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METAMORPHIC ZONES IN THE SNOW LAKE AREA, MANITOBA

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ABSTRACT

Three isograds, based on reactions in pelitic rocks, have been mapped in the Snow Lake area, separating four metamorphic zones: chlorite-biotite, chlorite-biotite-staurolite, biotite-staurolite-sillimanite, and biotite-sillimanite-almandine. The boundary between the two intermediate zones, generally characterized by the assemblage chlorite-biotite-staurolite-sillimanite, occurs near the kyanite-sillimanite transition and is represented in one locality by the assemblage chlorite-biotite-staurolite-kyanite. The compositions of ferromagnesian minerals from mineral assemblages defining the metamorphic zones display systematic variations. Depending on the specific assemblage, the Mg(Fe+Mg) ratio may either increase or decrease with metamorphic grade.

INTRODUCTION

The Snow Lake area is situated at the eastern end of the Flin Flon - Snow Lake greenstone belt. Various geological maps of the area are available (Armstrong 1941; Frarey 1950; Harrison 1949; Russell 1957; Williams 1966). The results of more recent mapping have been summarized by Moore & Froese (1972). A geological sketch map is shown as Figure 1. A considerable part of the area is underlain by volcanic rocks of the Amisk Group. Sediments consisting of alternations of pelitic and psammitic rocks are interlayered with the volcanic rocks. For this reason, they are also assigned to the Amisk Group. A body of "quartz-eye granite", a quartz dioritic gneiss with prominent quartz phenocrysts, probably represents a sub-volcanic intrusion. A sequence of uniform psammitic rocks, belonging to the Missi Group, overlies the Amisk Group. Diapiric uprise of granitoid gneisses has produced gneiss domes of uncertain stratigraphic position in the northern half of the area. Bailes (1975) has suggested that the granitoid gneiss domes represent granitized Missi rocks. Rocks of the Amisk and Missi Groups are cut by a variety of later intrusions.

Pelitic rocks of the Amisk Group make it possible to map metamorphic zones based on reactions among aluminous minerals. An earlier deformation has produced flattening of markers, such as pillows and fragments, parallel or subparallel to lithologic layering. This was folowed by the main deformation which gave rise to northeasterly-trending folds, accompanied in many places by an axial plane foliation expressed by a preferred orientation of minerals. Thus metamorphism was broadly contemporaneous with the main deformation.

DEFINITION OF METAMORPHIC ZONES

Isograds were mapped on the basis of specific reactions in pelitic rocks (see Carmichael 1970). Metamorphic zones, bounded by isograds, are characterized by a two-mineral or three-mineral assemblage in the Thompson projection (Thompson 1957). Because almandine has a high manganese content, it may be present as an additional phase.

Mineral assemblages of various zones are shown in Figure 2. The lowest grade encountered is the chlorite-biotite zone. With increasing grade, almandine is produced by a reaction represented by shifting of the triangle chlorite-biotite-almandine towards more Mg-rich compositions. It was impossible to map a separate chlorite-biotite-almandine zone because at slightly higher grade staurolite is formed by the reaction:

$$\text{chlorite} + \text{almandine} + \text{muscovite} \rightleftharpoons \text{biotite} + \text{staurolite} + \text{quartz} + H_2O \quad (1)$$

The biotite-staurolite isograd is based on this reaction. In the File Lake area, west of Snow Lake, Harrison (1949) also observed that "staurolite appears in argillite within a short distance north of the first appearance of garnet". The biotite-staurolite isograd marks the lower boundary of the chlorite-biotite-staurolite zone.

Chlorite is decomposed by a reaction represented by shifting of the triangle chlorite-biotite-staurolite towards more Mg-rich compositions and, finally, by breaking the tie line chlorite-staurolite according to the reaction:

$$\text{chlorite} + \text{staurolite} + \text{muscovite} + \text{quartz} \rightleftharpoons \text{biotite} + \text{sillimanite} + H_2O \quad (2)$$

The biotite-sillimanite isograd, based on this reaction, marks the lower boundary of the biotite-staurolite-sillimanite zone. This reaction occurs

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approximately near the kyanite-sillimanite transition and, in the vicinity of Anderson Lake, the isograd is represented by the assemblage chlorite-staurolite-biotite-kyanite. In Mg-rich rocks, the assemblage chlorite-biotite-kyanite is observed. The occurrence of kyanite near Anderson Lake has attracted attention for some time (Alcock 1917, 1920; Wallace 1924).

