

MATERIAL FOR GSA DATA REPOSITORY ITEM 9912

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METAMORPHIC HISTORY OF THE SHEAR ZONES

Mafwewu Hills

Garnet in the wallrock (grt_1) is poikiloblastic with inclusions of kyanite, plagioclase, hornblende, rutile, apatite and quartz. Garnet composition generally varies between alm_{47-54} , ppr_{32-41} , grs_{7-13} , sps_{0-2} (mineral abbreviations after Kretz, 1983) and andradite between 0–5% (Table A). In a few analysed cores, the grossular component is high (grs_{17-21}). Those garnets have tiny coronas with retrograde, anorthite-rich plagioclase (up to An_{71}) around them and probably reflect an earlier, high-pressure history of the metapelite. Garnet is slightly zoned with an increasing Fe/Mg ratio at the outermost ~0.3 mm. In that part of the profile in which the Fe/Mg ratio has been modified by net-transfer reactions with biotite, the grossular component of the garnet drops. Kyanite occurs as large (up to 5 mm long) crystals in which inclusions of plagioclase, biotite, rutile and quartz are common. Kyanite grew at the expense of garnet, but also formed with biotite from potassium feldspar and hornblende. Biotite is the only OH-bearing major rock-forming mineral (Table B). The composition of plagioclase in the matrix ranges from An_{28-36} (Table C). Plagioclase locally includes kyanite and quartz poikiloblastically. Hornblende is a minor constituent in some samples and has ferroan pargasitic composition (Table D).

Metamorphically the mylonitisation of the metapelite is characterized by the conversion of large kyanite crystals to fibrolitic sillimanite. Garnet is marginally replaced by biotite, plagioclase, and sillimanite. Plagioclase, potassium feldspar and rare cordierite also become unstable and are converted mainly to sillimanite, quartz, opaques and rare biotite. Most of these reactions are not isochemical, especially Si, Na, K and Ca have been removed from the local system (see also below). Continued mylonitisation, giving rise to mylonite II, is then characterized by almost complete breakdown of feldspar and biotite to form sillimanite, quartz and opaques (Table 1). Most OH-bearing minerals (mainly biotite, but also muscovite and hornblende) have been transformed to water-free minerals (i.e. basically sillimanite, garnet, quartz and opaques). In the course of mylonite II development, element mobility is of particular importance (Table 2).

Mkamasa River

The rare garnet (grt_1) in the wallrock varies in composition between alm_{45-62} , ppr_{30-41} , grs_{5-13} , sps_{1-4} (and andradite between 0%–5%, Table E) and has few inclusions of biotite, opaques, plagioclase and quartz. Garnet is zoned with an increasing Fe/Mg ratio, an increase in the spessartine component and a decrease in the grossular component at the outermost ~0.4 mm. Biotite is again the only OH-bearing major rock-forming mineral (Table F). The composition of plagioclase ranges from An_{38-44} (Table G). Muscovite and hornblende are minor constituents in some samples. Hornblende has ferroan pargasitic composition (Table H).

Mylonitisation of the gneiss is petrographically characterized by the incipient breakdown of feldspar, as well as biotite and muscovite. Garnet is occasionally replaced along its margins by sillimanite, biotite and plagioclase. The latter two, as well as potassium feldspar are converted into sillimanite, quartz and opaques. The development of mylonite II is then characterized by the almost complete breakdown of feldspar and biotite to form sillimanite (sil_2), quartz, and opaques (Table 3). Almost all OH-bearing minerals (mainly biotite, but also muscovite and hornblende) have been transformed to sillimanite, garnet, quartz and opaques.

