Subduction and syn-collisional exhumation of a Paleozoic continental margin: an integrated study based on structures and P-T paths of the Basal Units in the Ordenes Complex (Galicia, Spain)

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ABSTRACT

According to their metamorphic evolution, the Basal Units of the Galician Allochthonous Complexes are thought to represent a part of the margin of the Paleozoic Gondwana, subducted at the onset of the Variscan Orogeny. Variations in the P-T conditions of the first HP metamorphic event along the units suggest an important westward component for the direction of sucduction. Subsequent underthrusting of more continental material blocked the subduction and triggered the ascent and exhumation of the Basal Units whereas the convergence continued. Compressional and extensional structures were synchronous or alternated in time and, together, induced the thinning and tapering of the orogenic wedge. The unroofing took place locally under an inverted temperature gradient, caused by a detachment which carried a part of the hot mantle wedge, above the subduction zone, over the subducted units.

Key words: *continental subduction, syn-orogenic extension, high-pressure metamorphism.*

RESUMEN

Según se deduce de su evolución metamórfica, las Unidades Basales de los Complejos Alóctonos de Galicia representan una parte del margen del Gondwana paleozoico, subducida al comienzo de la Orogenia Varíscica. Variaciones en las condiciones P-T del primer evento metamórfico de alta presión en las diferentes unidades, indican una polaridad de la subducción hacia el Oeste. La consiguiente incorporación de nuevo material continental bloqueó la subducción y desencadenó el ascenso y la exhumación de la Unidades Basales mientras la convergencia continuaba. Se desarrollaron a la vez estructuras compresivas y extensionales, o alternaron en el tiempo y, juntas, indujeron el adelgazamiento y agudizamiento de la cuña orogénica. La denudación tectónica se produjo localmente bajo un gradiente inverso de temperatura, causado por un despegue que puso en contacto una parte de la cuña mantélica caliente, situada por encima de la zona de subducción, con las unidades subducidas.

Palabras clave: *subducción continental, extensión sin-orogénica, metamorfismo de alta presión.*

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Introduction

The Allochthonous Complexes of the NW Iberian Massif represent mega-klippen outcropping in synforms or structural basins formed in the late stages of the Variscan cycle. Three complexes occur in Galicia (Spain): Cabo Ortegal, Ordenes and Malpica-Tui (Fig. 1). They consist of several allochthonous units of diverse provenance, resting upon a sequence, essentially metasedimentary, of Paleozoic and possibly Upper Proterozoic age, which is often referred to as the Parautochthon. This was in turn tectonically emplaced above a set of metasediments and orthogneisses, called the Relative Autochthon. In spite of its name, the latter is strongly deformed and recumbent folds and thrust sheets are common on it.

The allochthonous units are grouped in four sets: Uppermost, Catazonal, Ophiolitic and Basal Units. The Uppermost Units consist of terrigenous metasediments, amphibolites, augengneisses and gabbros. The Catazonal Units include paragneisses, mafic rocks and ultramafic, rock, but the more characteristic are being the metabasites, commonly garnet-clinopyroxene granulites and eclogites, partiallyretrograded to the amphibolite facies. The Ophiolitic Units include basalts and basaltic andesites, broken pillow-breccias and hyaloclastites, diabases, metagabbros, often pegmatitic, plagiogranites, amphibolites and ultramafics, and depict a wide variety of metamorphic conditions ranging from the IP granulite facies to the greenschist facies. Finally, the Basal Units consist of monotonous pelitic and gresopelitic schists -common-

