An example on the tectonic origin of zebra dolomites: the San Martín beach outcrop (Santoña, North Spain)

Un ejemplo del origen tectónico de la dolomita cebra: el afloramiento de la playa de San Martín (Santoña, N España)

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ABSTRACT

El origen de la dolomita cebra o bandeada ha sido históricamente discutido. Su presencia en distintos contextos, normalmente asociadas a mineralizaciones de tipo MVT, ha llevado a asociarla mayoritariamente a dichos procesos. Los afloramientos de dolomita cebra estudiados en la playa de San Martín (Santoña) permiten caracterizar su formación a partir de múltiples eventos de fracturación-mineralización ligados a la circulación de fluidos hidrotermales dolomitizantes. Dichos fluidos migrarían desde zonas de cuenca más subsidentes hasta las plataformas carbonatadas, dispuestas en bloques tectónicos relativamente elevados, a través de la red de fracturas derivada de la intensa actividad tectónica sinsedimentaria que caracterizó el Abiense de la Cuenca Vasco-Cantábrica.

Key words: *Zebra dolomite, hydrothermal dolomitization, transtensional fractures, Albian, Basque-Cantabrian Basin.*

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Introduction

Zebra dolomites are banded dolomite textures made up of mm to cm thick layers of alternating dark fine-grained dolomite and light coarse-grained saddle dolomite. Its origin has been traditionally suggested to be purely diagenetic and closely related to MVT ores. Only few authors have proposed an origin related to strain deformation in the precursor carbonate (e.g., Martín, 1980).

Superb outcrops in Santoña village have provided a key-example to understand the origin of this common dolomite structure. The dolomites of this area are the northwest branch of a N-S trending regional dolomite-corridor related to the Ramales fault and are hosted in Albian carbonates.

The dolomites of the San Martín beach show zebra dolomites closely related to tectonic structures, pointing to their tectonic origin.

Geographical and geological context

The study area lies in the eastern coast of the Cantabria province, in northern Spain (Fig. 1). Here, Santoña village is located close to the limestone massif of Ganzo with a maximum higth of 370 m and spectacular cliffs with almost vertical walls falling to the sea. In its southern part, the cliffs of the San Martin beach show very well exposed outcrops of dolomites encasing in Albian limestones.

Geologically, Santoña is located in the western part of the Basque Cantabrian Basin (BCB), an area where E-W trending and NW-SE trending faults are joined by means of the N-S Ramales Fault. During the Albian this area was part of the large Ramales carbonate platform system with reefal belts to the north and south (Fig. 1). The sedimentation was mainly controlled by synsedimentary faults (López-Horgue, 2000; López-Horgue *et al.*, 2005). Closely related to those faults there are decametres to kilometre scale dolomite bodies hosted mostly in lower Albian carbonate successions. These dolomite bodies show irregular sharp boundaries with the limestones, christmas tree morphologies and pinch-out upwards. The dolomitization is pervasive near the faults and spreads out from them forming extensions some hundreds metres long at some points. Presently, the dolomite bodies are arranged along the N-S trending Ramales Fault, making up a dolomite-corridor that extends near 25 km northwards from the E-W trending Cabuérniga Fault, connecting the areas of Karrantza and Santoña (Fig. 1). Dolomite bodies show three main dolomite types: 1) grey to beige xenotopic dolomite mosaics with a crystal size under 0.5 mm; 2) sucrosic dolomite, showing subhedral to anhedral mosaics with crystal size between 0.1 and 1.5 mm; and 3) saddle dolomite, made up of anhedral to euhedral mosaics of large white to pink crystals up to 10 mm size. These main types combine to form distinctive structures. One of these is the zebra texture, an association of mm to cm thick bands of xenotopic-sucrosic dolomite and saddle dolomite.

Faulting and jointing controlled the dolomitization process. Fluid-pressure and regional to local tectonic stress regimes produced different scale fracture sets that acted as pathways for hydrothermal mineralizing fluids (López-Horgue *et al.*, 2005). The observed structural arrangement for the dolomitization is

