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Multiple fluid flow events in the Cantabrian Zone, NW-Spain

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Introduction

The Cantabrian Zone in NW-Spain belongs to the foreland fold and thrust belt of the Variscan Orogen (Fig. 1). It is composed of different units representing a Paleozoic shelf to basin transition, which was deformed during the Variscan Orogeny. The Cantabrian Zone is characterized by thin-skinned tectonics with a near absence of metamorphism and penetrative cleavage (JULIVERT, 1971, PEREZ-ESTAÚN ET AL., 1988).

After the predominantly siliciclastic sedimentation during the Ordovician to Silurian, the Lower Devonian La Vid Group marks a shift towards sediments dominated by carbonates, which prevailed during the Devonian. The different strata of the La Vid Goup and the overlying formations have been tilted vertically as a result of Variscan and Alpine deformation. The La Vid Group is divided from base to top in dolostones, limestones and the shales. This study addresses the nature of multiple fluid flow events within the Somiedo-Correcillas Unit by conducting a detailed investigation of the cement stratigraphy (Fig. 2) in the La Vid Group. A combination of different analytical methods, including petrographic observations, CL, SEM, XRD, microthermometry, stable isotope and trace element analyses were applied to unravel the history of fluid-rock interaction.

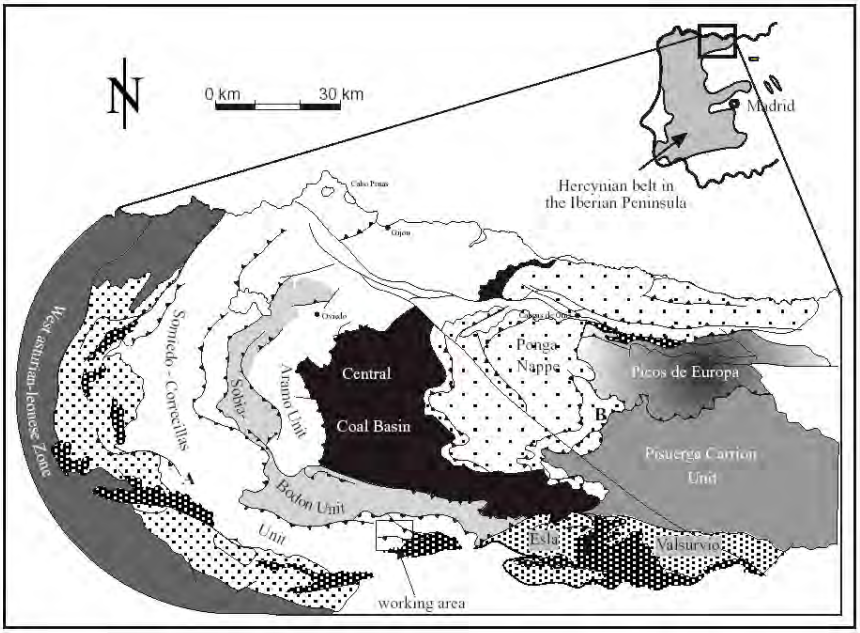

Fig. 1: *Geological sketch map of the Cantabrian Zone, showing the main thrusts and different tectonic units, after JULIVERT (1971) and PEREZ-ESTAÚN ET AL. (1988).*

Results

Petrographic observations and fluid inclusion data revealed a cement stratigraphy, presented in Fig. 2. In connection with this stratigraphy three major fluid flow events can be distinguished.

During the basin stage, barite (Bar) and iron-rich saddle dolomite (S-Dol 1) was precipitated, cementing the limestones and partly substituting LMC-shells. Bar and S-Dol 1 contain fluorescing primary hydrocarbon inclusions which show in S-Dol 1 homogenization temperatures ranging from 59°C to 106°C. The turbid and non luminescing crystals of the saddle dolomite contain also aqueous fluid inclusions with homogenization temperatures about 114°C. This temperature gives the lower limit for the maximum temperature range reached during burial diagenesis of the basin. The fluorescing hydrocarbon inclusions indicate the upper limit of 140°C. Hydrocarbon inclusions overprinted by a higher temperature would not fluoresce. Stable isotope values of this cement indicate a rock-buffered fluid, whereas oxidized samples show a strong depletion in $\delta^{13}C$, indicated by the stippled arrow in Fig. 3.

