Sociedad Geológica de España

GEOGACETA, 51, 2012

Kinematic characterization of cleavage in Permo-Triassic red beds of the Espadán Range (Castellón, NE Spain)

Caracterización cinemática de la esquistosidad en las capas rojas Permo-Triásicas de la Sierra de Espadán (Castellón, NE España)

Juan Gual Pérez, Andrés Gil Imaz and José Luis Simón Gómez

Departamento de Ciencias de la Tierra. Facultad de Ciencias. Universidad de Zaragoza. C/Pedro Cerbuna 12, 50009-Zaragoza, Spain.
juangual@gmail.com, agil@unizar.es, jsimon@unizar.es

ABSTRACT

In this paper the Alpine cleavage affecting the Permo-Triassic series of the Espadan Range (Castellón) is studied. Cleavage affects to argillites and sandstones in Saxonian and Buntsandstein facies. At cartographic scale it is linked with the Espadan box anticline with constant ONO-ESE trend. At microscoscopic scale it constitutes a "spaced cleavage" with a predominance of pressure solution and passive rotation mechanisms. At outcrop scale the cleavage characterizes by a sigmoidal geometry linked both the post-cleavage flexural slip as a cleavage-related flexural flow mechanism. The proposed kinematic model to explain its origin includes three main stages: 1) incipient development of cleavage linked to layer-parallel shortening, 2) buckling and increasing of cleavage penetrativity and 3) folfing amplification and layer-parallel shear.

Key-words: *Cleavage, folding, Permo-Triassic, kinematic model, Iberian Chain.*

RESUMEN

Se estudia la esquistosidad alpina que afecta a la serie Permo-Triásica de la Sierra de Espadán, (Castellón). La esquistosidad afecta a los tramos argilíticos y areniscosos en facies Saxoniense y Buntsandstein, con distinto grado de penetratividad. A escala cartográfica se asocia al anticlinal de Espadán con geometría en cofre y orientación ONO-ESE. A escala microestructural se clasifica como esquistosidad espaciada con predominio de los mecanismos de disolución por presión y rotación mecánica de filosilicatos. A escala de afloramiento destaca la geometría sigmoidal de las superficies de esquistosidad atribuida tanto a un mecanismo post-esquistoso de flexodeslizamiento en las capas competentes como a flexofluencia sin-esquistosa en capas incompetentes. El modelo cinemático para su génesis contempla tres estadios: 1) desarrollo incipiente de esquistosidad en relación a acortamiento paralelo a las capas, 2) buckling e incremento del grado de penetratividad y 3) amplificación de los pliegues y cizalla simple paralela a las capas.

Palabras clave: *Esquistosidad, plegamiento, Permo-Trías, modelo cinemático, Cordillera Ibérica.*

Geogaceta, 51 (2012), 75-78.
ISSN:2173-6545

Fecha de recepción: 14 de julio de 2011
Fecha de revisión: 3 de noviembre de 2011
Fecha de aceptación: 25 de noviembre de 2011

Introduction

The ocurrence of penetrative planar fabric due to deformation and affecting to the Permo-Triassic series in the Espadán Range was firstly cited by Gutierrez-Elorza and Pedraza-Gilsanz (1974). For these authors it was considered as "slaty cleavage". Simón-Gómez (1984) defined this tectonic anisotropy as a cleavage-related fold structure with an Oligocene age. In both cases the tectonic fabric is only studied from a morfological point of view.

The aim of this paper is to obtain a kinematic characterization of the cleavage in the Espadán Range (SE Iberian Chain) and to propose a mechanism of formation according to the observed cleavage-related structures. Also, a new interpretation of the tectonic framework of the Espadán Range will be proposed paying special attention to the cleavage developed in the Upper Permian and Lower Triassic materials. For that purpose a map of cleavage trajectories has been drawn.