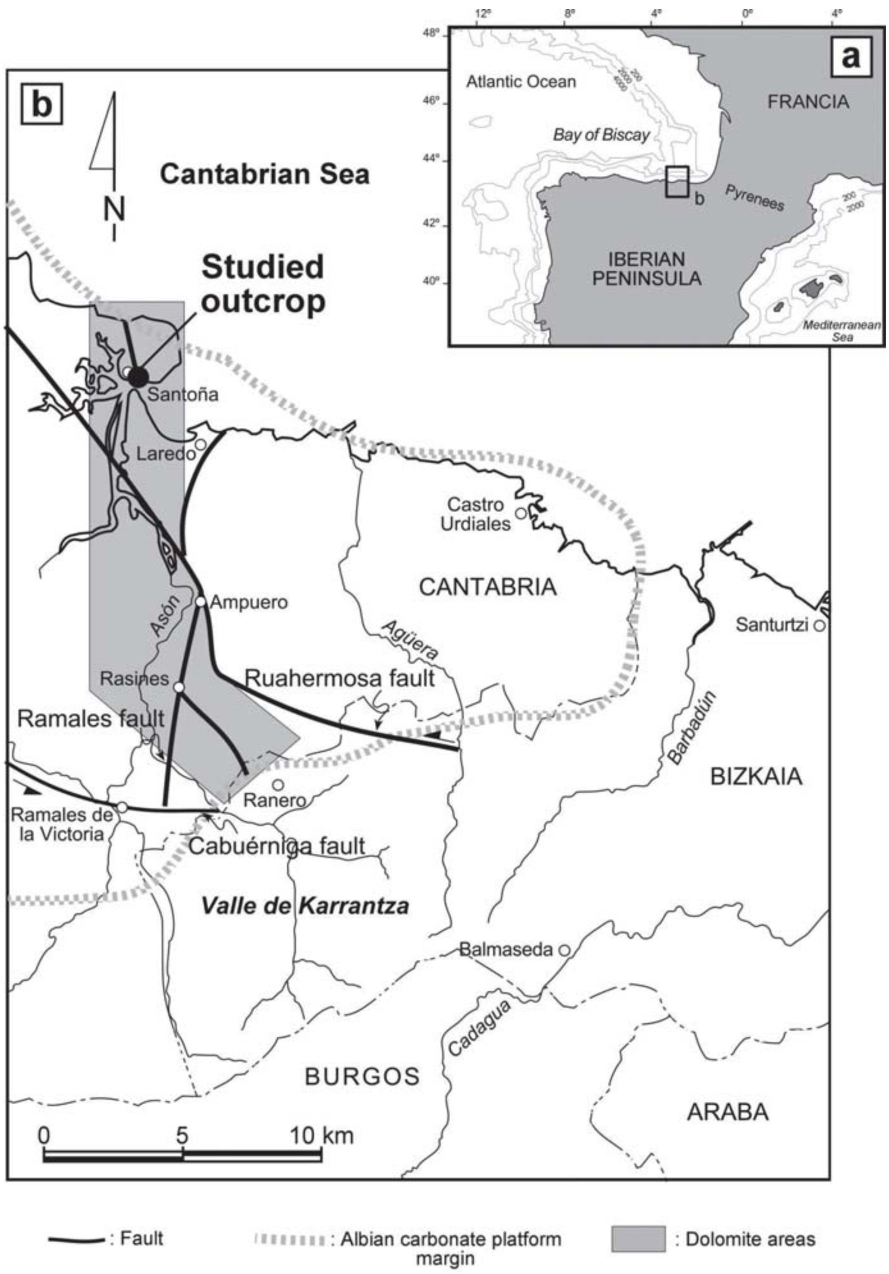

Fig. 1.- Location map of the dolomite corridor and the main faults mentioned in the text. The dashed line marks the position of the Albian Ramales carbonate platform magin.

Fig. 1.- Mapa con indicación de la zona dolomitizada y las principales fallas mencionadas en el texto. La línea discontinua representa el márgen de la plataforma carbonatada de Ramales durante el Albiense.

consistent with the strike-slip geodynamic context that controlled the sedimentation during the Albian.

The Dolomites of the San Martín beach

San Martín dolomite outcrop is located in the southern part of the Ganzo massif in Santoña village. This area is in the northern part of the N-S Ramales dolomite corridor and forms a tectonic block limited to the southwest by a NW-SE trending fault (Fig. 1). This block is made up of limestones from the Albian Ramales carbonate rimmed platform, showing backreef micritic stratified facies to the west. To the east, the Ganzo massif is made up of massive micritic facies of the rim belt (mud mounds). Dolomites replace both types of limestones showing irregular and patchy morphologies related to fractures. The dolomitization is mostly pervasive with locally preserved sedimentary structures and fossil ghosts. NW-SE trending and NE-SW minor fractures crosscut the area. Locally, Triassic evaporites crop out along these fractures.

