High-pressure, low-temperature metamorphism in the Sebtides nappes, northern Rif, Morocco.

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ABSTRACT

On the southern bank of the Gibraltar strait, the Permian-Triassic phyllites of the Sebtides-Alpujarrides nappes yielded eclogite and blueschist-facies relic assemblages. The various metamorphic units are juxtaposed through retrograde contacts. The HP-LT metamorphism indicates an Alpine subduction event.

Key-words*: HP-LT metamorphism, Mg-carpholite, Mg-chloritoid, Sudoite, Cookeite, Talc, Phengite, Gibraltar arc*

RESUMEN

Las metapelitas Permo-Triassicas de los mantos Sebtides-Alpurarrides cerca de Ceuta tienen asociaciones minerales de alta presion, baja temperatura (talco-fengita-distena-Mg-cloritoide-Mg-carfolita en la unidad piu baja; asociaciones de menor presion en las unidades mas alta). Los diferentes mantos estan superpuestos por medio de contactos retrogrados. El metamorfismo inicial de alta presion se debio producir como consecuencia de un processo de subduccion continental.

Palabras clave*: metamorfismo altas P y bajas T, Rif, Arco de Gibraltar.*

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Introduction

Fe-Mg carpholite, Mg-chloritoid, talc, phengite, sudoite and cookeite can be used as index-minerals to decipher the high-pressure, low-temperature (HP-LT) history of metapelites (Theye *et al.*, 1992; Vidal *et al.*, 1992, with references herein). We report here on the occurrence of these minerals in rocks so far considered to lack HP-LT metamorphism: the Permo-Triassic phyllites of the Sebtides = Alpujarrides nappes immediately south of the Gibraltar strait (Bouybaouene, 1993).

West of Ceuta (Sebta), the Sebtides-Alpujarrides nappes crop out from beneath the Ghomarides-Malaguides nappes in the Beni Mzala (BM) antiform (Fig. 1). The Beni Mzala window essentially includes four tectonic units, also known as the "Federico units", from base to top: BM1, BM2, Boquete Anjera (BA), and Tizgarine (Tz) units (Durand-Delga and Kornprobst, 1963). In addition, we recognized at the northern tip of the antiform, below the BM1 unit, a small "Benzu unit" which is not discussed here (see Bouybaouene, this vol). All the Federico units exhibit similar lithostratigraphical sequences, including Upper Paleozoic greywakes, Permo-Triassic reddish to greyish ("color de humo") psammites or phyllites, Triassic quartzites and dolomites. It was recognized early (Milliard, 1959) that these rocks suffered an Alpine metamorphism, the grade of wich increases from the uppermost unit to the lowest. The highest grade was thought to be a chloritoid-bearing greenschist-facies (Kornprobst, 1974). However, Michard *et al.* (1983) pointed to the occurrence of kyanite in the Permian phyllites of the southern prolongation of the Beni Mzala unit close to the Beni Bousera peridotites.

Mineralogy and metamorphic paragenesis

Magnesiocarpholite-bearing assemblages.- Magnesiocarpholite has been only found in the BM1 and BM2 units. This mineral appears as relics under the typical habit of hair-like microfibers included in quartz grains (Goffé and Oberhansli, 1992) of intrafolial quartz-carbonate-chlorite-chloritoid seggregations (BM1 and BM2 units), or in quartz-chlorite-kyanite seggregations (BM2 unit only). The composition of these fiber ranges from XMg=Mg/(Mg+Fe+Mn) = 0.50 to 0.59 in BM2, and from XMg=0.67 to 0.70 in BM1 (table 1). They are partially replaced by paragonite, muscovite, and chlorite. The composition of the associated chloritoid varies from XMg=0.20 to 0.38 in BM2, and from XMg=0.30 to 0.50 in BM1.

Talc-phengite assemblages.- They occur locally in the BM1 unit only within quartz-kyanite-carbonate intrafolial seggregations, and in the schist foliae included in, or juxtaposed to these seggregations. The talc composition is rather constant, and close to the ideal formula with XMg = 0.91 to 0.95. The phengite lamellae in sharp contact with talc yield substitution ranging from Si 3.15 to Si3.28 .The talc-phengite assemblages are partially replaced in a first stage by phlogopite-clinochlore assemblages, and later on by calcite-dolomite and tremolite associations, while kyanite is replaced by margarite-paragonite associations. In addition to these talc-phengite assemblages, talc associated with albite and hematite occurs in prismatic pseudomorphs after an undetermined phase (glaucophane?).