Geographical and geological setting

The studied area is located in the Espadán Range, in the SE part of the Iberian Chain (Fig. 1A). It is constituted by the terrigenous materials of the Permian and the Lower Triassic age. This area represents one of the most extensive outcrops of Permo-Triassic materials in Eastern Spain, (Martin-Martin *et al*., 2003). The Permian rocks of this area are in the Saxonian facies, whereas the Triassic ones are in the German facies (Garay, 2000) and are composed by the Buntsandstein facies, three members of the Muschelkalk facies (two dolomitic bars with an evaporitic member called Anhydritgruppe inserted between them) and the Keuper facies.

The stratigraphic units in the area were defined by Garay (2000). The studied terrigenous materials in Saxonian and Buntsandstein facies are included in the Calderona Group (Fig. 1B). The units defined

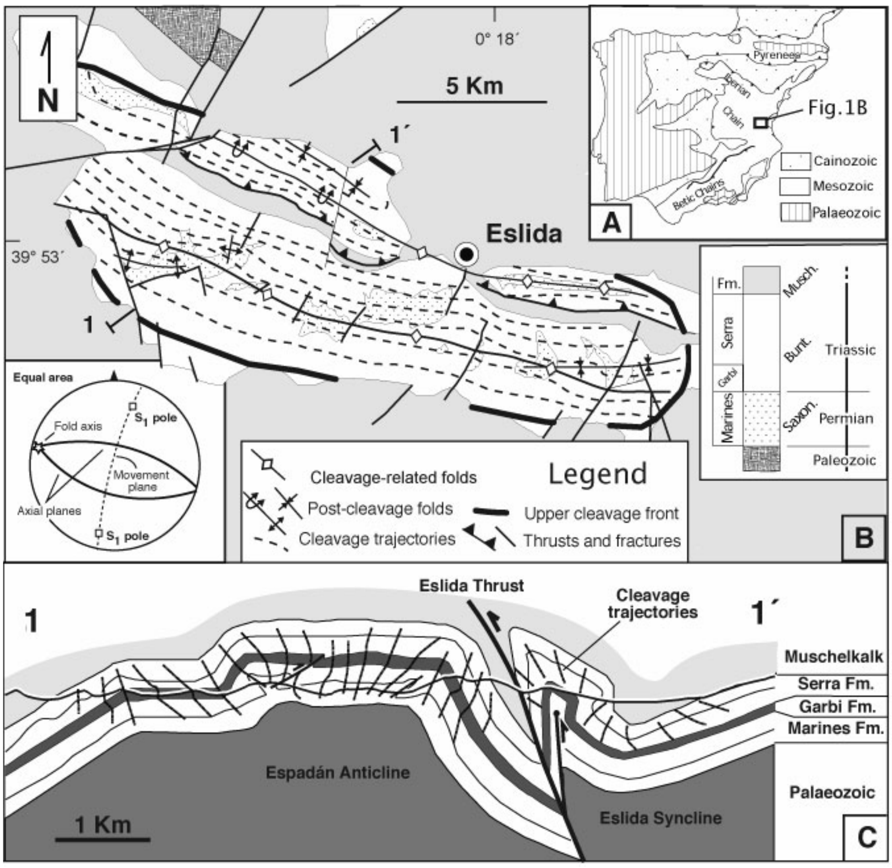

Fig. 1.- A) Location map of the studied area. B) Geological map of the studied area. C) Cross-section of the cleavage-related Espadán Range Anticline.

Fig. 1.- A) Localización del área estudiada. B) Mapa geológico del área de estudio. C) Corte geológico del anticlinal sinesquistoso de la Sierra de Espadan.

are: (1) Marines Formation: alternation of lutites and sandstones with a basal conglomerate; (2) Garbí Formation: predominately sandstones; (3) Serra Formation: lutites with some intercalations of sandstones. These units were chosen because they are useful to make the tectonic description and interpretation of the Espadán Range. Whereas both the Marines and the Serra Fm. have an incompetent behavior, the Garbí Fm. has a competent one.

