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Thin skinned tectonics in the Ponga region (Cantabrian Zone, NW Spain)

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With 8 figures and 1 table

Zusammenfassung

Die Variszische Front und damit verbundene Faltenstrukturen des Pongagebietes (Kantabrische Zone, NW Spanien), werden mit Hilfe von »thin skinned tectonic« mit dominierendem ostwärts gerichtetem Transport interpretiert. Eine 2,5 km mächtige Folge paläozoischer Gesteine wurde durch ostvergente Überschiebung deformiert. Dabei wurde ein Schuppenfächer und eine Duplexstruktur ausgebildet.

Das Ausbeißen der Überschiebungsbahn an der Oberfläche ist duch die Existenz longitudinaler und transversaler Faltensysteme sehr unregelmäßig. Ein Profil senkrecht zum Streichen verdeutlicht die Geometrie der Überschiebungen und Faltensysteme.

Die gesamte Transportweite beträgt mindestens 62 km.

In einem diagonalen Profil kann eine »tear fault« festgestellt werden.

Ein späteres Überschiebungssystem (z. B. Peña Ten Überschiebung), mit hauptsächlich Südwärts gerichtetem Transport hat das frühere Ostwärts vergierende System überprägt. Das jüngere Überschiebungssystem hat die älteren Lateralstrukturen als Frontstrukturen reaktiviert.

Abstract

The Variscan thrust and associated fold structures of the Ponga Region (Cantabrian Zone, NW Spain) are interpreted in terms of thin skinned tectonics, with a dominant eastward transport direction.

A 2.5 km thick sequence of Paleozoic rocks was deformed by an east vergent thrust system that includes an imbricate fan and a duplex. The thrust surfaces have a very irregular map outcrop pattern due to the existence of a set of folds (longitudinal and transverse systems). A strike-normal balanced section illustrates the geometry of the thrusts and their related folds. The minimum value of accumulate transport is about 62 km. A tear fault can be recognized in a transverse cross-section.

A later out-of-sequence thrust system (e.g. Peña Ten Thrust) with dominant southward direction is superimposed upon the earlier eastward verging thrust system. These thrust reactivate the earlier lateral structures as frontal structures.

Resumen

La estructura de la Región del Ponga (Zona Cantábrica, NO de España) es interpretada en el contexto de su situación en la zona externa de una cordillera, y consiste en un sistema de cabalgamientos que han sido emplazados predominantemente hacia el Este con un conjunto de pliegues asociados. Las superficies de cabalgamiento muestran un trazado cartográfico muy irregular debido a la existencia de un conjunto de pliegues transversales a ellos. La Ventana Tectónica del Río Monasterio representa una estructura lateral de estos mantos. El desplazamiento mínimo calculado en una sección a través de la parte central de la región es de 62 Km.

Posteriormente, tiene lugar el emplazamiento hacia el Sur de un nuevo sistema de cabalgamientos que reactivan estructuras laterales del sistema previamente emplazado, pasando a constituir éstas las estructuras frontales de los nuevos cabalgamientos.

Estas estructuras fueron formadas durante la orogénesis varíscica y afectan a un conjunto de materiales Paleozoicos de 2.5 Km. de espesor.

Краткое содержание

Фронт варисского надвига и связанные с ним складчатые структурные единицы в регионе Понга, зона Кантабрии, северо-запад Испании, интерпретируют, как тектонику маломощных подповерхностных структур с простиранием переноса на восток. Свиты палеозойских пород мощностью в 2,5 км оказались деформированными системой надвигов, вергентной на восток. При этом образовались веероподобные чешуйчатые и дуплексные структурные единица. Поверхность надвига неправильной формы и на карте отмечаются продольные и поперечные системы складок. Профиль, проходящий вертикально к простиранию, показывает определенную геометрию надвигов и систем складок.

Их общее перемещение составляет примерно 62 км.

При диагональном профиле удается установить слезовидный сброс. Позднейшая система надвигов – напр.: Пена Тен, с направленным гл. обр. на юг перед-

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вижением – преобразовали прежнюю вергирующую на восток систему структурных единиц. Позднейшая система надвигов реактивировала более древние боковые структуры, превратившиеся в лобовые.

Introduction

The external zone of the Variscan orogenic belt in the NW of the Iberian Peninsula, named the Cantabrian Zone (LOTZE, 1945), constitutes an arcuate foreland thrust and fold belt (Asturian Arc) where the displacement directions of the thrusts converge towards its core. The structural features are caracteristically thin skinned (RODGERS 1949, 1970), a feature which has been recognized by several authors (JULIVERT, 1971, MARCOS & PULGAR, 1982, BASTIDA et al., 1984, amongst others).

The Ponga region is located in the core region of the Cantabrian arc (Fig. 1). The area has been studied by several authors (JULIVERT, 1960, 1967a & 1967b, PELLO, 1967, MARCOS, 1967, MARTINEZ ALVAREZ, 1962, 1966 and SJERP, 1966). This paper is based on the reinterpretation of the published maps of JULIVERT (1960a & b), SJERP (1967), HEREDIA et al. (in press) and new data obtained by the authors mainly from the southern part of the region.

The structural interpretation of the Ponga region described in this paper is based mainly on a geometrical analysis using balanced cross sections (DAHLSTROM, 1979). This method has already been used by several authors in studies of other Cantabrian nappes (BASTIDA et al., 1984, HEREDIA, 1984, ALVAREZ MARRON, 1985, ALONSO, 1985). The aim of this work is to present an interpretation of the thrust geometry of the Ponga region and to produce a balanced cross-section and a preliminary kinematic interpretation. Two cross-sections, a longitudinal one and a transverse one, show the thrust geometry as well as the genetic relationships between folds and thrusts.