Quartz-chloritoid and quartz-kyanite seggregations.- In BM1 and BM2, quartz-chlorite-chloritoid and quartz-chlorite-kyanite seggregations (the latter type including talc-phengite assemblages in BM1) are systematically separated by decimeter-thick schist bands consisting of quartz, clinochlore and hematite assemblages. Black, tie-bow shaped Mg rich chlorite-hematite pseudomorphs after chloritoid are often seen within these schist bands. This suggest that the clinochlore-kyanite or talc-kyanite assemblages originated from the breakdown of a previous magnesiochloritoid (Chopin and Schreyer, 1983).

Sudoite.- This di, trioctahedral chlorite only occurs in the BA unit, as light green, elongated aggregates within intrafolial quartz-carbonate-chlorite seggregations. Its composition is close to the pure sudoite end-member (Fransolet and Bourguignon, 1978). XMg ranges from 0.86 to 0.95, while the Si value does not exceed 3.04. An in situ X ray analysis performed with an INEL CPS120 diffractometer using CoK* radiation showed all the main X-ray powder diffraction characters of sudoite (Fransolet and Bourguignon, 1978), with an intensity ratio R=I(002)/ I(003) + I(004)=0.63 also typical of sudoite (Fransolet and Schreyer, 1984). In quartz-carbonate seggregations, sudoite is associated with magnesian chlorite XMg=0,83, phengite Si3.15, and paragonite. In the surrounding schist, chloritoid (XMg=0.11 to 0.28) is associated with chlorite (XMg=0.60-0.70) and phengite Si3.10.

Cookeite.- This lithium-bearing chlorite occurs in the Tizgarine, BM1 and BM2 units. In the Tz unit, cookeite is found within the foliation as small tapered lamellae associated with pyrophyllite and phengite Si3.12, or within quartz-carbonate seggregations as radiating lamellae associated with chlorite. In both Beni Mzala units, cookeite is found in the