Geological structure of the Espadán Range

Previous authors (Garay, 2000; Martin-Martin *et al.*, 2003; Simón, 1984, among others), explain the structure of this area like an anticlinorium at regional scale. This interpretation is based in the presence of minor folds with the same axial trend as the major anticlinorium (Simón, 1984).

According to the new interpretation proposed in this paper, the structure of the Espadán Range is a great box anticline (Figs. 1B and C). From South to North, the cartographic structures include: (1) the cleavagerelated Espadán Anticline, with box morphology; (2) the Eslida thrust, with a very tight cleavage-related hanging wall anticline, nowadays eroded and (3) the post-cleavage Eslida Syncline. All these structures trend N095°E-N108°E. The morphology of these cartographic folds is governed by the competent units: Garbí Fm. and the Muschelkalk facies. The other units, with an incompetent behavior, accommodate the deformation developing both minor cleavage-related folds and post-cleavage folds, that are only located in some parts of these incompetent units, (Marines and Serra Fms).

Cleavage characterization and structural interpretation

At regional scale, the study has been based on cleavage trajectories (Fig. 1B). The information obtained comprises: 1) the upper cleavage front that is usually located in the contact between the Buntsandstein and Muschelkalk facies (within the Serra Formation), 2) the cleavage has a constant ESE–WNW trend, 3) the regional cleavage displays a convergent fan and 4) some post-clevage folds have been observed at different scales, being the Eslida Syncline the most important one.

From petrographical point of view, the cleavage can be classified as "spaced cleavage" (Paschier and Trouw, 1996). The characteristic features of the structure (spacing, morphology of the planes ...) can vary relatively but it always has microlithons and cleavage domains without features of continuous cleavage (Fig. 2A).

The most important microfabric structures are: (1) "S-C" planes, in some cases, and (2) stylolitic surfaces (Fig. 2B). The pressure solution is the main cleavage-related mechanism although its presence in several lutitic levels of clay minerals and other inequigranular ones is probably combined with mechanical rotation of inequigranular mineral grains. According to these observations, the petrofabric elements are cleavage planes and planar minerals.

An unusual relationship between cleavage and bedding was observed and identified as sigmoidal cleavage. The S-shape morphology has the same setting as if a passive marker had been deformed by shearing along the bedding planes. The first interpretation was as flexural slip over a preexistent cleavage (Simón, 1984).

The new data at microscopic and outcrop scale, show the presence, in many cases, of an increasing of the cleavage penetrativity at the ends of the sigmoids, close to the bedding surface (Figs. 2C and 3).

This fact strongly suggests two simultaneous deformational mecha- nisms involved in the cleavage formation: flattening and flexural flow. The flattening explains the presence of cleavage planes at higher angles (>45°) with respect to the bedding trace whereas the flexural flow mechanism explains the increasing of cleavage penetrativity towards the bedding surface (Fig. 2C y 3C). Thus, the deformation by flexural flow will be responsible for both new cleavage planes and its sigmoidal geometry in incompetent layers whereas in competent ones such a geometry will be the result of passive rotation of the previously formed cleavage planes as the result of flexural slip. Independently of the acting mechanism (flexural slip or flexural flow), at microscopic and outcrop scale, the cleavage planes are curved in the shear sense (Figs. 2C and 3).

