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HIGH PRESSURE METAMORPHIC CONDITIONS IN GARNET AMPHIBOLITE FROM A COLLISIONAL SHEAR ZONE RELATED TO THE TAPO ULTRAMAFIC BODY, EASTERN CORDILLERA OF CENTRAL PERU

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INTRODUCTION AND SETTING

A discontinuos belt of elongated ultramafic rock bodies (mostly serpentinites) occurs in the Eastern Cordillera of the central Peruvian Andes. One of the main occurrences is the Tapo Massif, a lense-shaped serpentinite body, ~2 km x 5 km, comprising small podiform chromitite deposits (Castroviejo et al., 2009) and bands or lenses of garnet-amphibolite, both strongly sheared and thrust upon the upper Paleozoic sediments of the Ambo Group (Fig. 1). Metabasite geochemistry suggests a mid-ocean ridge or an ocean island protolith. The whole sequence can be interpreted as a disrupted ophiolitic complex (Castroviejo et al., 2010). The geological setting of the Tapo occurrence is described by J.F. Rodrigues et al. (2010). To get information about its geotectonic setting we applied new geothermobarometric techniques to the garnet amphibolite. Finding representative samples with an adequate mineralogy to apply these techniques is in this case a difficult task. A common problem is the almost ubiquitous overprinting by serpentinisation or retrograde metamorphism and, locally, by metasomatism or alteration enhanced by deformation, producing a variety of rock types, as rodingites, birbirites and listvaenites. Nevertheless, careful sampling followed by petrographic examination of the rocks allowed to identify some samples in which useful assemblages are present.

ASSEMBLAGES AND MINERAL CHEMISTRY

We selected three garnet amphibolite samples[1] (090606-2, 090606-3 and 270607-7, Fig. 1) which contain the assemblage garnet-Ca-amphibole-epidote-chlorite-albite-quartz-titanite-ilmenite. Additionally clinopyroxene is present in sample 090606-3. This assemblage points to conditions of the albite-epidote amphibolite facies.

Garnet is essentially an almandine-grossular solid solution (almandine$_{0.46\text{-}0.62}$grossular$_{0.25\text{-}0.45}$pyrope$_{0.01\text{-}0.18}$spessartite$_{0.02\text{-}0.11}$). Almandine and pyrope contents increase from core to rim, whereas spessartite decreases and grossular contents show little variations. Amphibole compositions vary strongly between samples: in sample 090606-3 amphibole is actinolite to magnesiohornblende (Na 0.10-0.66 apfu, Na_A 0.0-0.66 apfu, X_{Mg} 0.42-0.68), in sample 270607-7 magnesiohornblende to tschermakite (Na 0.58-1.03 apfu, Na_A 0.36-0.82 apfu, X_{Mg} 0.25-0.46) and in sample 090606-2 tschermakitic hornblende to tschermakite (Na 0.05-0.80 apfu, Na_A 0.3-0.5 apfu, X_{Mg} 0.41-0.58). Epidote composition within all samples varies strongly ($X_{pistacite}$=0.4-0.9) contrasting that of chlorite (Si 5.3-5.7 apfu; X_{Mg} 0.35-0.51). Clinopyroxene composition is diopside$_{0.56\text{-}0.58}$hedenbergite$_{0.20\text{-}0.30}$acmite$_{0.07\text{-}0.10}$orthopyroxene$_{0.02\text{-}0.05}$tschermak component$_{0.02\text{-}0.07}$. Plagioclase is invariably albite.