Staurolite eventually becomes unstable according to the reaction:

$$\text{staurolite} + \text{muscovite} + \text{quartz} \rightleftharpoons \text{biotite} + \text{sillimanite} + \text{almandine} + H_2O \quad (3)$$

This reaction defines the biotite-sillimanite-almandine isograd and marks the lower boundary of the biotite-sillimanite-almandine zone.

Most sediments of the Missi Group are not sufficiently aluminous to allow the formation of staurolite. Nevertheless, as observed by Harrison (1949), quartz-sillimanite nodules appear in these rocks at a grade of metamorphism somewhat greater than that represented by the biotite-sillimanite-almandine isograd. The origin of quartz-sillimanite nodules is not understood. Recently, Losert (1968) has suggested a process of de-alkalization. Although this would produce the appropriate mineral assemblage, the geological controls of such a process are difficult to visualize. One reaction which could generate sillimanite in muscovite-biotite-almandine rocks is represented by shifting of the triangle biotite-sillimanite-almandine towards more Fe-rich compositions in response to rising temperature.

MINERAL COMPOSITIONS

Minerals from specific assemblages (Table 1) were analyzed by electron microprobe. Compositions are given in Table 2. Chlorites and biotites from the chlorite-biotite zone are relatively

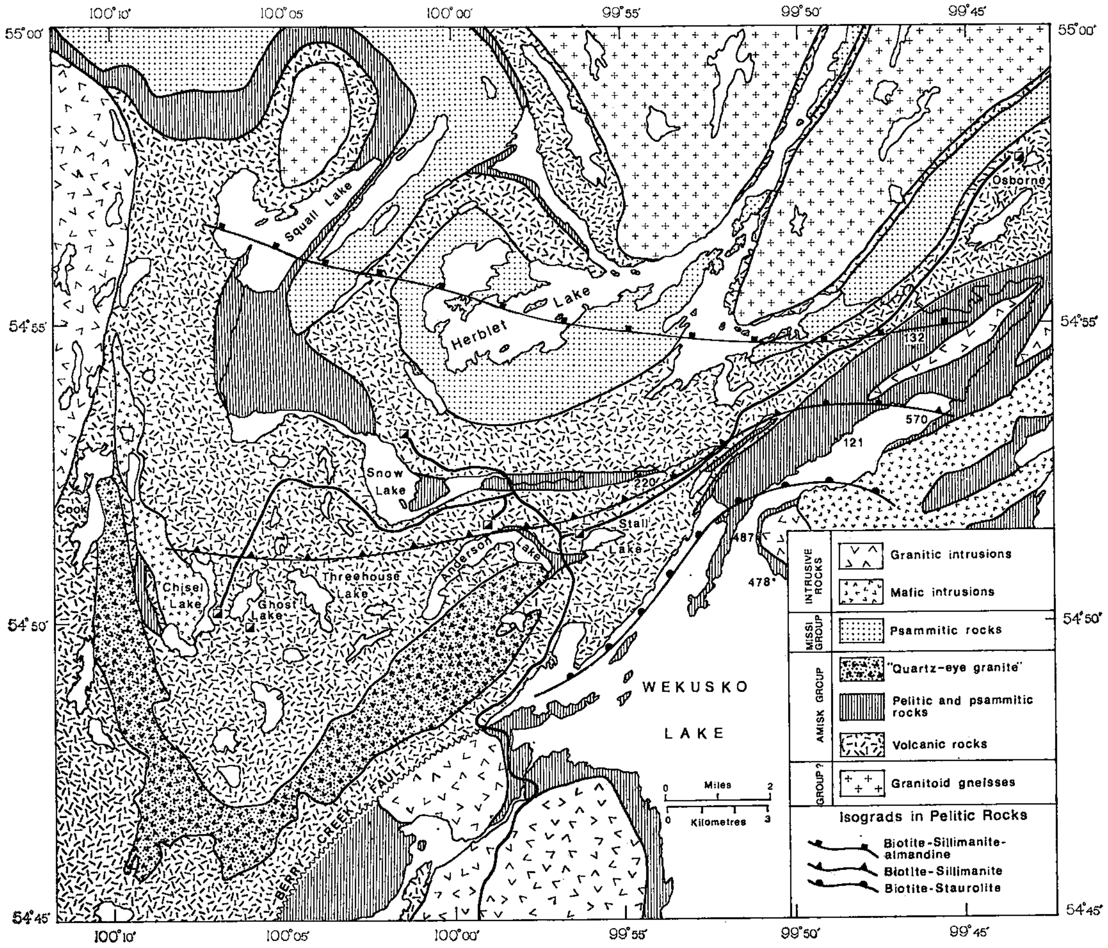

FIG. 1. Isograds in the Snow Lake area.