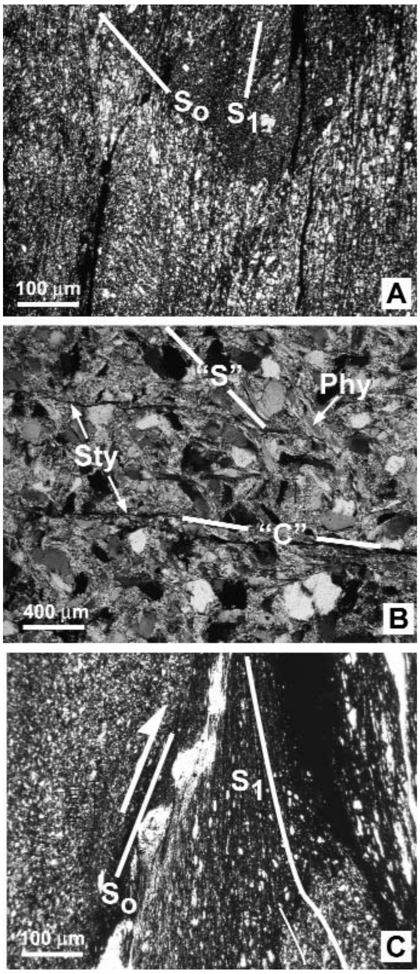

Fig. 2.- Photomicrographs of cleavage. A) Spaced cleavage in a fine-grain sandstone. So/S1 are bedding and cleavage traces. B) "S-C" fabric in a sandstone. Sty: stylolitic surfaces, Phy: phylosilicates C) Sigmoidal cleavage surfaces. Note both the increasing of cleavage penetrativity and the parallelism of cleavage (S1) respect to bedding towards the bedding contact (So). The microfabric is compatible with a dextal shear.

Fig. 2.- Microfotografías de la esquistosidad. A) Esquistosidad espaciada en una arenisca de grano fino. So/S1 son las trazas de la estratificación y esquistosidad. B) Fábrica "S-C" en una arenisca. Sty: superficies estilolíticas, Phy: filosilicatos. C) Superficies sigmoidales de esquistosidad. Notar tanto el incremento de penetratividad como el paralelismo de la esquistosidad (S1) respecto a la estratificación, hacia el contacto con la superficie estratificación. La microfábrica es compatible con una cizalla dextra.

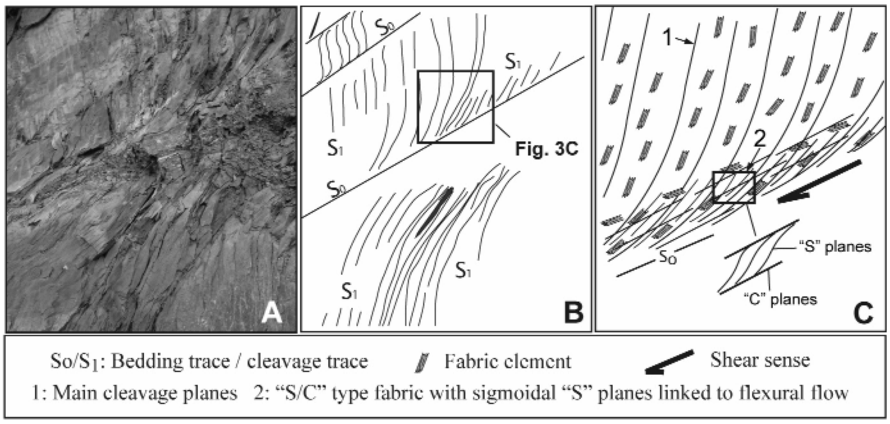

Fig. 3.- Cleavage geometry at outcrop scale. A) Sigmoidal pattern of cleavage in Upper Permian argillites. B) Sketch from the same photograph. C) Features of the rock-fabric pattern.

Fig. 3.- Geometría de la esquistosidad. a escala de afloramiento A) Patrón sigmoidal de la esquistosidad en argilitas del Pérmico Superior. B) Esquema de la misma fotografía. C) Carácterísticas del patrón de la petrofábrica.

Kinematic model for the alpine cleavage of the Espadán Range

Considering all the geometrical and reological features of the analized cleavage, it is possible to constrain its origin in relation to different folding mechanisms and strain processes. On the basis of the Lebedeva's analogue models of axial plane cleavage generation in detrital materials (Lebedeva, 1976), the proposed kinematic model includes three main stages characterized by different folding mechanisms, strain processes and reological conditions (Fig. 4).