Table A: Mafwewu Hills; representative garnet analyses

	Ka33	Ka33	Ka34	Ka34	Ka35	Ka36	Ka36	Ka30	Ka30
SiO ₂	39.00	38.68	38.43	38.78	37.63	38.57	38.78	38.72	38.51
TiO ₂	0.02	0.03	—	0.03	—	0.03	0.01	0.07	0.06
Cr ₂ O ₃	0.03	0.04	0.02	0.04	0.03	—	—	0.02	0.04
Al ₂ O ₃	22.25	21.62	21.86	21.83	21.78	21.81	21.73	22.10	21.89
Fe ₂ O ₃	0.92	1.58	1.73	1.34	2.05	1.94	1.19	1.21	0.92
FeO	24.75	24.63	24.38	24.18	26.48	26.50	27.23	26.98	27.09
MnO	0.51	0.87	0.88	0.91	0.59	0.69	0.62	1.21	1.39
MgO	10.20	9.41	9.48	9.69	7.44	9.31	8.87	9.74	9.86
CaO	2.98	3.61	3.77	3.65	4.84	2.58	2.53	1.44	1.38
Na ₂ O	0.02	0.01	—	—	—	0.03	0.03	—	—
Total	100.68	100.47	100.55	100.45	100.84	101.45	101.15	101.47	101.14
<i>Atoms on the basis of 8 cations</i>									
Si	2.957	2.957	2.933	2.957	2.901	2.933	2.975	2.937	2.938
Ti	0.001	0.002	—	0.002	—	0.002	0.001	0.006	0.005
Cr	0.002	0.002	0.001	0.002	0.002	—	—	0.001	0.002
Al	1.988	1.948	1.967	1.962	1.978	1.955	1.956	1.986	1.967
Fe ³⁺	0.052	0.091	0.099	0.077	0.119	0.111	0.068	0.069	0.052
Fe ²⁺	1.569	1.575	1.556	1.542	1.707	1.686	1.739	1.711	1.720
Mn	0.033	0.056	0.057	0.059	0.039	0.044	0.040	0.080	0.091
Mg	1.152	1.072	1.078	1.101	0.855	1.055	1.010	1.101	1.112
Ca	0.242	0.296	0.308	0.298	0.340	0.210	0.207	0.129	0.113
Na	0.004	0.001	—	—	—	0.005	0.005	—	—

Ka33, Ka34 and Ka35 are wallrocks

Ka36 is a mylonite I

Ka30 is a mylonite II

Table B: Mafwewu Hills; biotite analyses

	Ka33	Ka33	Ka33	Ka33	Ka34	Ka34
SiO ₂	36.17	36.14	35.48	36.03	35.82	35.45
TiO ₂	2.09	1.93	2.32	1.99	2.28	2.18
Cr ₂ O ₃	0.06	—	0.03	0.06	0.04	0.01
Al ₂ O ₃	19.18	19.50	18.13	18.57	17.82	18.38
FeO	14.11	14.14	14.92	15.02	14.76	15.50
MnO	0.06	0.19	0.23	0.24	0.18	0.14
MgO	12.60	12.94	12.56	12.66	12.93	12.42
CaO	0.02	0.03	—	0.10	—	0.03
Na ₂ O	0.13	0.17	0.17	0.21	0.19	0.16
K ₂ O	9.70	9.08	9.96	9.72	9.87	9.91
H ₂ O	3.90	3.93	3.86	3.90	3.87	3.87
Total	<u>98.00</u>	<u>98.04</u>	<u>97.65</u>	<u>98.50</u>	<u>97.75</u>	<u>98.06</u>
<i>Atoms on the basis of 7 cations</i>						
Si	2.781	2.754	2.759	2.769	2.776	2.746
Ti	0.121	0.110	0.135	0.114	0.132	0.126
Cr	0.004	—	0.002	0.004	0.002	0.001
Al	1.738	1.751	1.661	1.681	1.627	1.678
Fe ²⁺	0.907	0.901	0.970	0.965	0.956	1.004
Mn	0.004	0.012	0.015	0.015	0.012	0.010
Mg	1.444	1.469	1.455	1.450	1.493	1.433
Ca	0.002	0.002	—	0.008	—	0.002
Na	0.019	0.024	0.025	0.031	0.029	0.024
K	0.951	0.882	0.988	0.953	0.975	0.979

