Mineral compositions from Darondi rocks, central Nepal

Plagioclase rim compositions

Sample	DH17	DH19	DH22	DH23	DH26	DH38	DH58
XAn	0.12	0.23	0.19	0.20	0.13	0.32	0.19
XAlb	0.88	0.77	0.80	0.79	0.86	0.68	0.80
XOr	0.00	0.00	0.01	0.01	0.01	0.00	0.01

Sample	DH60	DH61	DH63	DH66	DH67	DH71	DH75a	DH75b
XAn	0.21	0.27	0.21	0.30	0.31	0.026	0.19	0.14
XAlb	0.78	0.72	0.78	0.69	0.68	0.971	0.80	0.86
XOr	0.01	0.01	0.01	0.01	0.01	0.003	0.01	0.00

Garnet Minimum-Mn compositions

Sample	DH17	DH19	DH22	DH23	DH26	DH30	DH38	DH57	DH58
XPrp	0.064	0.064	0.068	0.073	0.081	0.095	0.099	0.171	0.108
XAlm	0.774	0.788	0.807	0.783	0.713	0.870	0.641	0.771	0.724
XSps	0.092	0.039	0.060	0.045	0.158	0.002	0.071	0.005	0.022
XGrs	0.070	0.110	0.065	0.099	0.048	0.033	0.189	0.053	0.146
Fe/(Fe+Mg)	0.923	0.925	0.922	0.915	0.898	0.902	0.866	0.818	0.870

Sample	DH58*	DH60	DH61	DH63	DH66	DH67	DH71	DH75a	DH75b
XPrp	0.116	0.127	0.145	0.165	0.113	0.135	0.136	0.085	0.102
XAlm	0.549	0.710	0.652	0.708	0.586	0.619	0.813	0.773	0.837
XSps	0.130	0.048	0.082	0.026	0.124	0.098	0.036	0.003	0.004
XGrs	0.204	0.115	0.121	0.101	0.177	0.148	0.015	0.139	0.058
Fe/(Fe+Mg)	0.825	0.848	0.818	0.811	0.838	0.821	0.857	0.901	0.891

* Minimum Fe/(Fe+Mg) garnet composition, which is different from the minimum-Mn in garnets from this rock.

Mica/Amphibole compositions

Sample	DH17 Bt	DH17 Ms	DH19 Bt	DH19 Ms	DH22 Bt	DH22 Ms	DH23 Bt	DH23 Ms
Si	2.698	3.074	2.701	3.036	2.697	3.055	2.680	3.09
Al	1.777	2.796	1.753	2.868	1.744	2.853	1.718	2.763
Ti	0.056	0.013	0.081	0.012	0.087	0.016	0.094	0.013
Mg	0.946	0.064	0.942	0.044	0.907	0.048	0.910	0.08
Fe2+	1.424	0.089	1.393	0.072	1.472	0.062	1.426	0.091
Mn	0.006	0.001	0.008	0	0.006	0	0.006	0.003
Ca	0.002	0	0	0	0.006	0.003	0.000	0.001
Na	0.017	0.18	0.029	0.149	0.029	0.182	0.028	0.182
K	0.885	0.778	0.897	0.821	0.823	0.75	0.892	0.771
Fe/(Fe+Mg)	0.601	0.582	0.597	0.621	0.619	0.564	0.610	0.532

Sample	DH26 Bt	DH26 Ms	DH38 Hb	DH57 Bt	DH57 Ms	DH-58 Bt	DH-58 Ms	DH-60 Bt
Si	2.716	3.052	6.386	2.753	3.093	2.778	3.132	2.730
Al	1.709	2.851	2.807	1.717	2.767	1.626	2.635	1.678
Ti	0.091	0.015	0.042	0.099	0.027	0.126	0.046	0.140
Mg	1.08	0.070	1.886	1.229	0.092	1.088	0.116	1.158
Fe2+	1.277	0.063	2.033	1.092	0.066	1.222	0.123	1.132
Mn	0.008	0	0.036	0	0.002	0.014	0	0.006
Ca	0	0	1.778	0	0	0	0	0.002
Na	0.015	0.190	0.35	0.039	0.118	0.024	0.114	0.030
K	0.901	0.723	0.051	0.762	0.781	0.834	0.792	0.858
Fe/(Fe+Mg)	0.542	0.474	0.519	0.470	0.418	0.529	0.515	0.494

