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Dolomitisation and brecciation along fault zones in the Cantabrian mountains

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Abstract

Dolomitisation, brecciation, and dedolomitisation occurring in fault zones in the Variscan fold and thrust belt in the Cantabrian Zone (Northern Spain) in three different tectonic units (Ponga, Picos de Europa and Esla) have been investigated and compared. Cementation patterns are similar in all units: dolomite cements always predate calcite cements in brecciated limestone (Barcaliente Fm.). Moreover, carbon and oxygen isotopic composition trends are comparable. However, the precipitating fluids are distinct in each fault zone, as evidenced by microthermometry and Raman spectroscopy. The evolution of the fault zones is illustrated by the precipitation of cements from different types of circulating fluids in several pulses.

Keywords: tectonic breccia; Fluid inclusions; (de-)dolomitisation; barcaliente Fm

1. Introduction

The Cantabrian Zone (Fig. 1) has been established as a foreland thrust and fold belt of the Variscan collisional orogen in Northern Spain (e.g. Julivert, 1971; Peréz Estaún and Bastida, 1990) The regional structure of this zone represents thin-skinned tectonics which produced complex thrust units. The main thrust units were emplaced by rotational movements at diagenetic to shallow metamorphic conditions, causing the typical curved shape of this zone.

In the eastern part of the Cantabrian Zone, three tectonic units: Ponga, Picos de Europa and Esla (Fig. 1) are studied to obtain information about their diagenetic history and especially the origin of fault related breccias. Calcite-dolomite veins in tectonic breccias associated with faults and thrusts within the Barcaliente Fm. (Wagner, 1971) are studied. Only in the Pico Jano duplex the fault zone consists of a mixture of Alba Fm. (Dinantian) and Barcaliente Fm. (Lower Silesian, Namurian). The Barcaliente Fm. is characterised in the entire region by a bituminous and micritic bedded limestone, whereas the Alba Fm. consists of red nodular limestone.

Cements and fragments related to specific fault zones are studied with cathodoluminescence (CITL CCL 8200mk3), stable C–O isotope analysis (Finnigan Mat 252 gas mass spectrometer, Erlangen) and X-ray diffraction (Siemens D500). Luminescence colours are analysed with spectral measurements (Leica MPV). Fluid inclusions within the cements are examined

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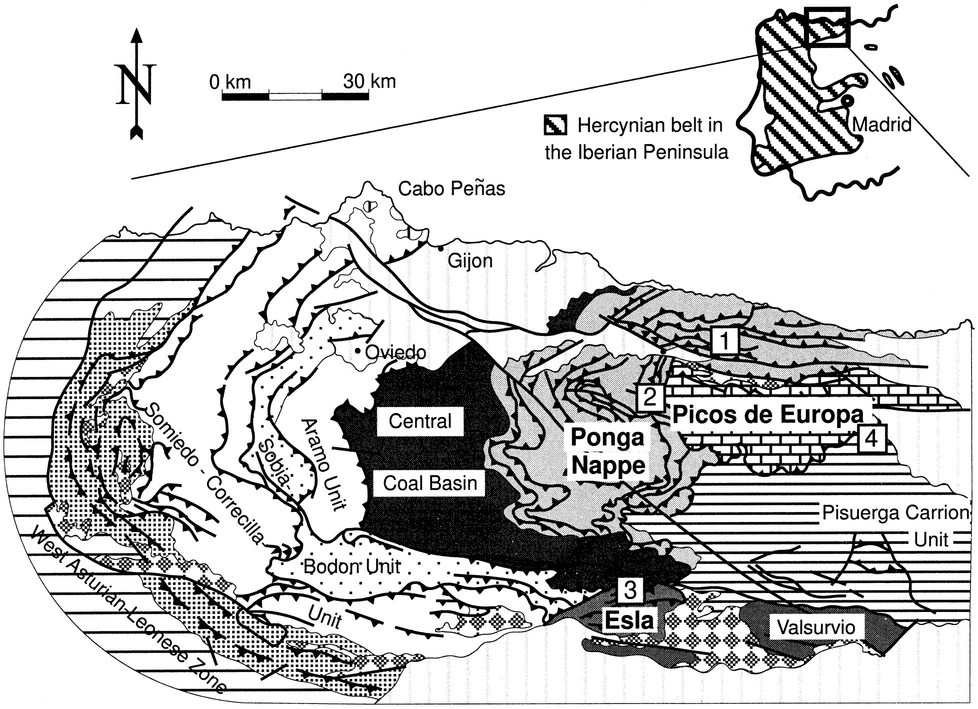

Fig. 1. Tectonic framework of the Cantabrian Zone (after Peréz Estaún and Bastida, 1990). Open squares indicate the studied areas: 1. Faultzone between the Meré-Peruyes and Cangas de Onis nappe; 2. Rio Color window; 3. Pico Jano duplex; 4. Faultzone between Liebana and Picos region (La Hermida canyon).

with microthermometry (Linkam THM600) and Raman spectroscopy (Dilor LABRAM, Leoben).

