Tourmalinites in supracrustal rocks in the Bjørnesund area, West Greenland

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In the mid-Archaean supracrustal rocks of Bjørnesund south of Fiskenæsset metre wide anthophyllite-rich zones are found hosted in mafic volcanics. These zones, which are locally associated with sulphides, are interpreted as alteration zones from hydrothermal solutions which circulated through the volcano-sedimentary pile; in places they contain thin tourmalinites. The tourmaline composition and geologic setting of the occurrences closely resemble stratabound tourmalinites of submarine hydrothermal origin which elsewhere are associated with metalliferous deposits. It is concluded that the presence of the Bjørnesund tourmalinites associated with anthophyllite zones indicates that hydrothermal processes were once active in the depositional environment where the Bjørnesund supracrustals were formed; in other regions such processes are known to have generated massive sulphide ore bodies.

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The recognition of tourmalinites of non-granitic pedigree occurring as stratabound layers in supracrustal sequences is a fairly recent discovery (Ethier & Campbell, 1977). Tourmalinite has tourmaline as a major component, together with silicates such as quartz, plagioclase and mica, locally anthophyllite and/or ore minerals such as pyrrhotite, chalcopyrite or scheelite. Stratabound tourmalinites are often spatially and genetically closely associated with stratabound massive sulphide deposits (Ethier & Campbell, 1977; Plimer, 1980, 1983a; Taylor & Slack, 1984). Tourmalinites are also found associated with, and interpreted as cogenetic with, stratabound tin deposits (Plimer, 1983b) as well as with stratabound tungsten mineralisation (Appel, 1986). It has been suggested that tourmalinites may be used as indicator rocks for such mineralisation (Plimer, 1983b; Taylor & Slack, 1984).

Stratabound tourmalinites have been shown to be of submarine exhalative origin and probably precipitated as tiny tourmaline crystals directly on or below the sea floor, in hydrothermally altered sediments or volcanics (Appel & Garde, 1987).

Geologic setting

The dominant rock types in the Fiskenæsset area are quartzo-feldspathic gneisses, which occupy well over two thirds of the area. The gneisses, which are derived from tonalites, granodiorites and granites yield radiometric ages of 2800 Ma (Myers, 1978; Kalsbeek & Pidgeon, 1980). Several supracrustal enclaves of varying composition and age occur within the gneisses. The Ravns Storø supracrustal rocks outcrop in the southernmost part of the area. A little further north the Bjørnesund supracrustal rocks outcrop in a long fairly narrow belt, which can be traced for about 40 km from the Inland Ice and along the southern shore of Bjørnesund towards the west. The age relationships between the two supracrustal belts are unknown. The present article deals with the westernmost extension of the Bjørnesund supracrustal rocks, outcropping on the northern shore of Bjørnesund (Fig. 1).

The supracrustal rocks are intruded by the Fiskenæsset complex, which is a chromite layered anorthosite with associated layered plutonic rocks (Myers, 1985). An age determination on molybdenite in anorthosite has yielded an intrusive age of 3080 ± 70 Ma (Herr *et al.*, 1967).

The gneisses, supracrustal rocks and the Fiskenæsset complex have been strongly deformed and metamorphosed. The greater part of the Fiskenæsset area has been affected by amphibolite facies metamorphism, but large areas were also subjected to granulite facies metamorphism. All rock types mentioned in this report are thus metamorphosed to varying degrees, although for simplicity, all rock names will be used without the prefix 'meta'.