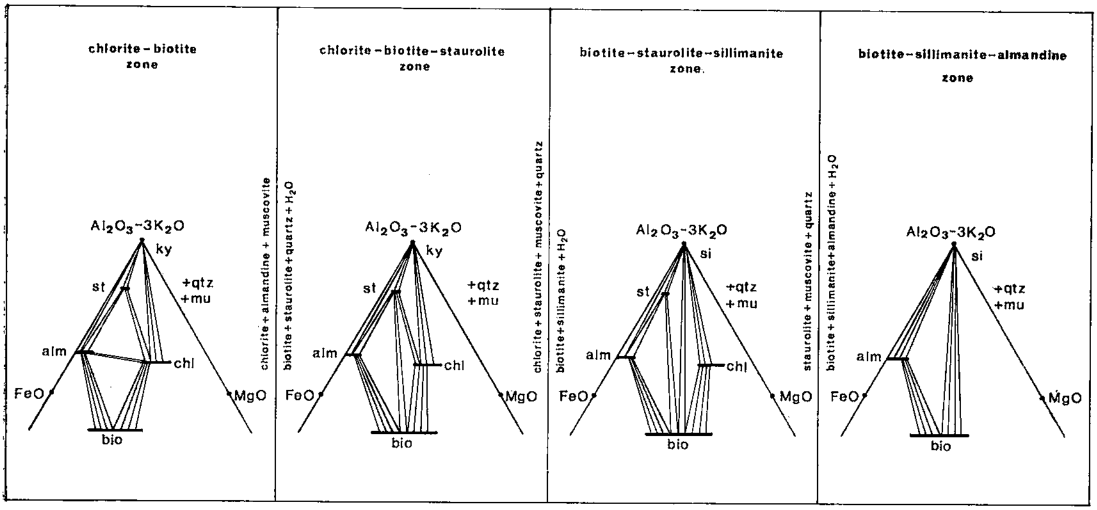

FIG. 2. Mineral assemblages of metamorphic zones.

TABLE 1. MINERAL ASSEMBLAGES OF ROCKS

	sample	qtz	plag	mu	chl	bio	st	si	alm
chlorite-biotite	478	x	x	x	x	x	-	-	-
zone	487	x	x	x	x	x	-	-	-
chlorite-biotite-	121	x	x	x	x	x	x	-	x
staurolite zone	570	x	x	x	x	x	x	x	x
biotite-staurolite-	220	x	x	x	-	x	x	x	x
sillimanite zone	132	x	x	x	-	x	x	-	x

Fe-rich. The two rocks from the chlorite-biotite-staurolite zone represent the maximum range observed in eight samples. The Mg/(Fe+Mg) ratio of the ferromagnesian minerals reaches a maximum in the assemblage chlorite-biotite-staurolite-sillimanite defining the biotite-sillimanite isograd. The ratio decreases somewhat in the assemblage biotite-staurolite-sillimanite. These relationships are shown in Figure 3. The same variation in mineral composition has been observed by Guidotti (1974).

ANALYTICAL TECHNIQUES

A Kevex lithium-drifted solid-state detector for energy dispersive analysis attached to a MAC electron microprobe was used for the analysis of all minerals with the following operating conditions: 20 kV accelerating voltage, specimen current 0.01 nanoamps measured on biotite, 40 seconds counting time, focused beam.

Three grains of each mineral were chosen in each sample and three spots from each grain were analyzed, generally one in the middle, one near the edge, and one half-way, in order to detect zoning if present. Since no appreciable compositional variation was found in any sample, average analyses were calculated. The standards used were: an analyzed kaersutite amphibole for Si, Al, Ti, Fe, Mg, Ca, Na and K, and an analyzed biotite for Mn.

Computer programs EDS 5C (Plant & Lachance 1973) and EMPADR VII (Rucklidge & Gasparrini 1969) were used to convert the data from the detector into oxide weight percentages by applying the necessary background corrections to the energy spectrum (EDS 5C) and the fluorescence, absorption, and atomic number corrections (EMPADR VII) to the net peak intensities calculated by EDS 5C.