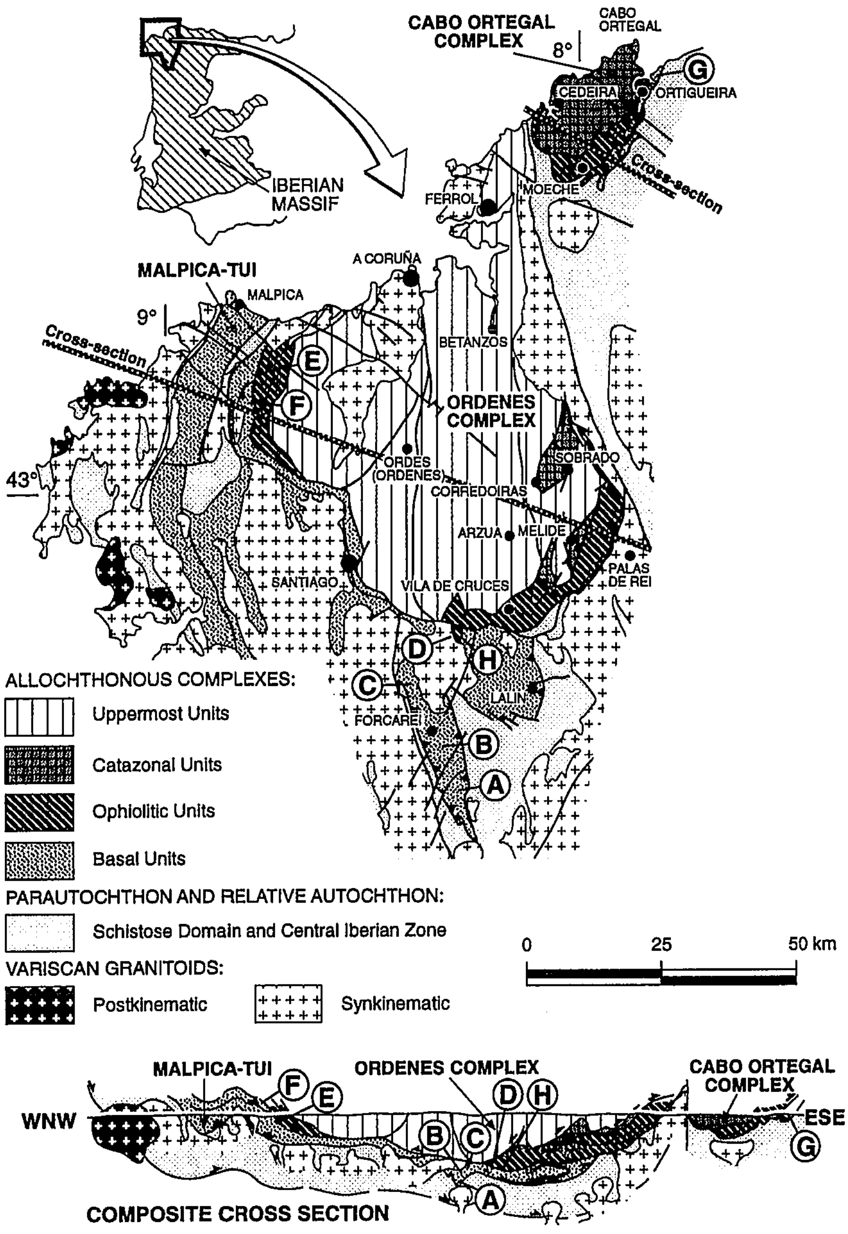

Fig.1. Geological map and cross section of the Galician Allochthonous Complexes.

ly rich in albite porphyroblasts, paragneisses, scarce quartzite horizons, felsic orthogneisses and biotitic augengneisses. There also orthoamphibolites and eclogites, mostly preserved as boudins included in orthogneisses.

Tectonothermal evolution

A structural and metamorphic study was carried out in the Basal Units of the Ordenes Complex. These units underwent an initial HP metamorphic event whose P-T conditions have been estimated by thermobarometry of the eclogites and of an old paragenesis formed by micro-inclusions preserved in albite porphyroblasts in the metasediments (Arenas et al., 1995, Martínez Catalán *et al.*, 1996). This event is related to the Eo-Variscan subduction of the leading edge of the Gondwana margin (Fig. 2, stage 1) under a colliding element consisting, from bottom to top, of ophiolific integrated by the Uppermost and Catazonal Units, which attained eclogitic conditions at its base. reached vary according to the position inside the crustal subduction complex. The paths followed by seven sites from the Basal Units, marked with the letters A to G, have been investigated for the peak P conditions and the subsequent evolution (Fig. 3). Sites A to F underwent progressively higher metamorphic conditions. Though, as a consequence of later recumbent folding, sites A to D inverted they relative positions, the unfolding of these structures. The final stages of the subduction may be situated 374 Ma ago, age of the immediately post-eclogitic white micas in Malpica-Tui (Van Calsteren et al., 1979). This is also the age (Dallmeyer et al., 1993) of the Corredoiras Detachment (CD), a normal ductile fault which separates the Uppermost and Catazonal Units in the E of Ordenes. This suggests that extensional structures developed in the upper parts of the orogenic wedge whereas convergence continued at depth.