The second, major fluid event is characterized by the third saddle dolomite generation (S-dol 3), which can be related to tectonic movements associated with brecciation of the host rock. S-Dol 3 is restricted to veins and cavities in the dolomite beds of the La Vid Group, showing clear crystals with growth zones containing few low-salinity inclusions with methane as the principle gas-phase. The isotope values, which are not shown in Fig. 3, are in the same range as the dolostones and also indicate a rock-buffering.

The most recent fluid flow event in the Cantabrian Zone is characterized by Calcite 3 (Cal 3) and Celestite (Cel). The calcite precipitated together with sulfate minerals in veins and cavities along reactivated fault sytems. All-liquid inclusions along growth zones in the clear, orange luminescing calcite crystals indicate a low temperature fluid, below 50°C. The stable isotopes of Cal 3 (Fig. 3) display an ambivalent distribution with two dif ferent groups. Group I has $\delta^{13}C$-values of around -4‰ V-PDB and moderate $\delta^{18}O$-values of -8‰ V-PDB. In contrast to this is Group II with enriched values in $\delta^{13}C$ of about 0‰ V-PDB and more depleted $\delta^{18}O$-values around -13‰ VPDB. This trend from depleted to enriched values in $\delta^{13}C$ of Cal 3 is also visble in samples of the overlying formations to the south of the La Vid section. The analyses show in general $\delta^{13}C$-values of Group II. This is acompanied by an enrichment in the iron content of Cal 3.

Interpretation

This study identifies three different fluid events within the La Vid Group and the overlying carbonates, which can be related to different evolutionary stages of the Cantabrian Zone.

The iron-rich saddle dolomite can be related to the basinal stage precipitated by compactionaldriven flow in association with hydrocarbons generated from the Formigoso shales as the most probable source for the oil. The fluid passed through the ferruginous San Pedro sandstone, where iron was reduced by the hydrocarbon-rich fluids, and was transported upward through fractures crosscutting the dolostones of the La Vid Group. In the overlying limestones, S-Dol 1 crystallized in porous fossil-rich beds, incorporating hydrocarbon inclusions. A pressure

induced downward flow (MANN and MACKENZIE, 1990) of the hydrocarbons can be excluded as other possible source rocks are absent in the overlying 500m of the Paleozoic succession. The maximum temperature reached during burial diagenesis lies between 114°C and 140°C. The subsequent temperature history did not exceed 140°C.