San Martin beach outcrop is 20 metres long and 10 metres thick in the cliff (Fig. 2). The dolomites replace micritic limestones of the carbonate platform rim, and are closely related to a main fracture oriented 80/260. According to other dolomite-body shapes from the area, it seems to be the upper termination of a larger lithosome rooted in depth. The main dolomites (D_1) of this body are dark grey fine to coarse-grained pervasive facies. Locally show a parallel-banded texture due to the alternation of dark-light laminae. This lamination is not parallel to the bedding of limestones. Under the microscope this facies is made up of tightly packed anhedral to subhedral crystals forming inequigranular mosaics. Their size varies from 0.15 to 0.5 mm. The crystals show dark rounded nucleus. This dark dolomite is crosscut by a main dextral transtensive fracture system (PDZ-Principal Displacement Zone, 1 in Figs. 2 and 3) defining a shear corridor oriented 45/30, along which different style and scale shear fractures (Riedel, 1929; Harding, 1974; Harding *et al.*, 1985) and dolomite facies occur. Centimetre sized clasts are cemented by coarse (up to 5 mm long) white saddle dolomite (D_2), and locally calcite fills the remnant porosity. Laterally to the breccias, fractures show «en echelon» synthetic transtensive joints oriented 66/94 (2 in Figs. 2 and 3) and small shear joints (3 in Figs. 2 and 3) with 68/360 orientation. A transpressive anticline possibly related to the dextral strike-slip strain regime in the shear zone has been identified affecting the limestones atop of the dolomite body here studied (Fig. 3). Along the fractures the dolomite show aggrading neomorphism textures from the host dark dolomite (D_1) to large (up to 1-2 mm long) crystals of saddle dolomite (D_2), with typical curved faces and sweeping extinction. Hence, the dark grey dolomite and the saddle white dolomite form zebra structures with mm to cm thick bands.

Discussion on the origin of the dolomites and zebra structures

Dolomite mineral

Xenotopic mosaics from the dark grey dolomite (D_1) suggest an hydrothermal origin with temperatures between 50° and 100° C (Gregg and Sibley, 1984 and our data). These temperatures and the texture are consistent with a shallow burial diagenetic environment. Darker nucleus are due to impurity concentrations, suggesting a replacement of organic-rich marly limestones, also supported by the dark