Stage 1: Incipient development of cleavage. The beds are initially horizontal (or subhorizontal). A flattening linked to layer-parallel shortening press the grains against each other accommodating the deformation, a likely rotation of the more competent ones and deforming the less competent ones. This leads to a perpendicular orientation of the incipient cleavage surfaces respect to bedding. This first stage of incipient cleavage generation includes shortening rates of around 10% without producing any folding (Lebedeva, 1976). The degree of orientation of planar fabric elements depends on the physical properties of each layer. The planar fabric within the softest layers (or with lower viscosity), is better developed and it is acquired more quickly than within the less plastic layers (or with higher viscosity). Plasticity factor is greatly influenced by the number of grains with incompetent behavior (phyllosilicates, clay minerals ...) and the content in fluids (Levedeva, 1976). In fact they are closely related since many elemental components are phyllosilicates, minerals with high proportions of fluid-filled porosity.

Stage 2: Buckling and increasing of cleavage penetrativity. In this stage the folding onsets and changes the orientation of the previously formed cleavage planes. The horizontal mechanism linked to folding (buckle shortening) has a tendency to keep the material markers parallel to the axial plane, normal to the shortening, to generate the fold and tilt the layers generating a cleavage fan. At this stage an increment of the cleavage penetrativity, linked to flattening, from the previously created master planes occurs. The cleavage fans are a consecuence of the different response of the layers to the different deformation mechanisms. The convergent cleavage fan, in the competent layers, is due to the passive tilting of the cleavage planes during the buckling. Whereas the incompetent ones are dominated by the flattening (and inverse tangencial longitudinal strain) linked to "buckle shortening" (Ramberg, 1964), giving rise to a preferent axial plane cleavage or divergent cleavage fan geometry.

Stage 3: Folding amplification and layer parallel shear. In the last stage of cleavage formation the complexity of the whole strain pattern is linked to layer parallel shear mechanism over the limbs of the regional folds. Two different processes operate in competent and incompetent layers. In the competent ones (sandstones), the flexural slip mechanism dominates giving rise to the passive rotation of the previously formed cleavage planes, and its sigmoidal geometry. The incompetent layers (argillites) are deformed by flexural flow. The acting of such mechanism, which is also responsible for a sigmoidal geometry of the cleavage surfaces, is evidenced by the gradual increasing of the cleavage penetrativity from

