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PRELIMINARY THERMOBAROMETRY AND MICROPROBE MINERAL COMPOSITIONS, FAIRBANKS AREA SCHISTS AND AMPHIBOLITES

by

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Preliminary thermobarometry and microprobe mineral compositions, Fairbanks Area Schists and Amphibolites

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INTRODUCTION

Metamorphic rocks in the Fairbanks mining district have confused geologists and petrologists for decades. Within the area immediately around the city of Fairbanks (Fig. 1) there have been several attempts made to categorize, classify, and map the rocks with inconsistent results (Pewe, et al., 1976; Forbes, 1982; Robinson et al., 1990). In particular, all workers agree that the rocks of the immediate Fairbanks area represent greenschist and/or amphibolite metamorphic facies, but disagree in placement of boundaries between rocks of these facies and in how many different metamorphic rock units are present. One potential explanation for the lack of agreement between different workers is the virtual lack of quantitative petrologic data. Metamorphic grade assignments in the Fairbanks area have been built around mineral grain sizes, abundance of retrograde minerals, and hand-specimen identification of key indicator minerals, but with the exception of Keskinen (1989), there has been no quantitative P-T information presented for these rocks.

In principle, the compositions of coexisting minerals in metamorphic rocks can be used to unambiguously determine P-T conditions for the rocks. In practice, relevant experimental data and sophisticated thermodynamic models are required to perform such P-T analysis. Partitioning of Fe and Mg between biotite and garnet and between amphibole and garnet is one such means of estimating temperatures for greenschist and amphibolite facies rocks. The laboratory calibration for the former (Ferry and Spear, 1978) used pure Fe-Mg garnet and biotite, and is strictly applicable only to natural garnet-biotite pairs lacking appreciable Ca, Ti, and/or Mn. Similar problems are posed by garnet-amphibole studies (Graham and Powell, 1984). Because Fairbanks area metamorphic minerals deviate significantly from the Fe-Mg end-members, these geothermometers give poor results.

In the last decade several workers have pursued theoretical and experimental corrections to the Fe-Mg studies to give geothermometers applicable to complex natural minerals. Based on such studies two different refined biotite-garnet geothermometers have been recently published, those of Hodges and Spear (1982) and Bhattacharya et al. (1992). Even with these complex thermodynamic models, some garnet-biotite pairs yield unrealistic results, either due to compositions not easily modeled thermodynamically and/or to lack of equilibrium between garnet and adjacent biotite. One way to check for such problems is to employ both geothermometer formulations: similar results from each gives confidence in the temperature derived, whereas considerable disagreement indicates the temperatures are not valid.

In order to address the problem of metamorphic grade, and hence, map units, for the immediate Fairbanks area, we have performed microprobe analyses on minerals from samples with key metamorphic assemblages. We have investigated samples from 8 sites (Fig. 1; Table 1), three from rocks previously mapped as Fairbanks schist/Cleary Sequence ("upper greenschist") and 5 from rocks previously mapped as Chena River Sequence ("mid-amphibolite"). Rocks from one site (FM17, Fig. 1) were previously studied by Keskinen (1989) and we choose this site to ensure that our results were compatible with past quantitative work. Our objectives were to (1) quantitatively determine P-T metamorphic conditions for these 8 sites and (2) compare the results to existing map boundaries.

ANALYTICAL TECHNIQUES

Twelve polished thin sections were made, to represent lithologic and mineral variability at the 8 sites. These thin sections were carefully studied to locate areas containing critical mineral assemblages for microprobe analysis. Only areas showing textural evidence for mineral equilibrium were selected for further analysis.

