### Serie I superior

Se apoya discordante sobre cualquiera de las series anteriores, si bien su contacto con la serie I intermedia puede ser, con frecuencia, aparentemente concordante. Su distribución espacial es muy similar a la de la serie I intermedia, aunque se extiende más que ella hacia el este y menos hacia el oeste.

Constituye la parte fundamental del escarpe de Jandía, dando sus cimas más elevadas. Su buzamiento, más ligero que el de la serie I intermedia, es divergente y hacia el sur (de SE a S). Es realmente la serie que condiciona los rasgos fundamentales de la morfología de Jandía.

Su espesor supera los 350m. estando compuesta por coladas potentes de ankaramitas, basaltos olivínicos-piroxénicos y en menor proporción rocas traquibasálticas.

El domo del Cuchillo del Palo y el dique que constituye su raíz son el único indicio claro de actividad sálica tardía en esta serie.

Abdel-Monen *et alt* (1971) datan, en la Degollada de Agua Oveja, tres coladas casi sucesivas que corresponden exclusivamente al tramo bajo de la serie I intermedia. Tales edades (17.), 16.3 y 14.7 Ma. recalculadas) no son coherentes entre sí, pues no es lógico que exista una diferencia tan grande entre ellas. Las dos más antiguas parecen en principio más de acuerdo con el resto de los datos existentes.

Casquet *et alt* (1989), basándose en datos previos y nuevos inéditos sitúan el conjunto de la serie I intermedia y superior entre los 17 y los 14 Ma. Los diques que las atraviesan tienen edades entre 15.4 y 14.2 Ma. (Feraud, 1981) lo que posiblemente se correspondería a la edad de los tramos altos de la serie I intermedia o los bajos de la serie I superior.

### Serie I tardía

El extremo occidental de la península de Jandía es diferente al resto de ella, tanto morfológicamente como geológicamente. Desde Talahijas hacia el oeste y noroeste los materiales existentes parecen mucho más recientes no estando atravesados por diques. Fundamentalmente son basaltos y en la zona de El Cotillo nefelinitas olivínicas. Se trata, por tanto, de una unidad composicionalmente diferente y más alcalina que las anteriores.

Su edad es desconocida, aunque al no estar atravesada por los diques de 15.4-14.2 Ma. sería posterior, y posiblemente bastante mas reciente.

### Agradecimientos

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**Pregunta de Alfredo Hernández-Pacheco:** Relacionado con la extrusión del domo de Mña. Azufrá existe un anillo de materiales piroclásticos que separan dos tramos de las series antiguas de esa zona. ¿A cuáles episodios corresponden esos dos tramos de estas series?

**Respuesta de los autores:** Dichos materiales piroclásticos están situados en el límite entre la serie I inferior y la serie I intermedia.

# High pressure mineral assemblages in the Trevenque Unit (Central Alpujarrides, Andalucía)

## *Asociaciones minerales de alta presión-baja temperatura en la unidad del Trevenque (Alpujárrides Centrales, Andalucía)*

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ABSTRACT

*The Trevenque Unit is located in the Alpujarride Complex. In this unit, the Fe-Mg carpholite, cloritoid, chlorite, kyanite aragonite assemblages show metamorphic evolution at HP-LT conditions The metamorphic peak is estimated to have been at 400-450° C and at least 10 Kb. The pressure conditions in the Alpujarride Complex are similar to those observed in the underlying Nevado-Filabrides Complex.*

RESUMEN

*En la formación de metapelitas Permo-Werfenienses de la Unidad del Trevenque (Alpujárrides centrales) se han encontrado asociaciones minerales que comprenden Fe-Mg carfolita, cloritoide, clorita, distena y aragonito. Estas asociaciones indican un episodio metamórfico de alta presión-baja temperatura. La presencia de carfolita y aragonito permiten estimar la presión mínima alcanzada y la sustitución Fe-Mg en la asociación cloritoide-carfolita puede ser utilizada como indicador térmico durante la fase progrado de la evolución metamórfica. Asimismo, la asociación distena Mg-carfolita señala el límite de estabilidad de la carfolita ante incrementos de temperatura. Las condiciones P-T para estas rocas han sido estimadas en 400-450° C y 10 Kb como presión mínima. Según estos valores, la presión alcanzada en ciertas unidades alpujárrides a causa del metamorfismo alpino es comparable a la ya conocida para los Nevado-Filabrides.*