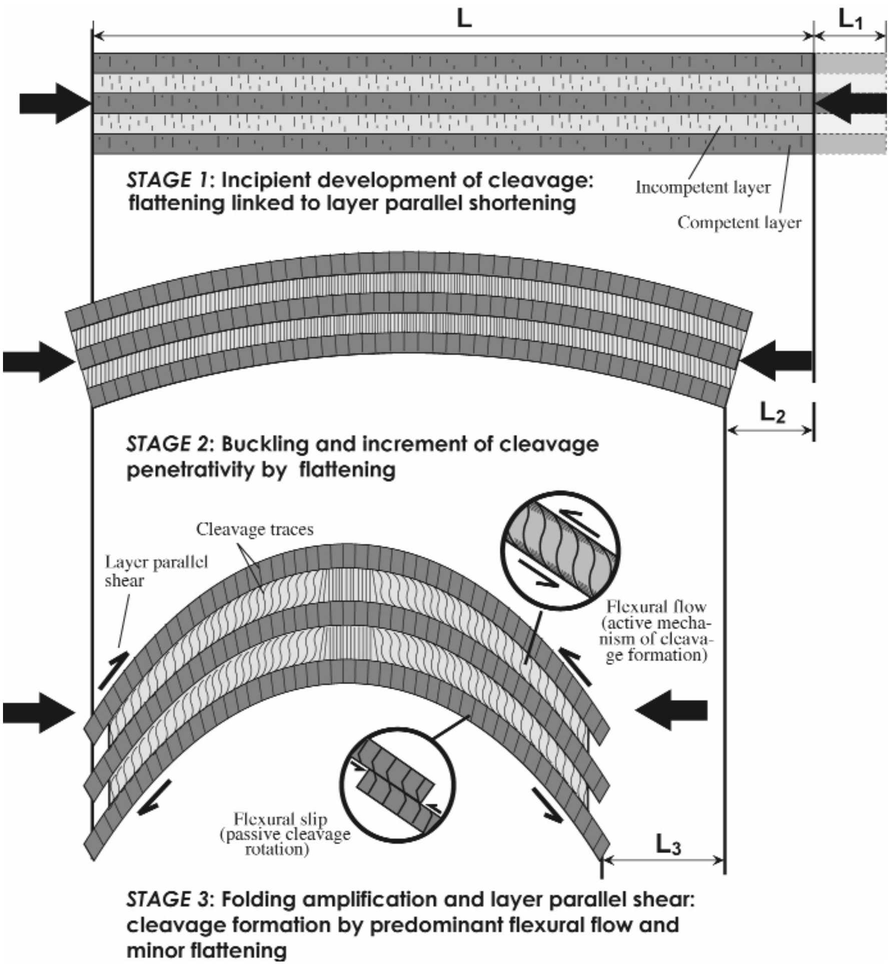

Fig. 4.- Kinematic model for the cleavage formation of the Espadán. See text for details.

Fig. 4.- Modelo cinemático de formación de la esquistosidad de la Sierra de Espadán. Detalles en el texto.

the center to the edges of each single layer. Thus, this is an "active" strain mechanism. Although the flexural flow is the main strain mechanism for cleavage formation, a certain amount of flattening can not to exclude.

Conclusions

It is proposed a new interpretation for the Espadán Range structure as a box anticline, which is affected by axial plane cleavage with a mean WNW-ESE trend. The upper cleavage front is located in the Buntsadstein/Muschelkalk contact. At mircrostructural scale, cleavage can be classified as spaced cleavage. The main forming mechanism is the pressure solution with probably mechanical rotation of inequigranular mineral grains. At regional scale, the cleavage shows a geometrical relationship of convergent fan. The presence of sigmoidal geometries of the cleavage planes is linked to both an "active" flexural flow mechanism in the incompetent materials responsible for the cleavage formation, and a "pasive" flexural slip mechanism in the more competent ones, causing the rotation of the pre-existing cleavage planes. The kinematic model explaining the cleavage formation includes three main stages with different folding an strain mechanisms: (1) incipient development of cleavage linked to layer parallel shortening, (2) buckling and increasy of cleavage penetrativity and (3) folding amplification and layer-parallel shear.

Aknowledgements

The results of this work are included in the objectives of the subjet "Structural Analysis" (4th Course of Geology Degree, Zaragoza Univ.). Financial supports comes from the Geotransfer Group of the Aragón Government (DGA). We thanks the comments and suggestions by the referees of the journal, Fernando Bastida and Emilio Luis Pueyo.

References

Garay Martin, P. (2000). *El dominio Triásico de Espadán–Calderona: Contribución al conocimiento geológico e hidrogeologico*. PhD Thesis, Univ. de Valencia, 692 p.

Gutierrez-Elorza, M. and Pedraza-Gilsanz, J. (1974). *Boletín Geológico y Minero,* 85, 269-270.

Lebedeva, N.B. (1976). *Geotectonics* 2 , 31-33.

Martin Martin, J.D., Sanfeliu Montolio, T. and Gomez Gras, D. (2003), *Mineralogía de arcillas cerámicas: el Permo-Trías de Castelló*. Universitat Jaime I, 280 p.

Paschier, C.W. and Trouw, R.A.J. (1996). *Microtectonics*, Springer, 289 p.

Ramberg, H. (1964). *Tectonophysics,* 1, 307-341.

Simón Gomez, J.L. (1984). *Compresión y distensión alpinas en la cadena Iberica Oriental.* PhD Thesis, Univ.de Zaragoza, 269 p.