Discussion on ”Evolution of the European Cenozoic Rift System: interaction of the Alpine and Pyrenean orogens with their foreland lithosphere” by P. Dèzes, S.M. Schmid and P.A. Ziegler, Tectonophysics 389 (2004) 1–33

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1. Introduction

The evolution and origin of the European Cenozoic Rift System (ECRIS) is a matter of debate for several decades (e.g., Tapponnier, 1977; Bergerat, 1987; Ziegler, 1992; Michon et al., 2003). This rift system was characterized by the development of several grabens in the Pyrenean and Alpine forelands and by a magmatic activity starting at the K/T transition. Dèzes et al. (2004) propose an additional reappraisal and interpret the ECRIS formation and the associated volcanism as resulting from the Alpine and Pyrenean collision and the emplacement of a mantle plume at depth below western Europe. Our remarks on this paper will be focused on three different topics which make the final conclusions of Dèzes et al. (i.e., origin of the extension in the ECRIS) highly questionable.

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2. The Late Eocene–Oligocene rifting event

Combining microtectonic data (e.g., Bergerat, 1987) and the Pyrenean and Alpine orogenic evolution, Dèzes et al. (2004) distinguish several periods of deformation. Their interpretation for the Late Eocene and Oligocene periods can be summarized as follows. In Late Eocene time, the formation of the Massif Central grabens (MCG) and the Upper Rhine graben (URG) resulted from a N–S compression which entailed the reactivation of preexisting Paleozoic main structures. During the Oligocene, although N–S compression still affected the Pyrenean and Alpine forelands, E–W/ESE–WNW extension in the MCG and URG occurred as the consequence of gravitational forces, such as the load of upwelling mantle plumes. This slight extension (5–7 km) led to a rotational westward displacement of France and compressive tectonics (i.e., inversion or up warping) in the Mesozoic basins in the Channel, Western Approaches, the Celtic Sea and the Weald–Artois, which was superimposed to the Pyrenean and Alpine collision-related stresses. To sum up, the formation of the URG and MCG which are the main ECRIS grabens results during Late Eocene and Oligocene from a combination of a regional N–S compression and local stress fields.

We consider that this interpretation proposed by Dèzes et al. (2004) faces major problems.

1—If the initiation of graben formation would result from a N–S compression during Late Eocene, syn-sedimentary strike–slip or reverse faults should be observed. However, only normal faults affect the Late Eocene–Oligocene sediments of the MCG and URG (Villemin and Bergerat, 1987; Michon, 2001; Rocher et al., 2003; Ustaszewski et al., in press). Such observations raise one question: Is the age of the Late Eocene compression in graben areas described from microtectonic measurements well constrained?

It is well known that the N–S Late Eocene compression which would have initiated the MCG and URG formation was inferred from microtectonic measurements in pre-Cretaceous and Paleozoic formations only, rendering the Late Eocene age for the main compressive event poorly constrained (Villemin and Bergerat, 1985, 1987; Blès et al., 1989; Rocher et al., 2003). Strictly speaking the N–S compression affecting these geological formations is post-Jurassic. In post-Jurassic times, the main graben inversion in the southern North Sea and the main Variscan massif uplift in Western and Central Europe occurred during the Late Cretaceous and Early Paleocene instead of Late Eocene (Malkovsky, 1987; Barbarand et al., 2002; De Lugt et al., 2003; Worum and Michon, 2005). This compressive phase involved (1) an uplift one order of magnitude higher than during Late Eocene in the southern North Sea grabens, and (2) an uplift of more than 1000 m controlled by the reactivation of large Paleozoic faults in the Variscan massifs (Massif Central and Bohemian Massif). In consequence, we believe as very likely that the N–S compressive event recorded in the pre-Cretaceous sediments results from the first compression phase in Late Cretaceous–Early Paleocene rather than from Late Eocene. This makes the link between the N–S Late Eocene compression and the graben initiation very weak. Additionally, one can wonder why a N–S Late Eocene compression (if so) would have entailed the development of large grabens whereas the Late Cretaceous–Early Paleocene event which was definitely stronger did not induce graben formation.

2—In the URG and MCG, recent microtectonic (Michon, 2001; Ustaszewski et al., in press) and seismic data (Le Carlier de Veslud et al., 2004) indicate a constant extension direction during the Late Eocene–Oligocene period. This has been confirmed for the southern URG by Laubscher (2004). The persistent extension direction is supported by (1) the superimposition of the Late Eocene, Rupelian and Chattian intra-basin depocentres, and (2) the constant faulting mode along both the graben border faults and the intra-basin oblique structures (i.e., the Lalaye–Lubine–Baden–Baden fault in the URG, the Aigueperse fault and the Combroz axis in the MCG). Variations of the extension directions during the Late Eocene–Oligocene period would have induced a change in the geometry and location of the depocentres as observed in the URG and the Roer Valley Graben when stress field changed at the Oligocene–Miocene transition (Schumacher, 2002; Michon et al., 2003). We consider that the above geological data are strong geological arguments proving that the URG and MCG developed during Late Eocene and Oligocene under a constant stress field instead of a polyphase evolution as proposed by Dèzes et al. (2004).

