

shows, taken with the new discovery of crystals T1 and T3, the gap between the only calcic amphiboles previously known and the original winchite analysis is almost bridged and leads to the reasonable supposition that the crystal studied by Fermor was essentially correctly analysed. This accords with his careful description (Fermor, 1904, 1906, 1909) of the procedures of separation. The original winchite was described as violet in colour but our sample is virtually colourless.

The amphiboles at Kajlidongri are extremely complex, ranging from Ti-rich to Ti-poor, from Mn-rich to Mn-poor, from magnesio-arfvedsonite to magnesio-riebeckite; there is winchite and tremolite. Nevertheless there still appears to be a significant gap in composition between the alkali amphiboles and the calcic to just sodic-calcic specimens of winchite (fig. 1). Even the original winchite was not close to the theoretical end-member formula. All the evidence suggests a miscibility gap in the sodic-calcic amphibole field, so that a complete series of solid solutions from

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*Department of Geology,
University of Glasgow,
Glasgow G12 8QQ, Scotland*

*Centre of Advanced Study in Geology,
University of Saugar, PO Saugar,
(MP) 470-003, India*

calcic to alkali amphiboles was not stable. The precise control on this gap remains to be elucidated.

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B. E. LEAKE
C. M. FARROW
F. CHAO
V. K. NAYAK

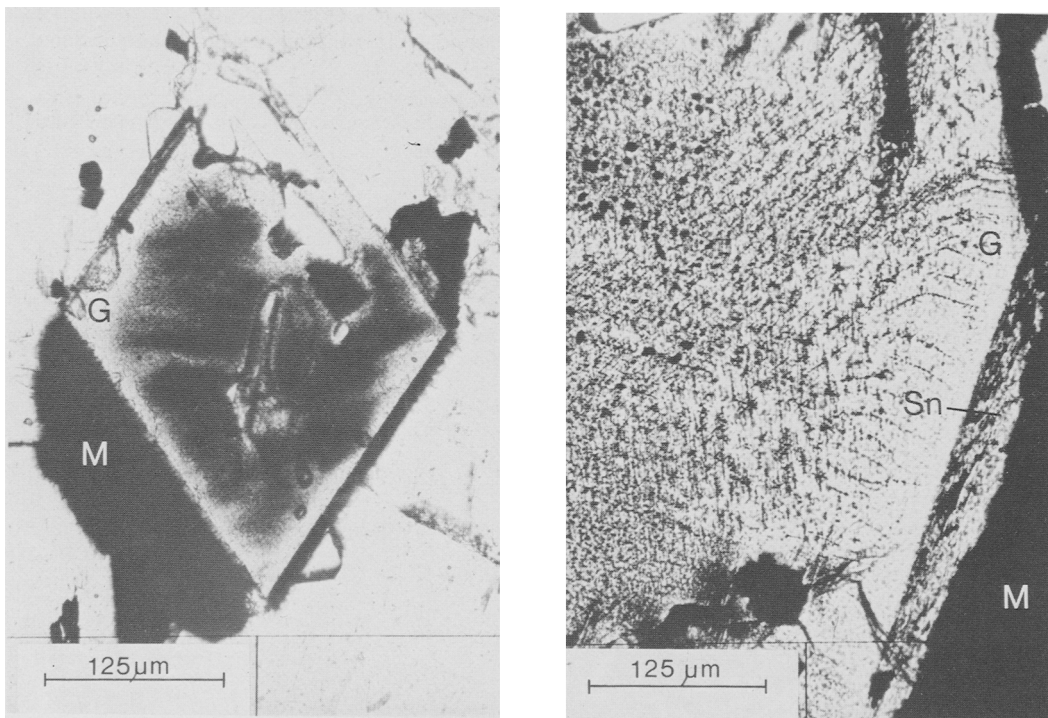
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Gahnite in an Archaean iron-formation, West Greenland

THE zinc spinel gahnite has been discovered in an iron-formation in the Archaean Malene supracrustal belt of West Greenland. The supracrustals, which are c.3000 Ma old and form extensive outcrops in the Godthåb area of West Greenland, consist of layered and massive amphibolites together with Mg-rich metasediments and calc-silicate horizons. The supracrustals have suffered several phases of deformation and been metamorphosed under amphibolite facies conditions. The iron-formation forms layers up to 2 m wide which can be traced with intervals for up to a few hundred metres along the strike, interlayered in quartz-cordierite-rich metasediments which are locally tourmaline-bearing. The iron-formation

consists of magnetite-rich layers alternating with layers composed mainly of anthophyllite-gedrite. In the magnetite-rich layers the magnetite is accompanied by grunerite, pyrite, pyrrhotite, chalcopyrite, molybdenite, and gahnite, locally with very small amounts of biotite, hornblende, ilmenite, and rutile. In the anthophyllite-gedrite layers small amounts of pyrite, pyrrhotite, chalcopyrite, molybdenite, ilmenite, and gahnite occur. The Malene metasediments are thought to represent Mg-rich clays comparable with modern deep-sea sediments (Beech and Chadwick, 1980). The iron-formation is interpreted as a chemical precipitate of submarine exhalative origin (Appel, 1983).