All microprobe analyses were performed at the Center for Microbeam Studies, University of Alaska, Fairbanks, Alaska, using a Cameca SX-50 microprobe and well-characterized natural mineral standards. Dr. K. Severin assisted with the analyses. Standardization was checked using well-characterized secondary standards. Beam conditions were 20 kv, 10mA, and 10-second count times. At least 3 mineral pairs/clusters were selected from each thin section and at least 3 spots on each mineral of a pair/cluster were selected for automated analysis. Analyses with poor totals and/or low K_2O (biotite/muscovite) contents were rejected; otherwise all analyses from a single mineral of a pair/cluster were averaged. In most cases, temperature estimates from mineral pairs were calculated separately, and then averaged for a single thin section. In a small number of cases, different pairs from the same section yielded widely divergent results, and these were separately averaged. Barometric calculations were performed and averaged similarly.

RESULTS

Biotite-garnet temperatures so generated for samples from the Fairbanks area (Table 2) show excellent agreement between temperatures generated by the two techniques, except for samples FM17 and RN336. These latter samples contain several garnet-biotite pairs, some of which yield consistent temperatures in the 520-550°C range and some of which yield highly inconsistent temperatures of 660-830°C (Table 2). As the latter temperatures are both widely varying and exceed temperatures for amphibolite-facies metamorphism, we reject them. Sample FM17 also has significantly lower-Ca garnets and higher-Ca plagioclases than the other samples and this may influence its calculated temperatures. One of the authors (BJ) is currently studying these samples in attempt to better understand their peculiar behavior.

Samples FS104 and FS203C contained hornblende-garnet pairs and these were also analyzed to establish temperatures (Table 3). We employed in the geothermometry the experimental data of Graham and Powell (1984), modified using the garnet mixing model of Bhattacharya et al. (1982). There is excellent agreement between temperatures determined from this garnet-amphibole geothermometer and those from the garnet-biotite geothermometers for sample site 104 (500, 495, and 500 °C; Tables 2,3). There is also excellent agreement between these results and those of Keskinen (1989).

Geobarometric determinations were made using the formulations of Ghent and Stout (1981) and Kohn and Spear (1990). The former involves the plagioclase-garnet-biotite-muscovite assemblage and the latter, garnet-hornblende-plagioclase-quartz. Both formulations require a temperature and compositional information to generate a pressure, and the averaged temperatures from the mineral geothermometry were employed. Not all samples could be so studied, as not all samples contained the required assemblages (Table 1).

Geobarometry was complicated by the presence, in most samples, of multiple plagioclase compositions. Most samples contained apparently prograde oligoclase surrounded, cut, or corroded by apparently retrograde albite (Table 4). These different plagioclase compositions yielded very different pressures: the higher-Ca plagioclase compositions yielded "reasonable" pressures of 3-6 kb, whereas, albite compositions yielded unreasonable (well outside of greenschist or amphibolite facies) pressures of >15 kb. Consequently, rather than averaging all plagioclase compositions from a single area of a thin section, we only averaged the non-albite compositions.

Estimated temperatures (Tables 2, 3) and pressures (Table 5) for the samples are all virtually identical, despite their classification from previous mapping efforts as either mid-amphibolite (a) or upper greenschist (g) metamorphic facies. Average data (Table 6) indicates that the temperatures generated for samples from the two mapped facies are within a standard deviation of each other--i.e., that there is no significant difference between the two. Because only two pressure estimates are available for the samples mapped as greenschist facies (Table 5), the comparison is less certain for pressure, but the average pressures for both suites are also quite close (Table 6).

In conclusion, our preliminary P-T work indicates that rocks mapped at Chena River sequence, Fairbanks schist, and Cleary Sequence all experienced identical peak metamorphic conditions of lower amphibolite facies. All these samples also variably experienced a retrograde greenschist event, characterized by secondary albite (Table 4) and chlorite (Table 1). Based on these considerations, there is no justification for breaking these three "units" out as separate entities.

Representative complete mineral chemical analyses are given as Tables 7-11.

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Table 1. Mineralogy of the samples.