2. Field observation

In all three tectonic units, products of dolomitisation, dedolomitisation and brecciation along fault zones have been observed. The fault zones in the studied areas are parallel to sub-parallel to limestone beds in the Barcaliente Fm. In La Hermida (4 in Fig. 1), close to the fault plane, the Barcaliente Fm. is completely replaced by saddle dolomite, with single crystals up to 5 mm diameter. The size of the crystals and the intensity of dolomitisation decreases with increasing distance to the fault plane in the hanging wall. The cemented breccias occur some meters above the fault plane. Fig. 2 shows a typical jigsaw puzzle texture of unimodal and internally undeformed fragments. The matrix between the fragments contains white-to-grey banded coarse grained calcite. Furthermore, several pyritised stylolites are observed. In the Ponga unit (Meré-Peruyes and Rio Color, respectively, 1 and 2 in Fig. 1) the faults are characterised by cemented brecciated zones (4–30 m thick). Pico Jano (3 in Fig. 1) is a complex composite of relatively undeformed fragments (up to 10 m) and cemented fault breccias. Zebra-textures (dolomite) have been observed in all studied areas.

3. Analytical results

In thin-sections from all studied regions fine-grained fragments in the brecciated zones show several degrees of dolomitisation. Large euhedral saddle-dolomite crystals (up to 1 mm) form the relatively oldest cement generation between fragments. Resolution textures of these crystals evidence dedolomitisation processes. Dolomite cements are partly replaced and overgrown by younger coarse-grained calcite cements. Cathodoluminescence has illustrated

