Cr mica from the Precambrian Erris Complex, NW Mayo, Ireland

MICHAEL D. MAX

Geological Survey of Ireland, 14 Hume Street, Dublin 2, Ireland

P. J. TRELOAR

Department of Geology, University of Zimbabwe, Harare, Zimbabwe

J. A. WINCHESTER

Department of Geology, University of Keele, Keele, Staffordshire ST5 5BG

AND

M. J. OPPENHEIM

c/o Geological Survey of Ireland, 14 Hume Street, Dublin 2, Ireland

ABSTRACT. Cr micas identified as chrome phengites occur in association with other Cr-rich minerals in a peculiar schist which lies along a complex shear zone within the pre-Caledonian Erris Complex. The schist generally has a chaotic internal structure but locally there is a crude planar mineralogical zoning with a serpentine-bearing zone structurally above a Cr mica zone. Chemical analyses indicate that the schist is a tectonic derivative of a mixture of rock with a pronounced metasomatic character.

A ZONE of complex tectonic imbrication of the Annagh Division (Annagh Gneiss) and the Inishkea Division (schists) of the Precambrian Erris Complex occurs in the Scotchport shear zone along the north side of Scotchport Bay, NW Co. Mayo (fig. 1). The Annagh Division (Max and Long, in press) is composed predominantly of a series of ortho-gneisses and a major Grenvillian event in them has been dated at about 1000 Ma (van Breemen et al., 1978; Max and Sonet, 1979), but preliminary U-Pb dating of zircons suggests that the oldest tectono-thermal events are at least as old as c. 2000 Ma (Max and Aftalion, in prep.). The Inishkea Division is dominantly paragneiss, which has been thoroughly deformed but still contains recogniz-able sedimentary features at several places which are characteristic of greywackes. Elsewhere the rock is a striped and banded semipelitic schist with a mylonitic character. An imprecise Rb-Sr whole-rock regression line suggests a major Rb-Sr equili-bration event at about 800 Ma, which indicates that the rocks and their thermal history are too old to be

considered as part of the Caledonian cycle (Read, 1961; Harris and Pitcher, 1975). The major litho-logical units are described by Sutton and Max (1969), Max (1970), Sutton (1972), Crow et al. (1971), Crow and Max (1975), and Max and Long (in press). Sutton and Max (1969) described the north side of Scotchport Bay and recognized the Cr mica but subsequent detailed mapping and geochemical work has distinguished the schist as a distinct lithology. NE-SW sinistral wrench faulting is commonly seen in the area, and a NW-SE fault probably passes through Scotch-port Bay.