After deformation the Fiskenæsset area was cut by

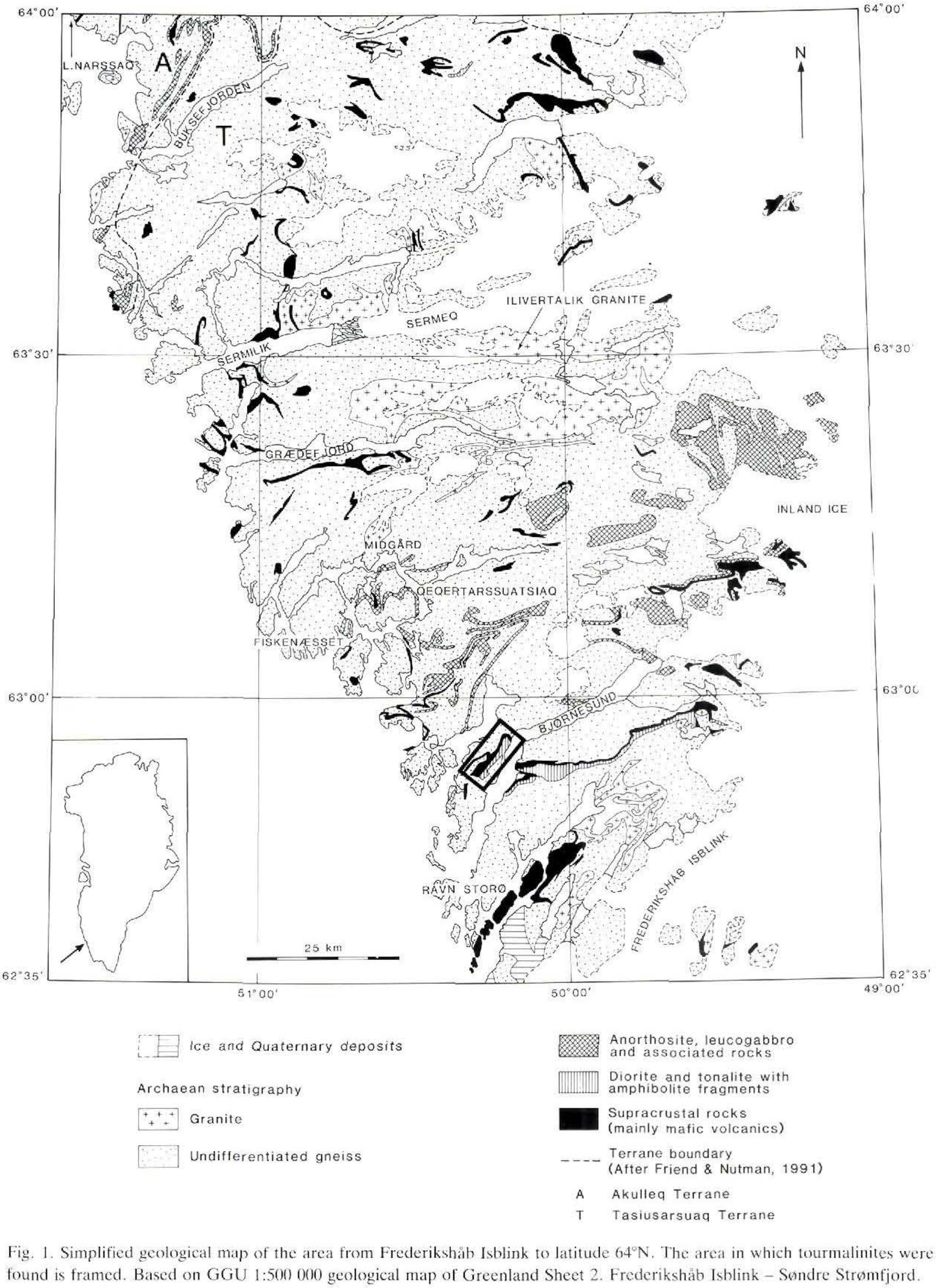

Fig. 1. Simplified geological map of the area from Frederikshåb Isblink to latitude 64°N. The area in which tourmalinites were found is framed. Based on GGU 1:500 000 geological map of Greenland Sheet 2. Frederikshåb Isblink – Søndre Strømfjord.

shear zones, some of which are associated with carbonate alteration, an alteration which mainly affected the supracrustal rocks. Preliminary investigation of some of these shear zones revealed up to 5.2 ppm gold in grab samples.

