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Tectonics and fluid flow at the northern Variscan front (Belgium)

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I. Introduction

In fold-and-thrust belts, major fluid expulsion is generally regarded to have occurred due to thrusting and nappe stacking. Fluids are expelled from the compressed rocks and focussed towards the foreland. In addition, large-scale gravity-driven flow systems formed as the result of the topographic relief created during the orogeny. However, major fluid flow in fold-and-thrust belts is not necessarily related to the orogenic stage but could have taken place during any stage of basin evolution. It is also often overlooked that the origin and geochemistry of the fluids expelled during the orogeny is determined by the earlier sedimentary and tectonic evolution of the basin.

II. Geological setting

The Lower Paleozoic basement of the Variscan fold-and-thrust belt in Belgium (Fig. 1) consists of low-grade metamorphic siliciclastic series of Cambrian to Silurian age. The basement north of the Variscan deformation front (the Brabant Massif) suffered a Late Silurian to early Middle Devonian orogenic event. The basement inliers in the Ardenne Allochthon (Rocroi, Stavelot-Venn, Serpont, Givonne, Fig. 1) underwent an Ordovician tectonometamorphic event prior to the Variscan deformation. The Devonian and Lower Carboniferous cover was deposited in a marginal basin along the northern passive margin of the Rhenohercynian Ocean (Oncken, 2000) in an extensional setting. Synsedimentary extensional faults mainly trend ENE-WSW south of the Brabant Massif, E-W tot NW-SE north of the Brabant Massif (Campine Basin). Late Carboniferous flysch and molasse sedimentation occurred in a foreland basin developing in front of the northwards prograding Variscan orogen (Plesch & Oncken, 1999). During the Mesozoic a reactivation of NNW-SSE trending faults and fractures can be related to the opening of the North Atlantic Ocean.

III. Fluid flow in the Variscan front zone

III.1 Pre-Variscan fluid flow

The normal faults cutting into the Lower Palaeozoic Brabant Massif are intensely mineralised with quartz. Fluid flow through the basement and overlying Devonian rocks has been suggested by Dejonghe et al. (1989) and Dejonghe (1990, 1998) for the genesis of the late Devonian sedex-type baryte deposit at Chaudfontaine (Vesdre Nappe, Fig.1). These fluids migrated upward along extensional faults and mixed with evolved seawater in the subsurface (Dejonghe et al., 1982). The geochemistry of the fluid inclusions in the barytes demonstrates an evaporative origin of the mineralising fluid, which was modified by an early stage of dolomitisation (Heijlen et al., 2000). Lead isotopic data (Cauet et al., 1982) indicate that metals contained in the Middle and Upper Devonian rocks could constitute the main source of the Pb.

