinotite + chlorite + epidote ± calcite ± garnet + pyrite in basic volcanogenic rocks; and quartz + muscovite + albite ± biotite ± calcite + pyrite in flyschoid rocks.

Scapolites analyses obtained on the Cambridge

EDS microprobe are listed in Table I. The average composition of the scapolites in terms of the two end members meionite–marialite is *c.* 40% Me. Whilst most scapolites are both optically and chemically homogeneous occasionally porphyroblasts in the coarser grained limestones are zoned with Na enrichment from core to rim, Table II.

Apart from the zoned crystals, scapolites in the limestone beds are modally less abundant, although larger and usually more euhedral than those occurring in the pelitic layers. Porphyroblasts in the pelitic layers tend to be rounded or ragged and often contain inclusions of quartz and graphite. The inclusions usually have preferred orientation, preserving a curved relict foliation. The inclusions are not continuous with the external fabric which is the main D_1–S_1 fabric developed with the syntectonic crystallization of micas. The spaced S_2–D_2 foliation associated with the crenulation folds is a pressure solution type. D_2 deformation of scapolite is most apparent in the pelitic layers and is typically seen as endulose extinction, kink banding or boudinage. In both limestones and pelitic lithologies scapolite is commonly rimmed by micas. In the coarser grained limestones the micas are dominantly biotite which is occasionally chloritized and the limits of the rim minerals are clear. In the pelitic layers the rim minerals are more irregular and consist of a fine grained matrix of muscovite and quartz.

From the discordance of the internal and external fabrics of the scapolites of the pelitic layers it is clear that this mineral grew at an early stage of S_1 development. Scapolites in the Pinkie Group have not been found to replace feldspars and there is no evidence of contact metamorphism or any related hydrothermal or pneumatolytic activity. The restriction of scapolite to certain layers and lack of any porphyroblast overgrowing compositional boundaries would rule out any regional metasomatic origin and it is concluded that this is a primary regional metamorphic mineral. If Hietanen's (1967) division of metamorphic grade based on meionite contents of scapolites is applied to the Forland complex, then biotite–almandine facies conditions of metamorphism are indicated for rocks with *c.* 40% meionite. That the Pinkie Group rocks attained this grade would seem to be supported by the occurrence of tremolite in the siliceous carbonates and garnet in the basic volcanogenic rocks.

It is partly on the basis of this apparently higher grade of metamorphism that the Pinkie Group is separated from the Grampian Group which only records biotite-grade conditions (cf. Manby, 1978).

The occurrence of scapolite as a primary metamorphic mineral in the Forland complex metasediments is not unique. Similar occurrences of this type have been reported from Australia (White, 1959) and North America (Hietanen, 1967). The mechanism first outlined by von Englehardt (1961) is favoured for the occurrence of scapolite in these metasediments. Briefly, the process involves the entrapment of brines (connate water) in the sediments during compaction. The clay minerals with an excess positive valency charge block electrolytes such as NaCl, SO_3^{2-} and CO_2^{2-}. During diagenesis the CO_2^{2-} would in part form calcite and the SO_3 be reduced to S^{4-} combining with Fe^{2+} to give pyrite. The halite is presumed to crystallize as solutions become more saturated. Later metamorphism produced the marialite component by the reaction of halite with albite, the meionite component being produced from a reaction between calcite, clay minerals and quartz.

From the greater abundance of scapolite in the pelitic layers nucleation sites were clearly more numerous than in the limestones. Diffusion spheres on the other hand must have been larger in the limestones; the quartz mica rims around scapolites in pelitic layers represent Ca-depleted zones. The masses of inclusions in the ragged scapolites from pelitic layers reflect rapid growth engulfing unused matrix phases. The more euhedral relatively inclusion-free porphyroblasts in the limestones are a product of much slower growth allowing time for rational face development and expulsion of unwanted phases and components. Differences in growth rates are also implicit in the occurrence of zoned scapolites in the limestone layers. Scapolites in these layers probably grew more slowly because diffusion distances were greater, the zoned crystals record a progressive Na enrichment in the matrix and possibly a decrease in temperatures favouring the marialite component.