Geological setting

The thrust system in the Ponga region presents a very irregular map pattern (Fig. 3) because the thrusts have been affected by a later set of folds. The thrust

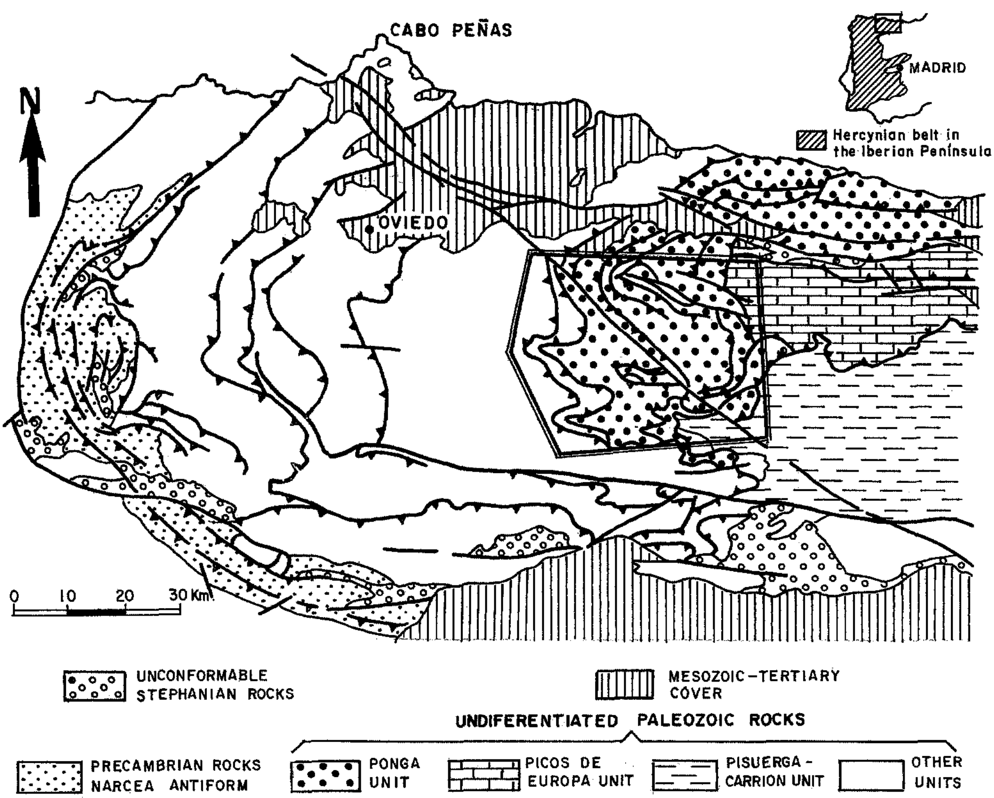

Fig. 1. Generalized geological and location map of the Cantabrian Zone. Studied area is outlined in the centre of the diagram.

system produced deformation in a sequence of Paleozoic rocks with a variable thickness where two main stratigraphic sequences can be broadly distinguished (Fig. 2). There are:

1. A Pre-Carboniferous sequence ranging from Lower Cambrian to Lower Ordovician in age (JULIVERT, 1960, ZAMARREÑO & JULIVERT, 1967). Fig. 2 shows the lithologies of this series. An important lateral thinning can be observed towards the east, from 1.000 m. to 500 m. Only Cambrian rocks can be found in the most external part. There is a general level of decollement in this region located within the Lancara Fm. (Lower-Middle Cambrian) (Fig. 2). Older rocks do not outcrop in the Ponga area.

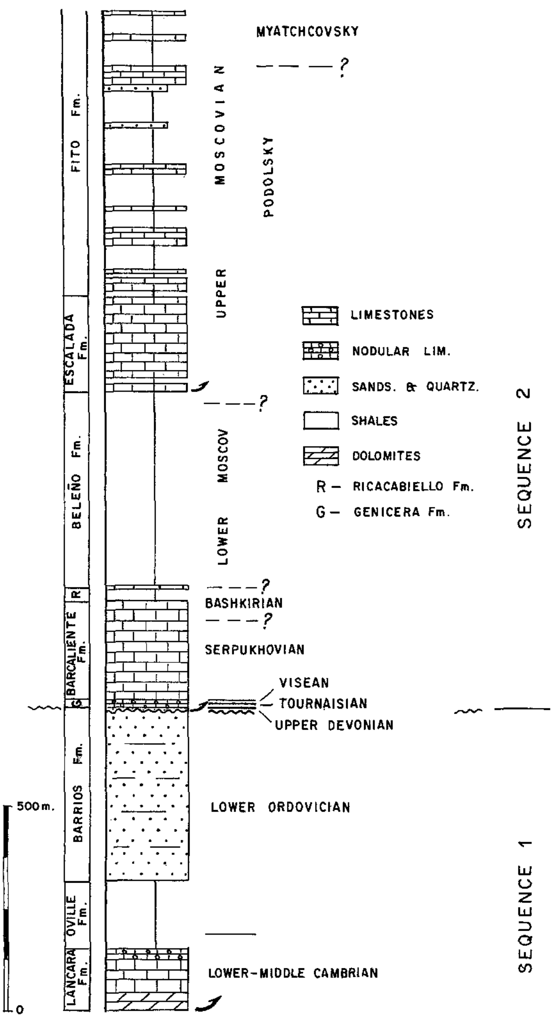

Fig. 2. Simplified stratigraphic section of the Espinaredo sheet. After TRUYOLS, 1923 and ZAMARREÑO & JULIVERT, 1967.