GEOTHERMOBAROMETRY

We calculated pseudosections for the three metabasite samples using the PERPLE_X software package (Connolly 2005). The thermodynamic data set of Holland & Powell (1998, updated 2002) for minerals and aqueous fluid was used. Calculations were performed using the following solid-solution models: for epidote, garnet, plagioclase, clinopyroxene, omphacite, amphibole and chlorite by Holland

& Powell (2003) and Powell & Holland (1999). For the calculation of the pseudosections the major element compositions analysed by XRF were simplified to a 9-component system (SiO_2-TiO_2-Al_2O_3-FeO-MgO-CaO-Na_2O-H_2O-O_2) normalized to 100% (Table 1). Water contents were augmented to excess water conditions that are considered to have prevailed during peak PT-conditions. Oxygen contents were arbitrarily chosen to account for epidote and Fe^{3+}-rich clinopyroxene present in the samples. Calculated compositions of minerals provide good coincidence with measured ones (Table 2) except partly for amphibole, because solid solution models for amphibole are still not optimal.

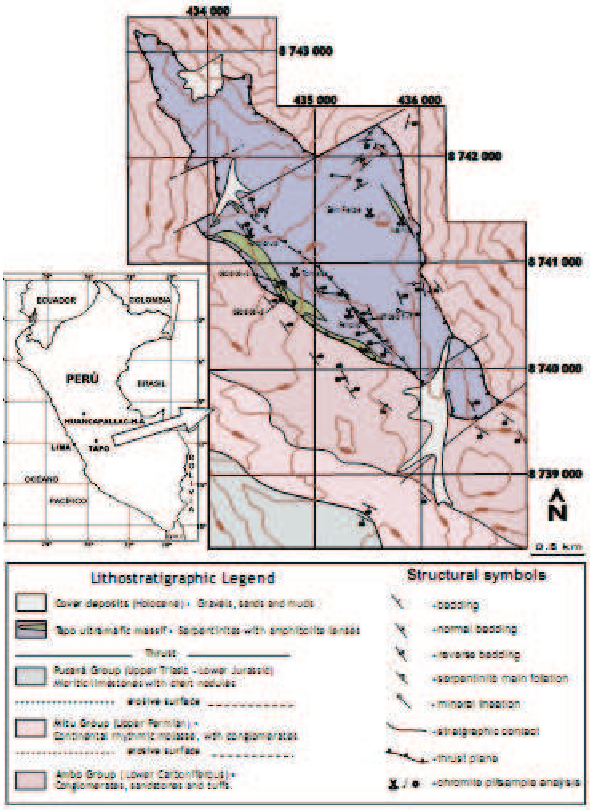

Fig.1. Geological map of the Tapo Ultramafic Complex with indications of the sample localities.

We simplified the pseudosections to present mere stability fields in the PT-range 400-600°C, 6-15 kbar in Fig.2. Garnet appears in the metabasite at conditions exceeding 8 kbar and 520°C. Whereas chlorite, epidote and Ca-amphibole are mostly stable in the considered PT-range, titanite is replaced at temperatures >520°C by ilmenite or rutile (>10 kbar). Albite is stable up to 520°C, 9 kbar and is partly replaced by plagioclase at higher temperature. Fe^{3+}-rich clinopyroxene is stable up to about 7 kbar, 450°C and 12 kbar, 550°C, whereas omphacite was not formed under the considered conditions and compositions according to our calculation.

The assemblages representing peak metamorphic conditions coincide for all three selected samples within a range of 525-575°C, 11-14 kbar, more restricted for sample 090606-2 at 12-13 kbar, 530-540°C. Chlorite, albite and ilmenite are considered as retrograde phases in sample 090606-3, as albite, quartz and titanite in sample 270607-7 and albite in sample 090606-2.