Sample	Qz	Pl	Mu	Bt	Gt	Cc	Am	Cl	Rt	Tm	Op	Ap	Cz	Zr	Sp
FM17	X	X	X	X	X			X	X		X		X	X	
FS101C	X	X	X	X	X	X				X	X	X		X	
FS104B		X		X	X		X	X			X		X		X
FS104H	X	X	X	X	X			X	X	X	X			X	
FS105H	X	X	X	X	X			X		X	X	X			
FS201B	X	X	X	X	X	X		X			X				
FS203C	X	X		X	X		X	X	X		X		X		
RN173	X	X	X	X	X	X		X	X		X	X			
RN336	X	X	X	X	X			X			X				

Qz: quartz, Pl: plagioclase, Mu: muscovite, Bt: biotite, Gt: garnet, Cc: calcite, Am: amphibole, Cl: chlorite, Rt: rutile, Tm: tourmaline, Op: opaques, Ap: apatite, Cz: clinozoisite, Zr: zircon, Sp: sphene

Table 2. Results of preliminary garnet-biotite thermometry.

Sample		Temperature (°C)	
	mapped facies[1]	Bhattacharya et al. (1992)	Hodges and Spear (1982)
FM17, G3	a	660	760
FM17, G2	a	555	535
81BT252	g	515	540
95RN173	a	473	483
95RN336, type1	g	515	532
95RN336, type2	g	680	833
FS101C	a	480	500
FS104H	a	495	500
FS105H	g	490	480
FS201B, G2R	a	470	470
FS201B, G2C	a	485	490
FS203C	a	515	515

[1]facies from Robinson et al. (1990); a=amphibolite, g=greenschist

Table 3. Results of preliminary garnet-amphibole thermometry.

Sample	Temperature (°C) Modified Graham and Powell (1984)[1]	mapped metamorphic facies
FS104B	500	a
FS203C	505	a

[1] Incorporates the garnet mixing model of Bhattacharya et al. (1992)

TABLE 4: MICROPROBE-DETERMINED PLAGIOCLASE COMPOSITIONS

Sample #	%An	Sample #	%An	Sample #	%An	Sample #	%An
95RN173	0.4	95RN173	15.1	FS105	0.5	FS201	10.9
95RN173	1.9	95RN173	3.3	FS105	0.5	FS201	13.7
95RN173	5.5	95RN173	0.9	FS105	0.5	FS201	4.2
95RN173	17.9	95RN173	16.8	FS105	1.8	FS201	13.7
95RN173	18.1	95RN173	16.1	FS105	0.9		
95RN173	14.4	95RN173	16.0	FS105	0.6	FS203	30.3
95RN173	15.7	95RN173	18.3	FS105	1.1	FS203	29.3
95RN173	11.5	95RN173	18.1			FS203	30.2
95RN173	1.2	95RN173	13.2	FM17	35.1	FS203	29.9
95RN173	13.3	95RN173	15.5	FM17	34.0	FS203	30.3
95RN173	13.7			FM17	34.9	FS203	29.3
95RN173	13.7	FS104	22.2	FM17	33.8	FS203	30.2
95RN173	14.1	FS104	22.7	FM17	43.2	FS203	29.9
95RN173	14.0	FS104	20.5	FM17	46.2	FS203	38.5
95RN173	15.4	FS104	21.8	FM17	37.9	FS203	33.3
95RN173	15.0	FS104	22.2	FM17	41.9		
95RN173	15.1	FS104	22.7	FM17	40.1	FS101	24.6
95RN173	15.9	FS104	20.5	FM17	39.8	FS101	24.7
95RN173	15.5	FS104	21.8	FM17	23.4	FS101	26.1
95RN173	15.7	FS104	20.5	FM17	39.1	FS101	23.8
95RN173	15.5	FS104	20.6	FM17	35.4	FS101	21.1
95RN173	15.5	FS104	19.9	FM17	39.5	FS101	23.0
95RN173	15.7	FS104	20.3	FM17	22.9	FS101	24.8
95RN173	15.6	FS104	20.5	FM17	17.6	FS101	25.8
95RN173	13.6	FS104	20.6	FM17	40.0	FS101	25.9
95RN173	15.3	FS104	19.9	FM17	39.6	FS101	24.9
		FS104	20.3			FS101	24.5
						FS101	23.6
						FS101	25.8

Table 5. Results of preliminary barometry using T values from garnet-biotite thermometry (Table 2).