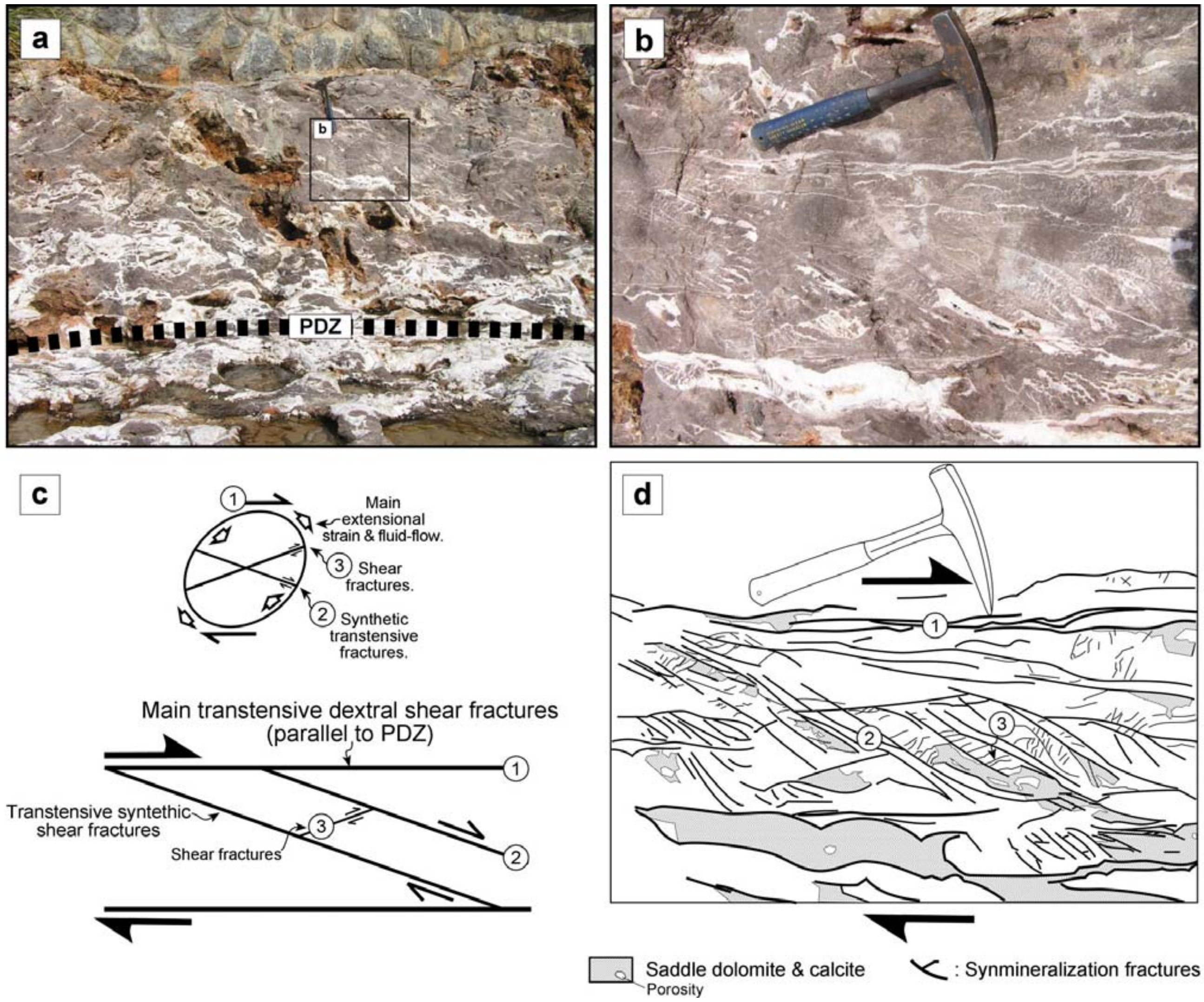

Fig. 2.- San Martín beach dolomites . A: Oblique view of dolomitized transtensive fracture zone (PDZ: Principal displacement zone). B: Transtensive shear fractures with saddle dolomite (D_2) infill. C: Proposed structural sketch to explain the fracturation and mineralization pattern. D: Synmineralization fracture sketch of «b» photograph.

Fig. 2.- Dolomitas de la playa de San Martín. A: Vista oblicua de la zona de fractura transtensiva dolomitizada (PDZ: Zona de desplazamiento principal). B: Fracturas transtensivas con rellenos de dolomita saddle (D2). C: Esquema estructural propuesto para explicar los procesos de fracturación/mineralización. D: Fracturas de la fotografía «B» coetáneas a la mineralización.

colour of the facies. The alignement of these inclusion-rich areas forms intracrystalline dark-light band alternation.

Saddle dolomite (D_2) is clearly a second stage of dolomitization: it is related to neomorphism from dark dolomite (D_1) and is present forming zebras and as cement in fractures and hydroclastic breccias in the principal displacement zone (PDZ) of the fracture zone observed in the outcrop (Fig. 2). This type of dolomite is frequently related to hydrothermal processes, indicating minimum temperatures of 60° to 150° C (Warren, 2000) or more (e.g., Al-Aasm *et al.*, 2000).

Zebra Dolomites

Zebra dolomites are banded textures formed by rhythmic millimetre to centimetre-scale alternations of dark-white dolomite-bands (e. g., Wallace *et al*., 1994). Its frequent association to MVT ore-deposits, occurring with sulphides, has traditionally suggested a coeval origin as repetitive sequences named diagenetic crystallization rhythmites (Fontboté, 1981). The zebras have been considered to form under a wide range of conditions, from syngenetic to early diagenetic (e.g., Fontboté and Amstutz, 1983) and epigenetic (e.g., Boni *et al*., 2000) and due to the replacement of evaporites (e.g., Beales and Hardy, 1980) and carbonates (e.g., Vandeginste *et al*., 2005), or cementation after dissolution or hydraulic fracturing (e.g., Krebs and Macqueen, 1984). In summary, it seems that zebras probably form in different settings but probably related to the same genetic processes. In San Martín outcrop, those genetic processes can be ascertained. The precipitation of D_1 is related to a first event of fracturing, forming fractures that acted as vents for the hydrothermal fluids affecting the original limestone. After a first dolomitization event, a new event of fracturation affected D_1 dolomites, forming hydroclastic breccias and «en-echelon» transtensional joints, at the same time of a second fluid-flow event (Fig. 2). In the fracture-related planar porosity the precipitation of saddle dolomite (D_2) formed zebras, and in the PDZ the D_2 saddle dolomite cemented the hydroclastic breccias leading to self-sealing of the hydrothermal system. In this way, San Martin outcrop provides a good example of two-phase hydrothermal dolomitization conditioned by fracturing. A last