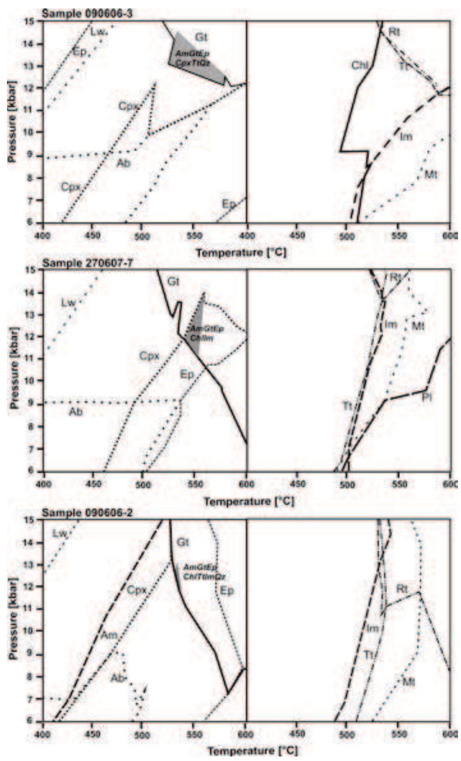

Fig.2 Stability fields of minerals deduced from PT-pseudosections calculated from whole rock compositions (Table 1) in the system SiO2-TiO2-Al2O3-FeO-MgO-CaO-Na2O-H2O-O2. Grey fields represent the stability field of the assemblages in the respective samples which represent peak PT-conditions. Abbreviations: Ab-albite, Am-Ca-amphibole, Chl-chlorite, Cpx-clinopyroxene, Ep-epidote, Gt-garnet, Im-ilmenite, Lw-lawsonite, Mt-magnetite, Pl-plagioclase, Rt-rutile, Tt-titanite.

CONCLUSIONS

We can restrict the peak metamorphic conditions for the Tapo Ultramafic Complex to 12.5±1 kbar and 535±20°C corresponding to 41-48 km burial depth (calculating with a mean crustal density of 2.8 g/ccm) and a low metamorphic geotherm of 10-13°C/km. Such conditions occur in subduction settings and collisional belts. Similar conditions were derived e.g. by Massonne & Calderón (2008) in a Devonian collision zone between an exotic microplate ("Chilenia") and the South America. A comparable situation might also be conceivable for the situation in the Eastern Cordillera of Peru.

REFERENCES

Castroviejo R et al. (2009) Proc. *10th. Biennial SGA Meeting*, Townsville, Australia: 927-929.

Castroviejo R et al. (2010) *Ophiolites in the Eastern Cordillera of the central peruvian Andes. IMA2010:* 20th General Meeting of the International Mineralogical Association (in press)

Connolly JAD (2005) *Earth and Planetary Science Letters* 236: 524-541.

Holland TJB, Powell R (1998) *Journal of Metamorphic Geology* 16: 309-343.

Holland TJB, Powell R (2003) *Contributions to Mineralogy and Petrology* 145: 492-501.

Massonne HJ, Calderón M (2008) *Revista Geologica de Chile* 35: 215-231.

Powell R, Holland TJB (1999) *American Mineralogist* 84, 1-14

Rodrigues JF et al. (2010) *Geología y Estructura de las Ultramafitas de Tapo y Acobamba (Tarma, Perú). Removilización tectónica andina de un segmento ofiolítico pre-andino*. (This vol.)

TABLE 1

(a) Whole rock compositions of metabasite				(b) Simplified compositions used for calculations of the pseudosections			
(wt-%)	**090606-3**	**090606-2**	**270607-7**	(wt-%)	**090606-3**	**090606-2**	**270607-7**
SiO2	49,43	40,01	40,35	**SiO2**	47,28	41,51	39,30
Al2O3	11,55	10,11	10,99	**Al2O3**	11,05	10,49	10,70
Fe2O3	14,13	21,86	23,35	**FeO**	12,18	20,43	20,49
MnO	0,15	0,18	0,25	**MnO**	0,14	0,19	0,24
CaO	10,84	8,11	8,88	**CaO**	10,37	8,41	8,65
MgO	6,80	7,96	6,82	**MgO**	6,50	8,26	6,65
Na2O	3,06	0,22	1,97	**Na2O**	2,93	0,23	1,92
K2O	0,12	0,06	0,12	**TiO2**	2,46	3,38	4,95
TiO2	2,57	3,26	5,09	**H2O**	7,00	7,00	7,00
P2O3	0,13	0,01	<0.050	**O2**	0,10	0,10	0,10
LOI	1,03	8,03	2,18	**Sum**	100,00	100,00	100,00
Sum	99,81	99,81	99,99				