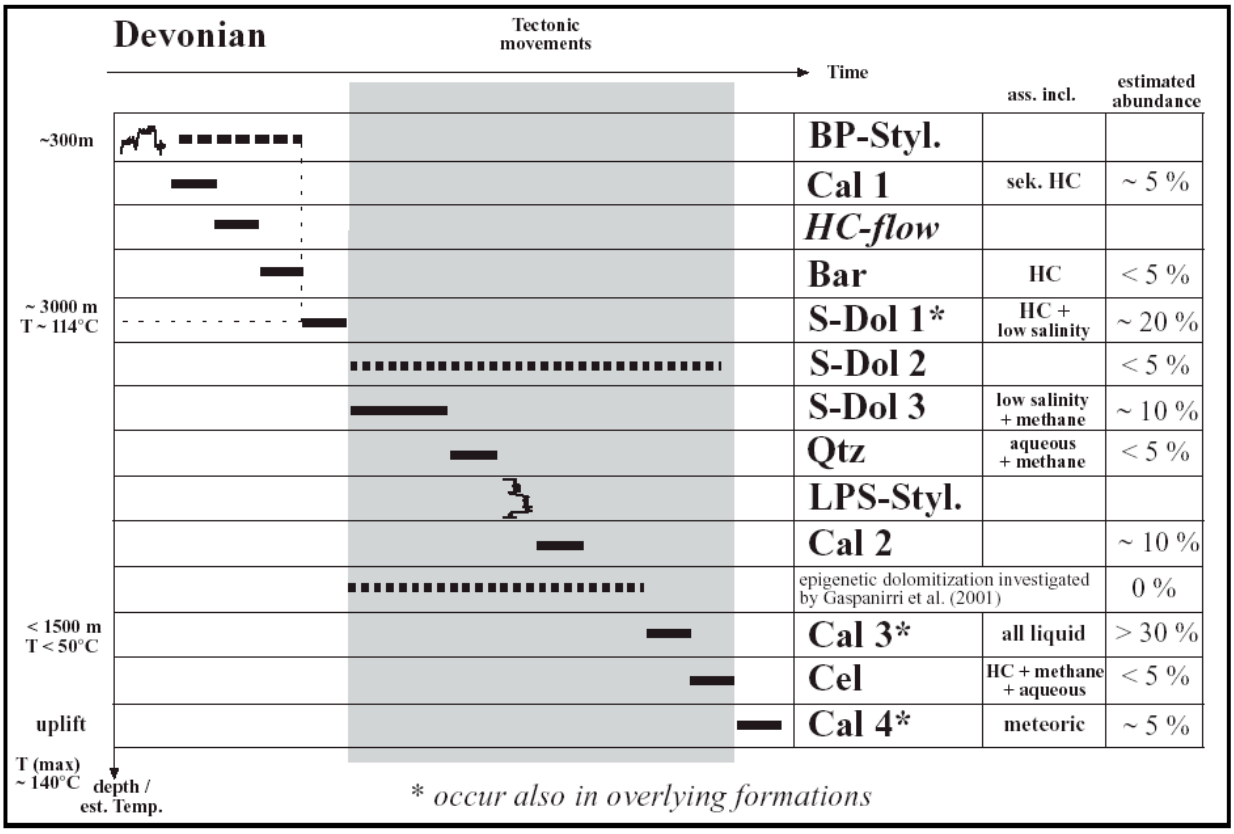

Fig. 2: *Cement stratigraphy in the Lower Devonian La Vid Group showing the different cement generations, the associated fluid and the estimated abundance of the cements in the La Vid Group. The major cement types of S-Dol 1, S-Dol 3 and Cal 3 are described in the text. Other minor cement generations, are not mentioned as they could not be clearly defined due Bar: Barite, BP-Styl.: Bedding-Parallel Stylolites, Cal: Calcite, Cel: Celestite, HC: Hydrocarbons, LPS-Styl: Layer-Parallel-Shortening Stylolites, S-Dol: Saddle Dolomite.*

S-Dol 3 belongs to a syn-Variscan fluid. Its syn-tectonic nature is indicated by brecciated fragments of the dolostones in fractures and cavities cemented by S-Dol 3. However, the flow direction of this fluid remains unconstrained.

A large-scale fluid event is associated with Cal 3. It probably relates to tectonic movements of the Alpine deformation. Cal 3 occurs in fault zones and overprints the surrounding limestones with all its constituents. It brecciated, oxidized and dedolomitized S-Dol 1. In the vicinity of Cal 3-bearing fault sytems, the oxidized S-Dol 1 (stippled arrow in Fig. 3), the limestones (the straight arrow in Fig. 3) and brachiopod shells analyzed by ALA (1996) show a depletion in $\delta^{13}C$. The oxidation processes of the iron-rich S-Dol 1 reduced the O2-fugacity of the fluid, which caused an enrichment in $\delta^{13}C$ (OHMOTO, 1972) and a depletion in $\delta^{18}O$. This is reflected

by carbon isotopes of Cal 3 from different locations in the Cantabrian Zone showing an enrichment from very negative values in the north (GASPANIRRI ET AL., 2001) to values around 0 in the south. This may confirm a North-South flowing fluid accompanied by an increase in iron, released due to the oxidation of the iron-rich saddle dolomite in the La Vid Group.