2. A Carboniferous package, up to 4.000 m thick in some of the thrust sheets. This sequence is mainly siliciclastic in composition with important calcareous units (Fig. 2) (TRUYOLS, 1983). The youngest age found is Myatchcovian. A few metres of Upper Devonian shales and siltstones (Upper Famenian, SJERP, 1967) are present at the base of the series. The thickness, sedimentary facies and age variations of this Carboniferous succession are of outstanding importance (VILLA & HEREDIA, in press). Although these changes appear laterally within the same thrust sheet, those observed between different sheets are much more significant. The stratigraphic column of Fig. 2 comes from the Espinaredo sheet (Fig. 4A) and is taken as a simplified lithological sequence characteristic of the Ponga region.

Between these two series there is a stratigraphic gap that includes the middle and upper Ordovician, the whole of the Silurian period, and most of the Devonian (Fig. 2) and that becomes more and more important towards the East where even the Lower Ordovician is absent (Fig. 3).

Structure

The most outstanding feature of the Ponga region (Fig. 3) is the existence of a set of thrusts affected by transverse folds with variable geometries and distribution. Thus, in the external part of this region two large antiforms give rise to two tectonic windows: that of Río Color to the north and that of Río Monasterio to the south (Fig. 3) (JULIVERT, 1967a & b). Between them, there is a broad flat bottom syncline (about 8 km. wide) with a box-like geometry in its external part.

The existence of the transverse folds allows analysis of the deep geometry of the thrust sheets and of the magnitude of the displacement, since a map view of the longitudinal section can be observed in the eroded cores of the antiforms. This feature makes of this region an exceptional area since it allows interpretations to be made of the geometry of deep structures when cross sections and restorations are carried out.

Four major thrust sheets (Campo de Caso nappe, Espinaredo nappe, Sebarga nappe and Tarna-Sajambre nappe), the Beleño imbricate fan system and the Beyos duplex form the thrust systeme of this region (Fig. 4A). Other important structures in the area are:

1. Two sets of superposed folds (JULIVERT, 1971, JULIVERT & MARCOS, 1973) are present: one with axial traces parallel to the map outcrop of the thrusts surfaces (longitudinal system), and another set with axial traces clearly transverse.