In summary, the scapolite in the metasediments is primary and not replacive after feldspar, its growth was partially syntectonic but ceased before the D_1–S_1 foliation was fully developed, and the meionite content indicates an upper greenschist facies of metamorphism.

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REFERENCES

Harland, W. B., Horsfield, W. E. T., Manby, G. M., and Morris, A. P. (1979) *Skr. Norsk Polarinst.* **167** (Symposium volume), 119–44.

TABLE I. Chemical analyses of Svalbard scapolites

Scapolite Analyses

	G3017A	G3017B	G3017C	G3017D	G3017E	G3017F	G3017G	G3020A	G3020B	G3020C
SiO_2	54.22	54.02	54.32	52.64	56.19	57.57	52.94	56.06	55.23	55.68
Al_2O_3	24.37	24.25	24.59	24.29	23.79	23.66	25.08	23.75	24.38	24.25
Cr_2O_3	-	-	-	-	-	-	-	0.18	-	-
FeO	-	-	-	0.74	-	-	-	-	-	-
CaO	9.92	10.81	10.69	10.80	8.49	8.84	11.90	8.53	10.63	9.49
Na_2O	8.05	7.90	7.30	7.15	8.72	8.47	7.15	8.31	7.82	8.31
K_2O	0.48	0.35	0.40	0.35	0.52	0.46	0.38	0.71	0.70	0.52
Total	97.05	97.33	97.40	95.37	97.70	96.99	97.45	97.54	97.76	98.27
				Formula ions basis of 24 oxygens						
Si	7.64	7.61	7.62	7.56	7.82	7.80	7.47	7.82	7.61	7.73
Al	4.05	4.03	4.08	4.11	3.91	3.92	4.17	3.91	4.03	3.97
Fe	-	-	-	0.02	-	-	-	-	-	-
Ca	1.50	1.63	1.61	1.66	1.27	1.33	1.80	1.27	1.60	1.41
Na	2.20	2.16	1.99	1.99	2.35	2.30	1.95	2.25	2.13	2.23
K	0.09	0.06	0.07	0.06	0.09	0.08	0.07	0.13	0.13	0.09
Total	15.48	15.49	15.37	15.40	15.44	15.43	15.46	15.40	15.50	15.45

Analyses of Zoned Scapolites

	Sc 4 (RIM)	Sc 5 (MID)	Sc 6 (CORE)	Sc 8 (CORE)	Sc 9 (RIM)	Sc 10 (RIM)	Sc 11 (RIM)	Sc 12 (CORE)	Sc 13 (RIM)	Sc 14
SiO_2	54.72	54.18	53.76	52.60	54.02	64.60	53.91	61.73	61.87	52.73
Al_2O_3	22.24	23.37	23.54	23.91	23.15	18.22	23.51	19.72	20.02	23.97
FeO	0.13	-	0.11	-	0.13	-	-	-	-	0.17
CaO	8.95	9.51	9.53	10.76	9.66	7.09	10.17	8.78	8.12	10.82
Na_2O	8.76	8.51	8.27	7.43	8.43	7.15	8.31	6.83	7.35	7.35
K_2O	0.53	0.55	0.53	0.64	0.53	0.55	0.38	0.29	0.38	0.58
Cl	2.57	2.43	2.27	1.93	2.29	2.08	2.52	1.86	2.08	1.99
Total	98.60	98.55	98.01	97.17	98.12	99.68	98.53	99.21	99.20	97.61
				Ions on basis of 24 oxygens						
Si	7.79	7.72	7.69	7.58	7.72	8.80	7.68	8.49	8.46	7.57
Al	3.85	3.92	3.97	4.06	3.90	2.92	3.95	3.20	3.23	4.06
Fe	0.02	-	0.01	-	0.02	-	-	-	-	0.02
Ca	1.37	1.45	1.46	1.66	1.48	1.03	1.55	1.29	1.89	1.67
Na	2.42	2.35	2.30	2.08	2.31	1.89	2.29	1.82	1.95	2.05
K	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.05	0.10	0.12
Cl	0.62	0.59	0.55	0.47	0.56	0.48	0.54	0.43	0.48	0.49
Total	16.17	16.13	16.07	15.95	16.08	15.21	16.08	15.28	15.37	15.96
Na	62.30	60.23	59.58	54.10	59.45	62.58	58.56	57.54	60.84	53.61
K	2.49	2.57	2.51	2.59	2.48	3.15	1.78	1.58	2.07	2.80
Ca	35.19	37.20	37.91	43.32	38.07	34.27	39.68	40.88	37.09	43.59