During the eighties GGU carried out regional stream sediment sampling in the Fiskenæsset area, and some gold anomalies were discovered in heavy mineral concentrates in the Bjørnesund area (Appel, 1989). In 1991 the Bjørnesund project was launched to follow up these anomalies (Appel, 1992). This follow up consisted partly in further stream sediment sampling, and partly in geological reconnaissance in the Ravns Storø and Bjørnesund supracrustals. The stream sediment sampling revealed gold anomalies in heavy mineral concentrates from streams draining these particular supracrustals (Erfurt *et al.*, 1992). The reconnaissance revealed the presence of hydrothermal alteration zones, of tourmalinites and of carbonate alteration zones.

Bjørnesund supracrustal rocks

The area dealt with in this article is the western extension of the Bjørnesund supracrustal belt on the north side of Bjørnesund (Fig. 1). The supracrustal belt, which is a few hundred metres wide, can be traced for several kilometres along strike, and consists of weakly to strongly deformed mafic pillow lavas and pillow breccias interlayered with acid volcanic horizons. Mafic agglomerates with felsic clasts are also found. A prominent feature of the area is a major rust zone which can be traced with intervals through most of the supracrustal enclave. The rust zone is a pyrrhotite-pyrite-rich quartz feldspar sillimanite mica rock with occasional anthophyllite-rich zones. It is up to several tens of metres wide. Channel and chip sampling has been carried out and the samples have been analysed for gold; the highest value found was 11 ppb over 0.75 m. In the amphibolites patches and thin zones mineralised with pyrite and/or pyrrhotite occur. A few of these were grab sampled and found to contain up to 176 ppb Au. Ultramafic sheets and lenses are frequently met within this supracrustal enclave particularly along the northern contact with the gneisses.

A sequence of anthophyllite-quartz-feldspar rocks tens of metres wide with varying amounts of sillimanite and biotite, and locally with up to 10% pale red garnet occurs adjacent to the prominent rust zone. The anthophyllite displays a well developed garben texture with a grain size up to several centimetres. Anthophyllite-rich rocks are also found as up to one metre wide stratabound zones in amphibolites.

In some of the anthophyllite-rich zones thin tourmalinites are found. Tourmaline often occurs as scattered grains in the anthophyllite rocks, but is locally found as up to one centimetre thick tourmalinite layers, where tourmaline makes up well over 25% of the rock. The tourmaline occur as black grains up to 0.5 cm in size with a preferred orientation parallel to the general fabric.

In thin section the tourmaline appears as euhedral to subhedral grains with a brownish green core exhibiting a sharp border to the surrounding bluish rim. Some of the brownish cores have slightly lighter greenish centres. The tourmalines are poikilitic with abundant inclusions of quartz.

A significant feature of the Bjørnesund supracrustal rocks is the abundance of quartz veins, which locally make up 5 to 10% by volume of the rocks. These occur in all sizes from millimetre wide veinlets to decimetre thick veins. There are several generations of quartz veins; these include a pre-deformation set of millimetre wide veinlets and a later post-deformation set of veins. The latter are mostly steeply dipping, parallel to the general orientation of the supracrustals. Another significant feature is the carbonate alteration in the area. Carbonates in hairline cracks are abundant and have locally replaced well over 25% of the supracrustal rocks. The carbonate veinlets are generally brownish, while locally malachite staining has been observed. Some of the carbonate alteration appears to be related to an obviously discordant major shear zone system which cuts both supracrustal rocks as well as gneisses, whereas other carbonate alteration appears to be of more local appearance. A few carbonate alteration zones were chip sampled; the highest grade found was 52 ppb gold over a width of 0.75 m.

Chemistry of tourmaline

Tourmalines from two samples (GGU 393846 & 393847) have been analysed with a Jeol Super 733 microprobe using the following standards: olivine, corundum, wollastonite and hematite at 15kV and 20 mA.

In sample 393846 five different tourmaline grains were analysed, and spot checks were made on several other tourmaline grains. The tourmaline grains did not show any marked difference in chemical composition from one grain to the next, neither were there any significant variations in composition within the grains. The analytical results are presented in Table 1, and an average composition in Fig. 2.