Geological position of the Cr mica

Two zones of Annagh Division gneisses are separated by a septum of Inishkea Division schists on the north side of Scotchport Bay. It could be that there are two separate slices of Annagh Division gneiss, although folding of a single slice is also possible (fig. 1d). In detail (fig. 1a, b) contacts are clearly cross-cutting with the eastern termination of the banded Annagh Division sliver sheathed in a fold of Inishkea schists (Scotchport Schist of Sutton and Max, 1969) while to the northwest banding in the Annagh Division slice is abruptly truncated both against the lower contact, which shows shear-ing only within 1-2 cm of the contact and the upper contact where there is near parallelism of banding with a marginal strongly foliated zone. The band-ing seen in the lower part of the slice is rotated into
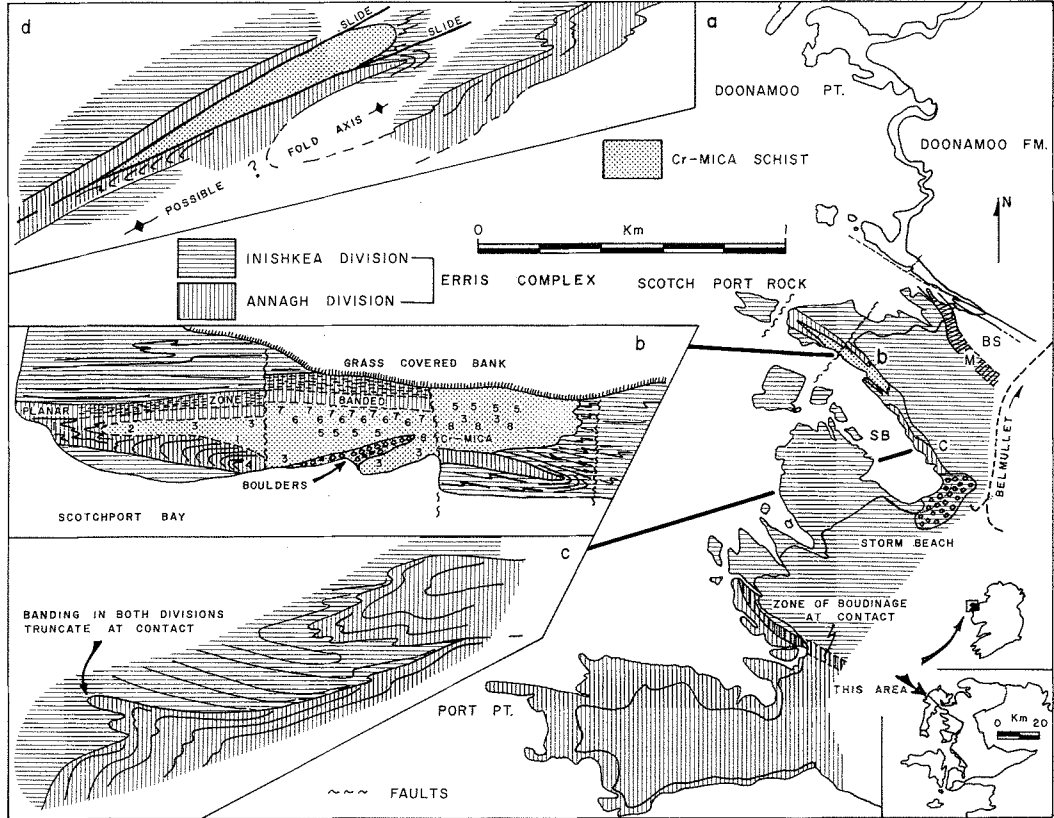
FIG. 1. (*a*) Detailed map of the geology around Scotchport Bay (SB). Road (dashed line). Full coastal exposures with isolated exposures away from coast. All dips are moderate to the northeast; strike is about parallel to contacts. M indicates recrystallized mylonites of the Inishkea Division at the contact with the overlying Caledonian supra-crystals. Sediments of the Caledonian supra-crystals are: BS (basal schists, 2 zones); Doonamoo Fm. (dominantly psammites). (*b, c*) Diagrams showing structural relationships and distribution of lithologies. Not to exact scale. View to NE down dip. 1, highly angular truncating of refolded banding in Annagh Gneiss; 2, complex, possibly repeated folding; 3, folding of weak foliation; 4, refolded fold; 5, imbricated foliation; 6, sheeted appearance; 7, garbenschiefer in schist; 8, serpentine common in elongated clots. Heavy lines show banding and striping in the Annagh and Inishkea Divisions. Planar zone contains banded platy quartzo-feldspathic bands and schists. (*d*) Structural diagram showing an interpretation of the restored position prior to faulting. Note the schist is largely slide bounded.

the more highly sheared upper contact in the NW end of the exposures. Pargasitic amphibole garbenschiefer in the strongly foliated upper contact zone are characteristic of the upper part of the Annagh slice and probably reflect recrystallization of basic and ultrabasic rocks.

Lying within this bifurcated Annagh Division slice is a discrete body of coarse grained schist which is unique in the pre-Caledonian Erris Complex. The schist contains the mineral assemblage: talc, serpentine, sillimanite (late), kyanite, garnet, zoisite, chromian mica, plagioclase, microcline, rutile, biotite, muscovite, and quartz. Banding in the Annagh and Inishkea Division rocks is truncated abruptly against this schist and there is little

evidence apparent for important shearing in the schist (fig. 1*b, c*). Although there is little internal structure, there is a crude mineralogical zoning with the Cr mica occurring only in the lower east–central area beneath a talc-serpentine rich zone, but the zonation is impersistent (fig. 1*b*). Immediately above the serpentine-rich zone area is apparent imbrication in a schuppen horizon. The central part of the northern contact is not as sharp for although the groundmass micas of the schist give way to what appears to be largely sheared Annagh Division rocks in a banded transition, the large amphiboles, which are common in the Annagh garbenschiefer, are found up to 40 cm into the schist.

A reconstruction (fig. 1*d*) indicates that the Annagh Division here could be represented by two discrete slices which may be in contact in the northwest and bifurcate toward the southeast. Alternatively, a single bifurcated slice may simply show greater local rotation of banding with shearing, and by inference the more important tectonic dislocation would lie along the structural top. In either case this pod of schist, which occupies the zone of bifurcation, contains no preserved structures or mineral textures which would give a clue as to the nature of the parent rock. The mineralogy with broad mineral segregation is characteristic of metamorphic partitioning.