Sample	DH60 Ms	DH61 Bt	DH63 Bt	DH63 Ms	DH66 Bt	DH66 Ms	DH67 Bt	DH67 Ms
Si	3.077	2.772	2.728	3.061	2.734	3.075	2.691	3.159
Al	2.754	1.588	1.684	2.773	1.659	2.691	1.718	2.567
Ti	0.038	0.115	0.101	0.032	0.099	0.052	0.096	0.039
Mg	0.098	1.371	1.243	0.073	1.205	0.093	1.239	0.153
Fe2+	0.082	1.007	1.119	0.100	1.166	0.13	1.154	0.132
Mn	0	0.026	0.004	0	0.01	0.001	0.017	0.002
Ca	0.003	0	0	0	0	0.001	0.004	0
Na	0.091	0.024	0.050	0.226	0.029	0.112	0.014	0.097
K	0.826	0.859	0.847	0.737	0.898	0.856	0.851	0.835
Fe/(Fe+Mg)	0.456	0.423	0.474	0.577	0.492	0.583	0.482	0.463

Sample	DH75a Bt	DH75a Ms	DH75b Bt	DH75b Ms	DH30 Bt	DH71 Bt	DH71 Ms
Si	2.729	3.031	2.799	3.134	2.792	2.743	3.099
Al	1.729	2.852	1.684	2.709	1.668	1.706	2.728
Ti	0.091	0.017	0.084	0.012	0.09	0.081	0.023
Mg	1.026	0.085	1.046	0.066	1.011	1.069	0.072
Fe2+	1.322	0.096	1.228	0.063	1.284	1.259	0.092
Mn	0.004	0.002	0	0	0.001	0.005	0.001
Ca	0.001	0.001	0	0	0	0.001	0
Na	0.04	0.236	0.059	0.238	0.052	0.048	0.325
K	0.79	0.653	0.81	0.796	0.821	0.87	0.675
Fe/(Fe+Mg)	0.563	0.530	0.540	0.488	0.559	0.541	0.561

Note: Biotite Fe/(Fe+Mg) in GHS sample DH60 increases by ~0.05 next to garnet, likely as a result of retrograde garnet dissolution (estimated at 13% dissolved from the original grains). However, biotite compositions are nearly constant •1 mm away; the composition reported is for biotite ~1 mm away. In other samples, biotite Fe/(Fe+Mg) is more nearly constant (to ±0.01), but is likely affected by retrograde reaction of the garnet, causing an increase in Fe. The importance of this effect can be evaluated from consideration of Mn-zoning profiles (Kohn and Spear, in press). The amount of garnet dissolution (in %) and estimated change to matrix biotite composition is: DH17 = 0, 0.00; DH19 = 0, 0.00; DH-22 = 0, 0.00; DH-23 = 0, 0.00; DH-26 = 0, 0.00; DH-57 = 0, 0.00; DH-58 = 45, 0.12; DH61 = 10, 0.00; DH-63 = 4, <0.01; DH-66 = 0.00; DH-67 = 10, <0.01; DH75a = 0, 0.00; DH-75b = 20, 0.04; DH-30 = 0, 0.00; DH-71 = 8, <0.01, with the original matrix biotite having a more Mg-rich composition than the current biotite. Note that a change in biotite Fe/(Fe+Mg) of 0.01 changes T by ~10-15 •C.

Mineral compositions and P-T path models of Darondi rocks, central Nepal

DH17	Grt Rim	Grt Core	Pl Rim	Pl Core	Biot	Chl	Ms
XMg	0.064	0.048			0.398	0.417	
XFe	0.774	0.684			0.599	0.579	
XMn	0.092	0.149			0.003	0.004	
XCa	0.070	0.119	0.125	0.230			
XNa			0.875	0.770			0.19
XK							0.81

DH19	Grt Rim	Grt Core	Pl Rim	Pl Core	Biot	Chl	Ms
XMg	0.064	0.034			0.402	0.415	
XFe	0.788	0.608			0.595	0.582	
XMn	0.039	0.188			0.003	0.003	
XCa	0.110	0.170	0.230	0.260			
XNa			0.770	0.740			0.15
XK							0.85