After the HP event, the P-T paths were governed by a strong decompression, which was syn-kinematic with the regional schistosity. This fabric transects the above-mentioned recumbent folds, and was followed by the Lalín-Forcarei Thrust (LFT). This fault carried the Basal Units onto the Parautochthon, which did not undergo any HP event. However, this compressional structure is contemporaneous with another normal accident, the Campo Marzo Detachment (CMD), which carried the hot, sub-ophiolitic mantle, over the underlying Basal Units (Fig. 2, stage 2). The CMD and locally a heating from above, giving rises to an inverted metamorphic gradient in the Basal Units during the decompression. As can be appreciated in paths B to E (Fig. 3), the heating was more intense close to the CMD. H in Fig. 3 is the decompressive path suggested for the mantle wedge above the subduction zone. The detachment followed the nucleation of the recumbent folds, but was contemporaneous with the development of the regional foliation and the LFT sugesting, again, contemporaneity between compressional and extensional structures.

The orogenic evolution continued with the development of recumbent folds and thrusts in the Parautochthon and Relative Autochthon, and of upright folds and transcurrent shear zones everywhere. Some detachments were also formed, the latter of which is that of Pico Sacro (PSD), which was preceded but also overprinted by episodes of upright folding (compare Fig. 2, stage 3, to the cross-section in Fig. 1). In the

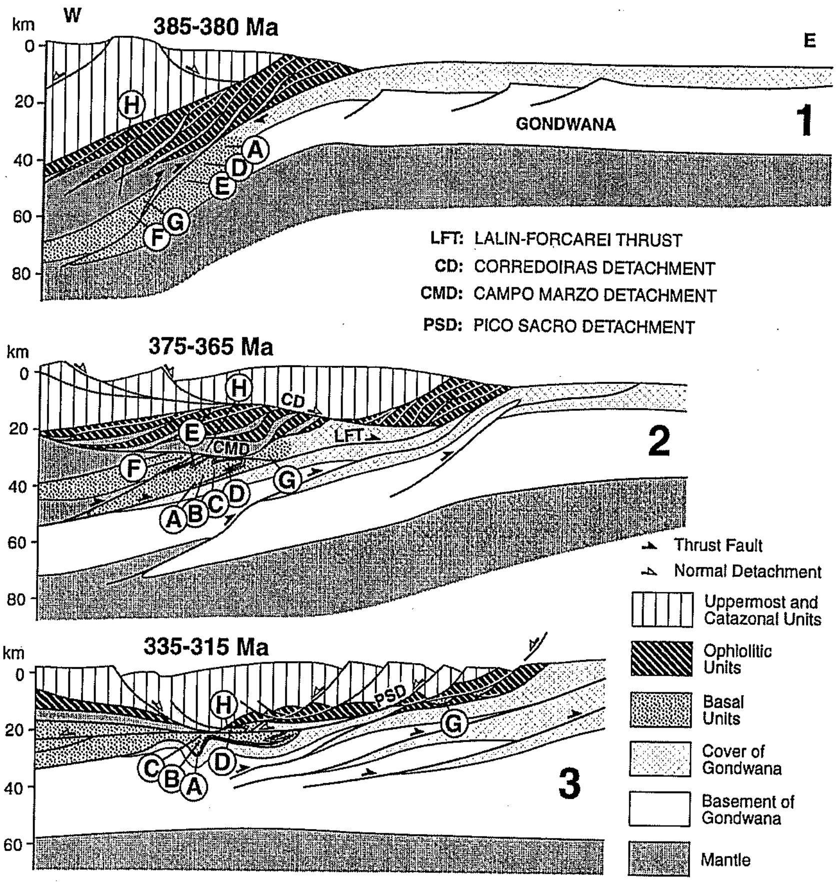

Fig. 2. Sketch of the main tectonic stages undergone by the Basal Units.

P-T paths, this third stage is characterized by a slightly decompressive cooling (Fig. 3), which probably reflects the effects of erosion and minor tectonic denudation.