**Key words:** *Alpujárride Complex, high pressure metamorphism, Fe-Mg carpholite.*

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## Introduction

The Trevenque Unit, whose formations of phyllites and quartzites attributed to Permian-Werfenian reveals high pressure-low temperature (HP-LT) assemblages, is part of the Alpujarride Complex on the western slope of the Sierra Nevada (Gallegos, 1975). Aldaya *et al.* (1982) have suggested its structural correlation with the nappes of La Herradura and Alfaguara, respectively situated to the S and to the N. In fig. 1, which is based on the Geological Map of Andalucia (Junta de Andalucia, 1985), the unit within the Middle Alpujarride Nappes is included.

The discovery of HP-LT assemblages in the Alpujarride Complex (Goffé *et al.*, 1989( has stimulated further studies to determine the specific conditions of this event. The new mineral assemblages we found in the Trevenque Unit enabled us to determine the pressure and temperature reached during the oldest alpine event registered in the Alpujarrides.

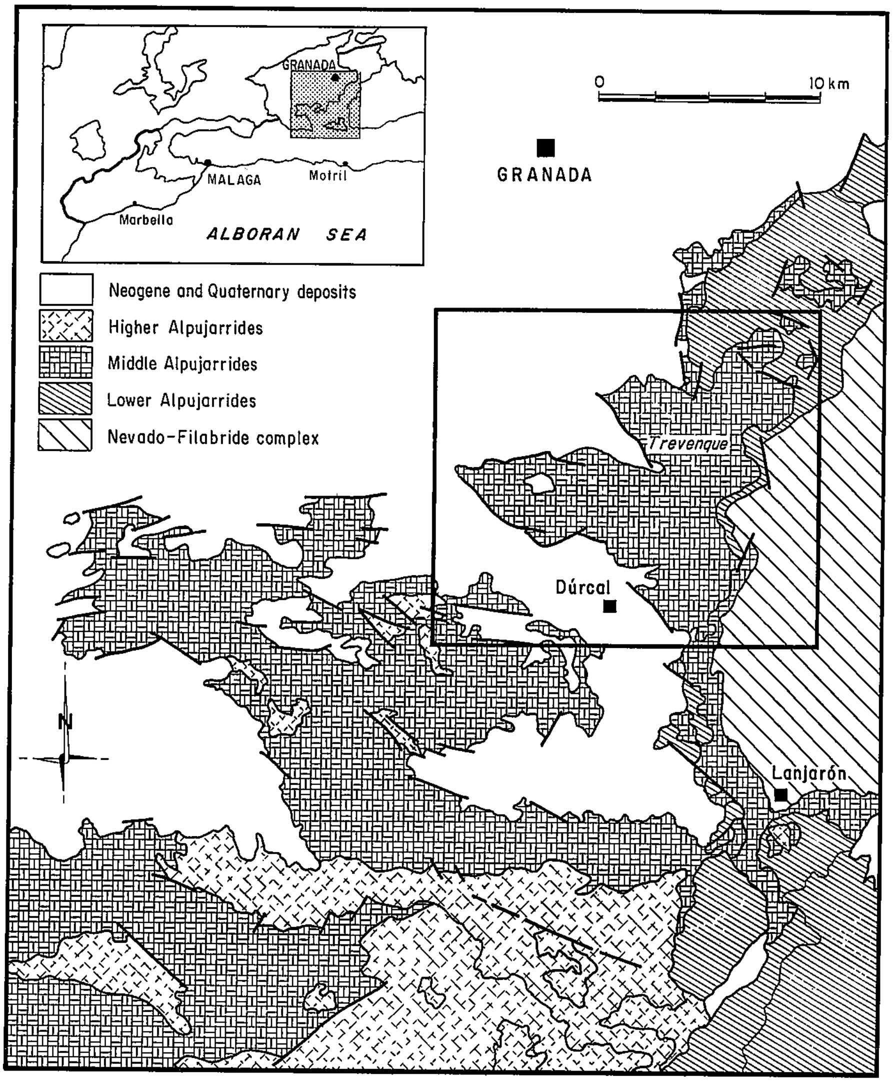


**Fig. 1.—Tectonic sketch of the Trevenque Unit area. Based on Geological Map of Andalucía (Junta de Andalucía, 1985).**

***Fig. 1.—Esquema tectónico del área en la que se sitúa la Unidad del Trevenque. Tomado del Mapa Geológico de Andalucía (Junta de Andalucía, 1985).***

## Mineralogy

The assemblages indicating HP-LT are preserved within intrafoliar quartz grains and veins in the phyllites. However, minerals such as aragonite, chloritoid, kyanite and, occasionally, carpholite can be found as planar fabric elements, though often replaced due to retrograde metamorphism.