Sample	Pressure (kbar)		
	Ghent and Stout (1981)	mapped metamorphic facies	Kohn and Spear (1990) (Fe reaction)
FM17, G3R	5.6	a	—
FS101C	3.0	a	—
FS104B[1]		a	7.5
RN173[2]	4.1	a	—
RN336, type 1	4.3	g	
BT 252	4.8	g	
FS104H	4.4	a	
FS201B[3]	5.1	a	—
FS203C[2]	—	a	5.6

[1] Plagioclase of variable composition coexists with albite.
[2] Plagioclase of consistent composition coexists with albite.
[3] Plagioclase is zoned and corroded.

Table 6: Summarized P-T data, Fairbanks area

mapped grade[1]	Avg Temp (oC)	Std Dv	Range	Avg P (kbar)	Std Dv	Range
amphibolite	497	23	470-555	5	1	3-7.5
greenschist	512	21	480-540	4.5	---	4.3-4.8

[1]from Robinson et al. (1990)

Table 7. Selected garnet analyses. Note that "R" and "C" stand for "rim" and "core," respectively.

Sample	FM17	FM17	FM17	FS101C	FS101C	FS101C	FS104B
Grain	G1R	G2R	G3R	G1R	G2R	G6C	G1R
SiO_2	37.608	36.066	38.032	38.423	37.903	37.435	38.261
Al_2O_3	21.487	20.416	21.483	20.897	20.957	20.884	21.475
FeO	29.609	31.537	30.218	29.375	29.930	28.521	26.541
MgO	3.993	2.340	4.312	1.322	1.168	0.886	1.472
CaO	6.242	6.015	6.233	9.272	9.302	9.330	12.249
MnO	0.658	1.733	0.429	1.363	2.415	3.900	1.443
Total	99.597	98.107	100.707	100.652	101.675	100.956	101.441
			Cations on the basis of 12 O				
Si	2.984	2.946	2.982	3.031	2.993	2.982	2.992
Al	2.009	1.964	1.986	1.963	1.950	1.960	1.979
Fe	1.964	2.136	1.976	1.935	1.971	1.896	1.734
Mg	0.472	0.286	0.504	0.155	0.137	0.105	0.172
Ca	0.531	0.527	0.524	0.784	0.787	0.796	1.026
Mn	0.044	0.120	0.029	0.091	0.162	0.263	0.096
X_{Alm}	0.652	0.696	0.652	0.653	0.645	0.620	0.573
X_{Pyr}	0.157	0.093	0.166	0.052	0.045	0.034	0.057
X_{Grs}	0.176	0.172	0.173	0.264	0.257	0.260	0.339
X_{Sps}	0.015	0.039	0.010	0.031	0.053	0.086	0.032

Sample	FS104B	FS104H	FS104H	FS105H	FS105H	FS105H
Grain	G2R	G1R	G2R	G3R	G4R	G5R
SiO_2	38.395	37.467	38.229	37.465	37.600	37.933
Al_2O_3	21.193	21.038	21.578	20.849	20.697	20.812
FeO	26.215	32.010	32.240	33.182	34.440	35.782
MgO	1.440	1.469	2.063	1.743	1.688	1.839
CaO	12.298	8.625	7.625	6.619	5.721	5.367
MnO	1.501	0.450	0.166	0.095	0.113	0.074
Total	101.042	101.059	101.901	99.953	100.259	101.807
			Cations on the basis of 12 O			
Si	3.008	2.979	2.997	3.007	3.015	3.003
Al	1.957	1.971	1.994	1.972	1.956	1.942
Fe	1.747	2.125	2.113	2.225	2.305	2.364
Mg	0.207	0.174	0.241	0.209	0.202	0.217
Ca	0.989	0.735	0.641	0.569	0.491	0.455
Mn	0.088	0.031	0.011	0.006	0.008	0.010
X_{Alm}	0.576	0.693	0.703	0.739	0.767	0.776
X_{Pyr}	0.068	0.057	0.080	0.069	0.067	0.071
X_{Grs}	0.326	0.240	0.213	0.189	0.163	0.149
X_{Sps}	0.029	0.010	0.004	0.002	0.003	0.003

Table 7. Selected garnet analyses, continued.