Ka33 and Ka34 are wallrocks

Table C: Mafwewu Hills; representative plagioclase analyses

	Ka33	Ka33	Ka34	Ka34	Ka34	Ka36	Ka36	Ka30	Ka30
SiO ₂	61.12	59.63	59.43	60.60	59.77	60.71	62.15	60.88	60.58
Al ₂ O ₃	25.06	25.14	25.76	24.58	24.87	25.96	24.41	23.92	25.12
Fe ₂ O ₃	0.23	0.16	—	0.03	0.07	0.08	0.10	0.04	0.12
CaO	6.56	6.65	7.26	6.30	6.92	6.52	5.55	5.09	5.11
Na ₂ O	7.82	7.63	7.23	7.75	7.52	7.81	7.83	8.52	8.38
K ₂ O	0.02	0.02	0.14	0.33	--0.31	0.23	0.15	0.26	0.18
Total	<u>100.82</u>	<u>99.23</u>	<u>99.82</u>	<u>99.61</u>	<u>99.47</u>	<u>101.31</u>	<u>100.18</u>	<u>98.70</u>	<u>99.49</u>
<i>Atoms on the basis of 8 cations</i>									
Si	2.702	2.677	2.659	2.710	2.679	2.702	2.767	2.738	2.731
Al	1.306	1.330	1.358	1.296	1.314	1.301	1.281	1.268	1.303
Fe ³⁺	0.008	0.006	—	0.001	0.003	0.003	0.004	0.001	0.005
Ca	0.311	0.320	0.348	0.302	0.332	0.306	0.265	0.230	0.222
Na	0.671	0.664	0.627	0.672	0.654	0.673	0.676	0.747	0.729
K	0.001	0.001	0.008	0.019	0.018	0.013	0.008	0.015	0.009
<i>Mol%</i>									
Ab	68.3	67.4	63.8	67.7	65.1	67.9	71.2	78.3	78.1
An	31.6	32.5	35.4	30.4	33.1	30.5	27.9	20.2	20.8
Or	0.1	0.1	0.8	1.9	1.8	1.6	0.9	1.5	1.1

Ka33 and Ka34 are wallrocks

Ka36 is a mylonite I

Ka30 is a mylonite II

Table D: Mafwewu Hills; representative hornblende analyses

	Ka33	Ka33	Ka34	Ka34	Ka36	Ka36	Ka30	Ka30
SiO ₂	39.23	39.91	39.81	38.95	39.52	39.73	38.97	38.91
TiO ₂	1.57	1.58	1.59	1.39	1.63	1.32	1.68	1.59
Cr ₂ O ₃	--	0.02	--	--	0.02	--	0.02	0.02
Al ₂ O ₃	12.07	11.89	12.13	11.89	12.27	11.48	12.09	12.28
Fe ₂ O ₃	14.88	12.86	14.65	15.01	12.98	12.84	12.54	11.92
FeO	8.17	9.00	8.54	7.76	10.29	10.38	10.99	10.09
MnO	0.93	0.90	0.89	0.85	0.92	0.91	0.81	0.99
MgO	7.13	7.40	7.12	7.25	6.75	7.49	8.64	8.73
CaO	11.14	11.05	11.03	11.28	11.12	11.37	10.34	10.51
Na ₂ O	1.59	1.48	1.54	1.55	1.40	1.13	1.09	1.15
K ₂ O	2.00	1.86	1.99	2.10	2.06	1.70	1.48	1.52
H ₂ O	1.98	1.98	1.98	1.97	1.98	1.96	1.96	1.96
Total	<u>100.69</u>	<u>99.91</u>	<u>100.65</u>	<u>100.01</u>	<u>100.94</u>	<u>100.31</u>	<u>100.61</u>	<u>99.67</u>
<i>Atoms on the basis of 15 cations</i>								
Si	5.937	6.058	5.935	5.937	5.984	6.057	5.944	5.936
Ti	0.179	0.180	0.181	0.159	0.186	0.142	0.190	0.180
Cr	--	0.003	--	--	0.002	--	0.002	0.002
Al	2.153	2.127	2.166	2.135	2.190	2.059	2.134	2.188
Fe ³⁺	1.695	1.469	1.670	1.722	1.479	1.468	1.494	1.452
Fe ²⁺	1.038	1.142	1.082	0.990	1.303	1.299	1.311	1.300
Mn	0.119	0.116	0.114	0.109	0.118	0.107	0.107	0.110
Mg	1.610	1.673	1.609	1.647	1.523	1.699	1.795	1.851
Ca	1.807	1.797	1.790	1.843	1.805	1.853	1.713	1.755
Na	0.466	0.435	0.453	0.458	0.410	0.326	0.305	0.322
K	0.385	0.359	0.386	0.409	0.398	0.322	0.291	0.295