In sample 393847 detailed analyses of six strongly zoned tourmaline grains were carried out; the results are presented in Table 1, and an average in Fig. 2. The analyses show that the brownish cores of the tourmaline

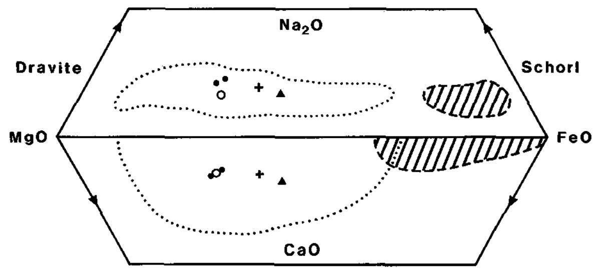

Fig. 2 Compositions of tourmaline from the Bjørnesund area (●), compared to average compositions of tourmalines from the Nuuk area. Key to symbols (all from Nuuk): (○) tourmalines from anthophyllite-cordierite-sillimanite-quartz rocks; (+) tourmalines from massive tourmaline-plagioclase tourmalinites; (▲) tourmalines from banded amphibolites. Data from Appel (1985, 1988) and Appel & Garde (1987). The hatched area shows the compositional field of granite related tourmalines. The area enclosed by the stippled line shows the compositional field of tourmalines of submarine exhalative origin. Data from Ethier & Campbell, 1977; Plimer, 1983a, b; Taylor & Slack, 1984; Henry & Guidotti, 1985).

grains are somewhat richer in TiO_2 than the rim. There is a slight tendency to lower Al_2O_3 contents in the core as compared with the rims, but the Al_2O_3 contents do fluctuate considerably through the grains. No significant differences in chemical composition were found between the different tourmaline grains in sample 393847.

The average composition of the Bjørnesund tourmalines is plotted in Fig. 2. Also shown are the compositional fields of tourmalines associated with granites (hatched area), as well as tourmalines of submarine exhalative origin (stippled area) (Ethier & Campbell, 1977; Plimer, 1983a,b; Taylor & Slack, 1984; Henry & Guidotti, 1985). The Bjørnesund tourmalines clearly fall well within the fields of tourmalines of submarine exhalative origin. Also plotted in Fig. 2 average compositions of tourmalines from tourmalinites in different supracrustal environments from the Nuuk area 150 km north of Fiskenæsset. It is evident that the chemistry of the Bjørnesund tourmalines corresponds closely to tourmalines hosted in anthophyllite-cordierite-quartz-sillimanite rocks of the Nuuk area, and the geologic setting of the two areas is also very similar.

Significance of tourmalinites

The tourmalinites in the Nuuk area have been interpreted as of submarine exhalative origin, where the boron was supplied by metalliferous brines and tourmaline was precipitated directly at the sea floor; alter-

Table 1. Average and range of microprobe analyses of tourmaline grains from supracrustal rocks in the Bjørnesund area

Grain	1		2		3		4		5		1	
GGU No.	393846		393846		393846		393846		393846		393847	
No. of analyses	(7)		(4)		(3)		(6)		(25)		(50)	
	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
SiO_2	35.40	34.76–35.88	35.23	34.89–35.58	35.32	35.02–35.51	35.47	35.02–35.86	35.58	34.96–35.94	35.75	34.59–37.99
TiO_2	0.42	0.23–0.57	0.60	0.49–0.65	0.32	0.13–0.49	0.57	0.39–0.72	0.50	0.18–0.75	0.36	0.01–0.82
Al_2O_3	33.71	33.05–34.56	32.97	32.52–33.78	33.08	32.88–33.41	33.56	32.84–34.77	33.77	33.20–34.80	33.46	32.08–34.56
Cr_2O_3	0.08	0.01–0.19	0.20	0.01–0.34	0.00		0.21	0.16–0.26	0.10	0.01–0.35	0.06	0.01–0.23
FeO	3.90	3.65–4.30	4.27	4.07–4.54	3.85	3.63–4.00	3.96	3.62–4.49	3.86	3.46–4.26	3.67	2.87–4.25
MnO	0.02	0.01–0.13	0.04	0.01–0.13	0.13	0.01–0.24	0.07	0.01–0.23	0.04	0.01–0.20	0.04	0.01–0.24
MgO	8.53	8.32–8.70	8.77	8.51–8.92	8.87	8.74–9.04	8.42	8.23–8.64	8.27	7.96–9.20	8.75	7.86–9.43
CaO	1.16	0.71–2.19	1.47	1.37–1.64	1.25	1.04–1.40	0.97	0.84–1.29	1.13	0.67–1.44	1.59	0.92–2.83
K_2O	0.00		0.00		0.00		0.00		0.00		0.00	
Na_2O	2.06	1.93–2.21	1.93	1.82–2.14	1.97	1.82–2.10	2.11	1.95–2.22	2.12	1.90–2.22	1.91	1.62–2.29
	85.28		85.48		84.79		85.34		85.37		85.59	