Table 2 Representative mineral analyses and mineral compositions calculated with PERPLE_X for comparison

Clino-pyroxene	090606-3	090606-3
SiO2	50.80	calc.
Al2O3	1.63	523°C/13.15
TiO2	0.17	kbar
Fe2O3	3.54	
FeOt	7.16	
MnO	0.09	
MgO	11.86	
CaO	24.14	
Na2O	0.34	
Sum	99.74	
Si	1,921	2,000
Alt	0,073	
SU1	1,994	
Alo	0,000	0,140
Ti	0,005	
Fe3+	0,101	
Fe2+	0,227	0,440
Mn	0,003	
Mg	0,668	0,330
Ca	0,978	0,840
Na	0,025	0,140
SU2	2,006	2,000
Ot	6,000	
Tcpx	0,005	
Mcpx	0,003	
Ts	0,048	
Acm	0,101	
Opx	0,047	
Hed	0,197	
Diop	0,580	
XFe	0,253	
XFe3	0,308	

Garnet	090606-3c	090606-3r	090606-3	090606-2r	090606-2	270607-7c	270607-7r	270607-7
SiO2	36.34	36.73	calc.	38.29	calc.	36.44	36.16	calc.
Al2O3	21.04	21.06	523°C/13.15	21.75	533°C/12.35	21.07	21.11	540°C/11.90
TiO2	0.15	0.15	kbar	0.06	kbar	0.17	0.12	kbar
Fe2O3	0.58	0.55		0.00		0.62	0.99	
FeOt	21.28	23.62		22.85		25.42	24.86	
MnO	4.39	0.94		0.80		4.84	2.27	
MgO	0.32	1.13		0.67		0.35	0.81	
CaO	14.28	14.18		14.11		10.75	11.17	
Sum	98.38	98.34		100.52		99.48	99.50	
Si	5,891	5,918	6,000	6,000	6,000	5,892	5,844	6,000
Alt	0,109	0,082		0,000		0,108	0,156	
SU0	6,000	6,000		6,000		6,000	6,000	
Alo	3,912	3,917	4,000	4,017	4,000	3,904	3,845	4,000
Fe3+	0,071	0,065		0,000		0,075	0,120	
Ti	0,018	0,018		0,007		0,021	0,015	
SU1	4,000	4,000		4,023		4,000	4,000	
Fe2+	2,884	3,183	3,450	2,994	3,480	3,435	3,430	3,740
Mn	0,603	0,128		0,106		0,663	0,311	
Ca	2,480	2,448	2,320	2,704	2,100	1,842	1,934	2,020
Mg	0,078	0,272	0,230	0,157	0,220	0,084	0,194	0,240
SU2	6,044	6,032	6,000	5,961	6,000	6,044	6,071	6,000
Andr	0,012	0,011		0,000		0,012	0,020	
Gros	0,399	0,395	0,387	0,454		0,294	0,299	
Spes	0,100	0,021		0,018		0,110	0,051	
Pyro	0,013	0,045	0,038	0,026		0,014	0,032	
Alm	0,477	0,528	0,577	0,502		0,548	0,598	

Cations based on 48 negative charges including 10 cations in the tetrahedral and octahedral site to calculate Fe3+; c core, r rim