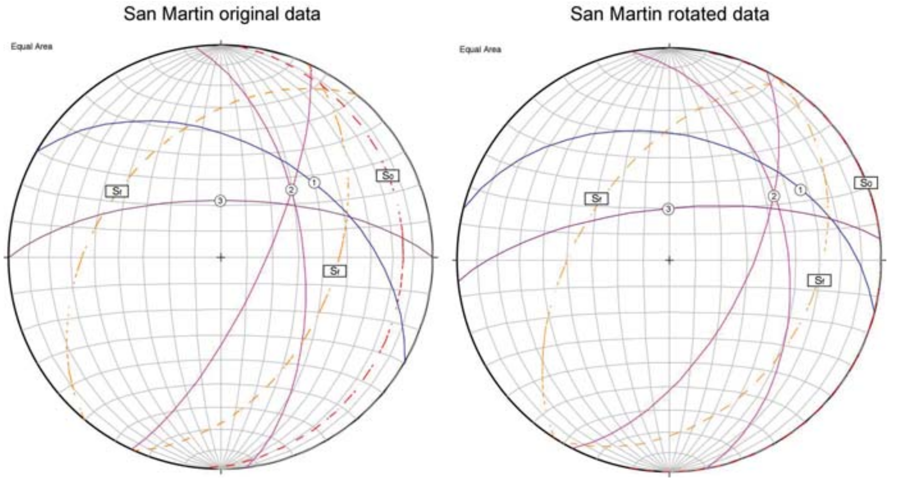

Fig. 3.- Original and restored (rotated) stereograms of the regional bedding (S_0), the anticlinal limbs (S_1) and the transtensive fractures (1, 2 y 3) measured in San Martín beach outcrops.

Fig. 3.- Estereogramas con las medidas originales y restituidas de la estratificación regional (S_0), de los flancos del anticlinal medido (S_1) y lde as fracturas transtensivas (1, 2 y 3) medidas en los afloramientos de la playa de San Martín (Santoña).

hydrothermal white calcite followed by a yellowish meteoric calcite complete the infilling of the remaining fracture porosity.

Tectonics

The dolomites of the Ramales Fault corridor are related to faults and different scale fractures showing branchy geometries within the host limestone. Angular unconformities, abrupt thickness and facies changes record a strong strike-slip synsedimentary activity of the main structures of this corridor (Ramales Fault, Cabuérniga Fault and Ruahermosa Fault; see Figure 1) during the Cretaceous. These fractures affected the Albian limestones and acted as main conduits for hydrothermal fluids. Hydrothermal fluid presences during Albian are in agreement with the tectonothermic framework proposed for Albian times and probably related to other geothermal events recorded during the latest Albian in neighbouring areas (e. g., Aranburu *et al.*, 2002; López-Horgue, 2000).

In this way, dolomite zebras from San Martín beach are interpreted as the result of replacement and precipitation along planar fractured zones, of different scale transtensional fractures (Figure 2), related to transtensional strains around main fault areas that acted as pathways during at least two hydrothermal fluid-flow events.

The late Albian high-subsidence phase was one of the most important tectonic events in the area, leading to high sedimentation rates in basinal subsiding areas and fracturing of the limestone platforms in less subsiding areas (García-Mondéjar *et al.*, 2005). Lithostatic pressure gradients expelling fluids from basinal areas and fault activity during latest Albian could originate an active fracture-porosity mesh and hydrothermal fluid-flow events that caused the multiphase dolomitization process observed in the eastern area of Cantabria province.

Results

Ongoing research project between the University of the Basque Country and TOTAL S.A. has permitted the study and characterization of the N-S trending Ramales Fault dolomite-corridor. In the northern part of the above cited dolomite-corridor, in Santoña village (San Martin beach), dolomites show characteristics that correspond to at least two-phases of fracture-controlled hydrothermal dolomitization events. Zebra dolomites from San Martín beach are clearly formed in the second phase of the dolomitization process, along transtensional shear fractures related to a major dextral transtensional fracture zone. They can be considered a clarifying example of the tectonic origin of this dolomite texture. All the structural features observed in San Martín beach outcrops and in other related adjoining areas can be explained by the syndolomitization strike-slip tectonic activity occurred during latest Albian times.

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