Sample	FS201B	FS201B	FS203C	FS203C	FS303D	FS303D	FS303D
Grain	G2R	G2C	G1R	G3R	G1R	G2R	G3R
SiO_2	37.883	38.263	38.483	38.457	38.269	37.852	38.346
Al_2O_3	20.834	21.445	21.413	20.921	21.510	21.168	21.454
FeO	29.434	29.567	27.633	28.681	27.422	27.701	27.101
MgO	1.299	1.203	1.999	2.120	2.393	2.483	2.364
CaO	10.620	11.159	10.130	9.813	11.009	10.457	10.610
MnO	0.615	0.718	1.596	0.501	0.864	0.980	1.218
Total	100.685	102.355	101.254	100.493	101.467	100.641	101.093
			Cations on the basis of 12 O				
Si	3.002	2.986	3.010	3.029	2.984	2.981	2.998
Al	1.945	1.973	1.974	1.942	1.977	1.965	1.977
Fe	1.946	1.927	1.806	1.884	1.786	1.821	1.770
Mg	0.154	0.140	0.233	0.249	0.278	0.292	0.276
Ca	0.902	0.933	0.849	0.828	0.920	0.882	0.889
Mn	0.041	0.047	0.106	0.034	0.057	0.065	0.081
X_{Alm}	0.640	0.632	0.603	0.629	0.587	0.595	0.587
X_{Pyr}	0.051	0.046	0.078	0.083	0.091	0.095	0.092
X_{Grs}	0.296	0.306	0.284	0.276	0.303	0.288	0.295
X_{Sps}	0.013	0.015	0.035	0.011	0.019	0.021	0.027

Table 8. Selected biotite analyses.

Sample	FM17	FM17	FM17	FS101C	FS101C	FS104H	FS104H	FS105H
Grain	B1	B2	B3	B1	B2	B1	B2	B3
SiO_2	35.021	36.751	36.614	35.038	35.961	36.653	37.537	36.145
Al_2O_3	18.961	19.054	17.758	20.488	19.519	19.915	19.039	19.915
FeO	16.859	19.201	19.234	21.852	21.403	20.054	18.071	20.054
MgO	9.592	9.329	11.541	9.335	9.076	10.217	10.174	10.217
CaO	0.190	0.105	0.050	0.012	0.056	0.033	0.223	0.033
MnO	0.037	0.119	0.080	0.160	0.137	0.108	0.077	0.108
TiO_2	1.392	1.336	1.308	1.229	1.739	0.953	0.966	0.953
K_2O	8.773	8.360	9.626	8.758	9.244	9.373	8.278	9.373
Na_2O	0.225	0.170	0.149	0.086	0.107	0.079	0.096	0.079
Total	91.050	94.425	96.180	96.958	96.242	97.385	94.461	97.385
			Cations on the basis of 12 anions					
Si	2.748	2.790	2.759	2.637	2.698	2.722	2.825	2.722
Al	1.751	1.705	1.561	1.818	1.726	1.743	1.689	1.743
Fe	1.110	1.220	1.212	1.377	1.343	1.245	1.138	1.245
Mg	1.261	1.057	1.296	1.048	1.015	1.131	1.141	1.131
Ca	0.016	0.017	0.004	0.001	0.005	0.003	0.018	0.003
Mn	0.002	0.008	0.005	0.010	0.009	0.007	0.005	0.007
Ti	0.082	0.076	0.074	0.070	0.098	0.053	0.055	0.053
K	0.882	0.810	0.925	0.840	0.884	0.888	0.795	0.888
Na	0.034	0.025	0.022	0.013	0.016	0.011	0.014	0.011
$^{(VI)}Al$	0.499	0.495	0.320	0.455	0.424	0.465	0.514	0.465
Fe/(Fe+Mg)	0.468	0.536	0.483	0.568	0.570	0.524	0.499	0.524