Rock chemistry

Table I shows the chemistry of three samples of the Cr-mica-bearing schists, and for comparison mean compositions of adjacent basic garbenschiefer, ultrabasic rocks from the Annagh Division gneiss possibly related to the basic garbenschiefer, Annagh acid gneiss, and Scotchport Schist of the

Inishkea Division. All were determined by XRF analysis at Keele University, England: sample preparation methods and operating conditions are described elsewhere (Winchester and Max, 1982; Floyd and Winchester, 1983). The schist is unusual in containing very high Al and Mg together with low Ca and Fe. The Cr-mica-bearing schists do not fit well compositionally into any normal sedimentary or igneous rock type, but show a slight resemblance to either the Annagh acid gneiss or the Scotchport Schist, rather than the basic rocks within either. However, numerous chemical modifications make it impossible to assign the schist to either formation. Notable chemical characteristics are high Al_2O_3, MgO, K_2O, Ba, Sr, and Rb, reflecting the coexistence in these rocks of talc and serpentine with fibrolite and kyanite in association with Cr mica and pale brown biotite. Equally significant are the low SiO_2, P_2O_5, Y, and Zr, shared also by the basic garbenschiefer, which otherwise show some resemblence to the ultra-basic pods in the Annagh Gneiss in possessing high MgO and CaO (but not high Cr). The latter characteristic

TABLE I. *Chemistry of the Cr mica schist and averages of associated Erris Complex rocks*

	Cr-mica-bearing schists			Adjacent basic garbenschiefer		Annagh ultra-basic pods		Annagh acid gneiss		Scotchport Schists	
	81–1426	80165	80166	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
SiO_2	46.39	48.82	47.10	46.19	0.59	51.88	2.73	66.30	8.16	59.47	3.27
TiO_2	0.57	1.09	0.15	0.56	0.23	0.50	0.13	0.63	0.35	0.97	0.12
Al_2O_3	24.23	23.28	26.61	15.44	1.67	8.93	2.55	15.30	2.95	18.32	1.44
Fe_2O_3	1.41	0.74	0.71	2.55	0.95	2.75	0.61	1.92	1.03	1.95	0.68
FeO	3.66	3.44	2.06	7.71	1.50	7.15	1.06	2.22	1.60	4.99	0.97
MnO	0.05	0.06	0.10	0.25	0.03	0.25	0.08	0.08	0.05	0.11	0.03
MgO	11.73	9.40	8.46	12.54	1.44	12.37	1.04	1.73	1.75	2.46	0.28
CaO	2.07	3.98	4.16	10.20	1.06	10.88	1.65	2.78	2.17	2.83	1.37
Na_2O	1.46	2.28	2.67	1.19	0.44	0.37	0.29	3.64	0.86	2.87	0.77
K_2O	4.98	4.68	3.34	0.88	0.35	2.62	0.82	3.86	1.21	3.58	1.20
P_2O_5	0.06	0.03	0.01	0.01	0.01	0.09	0.05	0.17	0.13	0.33	0.13
H_2O^+	3.66	2.28	4.60	2.57	0.26	2.18	1.43	1.35	0.87	2.11	0.74
Ba	1305	1258	486	432	383	347	202	913	250	868	271
Cr	33	38	10	176	71	1425	293	29	16	68	10
Nb	13	80	17	7	3	9	1	21	16	16	3
Ni	37	50	40	69	6	348	62	14	12	42	7
Rb	229	207	165	31	18	126	53	118	32	151	43
Sr	430	558	789	218	192	81	61	481	289	302	81
Y	5	2	3	13	2	27	13	28	22	41	13
Zr	1	9	1	4	4	53	29	247	173	192	40
La				3	2	18	10				
Ce				12	12	38	16				
Nd				8	4	19	6				
n =				3		6		29		24	

suggests that some Cr depletion may have occurred, and, as the unusual chemical characteristics of the Cr-mica-bearing schists cannot be produced by mixing different proportions of the other nearby rock formations during mylonitization within the Scotchport shear zone, metasomatism must have occurred. Hence fluid migration along the principal dislocation surfaces may have removed SiO_2, P_2O_5, Cr, Y, and Zr from both the Cr-mica-bearing and basic garbenschiefer and introduced Al_2O_3, MgO, Ba, K_2O, Sr, and Rb. The occurrence of Cr-rich micas in Cr-poor rocks may result from: (1) mixing of fragments of ultramafic and acid gneisses during mylonitization, and

(2) retention of Cr in chemically stable micas. Metasomatism would account for Cr depletion and release from less chemically stable MgO-bearing phases, thus explaining the unusually high MgO/Cr ratios characteristic of both basic and acid garbenschiefer.