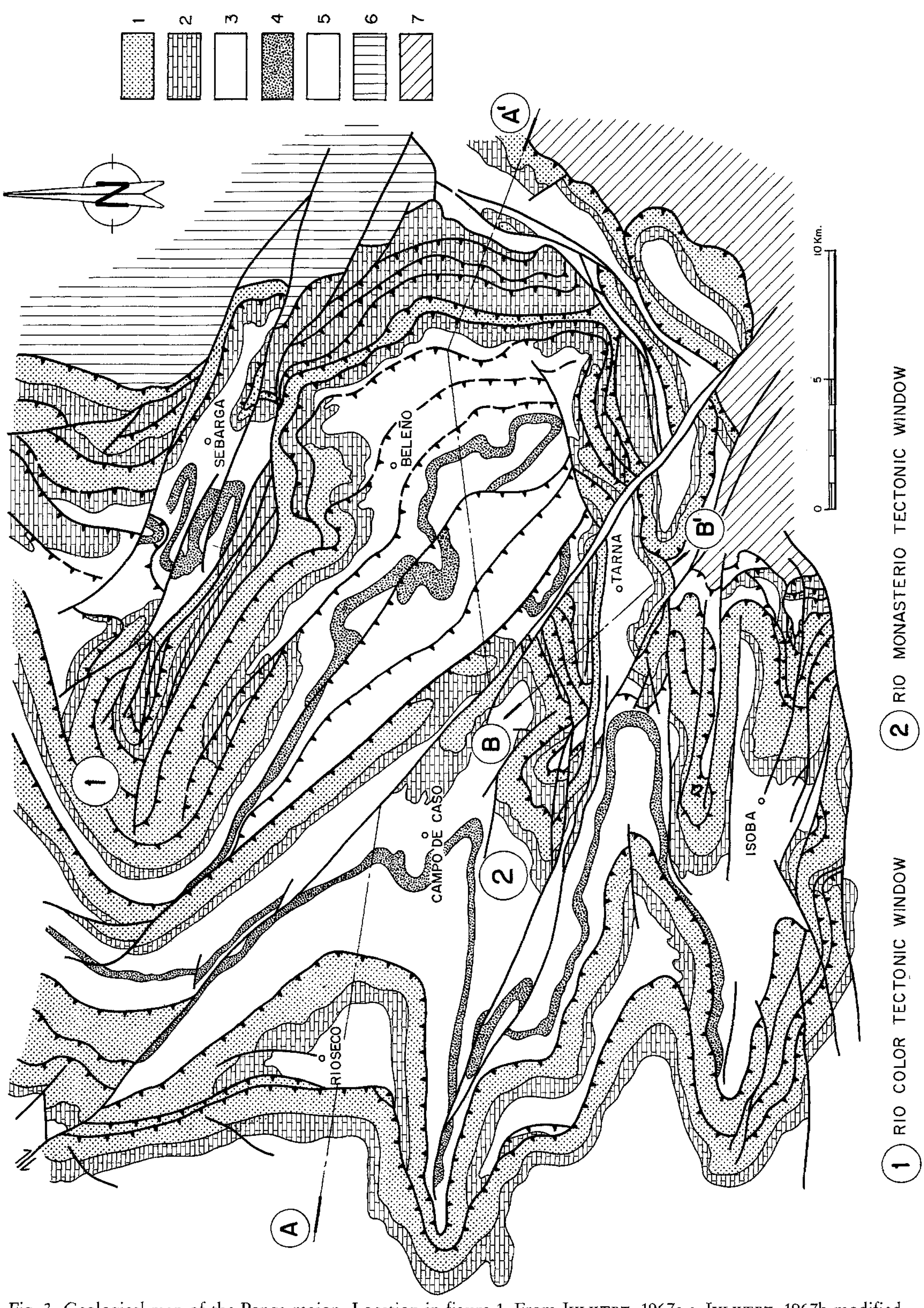

Fig. 3. Geological map of the Ponga region. Location in figure 1. From JULIVERT, 1967a & JULIVERT, 1967b modified.

2. A set of generally steep reverse faults that postdate the emplacement of the earlier east verging thrust sheets (Fig. 4B).
3. Ventaniella fault. This is a post Variscan, dextral strike slip fault that crosses the whole region in a NW-SE direction (JULIVERT et al., 1971) cutting through all the other structures (Fig. 3).

An structural sketch map showing the axial traces of the major folds and the main subsequent faults is presented in Fig. 4B.

Section parallel to the transport direction of the nappes

An approximately E-W cross-section through the Ponga region is shown in Fig. 5A. It has been constructed perpendicular to the axial directions of the longitudinal folds and parallel to the transport direction of the nappes (section location in Fig. 3).

The structure of this section consists of a system of thrusts branching from a sole thrust located near the base of the Láncara Formation (Lower-Middle Cambrian age). This sole thrust generally has a constant dip towards the west but in the external part of the thrust system the slope is more marked due mainly to the presence of a footwall ramp in the Pisuerga-Carrión Unit (Fig. 5A).

A prominent feature of this section is the gradual increase in the number of thrusts towards the external part of the system where a duplex is present (Tipstick, strongly emergent thrust front, MORLEY, 1986). Three different types of thrusts can be distinguished, the first two with a dominant eastward transport direction and the third with a dominant southward transport direction.

– The first group includes thrust surfaces that branch from the sole thrust which is parallel to the bedding in the allochthon along most of its trajectory. Most of the thrusts in this section are of this type. Only in their frontal part do these thrusts cut up section into younger stratigraphic levels (Fig. 3). Fig. 6 shows a map scheme corresponding to the Beleño imbricate fan. Here, footwall and hangingwall ramps and flats can be observed as well as the folds related to the hangingwall ramps. In this figure it is also possible to see a thrust that represents a decollement surface located at the base of the Carboniferous succession which has no stratigraphical repetition.

– The second group of thrusts are those that form the Beyos duplex. These also branch from the sole thrust, but converge upwards into a roof thrust that is the decollement of the Sebarga nappe (Fig. 5A).

– The third type comprises a thrust that started from a floor fault and propagated upwards, cutting the base of previously emplaced thrust slices. Because of this, it has been interpreted as an out-of-sequence thrust, named Peña Ten Thrust (Figs. 4A, 7 & 8). This fault reactivated the floor thrust of the Beyos Duplex and was responsible for the uplifting of the duplex. Related to its emplacement a large antiformal culmination was formed and produced the back rotation of the thrusts located behind it (Beleño imbricate fan).

Apart from the thrusts, this cross-section shows several folds of the longitudinal set that can be divided in two groups:

a) Folds developed within the thrust sheets and that did not affect the thrust surfaces. These folds are related to hangingwall frontal ramps (fault bend folds, SUPPE, 1983, leading edge folds, BOYER, 1986). They are often anticlines, although they may also include many minor folds, and are usually located at the frontal part of the sheets (Figs. 5A & 6).

b) Folds that fold the thrust surfaces. These folds are usually monoclines that represent dorsal culmination walls (BUTLER, 1982) related to footwall frontal ramps (e.g. Campo de Caso nappe) (Fig. 5A). Besides this type of folds, there are also folds caused by the accomodation of the overlying thrust sheets to the roof topography of underlying imbricated units (e.g. flexures in the Sebarga Nappe due to the geometry of the Beyos duplex, Fig. 5A). This type of fold has been described by several authors in other orogenic belts (e.g. HARIS & MILICI, 1977, ELLIOT & JOHNSON, 1980, BOYER & ELLIOT, 1982) and in the Cantabrian Zone they have been described by ALONSO (in press) as »drape folds«.

The process of formation of the longitudinal folds can be interpreted to be directly caused by the thrust emplacement.

In Fig. 5B a complete restoration of part of section 5A can be seen. In this section only the Campo de Caso nappe, Espinaredo nappe and imbricate fan of Beleño, have been restored, showing by means of a dashed line the position of the thrust surface. Some of these thrusts clearly have a staircase trajectories. The rest of the section has not been restored since the Peña Ten thrust and some of the thrusts associated with it have a different transport direction. Thus, this part of the section (the frontal part) is not a plane-strain section.

Río Monasterio tectonic window. Transverse structures

This structure was described for the first time by JULIVERT (1965). It is a large E-W striking antiform situated in the southern part of this region (Fig. 3).