DH22	Grt Rim	Grt Core	Pl Rim	Pl Core	Biot	Chl	Ms
XMg	0.068	0.047			0.389	0.410	
XFe	0.807	0.692			0.610	0.588	
XMn	0.060	0.147			0.001	0.002	
XCa	0.065	0.115	0.19	0.19			
XNa			0.81	0.81			0.175
XK							0.825

DH23	Grt Rim	Grt Int.	Grt Core	Pl Rim	Pl Core	Biot	Chl	Ms
XMg	0.073	0.058	0.036			0.389	0.423	
XFe	0.783	0.732	0.631			0.609	0.574	
XMn	0.045	0.058	0.164			0.002	0.003	
XCa	0.099	0.151	0.169	0.200	0.220			
XNa				0.800	0.780			0.19
XK								0.81

DH26	Grt Rim	Grt Core	Pl Rim	Pl Core	Biot	Chl	Ms
XMg	0.081	0.074			0.455	0.479	
XFe	0.713	0.682			0.542	0.516	
XMn	0.158	0.175			0.003	0.005	
XCa	0.048	0.070	0.130	0.130			
XNa			0.870	0.870			0.18
XK							0.82

DH75a	Grt Rim	Grt Int.	Grt Core	Pl Rim	Pl Core	Biot	Chl	Ms
XMg	0.088	0.060	0.041			0.436	0.446	
XFe	0.771	0.764	0.693			0.563	0.552	
XMn	0.006	0.010	0.067			0.001	0.002	
XCa	0.135	0.165	0.199	0.19	0.21			
XNa				0.81	0.79			0.25
XK								0.75

DH75b	Grt Rim	Grt Int.	Grt Core	Pl Rim	Pl Core	Biot	Chl	Ms
XMg	0.150	0.102	0.064			0.515	0.522	
XFe	0.751	0.729	0.612			0.484	0.476	
XMn	0.016	0.037	0.157			0.001	0.002	
XCa	0.084	0.132	0.167	0.20	0.21			
XNa				0.80	0.79			0.14
XK								0.86

All rocks were modeled with the observed solid assemblage Grt + Bt + Chl + Ms + Pl + Qtz in the MnNCKFMASH system. Compositional changes were derived from garnet and plagioclase compositional zoning produced as the garnet grew. A pure H_2O fluid at lithostatic pressure was also assumed to have been present. Activity models do not significantly affect the trends of retrieved P-T paths (Kohn, 1993), and all mineral solutions were assumed to be ideal, excepting garnet for which the Berman (1990) activity model was assumed. No staurolite, chloritoid, or carbonate minerals are present in these samples, either as matrix minerals or as inclusions in the garnet, nor do they occur in sub-garnet-grade rocks down section. The chemical zoning in the garnet is smooth and typical of garnet growth in the observed assemblage. Most plagioclase grains show core-rim zoning with higher-Ca cores and lower-Ca rims. This is also the expected consequence of garnet growth and fractional crystallization in a closed chemical system, as growth of garnet depletes the remaining matrix in Ca (Spear et al., 1990). Plagioclase grains in samples DH26 and DH75a/b are anomalous in that they have albite cores, that are overgrown by an oligoclase mantle that is either unzoned or slightly zoned to lower Ca towards its rim. Detrital albite grains are observed in lower-grade samples, and so we assume the albite cores in DH26 and DH75a/b are relict, that their oligoclase rims reflect metamorphic plagioclase growth, and that the decrease in X_{An} towards rims reflects garnet growth. If alternatively no change in plagioclase composition were assumed for these two samples, the calculated core pressures would be slightly higher, yielding similar exhumation paths. For some samples, an intermediate garnet composition was also used in the P-T path calculations to better account for non-linearity in the garnet zoning pattern. Paths can be equivalently modeled by using either four independently measured chemical components or two independent components coupled with mass balance constraints.

Monazite ion microprobe results from rocks collected along the Darondi drainage in central Nepal.