TABLE 2. CHEMICAL COMPOSITION OF MINERALS

	chlorite-biotite zone				chlorite-biotite-staurolite zone						biotite-staurolite-sillimanite zone			
	478		487		121			570			220		132	
	chl	bio	chl	bio	chl	bio	st	chl	bio	st	bio	st	bio	st
SiO_2	23.36	34.98	23.91	35.85	23.41	35.42	26.87	24.47	35.08	26.31	35.35	26.56	35.34	26.13
TiO_2	0.08	1.66	0.08	1.71	0.10	1.57	0.49	0.10	1.48	0.40	1.82	0.47	1.50	0.41
Al_2O_3	21.29	18.54	21.03	17.61	22.42	19.22	53.71	22.84	19.54	53.98	19.15	54.27	19.54	54.65
FeO	32.61	23.79	30.71	23.03	29.11	21.49	15.17	26.18	19.56	14.35	20.58	14.67	20.20	14.72
MnO	0.19	0.06	0.25	0.10	0.07	0.06	0.08	0.09	0.07	0.18	0.06	0.16	0.06	0.08
MgO	11.27	7.95	12.18	8.34	13.72	9.11	1.59	15.34	10.69	2.06	10.02	1.85	10.17	1.64
Na_2O	-	0.40	-	0.39	-	0.37	-	-	0.35	-	0.38	-	0.43	-
K_2O	-	8.60	-	9.10	-	8.39	-	-	8.83	-	8.71	-	8.54	-
H_2O	11.02	3.89	11.06	3.90	11.25	3.94	2.90	11.50	3.96	2.89	3.96	2.91	3.96	2.90
	99.82	99.87	99.22	100.03	100.08	99.57	100.81	100.52	99.56	100.17	100.03	100.89	99.74	100.53
Mg/(Fe+Mg)	0.381	0.373	0.414	0.392	0.457	0.430	0.157	0.511	0.493	0.204	0.465	0.184	0.473	0.166

The amount of water present in each mineral was then calculated from the stoichiometry of the mineral by means of the computer program SUPERRECAL (Rucklidge 1971) in order to obtain an indication of the quality of the analyses. Table 2 shows oxide weight percentages as calculated by EMPADR VII, as well as the stoichiometric amount of water given for each mineral by SUPERRECAL.

METAMORPHIC CONDITIONS

The three reactions defining the mapped isograds may be plotted on a diagram of $P_{H_2O} = P_{total}$ versus T (Fig. 4). Also shown are the stability fields of the aluminum silicates. The pressure-temperature conditions of the kyanite-andalusite transition are well-established (Holdaway 1971). In view of the low temperature of the triple-point determined by Holdaway (1971), we have used the mid-points of the uncertainty brackets of the kyanite-sillimanite transition given by Richardson *et al.* (1968) rather than their preferred boundary. The andalusite-sillimanite transition may then be calculated from a knowledge of the molar volumes (see Richardson *et al.* 1969).

Hoschek (1969) determined the equilibrium conditions of the reaction:

$$\text{chlorite} + \text{muscovite} \rightleftharpoons \text{biotite} + \text{staurolite} + \text{quartz} + H_2O$$

This reaction expresses an equilibrium among the minerals characteristic of the chlorite-biotite-staurolite zone. Reaction (1), stabilizing this assemblage, must occur at a somewhat lower temperature. Reaction (2) must pass through the sillimanite field because chlorite-biotite-staurolite-sillimanite is a well-known stable assemblage (Guidotti 1974). Reaction (3) is shown diagrammatically between reaction (2) and the preliminary upper stability of staurolite in the presence of quartz and muscovite (Hoschek 1969). Reaction (2) in the Snow Lake area commonly involves sillimanite, but near Anderson Lake kyanite is present instead. This suggests that the path of metamorphic conditions was near the intersection of reaction (2) with the kyanite-sillimanite transition at a pressure of 5-6 kb.

Rocks from the Snow Lake area are relatively Mg-rich. For this reason, the chlorite-biotite-staurolite zone and the biotite-staurolite-sillimanite zone may be distinguished. In more Fe-rich rocks, both zones would be represented by the