The most abundant HP-LT mineral in the Trevenque Unit is Fe-Mg carpholite, an aluminosilicate having the formula $(Fe,Mg)Al_2(Si_2O_6)(OH_4)$ found in the form of long, narrow fibers several micra in diameter. The composition of these fibers varies to a great extent ($X_{Mg}$ = Mg/Mg+Fe+Mn=0.3-0.8), depending on the specific mineral assemblage studied. Thus, carpholite with a greater magnesium content was found together with kyanite, chlorite ($X_{Mg}$= =0.6-0.7), and chloritoid ($X_{Mg}$=0.35), whereas Fe-carpholite was associated with more ferrous chlorite and chloritoid (Table 1).

| Muest. | TV261 | TV261 | TV262 | TV903 | TV873 | TV873 | TV903 | TV7 |
|---|---|---|---|---|---|---|---|---|
| Min. | Chl. | Car. | Car. | Car. | Car. | Ctd. | Ctd. | Ctd. |
| Nºana. | 14 | 4 | 16 | 40 | 3 | 17 | 27 | 37 |
| | | | | | | | | |
| SiO2 | 26.12 | 41.30 | 43.69 | 55.33 | 45.78 | 27.12 | 22.93 | 24.21 |
| Al2O3 | 24.93 | 29.64 | 36.90 | 24.53 | 28.51 | 39.95 | 37.28 | 39.59 |
| FeO | 13.23 | 5.75 | 5.16 | 6.95 | 16.10 | 23.33 | 24.67 | 20.07 |
| MgO | 21.32 | 9.03 | 7.03 | 6.58 | 3.51 | 1.12 | 3.49 | 5.59 |
| MnO | 0.23 | 0.11 | 0.09 | 0.06 | 0 | 0.15 | 0.16 | 0.14 |
| TiO2 | 0.021 | - | - | - | - | - | - | - |
| $F^-$ | 0.789 | 0.96 | 0.45 | 0.57 | 0.01 | - | - | - |
| | | | | | | | | |
| Tot.ox | 86.64 | 85.84 | 92.89 | 93.46 | 91.82 | 91.67 | 90.37 | 89.60 |
| | | | | | | | | |
| Si | 2.58 | 2.18 | 2.14 | 2.76 | 2.37 | 2.27 | 2.01 | 2.02 |
| Al | 2.90 | 1.97 | 2.23 | 1.94 | 1.99 | 4.13 | 3.77 | 3.89 |
| Fe3 | - | 0.03 | 0 | 0.05 | 0.01 | 0 | 0.23 | 0.11 |
| Fe2 | 1.09 | 0.24 | 0.22 | 0.34 | 0.67 | 1.71 | 1.54 | 1.29 |
| Mg | 3.13 | 0.76 | 0.54 | 0.66 | 0.33 | 0.15 | 0.45 | 0.69 |
| Mn | 0.02 | 0.006 | 0.004 | 0.004 | 0 | 0.01 | 0.008 | 0.01 |
| Ti | 0.002 | - | - | - | - | - | - | - |
| F | 0.244 | 0.171 | 0.073 | 0.121 | 0.08 | - | - | - |
| XMg | 0,74 | 0,76 | 0,71 | 0,66 | 0,33 | 0,08 | 0,23 | 0,35 |
| Calcu. | O 14 | 5 cat. y 8 oxig. | | | | 8 cat. y 12 oxig. | | |