Chlorite	270607-7	270607-7	090606-2	090606-2	090606-3
SiO2	24.44	calc.	25.85	calc.	24.99
Al2O3	17.90	540°C/11.90	20.36	533°C/12.35	19.58
TiO2	0.07	kbar	0.02	kbar	0.01
FeO	31.99		28.65		28.41
MgO	12.43		12.73		12.88
MnO	0.33		0.34		0.38
CaO	0.15		0.06		0.08
Na2O	0.07		0.00		0.00
H2Ot	11.18		11.22		10.98
Sum	100.40		99.27		97.52
Si	5,675	5,960	5,524	5,960	5,459
Alt	2,325	2,040	2,476	2,040	2,541
Alo	2,203	2,040	2,452	2,040	2,503
Ti	0,012		0,003		0,001
Mn	0,064		0,062		0,070
Fe	5,743	5,980	5,120	5,740	5,228
Mg	3,979	3,980	4,055	4,220	4,197
Sum	12,000	12,000	11,891	12,000	11,999
Na	0,028		0,000		0,000
Ca	0,034		0,014		0,018
OH	16,000	16,000	16,000	16,000	16,000

Cations based on 56 negative charges; H2O calculated on the basis of OH=16

Amphibole	270607-7	270607-7	090606-2	090606-2	090606-3	090606-3
SiO2	40.68	calc.	44.29	calc.	52.70	calc.
Al2O3	14.18	540°C/11.90	9.57	533°C/12.35	3.67	523°C/
TiO2	0.23	kbar	0.18	kbar	0.05	13.15 kb
Fe2O3	4.96		4.67		3.21	
FeOt	20.14		13.59		12.77	
MgO	4.69		9.79		13.32	
CaO	10.59		10.84		11.75	
BaO	0.00		0.01		0.02	
K2O	0.23		0.07		0.05	
Na2O	3.08		1.75		0.87	
MnO	0.10		0.19		0.18	
H2Ot	1.97		2.01		2.09	
Sum	100.34		98.95		100.88	
Si	6,206	7,164	6,891	7,560	7,573	7,521
Alt	1,794	0,836	1,109	0,440	0,427	0,479
Su1	8,000	8,000	8,000	8,000	8,000	8,000
Alo	0,755	0,986	0,570	0,420	0,194	1,259
Ti	0,027		0,020		0,006	
Mn	0,013		0,023		0,022	
Fe3+	0,549		0,533		0,348	
Fe2+	2,570	2,190	1,692	2,390	1,535	1,800
Mg	1,067	1,823	2,172	2,190	2,896	1,941
Su2	13,000	13,000	13,000	13,000	13,000	13,000
Ca	1,731	1,515	1,729	1,920	1,810	1,131
Ba	0,000		0,001		0,001	
Na	0,910	0,790	0,504	0,200	0,243	0,940
K	0,044		0,013		0,009	
Su3	2,686	2,305	2,246	2,120	2,063	2,091
OH	2,000	2,000	2,000	2,000	2,000	2,000

Proportion of cations is based on the sum of cations = 13 except for Ca, Na and K for estimation of Fe3+ and on 46 negative charges

Epidote	270607-7	270607-7	090606-2	090606-2	090606-3	090606-3
SiO2	38.16	calc.	37.44	calc.	37.98	calc.
Al2O3	28.18	540°C/11.90	28.33	533°C/12.35	23.53	523°C/
Fe2O3	7.49	kbar	7.27	kbar	13.19	13.15 kb
Mn2O3	0.05		0.04		0.01	
TiO2	0.11		0.10		0.09	
CaO	23.79		23.32		23.48	
H2Ot	1.91		1.87		1.90	
Sum	99.96		98.41		100.44	
Si	3,000	3,000	3,000	3,000	3,000	3,000
Al	2,611	2,330	2,674	2,400	2,190	2,520
Ti	0,006		0,006		0,005	
Mn	0,003		0,002		0,001	
Fe	0,455	0,680	0,438	0,600	0,784	
SU1	3,074	3,000	3,122	3,000	2,981	0,480
Ca	2,003	2,000	2,001	2,000	2,004	3,000
SU2	2,005		2,001		2,008	
OH	1,000	1,000	1,000	1,000	1,000	1,000
O'	12,133	12,000	12,187	12,000	11,980	12,000

Proportions of cations are based on normalisation of Si to three cations