Ka33 and Ka34 are wallrocks

Ka36 is a mylonite I

Ka30 is a mylonite II

Table E: Mkamasa River; representative garnet analyses

	Ka38	Ka38	Ka40	Ka40	Ka39	Ka39
SiO ₂	39.23	38.76	38.71	38.51	37.82	38.74
TiO ₂	0.04	—	—	0.06	0.07	—
Cr ₂ O ₃	0.06	—	—	—	0.01	—
Al ₂ O ₃	21.81	22.10	21.80	21.99	22.25	21.99
Fe ₂ O ₃	0.47	1.10	1.14	1.34	1.52	0.59
FeO	23.59	23.22	24.18	25.75	26.62	27.53
MnO	0.54	0.49	0.91	0.55	0.57	0.60
MgO	10.50	10.85	9.69	9.32	8.67	8.25
CaO	3.10	3.12	3.15	3.17	3.21	3.02
Na ₂ O	0.01	0.02	0.03	—	0.02	—
Total	<u>100.45</u>	<u>99.65</u>	<u>99.61</u>	<u>100.70</u>	<u>100.77</u>	<u>100.72</u>
<i>Atoms on the basis of 8 cations</i>						
Si	3.002	2.953	2.950	2.941	2.898	2.975
Ti	0.002	—	—	0.004	0.004	0.001
Cr	0.004	—	—	—	0.001	—
Al	1.967	1.984	1.992	1.979	2.009	1.956
Fe ³⁺	0.027	0.063	0.062	0.077	0.088	0.028
Fe ²⁺	1.510	1.479	1.542	1.645	1.706	1.789
Mn	0.035	0.032	0.059	0.036	0.037	0.039
Mg	1.197	1.232	1.091	1.061	0.990	0.929
Ca	0.254	0.255	0.246	0.259	0.263	0.241
Na	0.002	0.003	0.004	—	0.003	—

Ka38 and Ka40 are wallrocks

Ka39 is mylonite I

Table F: Mkamasa River; biotite analyses

	Ka38	Ka38	Ka38	Ka38	Ka38	Ka40	Ka40	Ka40
SiO ₂	37.88	37.63	36.94	37.45	37.34	37.13	37.22	37.63
TiO ₂	2.67	3.24	3.37	3.26	3.31	3.17	3.10	3.25
Cr ₂ O ₃	0.12	0.14	0.12	0.12	0.12	0.13	0.09	0.11
Al ₂ O ₃	16.67	16.21	16.24	16.12	15.88	15.78	16.15	16.36
FeO	12.51	14.75	14.31	15.45	14.30	14.90	14.10	14.63
MnO	0.02	0.03	0.01	0.05	0.03	—	0.06	—
MgO	15.11	14.28	14.59	14.53	14.68	14.86	14.80	14.69
CaO	—	—	—	0.01	—	—	0.04	—
Na ₂ O	0.37	0.33	0.46	0.36	0.40	0.38	0.44	0.40
K ₂ O	9.37	9.20	9.06	9.05	9.36	9.02	8.83	9.11
H ₂ O	3.97	3.98	3.96	4.01	3.96	3.97	3.97	4.01
Total	<u>98.69</u>	<u>99.79</u>	<u>99.07</u>	<u>100.40</u>	<u>99.41</u>	<u>99.31</u>	<u>98.82</u>	<u>100.18</u>
<i>Atoms on the basis of 7 cations</i>								
Si	2.862	2.834	2.797	2.800	2.824	2.801	2.814	2.815
Ti	0.152	0.183	0.191	0.183	0.188	0.179	0.176	0.182
Cr	0.007	0.008	0.007	0.007	0.008	0.006	0.006	0.006
Al	1.485	1.439	1.449	1.421	1.416	1.403	1.439	1.442
Fe ²⁺	0.790	0.929	0.906	0.966	0.905	0.939	0.891	0.915
Mn	—	—	—	0.003	0.002	—	0.004	—
Mg	1.702	1.603	1.646	1.619	1.655	1.670	1.667	1.638
Ca	—	—	—	0.001	—	—	0.004	—
Na	0.054	0.048	0.067	0.052	0.059	0.056	0.064	0.058
K	0.903	0.883	0.875	0.863	0.903	0.868	0.852	0.869