natively the boron may have been scavenged by clay minerals and tourmaline subsequently formed during diagenesis and metamorphism (Appel, 1988). It is reasonable to assume similar explanations for the Bjørnesund tourmalinites.

Some of the tourmalinites in the Nuuk area are spatially and genetically associated with stratabound scheelite mineralisation. Other Nuuk tourmalinites are associated with anthophyllite-rich rocks (Appel, 1988), some of which in the Nuuk area contain up to 0.51% copper and 1.1% zinc and carry up to 20 ppm silver, 0.12% tin and 0.19% molybdenum. The anthophyllite-rich zones probably represent hydrothermal alteration zones which are often associated with massive sulphide deposits (Beeson, 1988).

The presence of anthophyllite-rich zones and tourmalinites in the Bjørnesund supracrustal rocks may be taken as an indication that extensive hydrothermal activity took place within and above the volcano-sedimentary pile. It can thus be concluded that processes, which elsewhere led to the formation of ore bodies such as massive copper-zinc sulphides, were also active when the Bjørnesund supracrustal rocks were formed.

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References

Appel, P. W. U. 1985: Strata-bound tourmaline in the Archaean Malene supracrustals, West Greenland. *Can. J. Earth Sci.* **22**, 1485–1491.

Appel, P. W. U. 1986: Strata bound scheelite in Archaean Malene supracrustal belt, West Greenland. *Miner. Deposita* **21**, 207–215.

Appel, P. W. U. 1988: Stratiform tourmalinites in the Archaean tungsten province of West Greenland. *Miner. Petrol.* **39**, 79–91.

Appel, P. W. U. 1989: Investigations of heavy mineral concentrates from stream sediment samples collected during the period 1982 to 1986 in the Nuuk area, West Greenland. *Open File Ser. Grønlands geol. Unders.* **89/1**, 17 pp.

Appel, P. W. U. 1992: Bjørnesund Project – 1991, West Greenland. *Rapp. Grønlands geol. Unders.* **155**, 24–27.

Appel, P. W. U. & Garde, A. A. 1987: Stratabound scheelite and stratiform tourmalinites in the Archaean Malene supracrustal rocks, southern West Greenland. *Bull. Grønlands geol. Unders.* **156**, 26 pp.

Table 1 cont. Average and range of microprobe analyses of tourmaline grains from supracrustal rocks in the Bjørnesund area