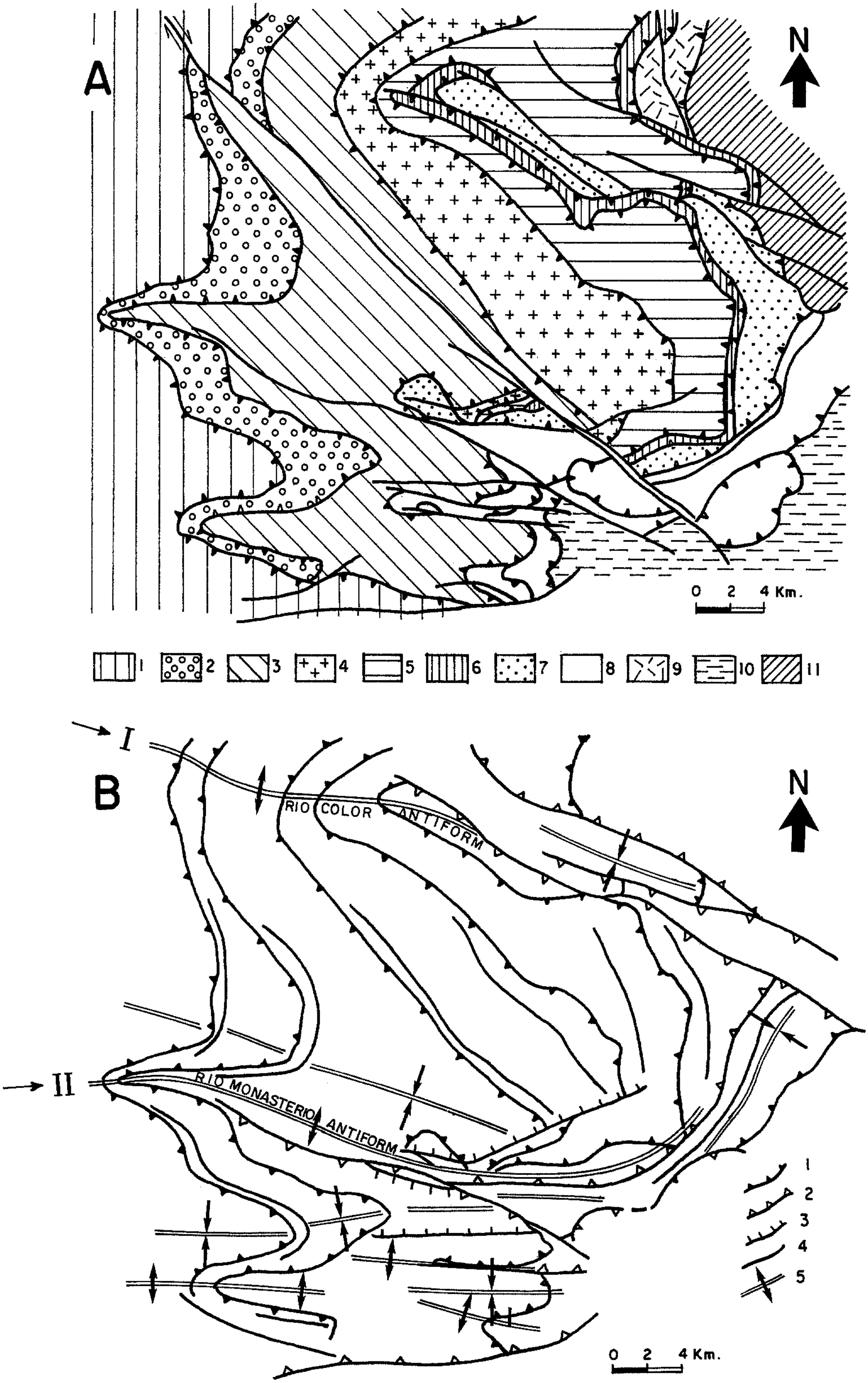
A
N
0 2 4 Km.
1 2 3 4 5 6 7 8 9 10 11
B
I
II
N
RIO COLOR ANTIFORM
RIO MONASTERIO ANTIFORM
1
2
3
4
5
0 2 4 Km.

Fig. 7 shows a sketch map of this structure. The horizontal displacement on the Ventaniella fault (a late dextral strike-slip fault, see Fig. 3) has been restored. Hence, the western part of the window (Río Monasterio area) can be matched with its eastern prolongation (Peña Ten area).

In the core of this structure, below the Campo de Caso thrust sheet (I, Fig. 7) two thrust sheets outcrop in its western part (a & b, Fig. 7), whilst in its eastern part at least three more thrusts (c, d & e in Fig. 7) branch from the afore-mentioned thrust. Besides, there are fewer thrust sheets in the south than in the north of this tectonic window (Fig. 8). Taking into account this change in the number of the thrust sheets, the existence of the Río Monasterio tear fault has been inferred. This fault would have acted as tear fault during the emplacement of thrust sheets structurally lower than the Campo de Caso nappe. Afterwards, this tear fault underwent a reactivation as a reverse fault with a listric geometry (Fig. 8).

In this region it is common to find reverse faults parallel to transverse antiforms. The structural sketch map (Fig. 4B) shows the trace of these faults and also some normal faults with a similar E-W trend. The reverse faults have two different types of map patterns, either rectilinear in the NE with a NW-SE strike (i.e. the Río Color fault zone, figure 4B), or slightly curved changing from an E-W direction in the internal part to NE-SW in the external zone (e.g. the Peña Ten Thrust, figure 7). The later are located in the central part of the region. This group includes the reverse faults of Fig. 8 and 5A that converge towards the sole thrust of the Beyos duplex.