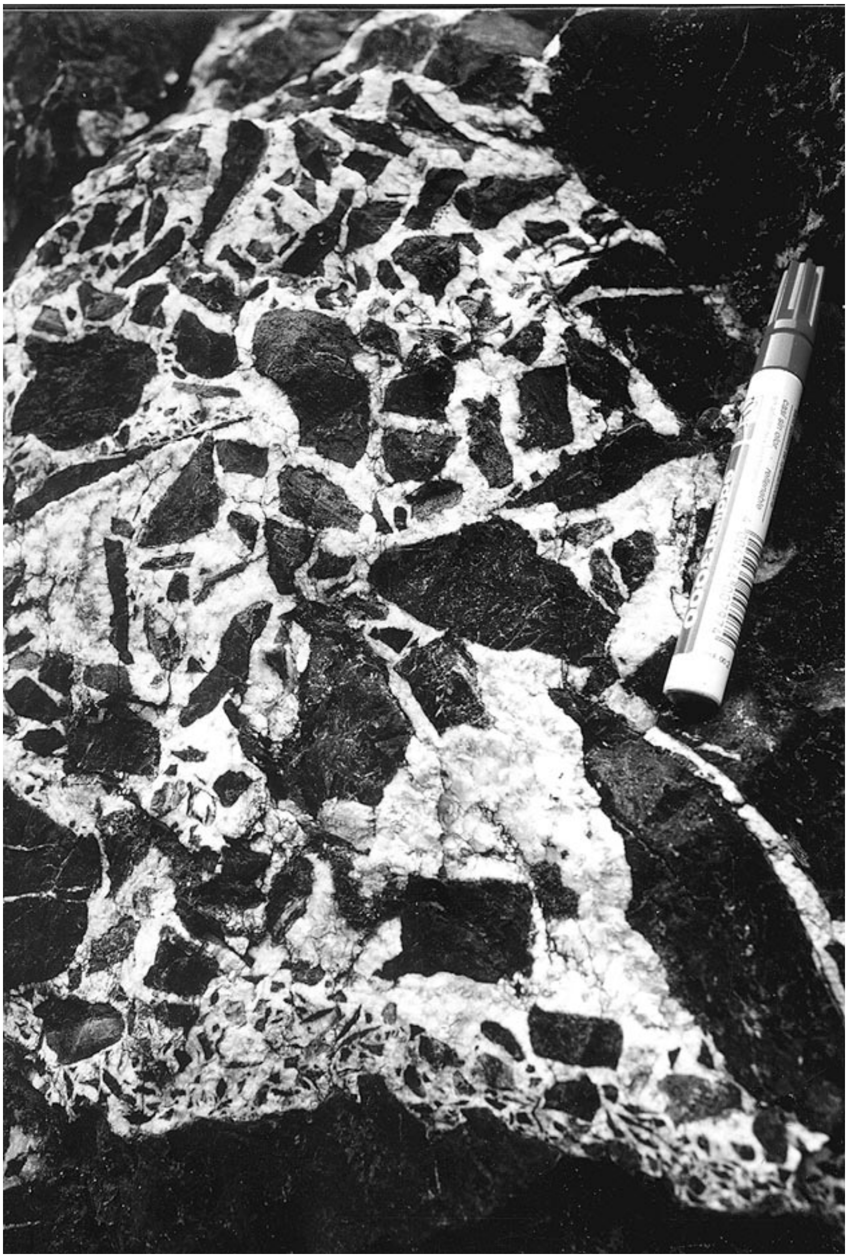

Fig. 2. Typical brecciated limestone of the Barcaliente Fm. with jigsaw puzzle texture.

the presence of several dolomite (*a, b, d*) and calcite (*2, 3, 4*) cement generations (Table 1).

Each dolomite cement has large amounts of small primary fluid inclusions (<1 μm in diameter), and only a few have dimensions up to 8 μm. These inclusions have a high degree of fill (up to 0.9). Salinities obtained from Table 1 range up to 28 eq. wt% $CaCl_2$.[1]

[1] Salinities are preferred to be expressed in eq. wt% $CaCl_2$ because final melting temperatures occurred below the eutectic temperature of $NaCl–H_2O$. The equation from Bakker et al. (1996) was used to transform melting temperatures into salinities.

Table 1
Cathodoluminescence colours with $L*a*b*$ values of 2° (CIE 1976) in italics, total range in homogenisation and final melting temperatures (italics in brackets) in °C of different cement generations in each studied locality. See text for further explanations

	Cement	Cathodoluminescence	Meré-Peruyes (1)	Rio Color (2)	Pico Jano (3)	La Hermida (4)
Calcite	4	Yellow-orange *16.9/19.3/27.5*	143.1 to 180.9[a] *(0.0 to 15.8)*			
	3	Dull orange *24.0/25.2/37.2*	95.0 to 276.3 *(−0.4)*			122.2 to 205.7 *(−25.4 to 2.1)*
	2 + 3	Non to brown –	91.2 to 242.9 *(−19.6 to 8.1)*	106.1 to 244.6 *(−6.7 to 5.7)*	126.5 to 241.4 *(−1.0 to 3.3)*	
Dolomite	D	Red to non (zoned) *4.1/18.1/6.3*				174.4 to 239.2 *(−28.1 to −12.8)*
	B	Bright red *20.4/34.5/34.0*	97.5 to 217.8 *(−23.5 to 2.8)*	129.6 to 246.9 *(−30.4 to −0.3)*	75.1 to 236.4 *(−30.7 to 9.7)*	
	A	Dull red *14.6/28.3/25.0*	105.2 to 133.2 *(−15.8 to −0.3)*		76.9 to 226.5 *(−35.2 to −14.2)*	

[a] These temperatures are obtained from only a few inclusions, that have probably leaked or stretched.

Most of final melting measurements (T_m) lie between −12 and −23°C (16–23 eq. wt% $CaCl_2$). The peak frequency values (*Pfv*) of homogenisation temperature (T_h) in Meré-Peruyes is lower (≈ 140°C) than in the other areas (≈ 200°C).

In calcite cements *2* and *3* two distinct types of primary inclusions are recognised. Small regular shaped inclusions (1–5 μm in diameter) with high degrees of fill (up to 0.9) coexist with larger dark irregular inclusions (5–10 μm). These dark inclusions contain a large vapour bubble, and both may represent heterogeneous trapping. The calcite grains in Rio Color are more strongly deformed and the inclusions reveal a larger range in T_h as in La Hermida. Pico Jano calcite *2 + 3* contains similar primary inclusions with a larger range in degree of fill, however, with larger sizes (up to 20 μm in diameter). Calcite *4* consists of very clear crystals with mainly low salinity all-liquid secondary inclusions, which may represent a late stage in the exhumation of the rock.

The *Pfv* of T_m are higher in all calcite cements (e.g. −8°C for calcite *3* in La Hermida and 0°C for calcite *2 + 3* in Pico Jano) than in dolomite cements (e.g. −32°C for dolomite *a* and 4°C for dolomite *b* in Pico Jano). Range and *Pfv* of T_h in calcite cements in La Hermida and Rio Color are lower than those in dolomite cements, whereas Meré-Peruyes shows the reverse relation. *Pfv* of T_h in Pico Jano are similar in both calcite and dolomite cements.