2		3		4		5		6			Grain
393847		393847		393847		393847		393847		Nuuk*	GGU No.
(50)		(50)		(50)		(50)		(50)		(55)	No. of
Average	Range	Average	Range	Average	Range	Average	Range	Average	Range		analyses
35.67	34.44–36.20	35.33	33.84–36.27	35.50	34.25–36.45	35.57	34.96–36.11	35.48	34.61–36.50	34.08	SiO_2
0.34	0.01–0.92	0.31	0.01–0.72	0.25	0.01–0.72	0.26	0.01–0.67	0.35	0.01–0.72	0.74	TiO_2
33.71	31.88–34.45	33.60	37.97–34.69	33.81	32.73–35.28	34.02	33.14–35.13	33.68	32.23–34.73	31.30	Al_2O_3
0.03	0.01–0.21	0.05	0.01–0.26	0.01	0.01–0.14	0.03	0.01–0.21	0.04	0.01–0.23		Cr_2O_3
3.73	3.07–4.37	3.60	3.03–4.23	3.57	2.85–4.55	3.58	2.98–4.36	3.78	2.96–4.50	4.19	FeO
0.03	0.01–0.16	0.05	0.01–0.24	0.04	0.01–0.26	0.03	0.01–0.22	0.03	0.01–0.26		MnO
8.87	8.24–11.37	8.72	7.68–9.63	8.72	7.84–9.24	8.65	7.78–9.26	8.89	8.37–9.37	8.73	MgO
1.34	1.04–3.37	1.26	0.64–2.39	1.23	0.66–1.94	1.22	0.64–1.68	1.39	1.01–1.76	1.69	CaO
0.00		0.00		0.00		0.00		0.00			K_2O
1.92	1.59–2.19	1.99	1.83–2.21	1.95	1.56–2.16	1.98	1.66–2.35	1.90	1.70–2.14	1.73	Na_2O
85.64		84.91		85.08		85.34		85.54		82.46	

ppel & Garde (1987).

Beeson, R. 1988: Identification of cordierite-anthophyllite rock types associated with sulphide deposits of copper, lead and zinc. *Trans. Inst. Min. Metall. (Sect. B: Appl. Earth Sci.)* **97**, B108–B115.

Erfurth, P., Appel, P. W. U. & Lind, M. 1992: Geochemical investigation of heavy mineral concentrates from stream sediments in southern West Greenland, 62° 30′N to 64° 00′N – 1991 results. *Open File Ser. Grønlands geol. Unders.* **92/1**, 39 pp.

Ethier, V. G. & Campbell, F. A. 1977: Tourmaline concentrations in Proterozoic sediments of the southern Cordillera of Canada and their economic significance. *Can. J. Earth Sci.* **14**, 2348–2363.

Friend, C. R. L. & Nutman, A. P. 1991: Refolded nappes formed during late Archaean terrane assembly, Godthåbsfjord, southern West Greenland. *J. geol. Soc. Lond.* **148**, 507–519.

Henry, D. J. & Guidotti, C. V. 1985: Tourmaline as a petrogenic indicator mineral: an example from the staurolite-grade metapelites from NW Maine. *Am. Miner.* **70**, 1–15.

Herr, W., Wölfle, R., Eberhardt, P. & Kopp, E. 1967: Development and recent applications of the Re/Os dating method. *In: Radioactive dating and methods of low-level counting,* 499–508. Vienna: Int. Atomic Energy Agency.

Kalsbeek, F. & Pidgeon, R. T. 1980: The geological significance of Rb-Sr whole rock isochrons of polymetamorphic Archaean gneisses, Fiskenæsset area, southern West Greenland. *Earth Planet. Sci. Lett.* **50**, 225–237.

Myers, J. S. 1978: Formation of banded gneisses by deformation of igneous rocks. *Precambrian Res.* **6**, 43–64.

Myers, J. S. 1985: Stratigraphy and structure of the Fiskenæsset Complex, southern West Greenland. *Bull. Grønlands geol. Unders.* **150**, 72 pp.

Plimer, I. R. 1980: Exhalative Sn and W deposits associated with mafic volcanism as precursors to Sn and W deposits associated with granites. *Miner. Deposita* **15**, 275–289.

Plimer, I. R. 1983a: The association of tourmaline-bearing rocks with mineralisation at Broken Hill, N. S. W. *Proc. Ann. Aust. Inst. Metall. Conf. Broken Hill* **1983**, 157–176.

Plimer, I. R. 1983b: The geology of tin and tungsten deposits. Course handbook, 212 pp. Mining Univ. Leoben, Austria.

Taylor, B. E. & Slack, J. F. 1984: Tourmalines from Appalachian–Caledonian massive sulphide deposits: textural, chemical, and isotopic relationships. *Econ. Geol.* **79**, 1703–1726.