Ka38 and Ka40 are wallrocks

Table G: Mkamasa River; representative plagioclase analyses

	Ka38	Ka38	Ka40	Ka40	Ka39	Ka39	Ka39
SiO ₂	58.96	58.07	58.77	57.11	57.70	57.55	56.41
Al ₂ O ₃	26.54	26.27	26.21	26.09	26.99	26.89	27.87
Fe ₂ O ₃	0.01	0.08	0.07	0.32	0.27	0.08	0.26
CaO	8.12	8.47	8.40	8.33	9.21	9.26	10.17
Na ₂ O	6.85	6.99	6.81	6.66	6.22	6.20	5.62
K ₂ O	0.06	0.01	0.08	0.13	0.08	0.10	0.08
Total	<u>100.68</u>	<u>99.90</u>	<u>100.34</u>	<u>98.64</u>	<u>100.48</u>	<u>100.07</u>	<u>100.40</u>
<i>Atoms on the basis of 8 oxygens</i>							
Si	2.622	2.598	2.621	2.592	2.580	2.583	2.532
Al	1.391	1.385	1.378	1.395	1.423	1.422	1.475
Fe ³⁺	0.005	0.003	0.003	0.011	0.010	0.003	0.010
Ca	0.387	0.406	0.402	0.405	0.441	0.445	0.489
Na	0.591	0.607	0.589	0.586	0.540	0.540	0.489
K	0.004	0.001	0.005	0.008	0.005	0.006	0.004
<i>Mol%</i>							
Ab	60.2	59.9	59.2	58.7	55.8	54.5	49.8
An	39.4	40.0	40.4	40.6	44.8	45.0	49.8
Or	0.4	0.1	0.4	0.7	0.5	0.6	0.4

Ka38 and Ka40 are from the wallrock

Ka39 is mylonite I

Table H: Mkamasa River; representative hornblende analyses

	Ka38	Ka38	Ka38	Ka39	Ka39
SiO ₂	40.28	39.01	39.85	38.67	39.42
TiO ₂	1.10	1.48	1.43	1.08	1.60
Cr ₂ O ₃	—	—	—	0.04	—
Al ₂ O ₃	11.66	12.05	12.07	11.67	12.20
Fe ₂ O ₃	13.85	14.26	14.37	15.39	13.98
FeO	9.13	8.72	8.55	7.91	9.01
MnO	0.86	0.77	0.82	0.73	0.82
MgO	7.35	7.13	7.27	7.57	6.75
CaO	11.14	11.11	10.97	11.10	11.12
Na ₂ O	1.41	1.47	1.62	1.47	1.49
K ₂ O	1.75	2.03	1.89	1.77	1.86
H ₂ O	1.98	1.97	1.99	1.98	1.98
Total	100.50	100.00	100.83	100.39	100.23
<i>Atoms on the basis of 15 cations</i>					
Si	6.088	5.948	6.005	6.003	5.989
Ti	0.125	0.170	0.162	0.123	0.180
Cr	—	—	—	0.005	—
Al	2.076	2.166	2.144	2.082	2.167
Fe ³⁺	1.575	1.636	1.629	1.752	1.551
Fe ²⁺	1.154	1.111	1.078	1.002	1.110
Mn	0.110	0.100	0.104	0.094	0.091
Mg	1.655	1.620	1.634	1.707	1.511
Ca	1.804	1.815	1.771	1.800	1.812
Na	0.414	0.433	0.473	0.433	0.410
K	0.338	0.395	0.364	0.341	0.368

Ka38 is from wallrock

Ka39 is mylonite I