All these reverse faults that cut higher thrusts can be interpreted as a system of out-of-sequence thrusts whose movement direction was at high angle to that of the earlier east-verging thrusts. For that reason, some lateral structures related to earlier thrusts (e.g. the Río Monasterio tear fault), reactivated as frontal structures to the out-of-sequence thrusts causing the amplification of the pre-existing hangingwall antiforms. During this process passive-back thrusts (Banks & Warburton, 1986) were also generated (i.e. that in Fig. 8 which produced the Valdosín-Zalambral klippe, situated to the south of this region, see Fig. 7).

There are frequently normal faults in the limbs of the important transverse folds. Those present in the northern limb of the Río Monasterio window are of outstanding importance (Figs. 4B, 7 and 8). Some of the normal faults could have been extensional faults produced on lateral ramps of the earlier east-verging thrust sheets (drop faults, Butler, 1982).

The kinematics of emplacement of the thrust sheets

From the map and from the cross-section described in this paper, preliminary conclusions may be made on the kinematics of emplacement of the Ponga thrust sheets.

Using tectonostratigraphic arguments Marcos & Pulgar (1982) inferred a forward-stepping sequence for the major allochthonous units in the Cantabrian Zone. Similarly, Alonso (1985) adding kinematic and geometric relationships, postulated the same emplacement sequence for a thrust system which forms one of these major allochthonous units (Esla nappe).

Such an emplacement sequence has been assumed for the construction of the restored section (Fig. 5B). That is to say rear-most (western) nappes formed before the frontal (eastern) nappes. Geometrical arguments, such as the flexure of upper sheets caused by the later emplacement of lower ones, have been used for this analysis. It has been assumed that the emplacement occurred from west to east for the first thrust system (as it is illustrated by the frontal and lateral structures of the thrust sheets, in Fig. 5A & 7).

Comparing sections 5A & 5B the displacements of the different thrust sheets and thrust systems have been calculated (Table 1). The Beyos duplex, which does not appear in Fig. 5B, has been balanced sepa-

Thrusts & Thrust-Systems	Displacement (km)	Accumulated Displacement
Campo de Caso Thrust	9,40	9,40
Espinaredo Thrust	6,80	16,20
Beleño Imbricate System	10,80	27,00
Beyos Duplex	31,40	58,40
Peña Ten Thrust	3,80	62,20

Table 1. Displacement of the main thrusts and thrust systems of the Ponga Region.

◀Fig. 4. A) Simplified map showing the distribution of the thrust sheets in the Ponga Unit. 1; Laviana Thrust-sheet. 2; Rioseco Thrust-nappe. 3; Campo de Caso Thrust-nappe. 4; Espinaredo Thrust-nappe. 5; Beleño Imbricate System. 6; Sebarga Thrust-nappe. 7; The Beyos Duplex. 8; Tarna-Sajambre Unit. 9; Tornín Unit. 10; Pisuerga-Carrión Unit. 11; Picos de Europa Unit. B) Tectonic sketch map of the major structures in the Ponga region. The dextral strike slip fault of figure A has been restored. 1; Thrusts. 2; Later thrusts and reverse faults. 3; Normal faults. 4; Axial trace of major longitudinal folds. 5; Axial trace of the major transverse folds.