Sample (monazite_spot)*	Age (Ma) (±1σ)	Weighted Mean Age (Ma)† (±1σ)	MSWD‡
DH58a		n.c.	n.c.
5a_1	21.6 (1.5)		
5a_2	366 (21)		
DH71			
68_1§	21.1 (0.8)	21.3 (0.7)	0.2
67_1§	21.7 (1.2)		
DH73			
72_1§	11.9 (0.6)	12.0 (0.3)	1.5
73_1§	14.6 (1.5)		
73_2§	11.9 (0.4)		
DH51			
108_1§	10.6 (1.2)	10.4 (0.3)	8.3
111_1§	9.9 (1.2)		
109_1§	9.2 (1.8)		
110_1§	10.6 (0.4)		
112a_1	9.4 (1.1)		
113_1	10.1 (2.7)		
DH39			
1_1	9.8 (1.3)	8.9 (0.7)	0.7
2_1	9.8 (1.6)		
3_1	8.2 (0.9)		
DH30			
84_1§	7.8 (0.9)	7.9 (0.2)	3.3
87_1	7.7 (0.4)		
87_2	6.9 (0.5)		
6_1§	8.9 (0.7)		
7_1§	9.3 (0.5)		
86_1	7.8 (0.7)		
DH75B			
79sp1§	7.6 (0.2)	7.9 (0.1)	10.2
78sp1§	7.8 (0.2)		
77sp1§	10.3 (0.9)		
82sp1§	11.1 (0.7)		

* The nomenclature indicates the grain and spot, respectively, of the analyzed monazite.
† Weighted mean age, using 1σ error, of all monazite analyses from this sample; n.c. = not calculated.
‡ Mean square weighted deviation using 1σ error; n.c.=not calculated.
§ Monazite inclusion in garnet.
Note: Samples analyzed using the method of Harrison et al. (1995). For sample DH58a, the one old age may reflect an earlier Paleozoic event or possibly Pb-loss from an even older event, and was not used for estimating an age for Miocene metamorphism.

Mineral assemblages and textures of Darondi rocks, central Nepal

	Grt	Chl	St	Ky	Pl	Garnet Textures
DH16	X	X			X	Crosscuts(?) main fol'n; weak P-shadow
DH17	X	X			X	Crosscuts(?) main fol'n; weak P-shadow
DH19	X	X			X	Spiral inclusion trails at angle to main fol'n; P-shadows
DH22	X	X			X	Cross-cuts main fol'n; inclined inclusion trails
DH23	X	X			X	Cross-cuts main fol'n
DH26	X	X			X	Main fol'n warped around garnets
DH28	X	X			X	Spiral inclusion trails in cores; rims overprint fabric
DH30	X	X				Straight inclusion trails in core, inclined to outer main fol'n; rims overprint(?) outer foliation
DH75	X	X/R			X	Well-developed spiral inclusion trails, subparallel to outer main fol'n at rim; well-developed P-shadows
DH33	X	X, R				Crosscuts main fol'n
DH38	X	X, R			X	Crosscuts hornblende
DH39	X	R				Crosscuts main fol'n; weak P-shadows; asymmetric chlorite alteration tails
DH49	X			X		Sigmoidal inclusion trails - may reflect overgrowth of earlier folds
DH51	X		X	X		Well-developed P-shadows
DH73	X		X	X		Overprints earlier fabric; fol'n warped around garnets
DH57	X	R	X	X		Inclined inclusion trails in core; well-developed P-shadow; inclusions near rim parallel to crystal faces; rim overprints(?) matrix.
DH71	X	R			X	Sigmoidal inclusion trails in core; fol'n warped around garnets
DH58	X	R			X	Sigmoidal inclusion trails in cores; strongly resorbed
DH60	X				X	Overprints fol'n; fol'n warped around garnets
DH61	X				X	Crosscuts main fol'n; fol'n warped around garnets
DH66	X				X	Crosscuts main fol'n; fol'n warped around garnets
DH67	X				X	Crosscuts main fol'n; fol'n warped around garnets
DH62	X	R			X	Fol'n warped around garnets
DH63	X		X		X	Crosscuts main fol'n

Note: All samples contain prograde quartz, muscovite, biotite and ilmenite. Sample DH-38 also contains hornblende (it is a metabasite). Sample DH-49 was collected near DH-51. Sample DH-56 was collected between and slightly below DH-57 and DH-71. X = a prograde mineral; R = a retrograde mineral; X,R = both prograde and retrograde present; X/R = present, but prograde/retrograde distinction unclear. P-shadow = pressure shadow; fol'n = foliation.