The Cr mica

The metamorphic history of the schist in which the Cr mica occurs is complex in that plagioclase and kyanite contain oriented inclusions of talc, which implies that two distinct metamorphisms are recorded with kyanite growing in a hydrated

TABLE II. *Average of thirty-two Cr muscovites from Mayo*

	$\bar{X}$	s	max	min		$\bar{X}$	s
SiO_2	47.57	1.35	51.90	46.01	Si	3.148	0.071
TiO_2	0.81	0.14	1.10	0.53	Ti	0.040	0.007
Al_2O_3	33.24	1.30	35.37	29.95	Al (tet)	0.834	0.082
Cr_2O_3	0.87	0.18	1.24	0.59	Al (oct)	1.761	0.043
Fe_2O_3	1.35	0.15	1.72	1.10	Cr	0.046	0.010
MgO	1.28	0.37	2.20	0.74	Fe	0.067	0.008
K_2O	9.27	0.60	10.15	7.89	Mg	0.126	0.037
Na_2O	0.71	0.33	1.49	0.31	K	0.783	0.052
Total	95.10				Na	0.090	0.041

All iron as Fe^{3+}. Element means ($\bar{X}$) and standard deviations (s) are number of ions calculated on the basis of 11 (O).

TABLE III. *Cr-rich muscovites and phengitic muscovites*[*]

	a	b	c	d	e	f
SiO_2	48.58	47.29	46.01	46.80	51.90	49.21
TiO_2	0.53	0.74	0.94	0.92	0.89	0.75
Al_2O_3	31.56	33.29	33.93	34.20	29.95	32.99
Cr_2O_3	1.24	1.08	1.05	1.01	0.86	0.59
Fe_2O_3	1.36	1.37	1.50	1.24	1.33	1.26
MgO	1.77	1.13	0.97	1.02	1.35	1.49
K_2O	10.06	9.94	8.90	9.06	8.98	9.81
Na_2O	0.44	0.31	0.90	1.11	0.63	0.39
Total	95.53	95.05	94.20	95.36	95.89	96.49
Si	3.215	3.143	3.079	3.093	3.379	3.206
Ti	0.026	0.037	0.047	0.046	0.044	0.037
Al (tet)	0.769	0.837	0.905	0.879	0.539	0.770
Al (oct)	1.693	1.763	1.772	1.786	1.760	1.764
Cr	0.065	0.057	0.056	0.053	0.044	0.030
Fe	0.067	0.068	0.075	0.061	0.065	0.061
Mg	0.175	0.112	0.097	0.100	0.131	0.145
K	0.848	0.843	0.760	0.764	0.746	0.815
Na	0.056	0.040	0.117	0.142	0.080	0.049

[*] Other analyses available from the authors.

mixture of mylonites which included basic rock. The available lithologies were originally high-grade metamorphic rocks. Books of biotite up to 5 mm across are separated from a green 'muscovite' by broad transition bands.

Chemistry. Green muscovite micas in the assemblage biotite-green-muscovite-quartz-rutile have been analysed on the EDS microprobe in Cambridge University (Tables II and III).

The analysed micas show evidence of three substitutions into the standard muscovite structure: fuchsitic ($Cr = Al^{VI}$); paragonitic ($Na = K$); and phengitic ($Fe, Mg, Si = Al^{VI}, Al^{IV}$). Each of these substitutions is variable throughout the sample, none more so than the paragonitic one which is defined by a range in the ratio $Na/(Na+K)$ of between 5.6 and 20.1. Even at the low levels of Na present this range is still statistically significant. Each of the substitutions in individual crystals behaves independently of the others with no correlation between them.

The Cr content of the micas ranges from 0.034 to 0.066 formula units per eleven oxygens corresponding to a range of wt. % Cr_2O_3 from 0.59 to 1.24% with a mean of 0.87%. This range of values spans that point at which Deer *et al.* (1962) separated fuchsites, with more than 1% Cr_2O_3, from chromian muscovites with less than 1% Cr_2O_3. By this definition some of the grains are indisputably fuchsitic, although the majority can not be termed as such.

The pattern is clouded by the high degree of phengitic substitution which involves a compositional shift towards the chrome phengite, mariposite. The ratio $Si + Ti$ to Al^{IV} reaches a maximum of 3.42:0.54 (Table III,e) which is close to the theoretical ratio for mariposite of 3.5:0.5 (Heinrich, 1965). There is an almost continuous sequence of increasing phengitic substitution towards this point, which is coupled with a varying degree of fuchsitic

substitution. Consequently the general name chrome phengite is most appropriate.