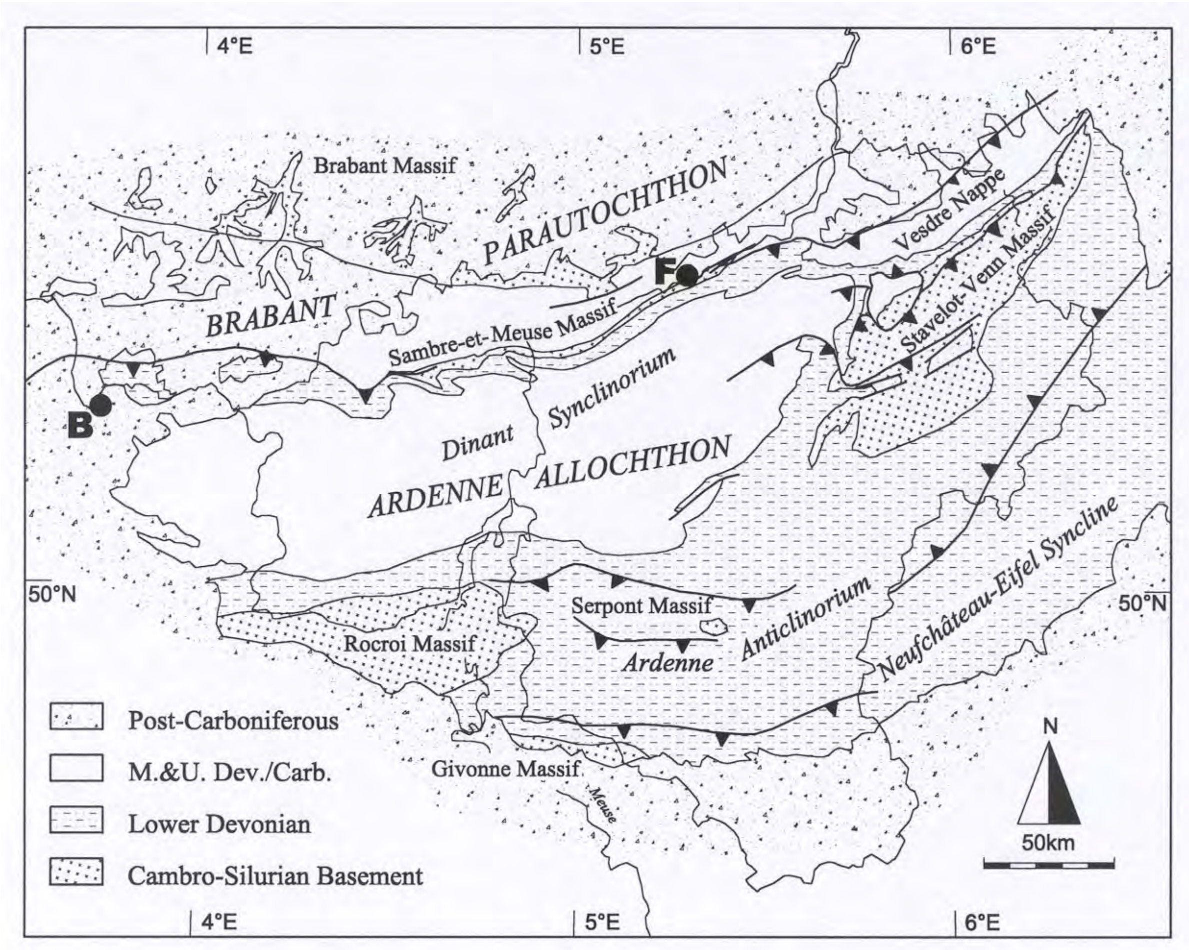

Figure 1: Main structural domains of the northern Variscan front zone (Ardennes, Belgium). B: Bettrechies Quarry (example of Variscan fluid flow, see Kenis et al., 2000), F: Flône Quarry (example of post-Variscan fluid flow, see Muchez & Sintubin, 1998).

III.2 Variscan fluid flow

Extensive carbonate-filled fractures developed in folded and faulted strata during the Variscan orogeny. The carbonate veins in the folded strata are typically rock-buffered and are interpreted to have formed in a closed fluid system (Muchez et al., 1995, 2000; Kenis et al., 2000). At present, only veins associated with the major thrust faults north of a greenschist metamorphic zone indicate an open fluid system (Muchez et al., 1998). Fluids likely originated from the metamorphic zone a few tens of kilometers to the south, and migrated along the sole thrust towards the foreland (Lünenschloss et al., 1997; Lünenschloss, 1998; Schroyen & Muchez, 2000). In addition, zebra dolomites in the Dinantian of the Vesdre Nappe (Fig. 1) formed syntectonically, but as a result of vault-valve activity related to reverse faulting (Nielsen et al., 1998). The geochemistry of fluid inclusions in these dolomites indicates the fluids originated from evaporated seawater, whose composition was modified during subsequent dolomitisation. The Upper Givetian and Viséan carbonates are dolomitised by an early diagenetic reflux dolomitisation (Préat & Rouchy, 1986; Nielsen et al., 1994).

III.1 Post-Variscan fluid flow

The Mesozoic is characterised by successive fluid migrations within extensional and transpressional regimes (Muchez et al., 1995; Muchez & Sintubin, 1998). NNW-SSE trending faults crosscut all Variscan structures. During the Jurassic (de Magnée, 1967; Schneider et al., 1999), they caused the formation of the Mississippi Valley-type deposits in eastern Belgium (Vesdre Nappe, Fig. 1) and at Maubach-Mechernich (Dejonghe, 1998; Voigt, 1952). The Zn-Pb mineralising fluids also originated from the evaporation of seawater during the Middle and Late Palaeozoic (Heijlen et al. 2000, 2001). However, their geochemistry not only reflects dolomitisation but also albitisation. The latter implies a circulation of the fluids into the Lower Palaeozoic basement. Already in 1967 Pelissonnier stressed the importance of fluid migration, however of meteoric waters, through the basement and along faults for the origin of Mississippi Valley type deposits. This implies that the fluids remained for almost 200 My in the subsurface. Investigations by Cai et al. (2001) and Martel et al. (2001) indeed demonstrate that fluids present in Palaeozoic strata of Central Tarim (China) and of the Sydney Coalfield (Atlantic Canada) were trapped during the Cambrian and Carboniferous. The thin-skinned tectonics of the northern Variscan fold-and-thrust belt did not cause the expulsion of fluids from the basement.

IV Discussion and conclusion

During the Devonian and Carboniferous, fluids migrated through the basement and its sedimentary cover of the Variscan foreland. Migration occurred downward in the sedimentary basin, but also laterally through the basement, bordering and underlying the foreland. Both meteoric and seawater (eventually modified by evaporation and water-rock interaction) could have originated from these areas. Extensional faults are interpreted as important fluid conduits. Fluid migration during the Variscan orogeny took place in a closed (first-order folds in allochthon) and an open system (sole thrust at the base of allochthon). It did not occur on a scale of hundreds of kilometers, but was immediately related to reverse faulting (e.g. zebra dolomites) or to the migration of metamorphic fluids. The latter were generated south of the thrust front and were expelled along the sole thrust. Several periods of major fluid expulsion in the Variscan foreland are associated with Mesozoic extensional tectonics. Fluids were sourced from the underlying basement, intersected by crustal-scale faults, and migrated into the Devono-Carboniferous cover. In all three stages, the fluids expelled were mainly generated within the area itself. Large-scale horizontal fluid movements are generally proposed in fold-and-thrust belts and are tectonically induced or gravity-driven. In contrast, fluid flow at the northern Variscan front is predominantly characterized by vertical migration. In addition, small-scale horizontal fluid flow is envisaged through the basement, bordering and underlying the foreland.

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