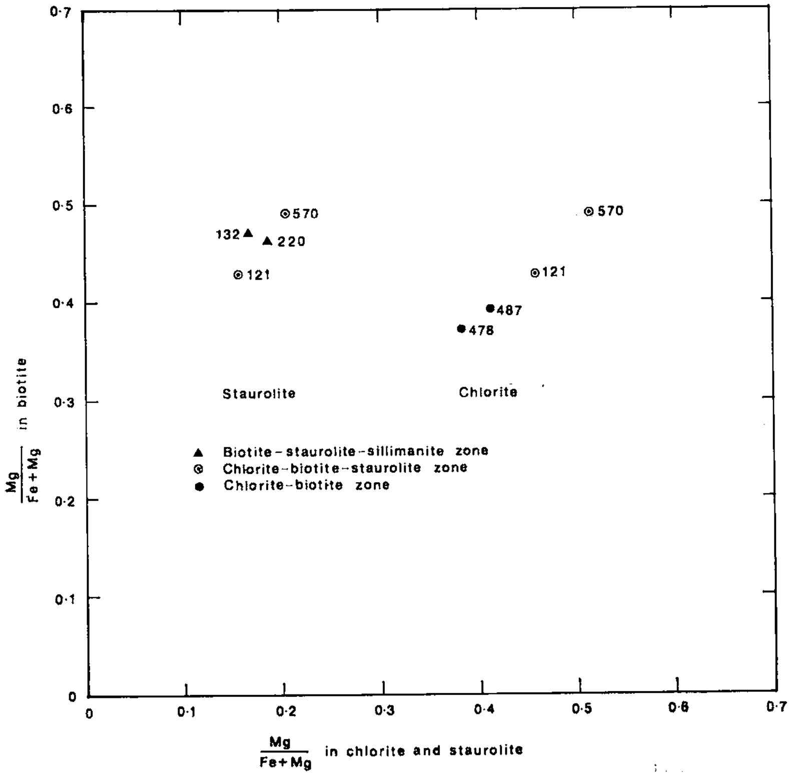

FIG. 3. The Mg/(Fe+Mg) ratios of chlorite, biotite, and staurolite.

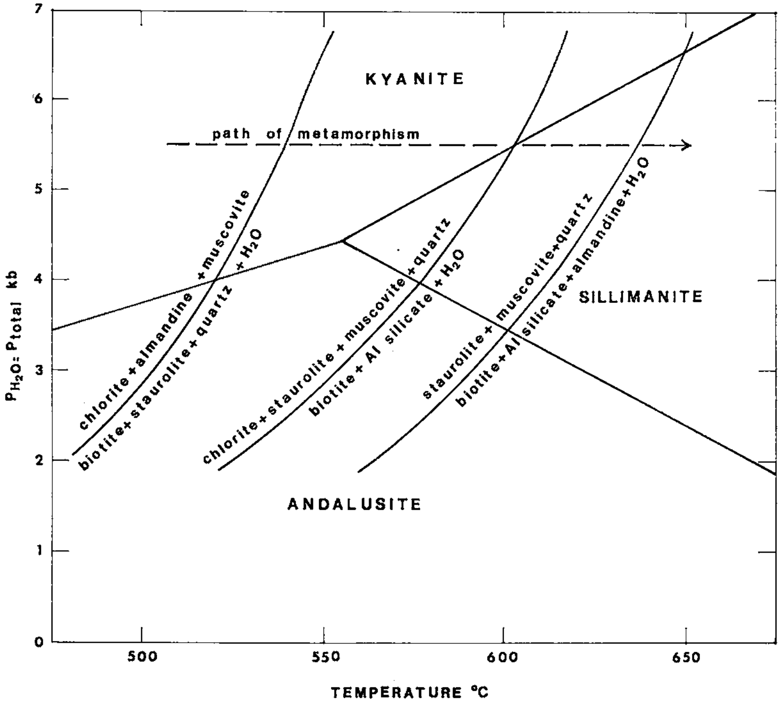

FIG. 4. Path of metamorphism in the Snow Lake area.

assemblage biotite-almandine-staurolite. The Mg-rich composition could also account for the absence of a mappable chlorite-biotite-almandine zone. Most rocks plot in the chlorite-biotite field at a metamorphic grade lower than the chlorite-biotite-staurolite zone.

Zones other than the chlorite-biotite zone are represented by a diagnostic three-phase assemblage in the Thompson projection. These triangles shift in response to changes of total pressure, water pressure, and temperature. The formation of staurolite in the chlorite-biotite-staurolite zone produces chlorites and biotites enriched in Mg relative to the composition of these minerals in the chlorite-biotite zone. The triangle chlorite-biotite-staurolite shifts towards the Mg side of the diagram until reaction (2) is encountered. By way of contrast, the newly-stabilized assemblage biotite-staurolite-sillimanite shifts towards compositions richer in Fe with progressive metamorphism.

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