The Cr phengites occur in association with chrome-bearing (mean $Cr_2O_3 = 0.73\%$; Table IV) biotites, chrome rutiles with about 1% Cr_2O_3, and quartz. The biotites contain less chrome than the associated muscovites.

The assemblage fuchsite-biotite-quartz, with or without rutile, is one of the typical parageneses listed by Whitmore *et al.* (1946) and assumed by them to be of hydrothermal origin. Heinrich (1965) noted that the mariposite end-member becomes dominant in hydrothermal metamorphic systems. Pure fuchsites appear to be limited to metamorphosed chrome-bearing schists and quartzites (Fabries and Latouche, 1973) and meta-volcanics (Schreyer *et al.*, 1981) or non-metamorphic ore-related hydrothermal systems (Chen and Lee, 1974). The veined mode of occurrence of this sample, together with the Cr phengitic, rather than fuchsitic nature of the grains, is indicative that these micas reflect a hydrothermal origin probably related to the regional tectono-metamorphic episode with associated metasomatism.

Crystal character. XRD analysis was carried out on a Cr mica mineral by I. A. Weaver of the Institute for Industrial Research and Standards, Dublin, using Cu-$K\alpha$ (Ni filter) gave d Å, and I/I_0 of 9.97(65), 4.98(30), 4.48(5), 3.38(5), 3.49(10), 3.36(15), 3.32(100), 3.20(18), 2.99(20), 2.86(18), 2.79(18), 2.56(8), 2.49(9), 1.99(50).

Optical properties. The determined values of α 1.566, β 1.595, γ 1.597, $2V_\alpha$ (measured) 38–39° negative compare closely with fuchsite reported by Clifford (1957) with 2V measured at $38 \pm 1°$, α 1.566, β 1.597, γ 1.602. The Cr mica mariposite is not so well known optically. Deer *et al.* (1962) cite only one example with the single index β 1.624 and a very small 2V, which is significantly different from the optical properties of the Scotchport Cr mica.

TABLE IV. *Average of seven co-existing biotites with Cr muscovite*

	$\bar{X}$	s	max	min		$\bar{X}$	s
SiO_2	39.33	0.43	39.98	38.89	Si	2.795	0.014
TiO_2	1.40	0.07	1.49	1.26	Ti	0.075	0.004
Al_2O_3	18.90	0.14	19.19	18.77	Al	1.583	0.012
Cr_2O_3	0.73	0.15	0.94	0.55	Cr	0.041	0.008
FeO	10.29	0.17	10.56	10.05	Fe	0.612	0.012
MgO	16.74	0.24	17.08	16.41	Mg	1.774	0.024
K_2O	9.50	0.10	9.71	9.43	K	0.862	0.010
Total	96.89						

All iron as Fe^{2+}. Element means ($\bar{X}$) and standard deviations (s) are numbers of ions calculated on the basis of 11 (O).

Discussion

Various authors have at times attempted to link the type of chrome-bearing muscovite to particular parageneses. The assemblage fuchsite–biotite–quartz, with or without rutile, is one of the 'typical' parageneses listed by Whitmore et al. (1946) and assumed by them to be of hydrothermal origin. Heinrich (1965) subsequently noted that the mariposite end member becomes dominant in hydrothermal metamorphic systems. Pure fuchsites appear to be limited to metamorphosed chrome-bearing schists and quartzites (Fabries and Latouche, 1973) and meta-volcanics (Schreyer et al., 1981) or non-metamorphic ore-related hydrothermal systems (Chen and Lee, 1974).

The Cr-mica and the schist within which it occurs appear to be a complex metamorphic and metasomatic product wherein the chemical constituents of ultrabasic to acid rocks (all of which are seen in the Erris Complex) have been recombined, almost certainly under structural control. That the micas grew under hydrothermal influences is indicated by: the veined mode of occurrence of the sample; the presence of large books of Cr mica in rather a Cr-poor schist; and the chrome-phengitic, approaching mariposite, rather than fuchsitic nature of the micas.

The often sharp margins of the schist indicate at least late movement as a mass. The schist is probably Precambrian in its formation as the Scotchport shear zone imbricates basement while the tectonic basement–Caledonian cover contacts nearby are more clearly mylonites with less annealling recrystallization, but many of the minerals may be Caledonian in age. Kyanite–staurolite facies was reached in nearby Dalradian rocks of the region (Max, 1973) immediately to the east where the Grampian thermal peak mineral assemblages occur.

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