Sample	FS105H	FS105H	FS201B	FS201B	FS203C	FS303D	FS303D	FS303D
Grain	B4	B5	B2-G2R*	B2-G2C*	B3	B1	B2	B3
SiO_2	36.378	35.197	36.326	35.526	35.123	35.806	36.918	37.103
Al_2O_3	21.202	18.706	19.069	20.316	17.723	16.948	17.298	18.090
FeO	18.323	21.311	19.527	21.710	16.825	19.923	20.555	19.061
MgO	9.088	9.793	10.676	9.660	12.536	11.670	10.725	12.289
CaO	0.080	0.161	0.885	0.259	0.161	0.358	0.122	0.049
MnO	0.008	0.000	0.085	0.050	0.056	0.111	0.071	0.010
TiO_2	1.009	1.178	1.586	0.523	1.556	1.595	1.215	1.303
K_2O	8.162	7.643	6.665	7.618	8.978	6.317	9.235	9.494
Na_2O	0.271	0.174	0.046	0.101	0.072	0.062	0.027	0.053
Total	94.521	94.163	94.865	96.763	93.030	91.790	96.166	97.452
			Cations on the basis of 12 anions					
Si	2.737	2.710	2.731	2.684	2.708	2.762	2.791	2.747
Al	1.878	1.698	1.690	1.809	1.610	1.541	1.541	1.579
Fe	1.157	1.372	1.227	1.372	1.085	1.285	1.300	1.180
Mg	1.018	1.124	1.196	1.088	1.441	1.342	1.208	1.356
Ca	0.007	0.013	0.072	0.021	0.013	0.030	0.010	0.004
Mn	0.004	0.000	0.006	0.003	0.004	0.007	0.005	0.001
Ti	0.057	0.068	0.090	0.030	0.090	0.092	0.069	0.073
K	0.782	0.751	0.639	0.734	0.883	0.621	0.891	0.897
Na	0.039	0.026	0.007	0.015	0.011	0.009	0.004	0.008
$^{(VI)}Al$	0.615	0.408	0.421	0.493	0.318	0.303	0.332	0.326
Fe/(Fe+Mg)	0.532	0.550	0.506	0.558	0.430	0.489	0.518	0.465

*Adjacent to garnet G2R and included within G2C, respectively.

Table 9. Selected amphibole analyses.

Sample	FS104B	FS104B	FS203C	FS203C	FS303D	FS303D	FS303D
Grain	A1	A2	A1	A3	A1	A2	A3
SiO_2	45.121	44.717	44.340	43.768	44.438	45.274	44.754
Al_2O_3	15.613	14.896	16.273	16.028	16.584	16.033	16.623
FeO	18.275	16.276	15.540	15.920	16.744	15.760	16.051
MgO	8.947	10.141	9.242	9.312	9.122	10.182	9.537
CaO	10.708	10.636	10.507	10.317	10.142	10.481	10.359
MnO	0.218	0.198	0.155	0.061	0.118	0.268	0.237
TiO_2	0.266	0.383	0.434	0.381	0.532	0.439	0.432
K_2O	0.572	0.508	—	0.384	0.360	0.402	0.405
Na_2O	1.504	1.577	1.532	1.641	1.467	1.461	1.519
Total	101.224	99.342	—	97.812	99.507	100.300	99.917
			Cations on the basis of 24 anions				
Si	6.191	6.207	6.245	6.150	6.141	6.185	6.146
Al	2.525	2.439	2.531	2.654	2.701	2.582	2.690
Fe	2.097	1.890	1.831	1.871	1.935	1.801	1.843
Mg	1.830	2.098	1.940	1.951	1.879	2.073	1.952
Ca	1.575	1.630	1.585	1.553	1.502	1.534	1.524
Mn	0.084	0.023	0.018	0.007	0.014	0.031	0.028
Ti	0.028	0.040	0.046	0.040	0.056	0.045	0.044
K	0.100	0.090	—	0.069	0.064	0.070	0.071
Na	0.400	0.424	0.419	0.447	0.394	0.387	0.405
$^{(VI)}Al$	0.716	0.646	0.776	0.804	0.842	0.767	0.836
Fe/(Fe+Mg)	0.534	0.474	0.486	0.490	0.507	0.465	0.486
Leake classification	ferroan pargasite	ferroan pargasite	—	ferroan pargasite	ferro-Tschermak -ite	alumino-Tschermak -ite	alumino-Tschermak ite