Tabla I.—Microprobe analyses of the most representative samples and minerals in the metamorphic evolution. Fe-Mg carpholite analyses have a SiO2 excess owing to fiber size (several micra) and the location of these fibers within the quartz. Therefore, the calculation of the SiO2 molecular content is independent. XMg=Mg/Mg+$Fe^{+2}$.

*Tabla 1.—Análisis de microsonda de los minerales más representativos en la evolución metamórfica. Igualmente se han seleccionado varias láminas delgadas representativas de dicha evolución. En los análisis de Fe-Mg carfolita se observa un exceso de SiO2 debido a la dimensión de las fibras (varias micras) y a que dichas fibras se encuentran inmersas en el interior del cuarzo. Para corregir dicho exceso el cálculo del contenido molecular de SiO2 se ha efectuado de manera independiente. XMg=Mg/Mg+$Fe^{+2}$.*

Kyanite also appeared in a largely destabilized form. It was closely linked to carpholite and was found superimposed upon or adjacent to carpholite. This assemblage, heretofore described only in Samos, Greece (Okrusch 1981; Okrusch *et al.*, 1984), is shown in fig. 2. Chloritoid was formed in different stages of metamorphic evolution, as we will see later. The chlorite has $X_{Mg}$=0.6-0.7 and 2.6-2.7. Si per formula unit (based on 14 oxygen atoms; see Table 1). Aragonite, chloritoid and chlorite develop parallel to the main foliation (Goffé *et al.*, 1989). The SrO content of aragonite has been used in the Alps to estimate the origin and crystallization conditions of this mineral. In our study, two types of aragonite were distinguished by texture: one, associated with chloritoid, formed part of the main foliation, the other having been crystallized in veins located transverse to this foliation. In the former case, SrO content was very low (800-1000 ppm), whereas in the latter the SrO content was considerably higher (>6000 ppm).

## Metamorphic evolution and P-T conditions

Metamorphic evolution was studied in various samples. Table 1 shows the composition of some of the key minerals of our study. Fe-Mg carpholite-chloritoid-chlorite-quartz assemblages were encountered frequently, whereas kyanite was only occasionally present. The Mg/$Fe^{+2}$ relationship in the coexisting carpholite and chloritoid varied depending on the sample. Fe-Mg carpholite is transformed into chloritoid + quartz (Chopin and Schereyer, 1983; Vidal *et al.*, 1991) under increased temperature. This reaction produces a different temperature depending upon the composition of the coexistent minerals (Vidal *et al.*, 1991). In the case of the Trevenque Unit, this mineral transformation can be observed in different compositions; the subsequent Car⇄Ky+Chl+Qtz+H2O, dehydration reaction was also observed. This indicates that increased temperature causes the system to be displaced toward the field of stability of kyanite.

The presence of aragonite and of assemblages with carpholite made it possible to estimate the minimum pressure conditions. Temperature conditions could be deduced from the Fe-Mg substitution in chlorite, carpholite and chloritoid, as well as from the presence or absence of kyanite. Although the minerals in the FMASH system become increasingly magnesian under higher temperatures, there exists a limit for Fe-Mg substitution which is controlled by the chemism of the rock (molar fraction of initial magnesium). The chemical composition of the minerals is fixed and does not evolve beyond this limit, which means that the system loses a certain degree of freedom. For this reason, the system must bypass one or more phases during the process of adaptation, and therefore exhibits greater variance. Hence, the assemblages greater in magnesium and having lesser variance were used to establish the P-T condition corresponding to the metamorphic peak, and the more ferrous assemblages having greater variance were used to determine the transitory P-T conditions reached in successive stages of the prograde metamorphic evolution.