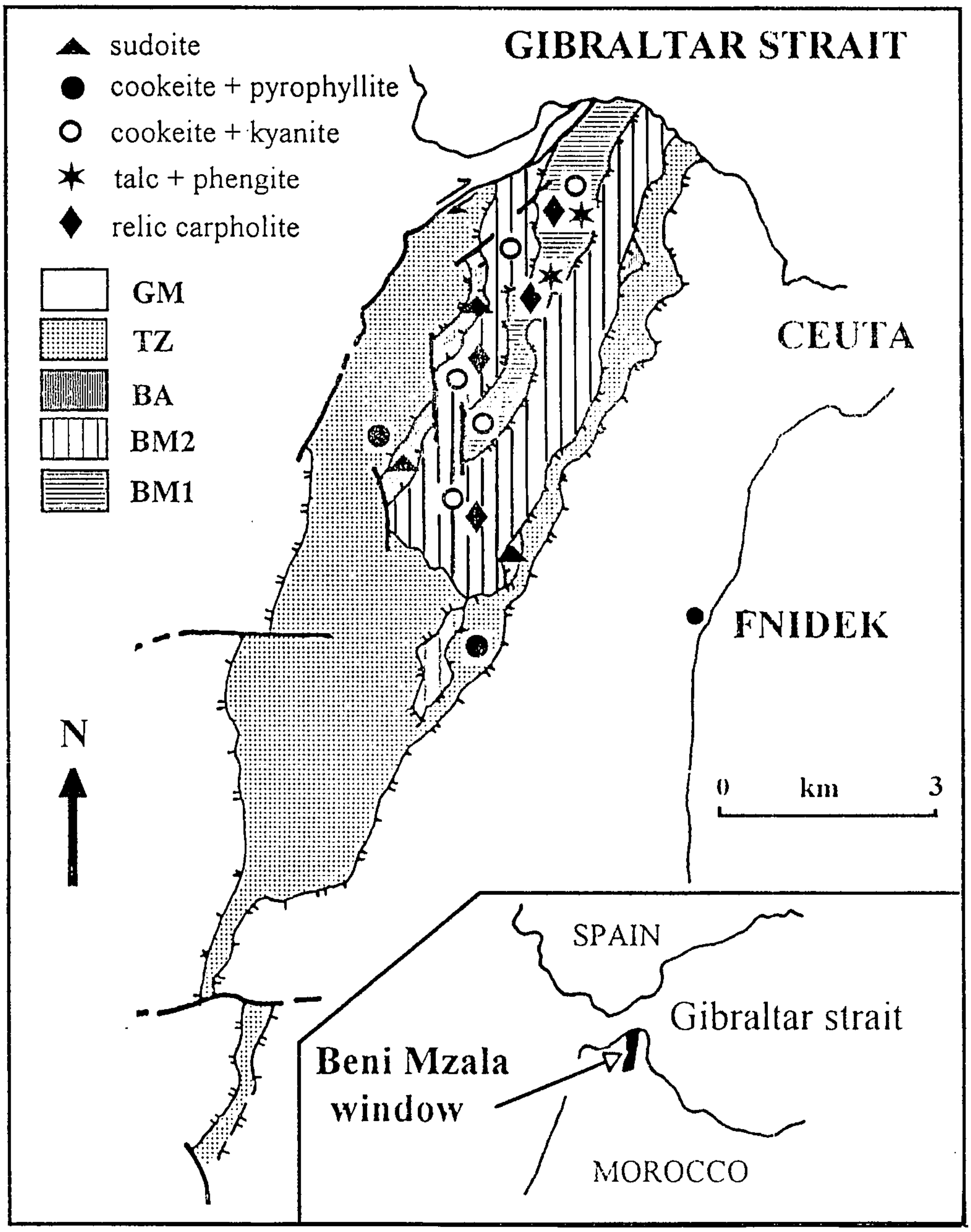

Fig. 1.- Distribution of index minerals in the Beni Mzala window (structural sketch after the geological map of the Rif belt 1/50 000, sheet Sebta, Geological Survey of Morocco, Rabat).

Fig. 1.- Distribución de los minerales índices en la ventana deBeni Mzala (esquema estructural segun el mapa geológico de la Cordillera Rifereña, a escala 1/50.000,hoja de Ceuta,Servicio Geológico de Marruecos, Rabat)

quartz-kyanite seggregations associated with kaolinite, phengite, paragonite and chlorite as an alteration product after kyanite. X-ray powder diffraction pattern on Tz cookeite showed the main characteristic diffraction lines of typical cookeite (Goffé, 1977; Bailey and Lister, 1989). The Li20 content (1.95 wt%) has been analysed (ionic probe) and falls in the range of the observed values for natural cookeite (Cerny, 1970; Flehming and Menschel, 1972).

P-T estimates

Each unit is characterized by its own peak pressure-temperature conditions. These P T conditions can be estimated by calculation of phase equilibria using P T A X, a development of Geo-calc software (Berman and Perkins, 1987), with the internally consistent data set of Berman (1988) for chlorite, pyrophyllite, quartz, kyanite, andalousite complemented with consistent thermodynamic properties for cookeite, spodumene from Vidal and Goffé (1991), for magnesiocarpholite and sudoite from Vidal and al (1992) and for magnesiochloritoid from Patrick and Berman (unpub. data, 1989). In the Tizgarine unit, cookeite associated with pyrophyllite and low-substituted phengite with neither carpholite nor chloritoid corresponds to low-temperature, low-pressure conditions, close to 300°C, 1-3 kbar. In the Boquete Anjera unit, the occurrence of sudoite associated with magnesiochlorite and low-substituted phengite in the quartz veins, with chloritoid in the surrounding schists, but without carpholite corresponds to medium pressure conditions, close to 7 kbar, under temperature close to 300-350°C. In the BM2 unit, magnesiocarpholite relics in chloritoid-quartz or kyanite-quartz veins are relevant to blueschist-facies conditions evolving from 8-10 kbar, 380-420°C to 12-15 kbar, 430-450°C. In the BM1 unit, magnesiocarpholite relics in magnesio-chloritoid-quartz veins, and talc-phengite assemblages in quartz-kyanite seggregations point to eclogite-facies conditions, evolving from 12-15 kbar, 430-480°C to about 20 kbar, 550°C.

The retrograde P-T path is only constrained for the BM units. The occurrence of tremolite-talc and phlogopite chlorite associations in BM1 indicates an early unloading evolution down to 8 kbar, either isothermal or at slightly increasing T. Further unloading under decreasing T corresponds to the crystallization of late paragonite, muscovite, chlorite, kaolinite and cookeite in both BM1 and BM2.

Discussion and conclusion

In the Gibraltar arc, the Alpujarride-Sebtide metamorphism has been frequently regarded, since Loomis (1975), as the result of the hot emplacement of the Ronda-Beni Bousera lherzolites during Early Miocene time. Some recent geodynamic models still postulate similar concepts (Platt and Vissers, 1989; Doblas and Oyarzun, 1989). The occurrence of HP-LT assemblages in the Sebtides units BM1 and BM2 precludes such interpretations. In contrast, these assemblages imply that metamorphism developped in a subduction, collision or obduction setting. Similar HP-LT associations were also reported recently in various Alpujarride nappes (Goffé *et al.*, 1989; Bakker *et al.*, 1989; Azanon and al. 1992). Tubia and Ibarguchi (1991) also reported on eclogitic relics in the Lower Alpujarride nappe beneath the Sierra Alpujata lherzolite.