Table 10. Selected plagioclase analyses.

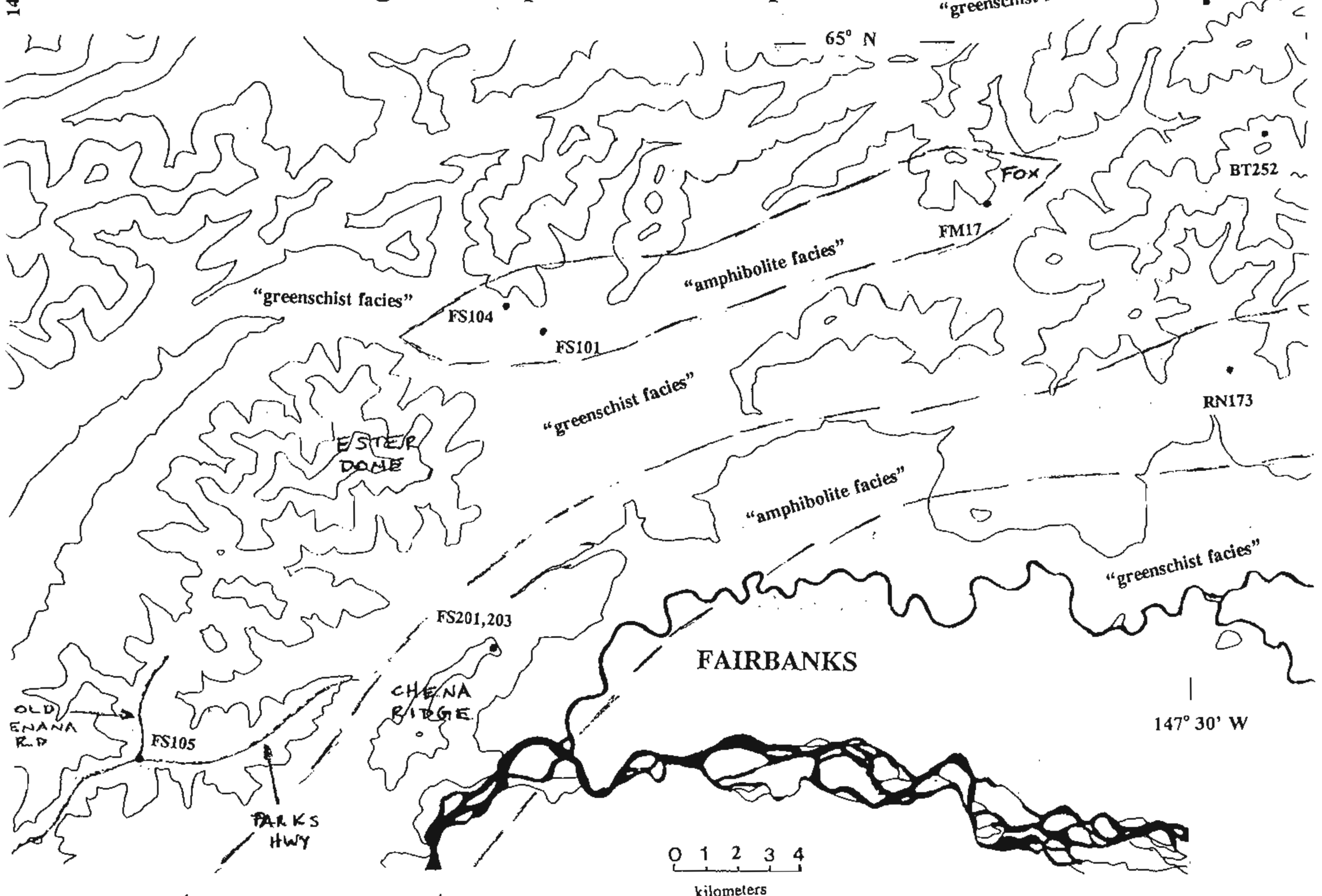
Sample	FM17	FM17	FS101C	FS101C	FS101C
Grain	P1	P3	P1	P2	P3
SiO_2	58.715	57.848	62.545	63.671	63.072
Al_2O_3	27.642	27.485	25.336	24.935	25.200
CaO	8.128	8.440	5.409	4.871	5.351
Na_2O	6.799	5.700	8.812	9.163	8.733
K_2O	0.073	0.122	0.140	0.070	0.118
Total	101.357	99.595	102.242	102.710	102.474
X_{An}	0.396	0.446	0.251	0.226	0.251
X_{Ab}	0.600	0.547	0.741	0.770	0.742
X_{Or}	0.004	0.008	0.008	0.004	0.007