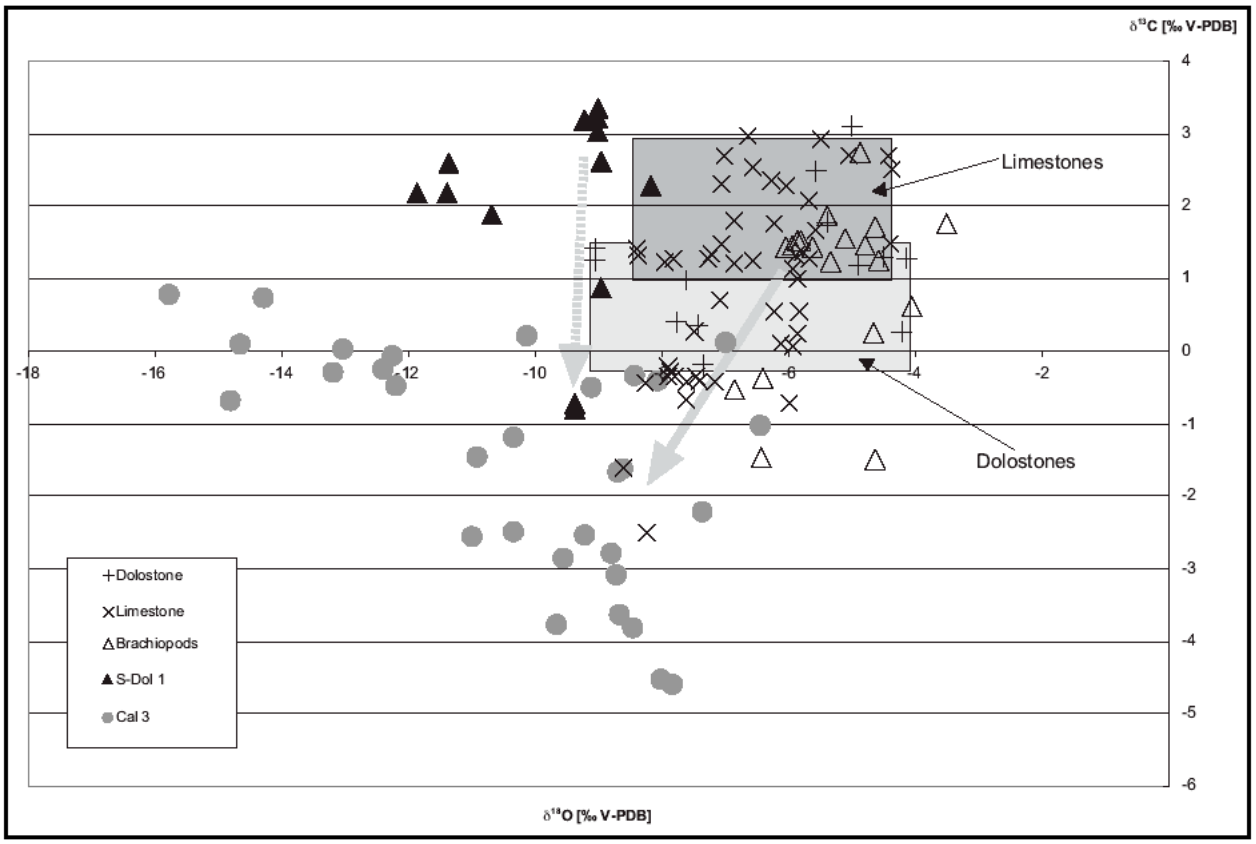

Fig. 3: *Stable carbon vs. oxygen isotopes of the host rocks, brachiopods and the major cement generations of the La Vid Group. The limestone and the majority of the dolostone values in the shaded boxes show only a slight early diagenetic overprint in comparison to the brachiopod data from ALA (1996). The brachiopods should reflect the composition of seawater carbonates at the time of their deposition (POPP, 1986). The arrows indicate an alteration of the limestones and the brachiopods samples, which lie outside of the dark shaded box, as well as of S-Dol 1, towards the depleted* $\delta^{13}C$*-values of Cal 3.*

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