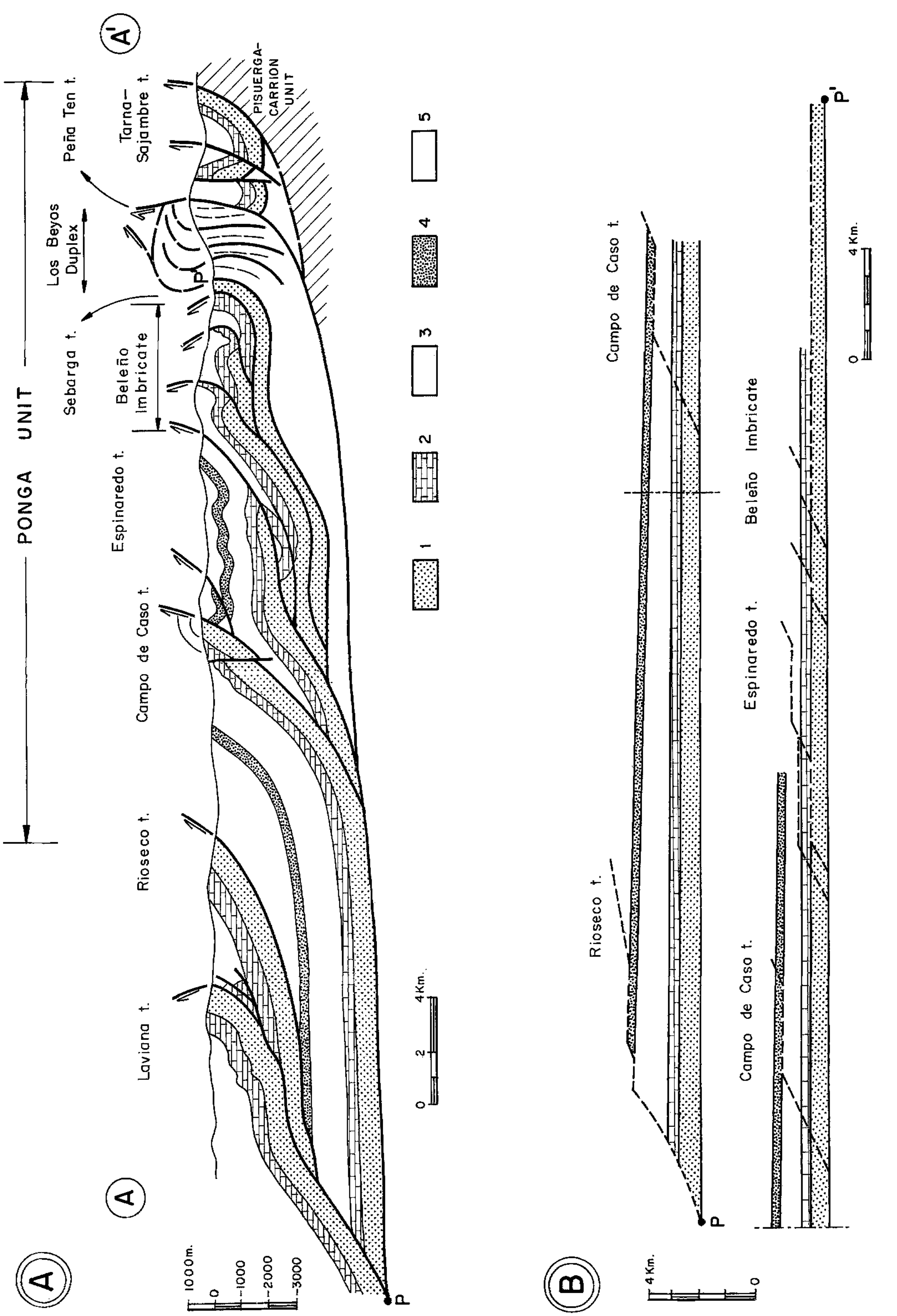

Fig. 5. A) Balanced cross-section. A-A' in figure 3. 1; Cambro-Ordovician rocks. 2; Barcaliente Fm. 3; Beleño Fm. 4; Escalada Fm. 5; Fito Fm. B) Restored section of part of section A. P and P' correspond to those of section A.

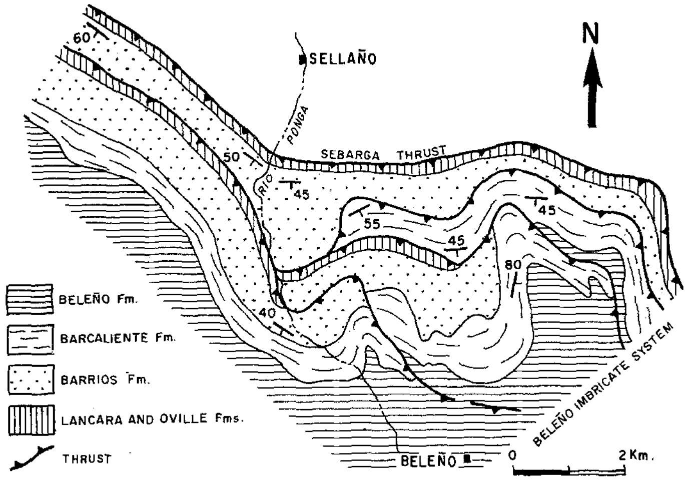

Fig. 6. Geological map of North Beleño area. See Beleño in figure 3 for location.