Sample	FS104B	FS104H	FS201B	FS203C	FS303D
Grain	P2	P1	P2	P1	P1
SiO_2	62.724	64.088	67.548	62.818	60.910
Al_2O_3	24.760	24.410	23.132	26.017	26.547
CaO	4.502	4.324	2.988	6.373	7.090
Na_2O	8.720	9.300	10.322	8.217	7.814
K_2O	0.293	0.102	0.054	0.050	0.056
Total	100.999	102.224	104.044	103.475	102.417
X_{An}	0.218	0.203	0.137	0.299	0.333
X_{Ab}	0.765	0.791	0.860	0.698	0.664
X_{Or}	0.017	0.006	0.003	0.003	0.003

Table 11. Selected muscovite analyses.

Sample Grain	FM17 M1	FM17 M3	FS101C M1	FS101C M2	FS104H M1	FS201B M2
SiO_2	48.630	49.886	47.116	48.601	48.089	52.211
Al_2O_3	33.191	31.860	35.965	33.271	34.340	30.009
FeO	2.534	1.965	1.997	2.252	1.742	2.548
MgO	1.946	2.456	1.091	1.914	1.798	3.198
MnO	0.017	0.021	0.016	0.014	0.007	0.031
TiO_2	0.485	0.448	0.478	0.203	0.501	0.262
K_2O	10.315	10.552	10.856	10.973	10.186	10.376
Na_2O	0.569	0.631	0.682	0.532	0.840	0.470
CaO	0.023	0.005	0.010	0.007	0.020	0.010
Total	97.710	97.824	98.211	97.767	97.483	99.115
			Cations on the basis of 12 anions			
Si	3.168	3.239	3.065	3.171	3.128	3.342
Al	2.549	2.438	2.743	2.558	2.633	2.264
Fe	0.139	0.107	0.109	0.123	0.095	0.136
Mg	0.189	0.238	0.106	0.186	0.174	0.305
Mn	0.001	0.001	0.001	0.001	0.000	0.002
Ti	0.024	0.022	0.023	0.010	0.025	0.013
K	0.857	0.874	0.901	0.913	0.846	0.847
Na	0.072	0.080	0.086	0.068	0.106	0.058
Ca	0.006	0.000	0.001	0.000	0.001	0.001
$^{(VI)}Al$	1.717	1.677	1.808	1.729	1.761	1.606
$X_{muscovite}$	0.764	0.751	0.805	0.785	0.761	0.728
$X_{paragonite}$	0.064	0.069	0.077	0.058	0.095	0.050

Fig 1: Sample location map



Metamorphic facies designations from Robinson et al. (1990)