The metamorphic evolution of the footwall to the complexes was of Barrovian type or transitional to one of lower pressure (Gil Ibarguchi and Arenas, 1990). It differs strongly from the evolution of the basal units because: 1- It does not include HP events; 2- Its thermal evolution is usually controlled by normal temperature gradients, and 3- The P-T path is opposed and diachronic in relation to that of the HP units, because the footwall units underwent a P-T increase while the basal units were being thrust over them.

Conclusions

We interpret that the Basal Units formed part of an accretionary complex created by subduction of the leading edge of the Gondwana margin to the W under a colliding element assembled prior to the continental subduction. The eclogitic metamorphism in the Catazonal Units of Cabo Ortegal has been dated at 395 Ma (Schäfer et al., 1993) and the amphibolite facies metamorphism in the ophiolites at 390-380 Ma (Peucat et al., 1990; Dallmeyer and Gil Ibarguchi, 1990; Dallmeyer et al., 1991). The first must predate the continental subduction, but the latter could have been partly contemporaneous. This, together with the data of Van Calsteren et al. (1979), situates the continental subduction between 385 and 375 Ma approximately. The polarity of the subduction is indicated by the pressure gradient of the first metamorphic event, and agrees with the general sense of shear of the compressional structures in the footwall to the Allochthonous Complexes (Pérez-Estaún et al., 1991).

The strongly decompressive paths of stage 2 was probably due to buoyancy forces exerted by the accretion of new continental slices. Apparently, the prolonged underthrusting of continental material blocked the subduction and triggered the ascent and exhumation of the basal units whereas the convergence continued. The thinning and tapering of the orogenic wedge and its lateral spreading reflect the squeezing of huge volumes of rocks, induced by the gravity-driven vertical shortening and accomplished by the detachments. Most of the unroofing occurred in the 10 Ma following the end of the subduction, but compressional and extensional structures developed simultaneously and alternated along a time span of around 60 Ma, which corresponds to the intracontinental collisional stage (Fig. 2, stages 2 and 3). The present geometry of the allochthonous complexes and the dispersion of their units may be explained by these mechanisms.

The structural and thermobaric analyses show the complexities that the dynamic model of an orogenic wedge, which extends in its upper parts while convergence continues at depth (Platt, 1986), may show in a particular case. The Ordenes Complex offers a regional framework to study the dynamic evolution of orogenic wedges and the thermal evolution of subduction zones and shows the role that the mantle wedge above the subducted margin may play in the whole dynamics. This wedge may account for the development of regional metamorphic inversions during the exhumation of the subducted ensembles.

Acknowledgments

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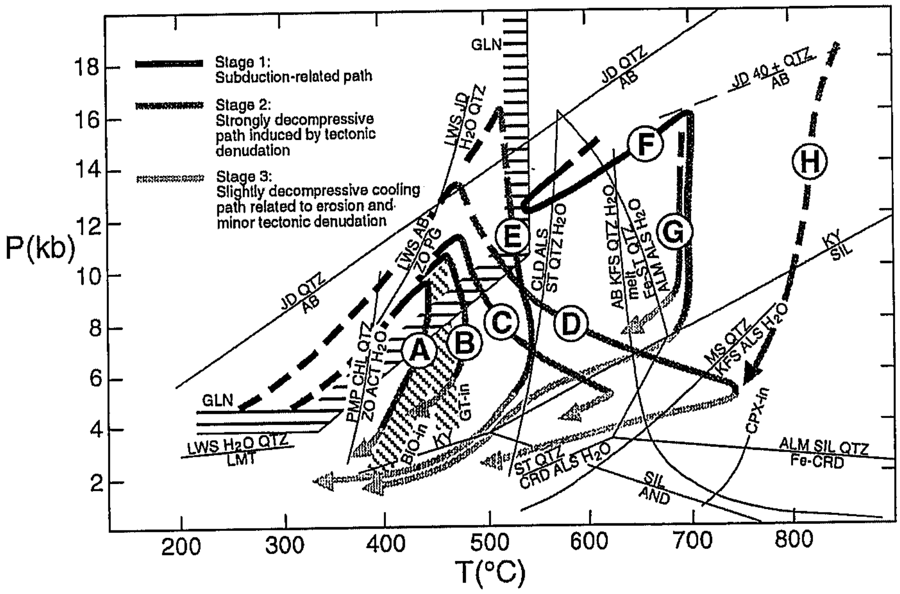

Fig. 3. P-T paths followed by the Basal Units (A to G) and the mantle wedge above the subduction zone (H).