Consequently, the assemblage richest in magnesium - formed by Mg-carpholite $X_{Mg}$=0.75, chloritoid $X_{Mg}$=0.36, and chlorite $X_{Mg}$=0.70, together with kyanite and quartz - indicates the P-T conditions correspon-

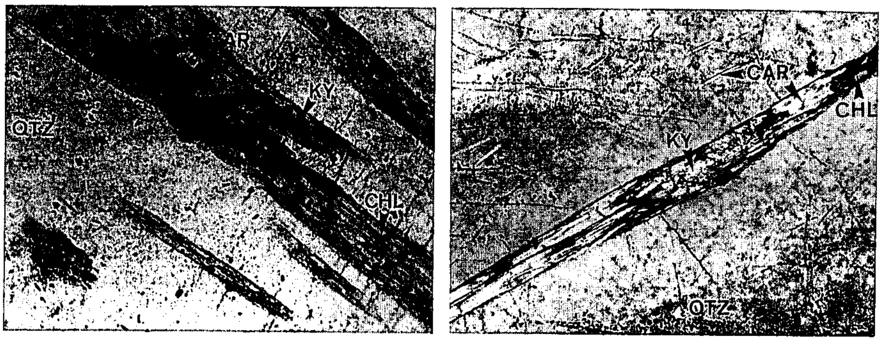


**Fig. 2.—Photomicrographs showing Mg-carpholite (Car) + Kyanite (Ky) + Chlorite (Chl) + Quartz (Qtz). Fe-Mg carpholite is a relic mineral partially replaced by kyanite+chlorite+quartz. Real length of picture is 0.9 mm.**

***Fig. 2.—Microfotografía que muestra la asociación Mg carfolita (Car) + Distena (Ky) + Clorita (Chl) + Cuarzo (Qtz). Se observa que la Mg-carfolita es un mineral relicto que se desestabiliza a distena+clorita+cuarzo. La longitud real de las fotografías es de 0,9 mm.***

ding to the metamorphic peak registered in the phyllites of the Trevenque unit. The intersection of the Car⇄Ctd+Qtz and Car⇄Ky+Chl+ +Qtz+H2O curves for an Mg-carpholite with $X_{Mg}$=0.8 occurs at 12 Kb and 425°C (Vidal *et al.*, 1991). The minimum conditions of the metamorphic peak for Trevenque phyllites are slightly lower than those indicated above, due to the fact that the Mg-carpholite of our study was found to have $X_{Mg}$=0.75 (Table 1).

## Conclusions

From a petrological standpoint, the Mg-carpholite-kyanite assemblage marks the limit of carpholite stability when temperature increases. This limit is fixed by the Car⇄Ky+Chl+Qtz+ +H2O dehydration reaction, and was clearly observed in the Trevenque Unit. The P-T conditions estimated for this assemblage correspond to the transition from blue schist facies to eclogitic facies, making the assemblage useful as a thermobarometric indicator in pelitic rocks. The conditions estimated for the metamorphic peak of P-T evolution in the Trevenque Unit are 400-450°C with pressure over 10-11 Kb. On the other hand, the presence of stable aragonite places certain restrictions on the retrograde path. According to studies dealing with the kinetics of the aragonite-calcite reaction (Carlson and Rosenfeld, 1981; Madon and Gillet, 1984), aragonite is preserved when the path intersects the reaction curve below 200°C temperature and 4-5 Kb pressure. The thermodynamic consequences of such a situation imply cooling under high pressure, as Gillet and Goffé (1983) propose in the case of Vanoise (western Alps).

The conditions determined for the metamorphic peak in the Trevenque Unit are similar to those found for other Alpujarride units. They contrast notably, however, with the results (450°C and 7 Kb) obtained by Bakker *et al.* (1989) for the Almanzora Unit, which has a structural position approximaterly equal to or lower than that of the Trevenque Unit.

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