The gahnite, which in some thin layers within the



FIGS. 1 and 2. FIG. 1 (left). Magnetite 'dust' in euhedral gahnite (G) crystal. Black is magnetite. Plane polarized light. Geological Survey of Greenland (GGU) No. 293582. FIG. 2 (right). Sn-Ti-bearing rim (Sn) on the border between gahnite (G) and magnetite (M). Plane polarized light. GGU No. 293584.

iron-formation amounts to as much as 10%, is black to dark green in hand specimen. In thin section it is bright, grass green, sub- to euhedral in crystals up to 5 mm in size with inclusions of silicates, magnetite, and sulphides of iron and copper. Many gahnites have a 'dusty' appearance due to numerous tiny inclusions of magnetite (fig. 1) and most have a 0.1 to 0.5 mm wide rim or corona where they border magnetite (fig. 2). This rim, which contains abundant inclusions of magnetite, is slightly brownish and anisotropic in thin section. The corona is never present where gahnite grains border silicates. The gahnite corona microscopically resembles the högbomite described by McKie (1962) and the nigerite described by Bannister *et al.* (1947) and by Jacobson and Webb (1947).

Thirty-three gahnite analyses and thirteen analyses of gahnite coronas have been carried out on a microprobe, with a Norwegian gahnite as standard, and the results are shown in Table I. The gahnite grains from different layers do not vary in composition, and are thus grouped together in the table. The brownish anisotropic corona on gahnite contains significant amounts of tin and titanium

replacing zinc. The chemical composition of the gahnite yields the following structural formula, $(Zn_{0.60}Fe_{0.26}Mg_{0.14})Al_2O_4$.

X-ray determination of a gahnite gave the unit cell dimensions of $8.101 \pm 0.001 \text{ \AA}$, which is in close agreement with gahnites from Bleikvassli, Norway (Vokes, 1962). X-ray determination and chemical composition of the brownish anisotropic corona on the gahnite grains showed that the corona is neither nigerite nor högbomite.

The chemical composition of the Malene gahnites compare fairly well with gahnites associated with stratabound sulphide ore deposits (Geijer, 1917, 1965; Vokes, 1962; Plimer, 1977; Atkin, 1978; Dietworst, 1980). The Malene gahnites, however, appear to be consistently higher in MgO than other gahnites.

Different modes of formation of gahnite have been proposed. Plimer (1977), Wall and England (1979), and Williams (1983) suggested that gahnite was formed by desulphidation of sphalerite. Atkin (1978) and Stoddard (1979) suggested that zinc spinels were formed by breakdown of staurolite, whereas Dietworst (1980) suggest that breakdown

TABLE I. Microprobe analyses of gahnites and Sn-Ti-bearing gahnite coronas from the Malene supracrustals. All iron as FeO.

	Malene gahnite 33 anal.		Malene gahnite rim 13 anal.	
	Average	Range	Average	Range
Al ₂ O ₃	58.18	57.37- 59.40	58.39	57.12- 59.24
FeO	10.50	9.37- 11.23	10.51	9.76- 10.99
ZnO	27.71	27.05- 28.88	25.06	23.31- 26.70
MnO	0.08	0.00- 0.25	0.05	0.00- 0.16
MgO	3.30	3.11- 4.10	3.53	3.40- 3.74
TiO ₂	0.00		0.36	0.12- 0.52
SnO	0.00		1.88	0.66- 2.88
Total	99.77		99.78	

of biotite could form gahnite. Sandhaus in Craig (1983) found no correlation between sphalerite and gahnite and attributed gahnite to metamorphism of zinc oxides. In the Malene iron-formation staurolite is absent and there is no correlation between gahnite and biotite. It is thus not likely that gahnite formed by breakdown of these silicates. So far sphalerite has not been found in the Malene iron-formation, so an origin of the gahnite by desulphidation of sphalerite seems unlikely.

The depositional environment of iron-formations is characterized by rather low pH and low redox potential (Eh), conditions which do not favour precipitation of zinc oxide. A more likely explanation of the gahnite formation is that zinc ions from submarine exhalations were scavenged by the Mg-rich clays contemporaneously with the chemical precipitation of iron compounds. During subsequent diagenesis and metamorphism the Mg-rich clay minerals reacted with the iron compounds to form anthophyllite-gedrite, and with the zinc to form gahnite. At the highest metamorphic grades the gahnite incorporated substantial amounts of magnetite, thus forming a solid solution of the two spinels. During declining metamorphic conditions

the two spinels became immiscible as a result of which the minor component, magnetite, was exsolved as tiny grains along the cleavage planes of the gahnite.

The formation of the Sn-Ti-bearing corona along borders between gahnite and magnetite is puzzling. It indicates that the Sn and Ti were originally contained in the magnetite and that, sometime during metamorphism, the magnetite reacted with gahnite to form the Sn-Ti-bearing phase. The first formed Sn-Ti phase contained high amounts of magnetite, which was exsolved during declining metamorphic conditions and which later started to replace the gahnite corona (fig. 2).

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Geological Survey of Greenland,
Øster Voldgade 10, DK 1350,
Copenhagen, Denmark

PETER W. UITTERDIJK APPEL