It is worth to note that the Tz and BA metamorphism is not only of lower grade than that of the underlying BM units, but also of significantly higher geothermal gradient. By reference to thermal modelling of subduction zones (Van der Beurkel and Wortel, 1988) we suggest that the subducted Sebtides units have been temporarily located at various depth of a tectonic wedge, accreted to the upper plate of a subduction zone. This zone would have operated between Europe and Africa during Late Cretaceous-Paleogene time (Michard *et al.*, 1991; de Jong, 1991). Van der Wals (1993) also concluded that the Ronda protolith was located in the upper plate of this subduction zone.

Mineral sample	sudoite BA441	cookeite TZ1	Mgcarpholite BM451	chloritoid BM451	talc BM460	phengite BM460
SiO_2	33.65	37.33	78.90**	24.62	62.75	49.36
TiO_2	0.03	0.01	0.13	0,00	0,00	0.2
Al_2O_3	35.24	45.02	11.84	37.85	0.45	30.53
Fe_2O_3	2.76*	nd	nd	nd	nd	nd
FeO	1.35	0.41	2.8	20.53	3.12	2.94
MnO	0,00	0.02	0.2	0.58	0,00	0,00
MgO	14.34	0.15	3.39	7.81	28.79	2.15
CaO	0.07	0.12	0,00	0,00	0,00	0,00
Na_2O	0.03	0.01	0,00	0,00	0,00	0.2
K_2O	0,50	0,00	0,00	0,00	0,00	10.51
Li_2O	nd	1.95	nd	nd	0,00	0,00
F	0,00	0,00	0.03	0,00	0,00	0,00
total	87.97	85.02	97.29	91.39	95.11	95.89
calc-bas	14 Ox	14 Ox	fixed cation number		11 0x	11 0x
Si	3.026	3.289	3.926 **	2	4.017	3.28
Ti	0.002	0.001	0.005	0,000	0,000	0,010
Al	3.735	4.675	1.946	3.62	0.034	2.391
Fe+++	0.187*	0,000	0.049	0,380	0,000	0,000
Fe++	0,102	0.03	0.275	1.01	0.167	0.163
Mn	0,000	0.001	0.024	0,040	0,000	0,000
Mg	1.922	0,020	0.701	0.945	2.747	0.213
Ca	0.007	0.011	0,000	0,000	0,000	0,000
Na	0.005	0.002	0,000	0,000	0,000	0.026
K	0,000	0,000	0,000	0,000	0,000	0.891
Li	0,000	0.691	0,000	0,000	0,000	0,000
F	0,000	0,000	0.128	0,000	0,000	0,000
sum	9.043	8.72	3.000 **	7.995	6.965	6.973
XMg	0.95		0.7	0.47	0.94	

Table 1.- Electron micrprobe and structural formulae of the main index minerals. Analytical procedure: analyses were performed on a Camebax electron microprobe at Paris VI university (15 Kv, 10 nA, PAP correction procedure) using Fe_2O_3 (Fe), $MnTiO_3$ (Mn), diopside (Mg, Si), CaF_2 (F), ortoclase (Al) as standards. Sudoite and cookeite are calculated on 14 oxygens; Talc and phengites on 11 oxygens. Chloritoid is calculated on fixed atomic number (8). Mg carpholite is calculated following the Goffé and Oberhanslli (1992) procedure: on the basis of a fixed atomic number of cations: 5 for the Si (with consideration of the other cations), 3 for Al, Fe,Mn,Mg (Si is not considered). This mode of calculation is used to avoid the consequential effect of the cotamination by the surrounding quartz when calculating Al, Fe, Mg, Mn content of carpholite microfibers. Fe^{3+} is calculated as (2-Al), XMg = Mg/ (Mg=Fe=Mn).

*** caculated to equilibrate the theoritical strutural formula.**

**** polluted by surrounding quartz.**

Tabla 1.- Análisis y fórmulas estructurales de los principales minerales índices. Los análisis han sido efectuados con microsonda Camebax en la Universidad de Paris VI

The reported mineralogical data make appearent that the Sebtide nappes of the Beni Mzala window were juxtaposed through dramatic metamorphic gaps during their retrograde evolution. The resulting tectonic pile is normally ordered with respect to the metamorphic grade. Unloading operated at first either under constant or slightly increasing temperature, at least for the lowest units (BM1, BM2). Such a metamorphic evolution and exhumation history would result from the extensional tectonics that actually affected the Alboran domain during Oligo-Miocene time and later on (Garcia-Duenas *et al.*, 1986, 1992; Galindo Zaldivar *et al*, 1989; Platt and Vissers, 1989; Feinberg *et al.*, 1990; Zeck et al., 1992, Chalouan *et al*, this vol).

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