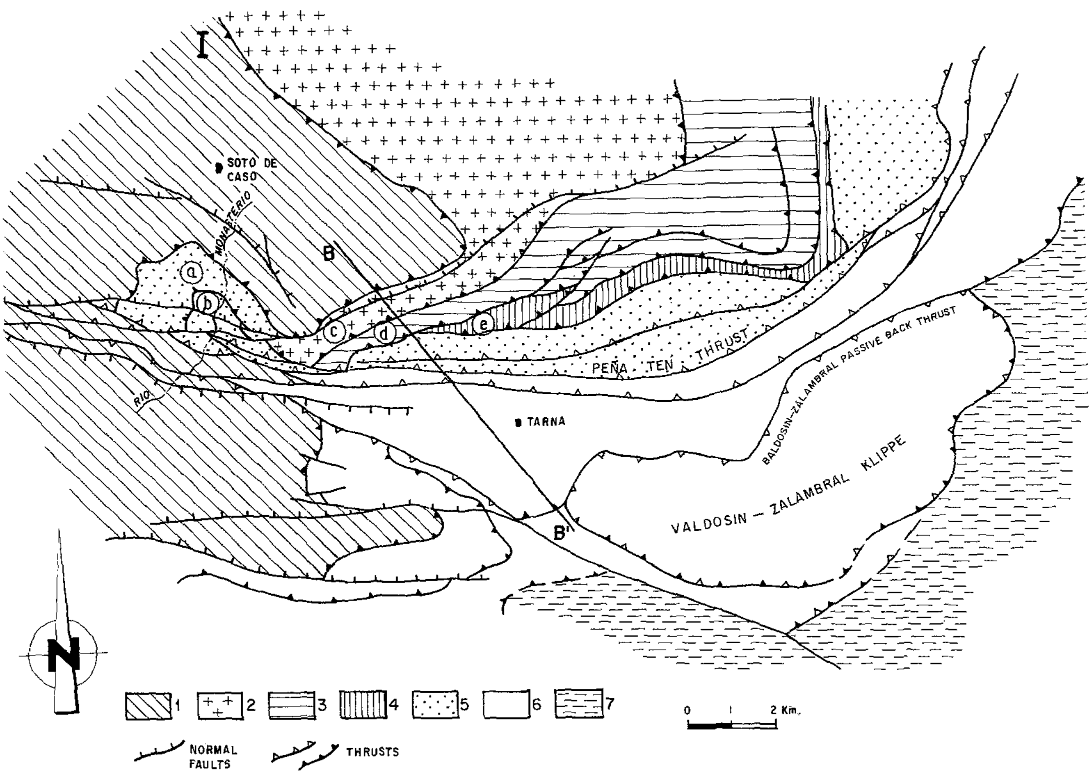

Fig. 7. Geological sketch of the Río Monasterio Tectonic Window. See figure 3 for location. The dextral strike slip fault (i.e. Ventaniella fault) has been restored. 1; Campo de Caso Thrust-nappe. 2; Espinaredo Thrust-nappe. 3; Beleño Imbricate System. 4; Sebarga Thrust-nappe. 5; The Beyos Duplex. 6; Tarna-Sajambre Unit. 7; Pisuerga-Carrión Unit.

rately using area conservation (described by Hossack, 1979). The total accumulated displacement for the section in Fig. 5, calculated without the displacement on the Laviana and Rioseco thrusts, is of the order of 62 km. The shortening undergone by the restored set (Fig. 5B) is about 49 %.

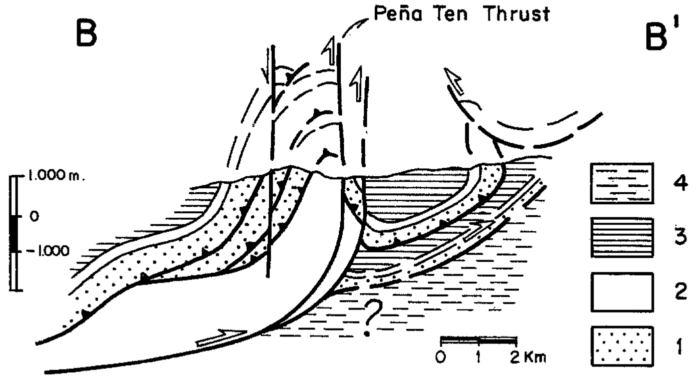

Fig. 8. Cross-section of Río Monasterio Tectonic Window. B-B' in figure 3. 1; Cambro-Ordovician rocks. 2; Barcaliente Fm. 3; Beleño Fm. 4; Pisuerga-Carrión Unit.

The emplacement of the Beyos duplex caused the bending of the thrust sheets located above it, the curvature reflecting the topography of the duplex. The later Peña Ten Fault caused the frontal part of the duplex to be uplifted and the back-rotation of the rear thrusts.

After the emplacement of the earlier thrusts towards the east, movement on the Peña Ten Thrust took place, as well as on related faults (e.g. Valdosín-Zalambral passive-back thrust, figure 7). The displacement direction of this thrust trends south to south-eastwards. This implies a shortening direction that would be subperpendicular to that of the earlier thrust system. The earlier lateral structures reactivated as frontal structures to the new thrust system. This different direction of shortening during the successive emplacement of each nappe in the Cantabrian Zone (Fig. 1) is a consequence of the formation of the Asturian Arc (PEREZ-ESTAUN et al., in press). In this way the previous nappes must be cut by oblique out-of-sequence structures or must be transported in a direction oblique to their original movement direction.

Some major faults which were transverse to the east verging thrusts in the Ponga region were first lateral structures and then acted as reverse faults due to the southward emplacement direction (MARQUINEZ 1978; FARIAS, 1982) of Picos de Europa Unit (located in front of the Ponga region to the NE, see figure 1).

Conclusions

The Ponga region forms one of the most external thrust units in the arcuate foreland thrust and fold belt of the Variscan orogenic belt in the Iberian Peninsula. The Ponga region is located in the core of the arc and its main structural feature is the presence of several thrusts branching from a sole thrust located in the Láncara Fm. (Lower-Middle Cambrian) and a cross-folding system. An Upper Westphalian age for the formation of these structures can be inferred from the olistostrome deposits related to the thrusts emplacement and from the palinspastic restoration of synorogenic sediments (PULGAR & MARCOS, 1982).

The first thrust system, with dominant eastward transport direction, presents four major thrust sheets as well as an imbricate fan system and a duplex. The minimum value of accumulated displacement is 62 km. Folding within the sheets are related to frontal hangingwall ramps. The folds deforming the thrust surfaces are related to roof topography of underlying thrust systems.

The tear fault of Río Monasterio acted as a lateral structure with a dominant E-W movement direction.

Some of the folds with axial trace subperpendicular to the thrusts traces can be interpreted as amplified lateral structures of the first thrust system. The Río Monasterio antiform is placed on a lateral structure with a dominant E-W direction.

After the emplacement of the east verging thrust system, a system of later reverse faults were developed. In this group, the Peña Ten Thrust is an out-of-sequence thrust that reactivated the Río Monasterio tear fault. This system of faults forms a second thrust system (including back thrusts) with a dominant southward movement direction, and reactivated the lateral structures of the earlier thrust system.

The second thrust system and its associated folds (transverse folds) could be related to the emplacement of the Picos de Europa Unit. As such, the Peña Ten Thrust would accomodate part of this movement, cutting upwards into the Ponga region and into the Río Monasterio antiformal core.

Acknowledgements

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