Combined Raman and microthermometry analyses have been used to identify specific salt-hydrates, eutectic temperatures (T_e) and gases. Low salinity in the calcite cement from both Pico Jano and Rio Color is confirmed by Raman, showing only an ice-peak at temperatures below 0°C. High fluorescence in dolomite crystals hindered any useful Raman analysis. In Meré-Peruyes, Raman indicated hydrohalite peaks at −100°C in dolomite cements, although the measured T_e lie between −25 and −30°C, which implies the presence of small amounts of other salt types. Ice crystals are the last to melt, indicating salinities lower than the eutectic value. In calcite cement from La Hermida hydrohalite crystals are the last to melt in inclusions. Therefore, the relative large range in T_m (Table 1) correspond to only a small range in higher salinities: between 23.2 and 26.3 wt% NaCl. Raman analysis has also evidenced the presence of small amounts of $MgCl_2$ and $CaCl_2$. In dolomite cements hydrohalite is observed in inclusions, where T_e values below −30°C indicate the presence of other salts. Here, ice is always the last phase to melt.

Reproducible metastable melting in some fluid inclusions is evidenced by positive melting temperatures of ice and hydrohalite. Crushing tests and Raman analyses did not reveal the presence of gases.

The brecciated zone in Meré-Peruyes contains a clay mineral of montmorillonite–chlorite–illite composition, whereas the undeformed Barcaliente Fm. has a mixture of kaolinite–illite. The other regions have similar clay-mineral assemblages

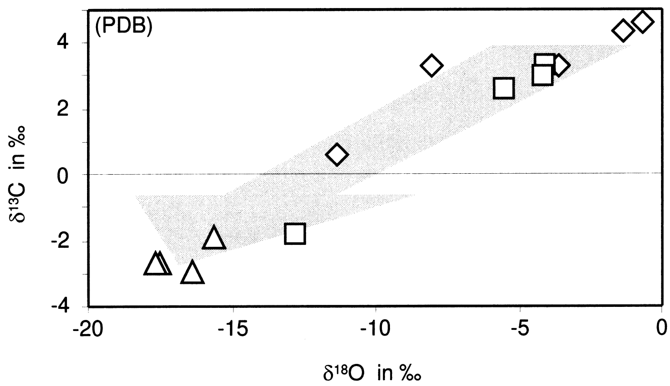

Fig. 3. C–O isotope analyses of Pico Jano for unbrecciated Barcaliente Fm. (diamond), dolomite cements (square) and calcite cements (triangle).

(kaolinite–illite) in both deformed/altered and undeformed rock.

Carbon and oxygen isotope analyses show similar trends within all studied regions, as exemplified by Pico Jano in Fig. 3. The unbrecciated Barcaliente Fm. outside the fault zones contains the highest $\delta^{13}C$ and $\delta^{18}O$ values. The lowest isotope ratios are found in calcite cements in the fault zones, whereas the dolomite cements have intermediate values.

4. Discussion

The evolution of the fault zones is illustrated by the precipitation of cements from different types of circulating fluids in several pulses. Fluid inclusion data obtained from several calcite and dolomite cements indicate a distinct diagenetic history of the four studied fault zones.

The classification of cements according to cathodoluminescence does not necessarily imply an equal origin of similar luminescent cements. Calcite cements are always younger than dolomite cements, and have lower or similar formation temperatures. Only the calcite cement in Meré-Peruyes has higher temperatures than dolomites. The cement generations in this fault zone reveal a prograde temperature development from dolomite to calcite precipitation, in the presence of montmorillonite-chlorite, which is absent in the other regions. In Rio Color and La Hermida dolomitisation processes must have occurred at higher temperatures than calcite precipitation and dedolomitisation.

Dolomites were precipitated from higher saline fluids than calcite (nearly pure water), except for the La Hermida region, where inclusions in calcite have the highest observed salinity. The composition of this saline fluid is NaCl-rich in addition to some other salts, like $MgCl_2$ and $CaCl_2$. A similar type of saline fluid must have circulated in the Meré-Peruyes region. Both fault zones are E–W striking and belong to a regional end phase of nappe emplacement, which is relatively younger than faulting processes in Rio Color and Pico Jano.

The observed tendency to lower oxygen and carbon isotopes could be interpreted as the effect of burial diagenesis (e.g. Moore, 1989), especially for the Meré-Peruyes area in accordance to microthermometric data. On the other hand, different degrees of wall-rock interaction during the precipitation of dolomite and calcite cements may have also played a role in the observed trend. Dolomites reveal an intense interaction and obtain isotopic compositions similar to the wall rock, whereas fluids from which calcite precipitated have a low interaction. Therefore, the isotopic composition of calcite cements is closer related to the precipitating fluid.

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