Hietanen, A. (1967) *Geol. Soc. Am. Special Paper* 86, 56 pp.
Manby, G. M. (1978) *Geology of North Central Prins Karls Forland, Svalbard.* Unpubl. Ph.D. thesis, Univ. Cambridge.
Morris, A. P. (1979) *Geology of South Central Prins Karls Forland, Svalbard.* Unpubl. Ph.D. thesis, Univ. Cambridge.
von Englehardt, W. (1961) *Bull. Geol. Inst. Univ. Uppsala,* **40,** 189-204.
White, A. J. R. (1959) *Geol. Mag.* **96,** 285-307.

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A new occurrence of dalyite

THE potassium (sodium) zirconium silicate dalyite has been discovered during an electron microprobe investigation of a potassic peralkaline syenite dyke from the Sunnfjord area of Western Norway. Dalyite was first discovered in a peralkaline granite from Ascension Island (Van Tassel, 1952) and was subsequently shown to be a new type of phyllosilicate containing four-, six-, and eight-membered rings of SiO_4 tetrahedra (Fleet, 1965). The mineral has also been recorded in peralkaline quartz syenites from Sáo Miguel, Azores (Cann, 1967).

The Sunnfjord syenite occurs as an inconspicuous E.-W. dyke, 10 cm wide, cutting brecciated mangerites on the north side of Dalsfjord, Sunnfjord, W. Norway. The medium-grained syenite resembles a sandstone and was described as such when first noticed and sampled by Professor N. H. Kolderup in 1921. The syenite consists largely of microcline and a Si-rich and Al-poor phlogopite together with small amounts of eckermannite, carbonate apatite, calcite, celadonite, saponite, and labuntsovite (Semenov and Burova, 1955) and accessory dalyite and baryte (Furnes, Mitchell, Robins, Ryan and Skjerlie, in prep.). The dyke has a K-Ar age of 260±2 Ma (Furnes *et al.*, op. cit.).

The presence of dalyite in the syenite has been confirmed in the X-ray diffraction pattern of a heavy-liquid separate (> 2.75 g/cc) (Table I). It occurs as colourless, transparent to brown, translucent grains often with subhedral to euhedral K-feldspar inclusions and commonly surrounded by phlogopite. It is strongly fluorescent under the electron beam, and in this respect resembles benitoite and wadeite (Carmichael, 1967).

TABLE I. *d-spacings and relative X-ray intensities for dalyite from Sunnfjord*

Dalyite, Ascension (Van Tassel, 1952)		Dalyite, Sunnfjord	
d	$I_{est.}$	*d*	$I_{est.}$
6.54	60	6.51	40
5.90	80	5.90	80
4.31	80	4.31	75
4.20	100	4.21	100
3.58	100	3.59	100
3.36	60	*	
3.08	100	3.08	100
2.85	60	*	
2.62	100	2.65	100
2.42	60	2.42	50

Cu-$K\alpha_1$ radiation, Phillips APD 10 system.
* = Masked by other minerals.

The single published analysis of dalyite (Van Tassel, 1952) showed it to have the formula $K_2Zr\,Si_6O_{15}$ with sodium and small amounts of Fe replacing part of the K (Table II). Electron microprobe analyses of the Sunnfjord dalyite were carried out on an ARL SEMQ housed at the Geological Institute of the University of Bergen using an accelerating voltage of 15 kV, a beam current of 7 nA, standard wavelength-dispersive techniques (Reed, 1975) and ZAF data reduction. The following synthetic oxides, pure metals and well-characterized or simple, stoichiometric minerals were employed as standards: jadeite (for Na); Al_2O_3; wollastonite (for Ca and Si); Beeson apatite (for P); PSU orthoclase (for K); TiO_2; pure Mn, Fe, and Zr; benitoite (for Ba). Individual point analyses of five crystals are reported in Table II. They show significant substitution of Ti for Zr,