3—Gravitational forces related to the load of upwelling mantle plumes are invoked by Dèzes et al. (2004) to explain the Oligocene extension in the MCG and URG. It is widely accepted that such forces induce an uplift of the lithosphere and that the mantle upwelling is associated with a syn-rift widespread volcanism (e.g., Ruppel, 1995). In the MCG and URG, the Oligocene period is characterized by a lack of crustal doming as demonstrated by marine sedimentation (Briot and Poidevin, 1998; Sissingh, 2001). Furthermore, no volcanic activity affected the URG at this period and only a few volcanoes developed during Late Oligocene and Early Miocene in the western part of the Massif Central rift where the maximum crustal thinning occurred. Conversely, if we consider a “not very energetic plume” to explain the lack of volcanism during the sedimentation period, as advocated by the authors, this means that the thermal anomaly at the base of the lithosphere is not high enough to induce thermal erosion. In this case, there is no gravitational upward loading to trigger graben formation. Consequently, we reject the gravitational forces related to mantle upwelling as a potential motor of extension in the URG and MCG during the Oligocene (Dèzes et al., 2004) and interpret the Late Eocene–Oligocene in terms of passive rifting due to E–W extension in the MCG and ESE–WNW/SE–NW extension in the URG.

3. The Paleocene and Miocene volcanism: mantle plume vs. lithospheric folding

Like many authors (e.g., Granet et al., 1995; Goes et al., 1999), Dèzes et al. (2004) interpret most of the ECRIS Cenozoic volcanism as resulting from the emplacement of a large mantle plume at depth which fed small-scale mantle plumes. Decompressional partial melting of the asthenosphere and lower lithosphere in response to lithospheric folding is a complementary mechanism proposed by Dèzes et al. (2004) to explain local volcanism in the URG area during the Miocene. It may be asked why the ECRIS Paleocene volcanism and the Miocene volcanism of the URG southern area are interpreted in two different ways since both (1) are emplaced in a similar geodynamical context (i.e., crustal uplift related to the Alpine collision) and (2) are characterized by an identical petrology (i.e., nephelinite to melilitite). The difference in the interpretations suggests that no lithospheric folding occurred before the Miocene. However, it is widely admitted that the strong deformation which affected the European lithosphere around the K–T transition is the expression of a large lithospheric folding related to the closure of the Piemont Ocean (e.g., Lefort and Agarwal, 1996; Michon and Merle, 2001; Bourgeois et al., 2004). It has been shown that the provinces affected by the Paleocene volcanism are strikingly superimposed to the lithospheric anticline structures related to this folding (Bourgeois et al., 2004). According to these data, (1) there is no need to invoke the influence of mantle plumes to explain the development of the Paleocene volcanism in the ECRIS, and (2) the very low partial melting may result from an adiabatic decompression of the lithospheric thermal boundary layer during the main lithospheric folding event around the K–T transition.

Obviously, such a different interpretation stresses the question of the age of the thermal anomalies revealed by seismic tomography (Granet et al., 1995; Ritter et al., 2001). In the MCG, the major volcanic phase (Cantal, Deves, Velay, Aubrac) is centered above the lithospheric thinning resulting from thermal erosion (Sobolev et al., 1997; Michon and Merle, 2001), which is one of the main arguments suggesting that the plume-like structure underneath is of Late Miocene. Likewise, considering that the plume-like structure is already active at the K–T transition and responsible for the Eocene volcanism makes it difficult to understand why the major Miocene magmatic phase of volcanism followed an Oligocene period which lacks volcanism. In the Rhenish Massif, the thermal anomaly is restricted to the western part of the massif below the Eifel province which was characterized during the Pleistocene by coeval crustal uplift and volcanic activity (Garcia-Castellanos et al., 2000; Ritter et al., 2001). This evolution which is typical of mantle plume emplacement suggests a Pleistocene age of the present-day visible mantle anomaly. Nevertheless, the Miocene volcanism and the coeval uplift of the eastern part of the Rhenish Massif could correspond to the emplacement of an older plume-like structure invisible nowadays in seismic tomography. Note that the huge volume of magma related to these periods is fundamentally different from the nearly negligible amount erupted during Paleocene–Eocene times, which is interpreted by Dèzes et al. (2004) as associated with a mantle plume emplacement at depth.

4. Discussion

Three main features characterized the Alpine foreland from the Late Cretaceous: (1) An intraplate volcanism starting at the K–T transition, (2) Local inversion phases and basement uplift, and (3) The formation of large grabens since Late Eocene. Dèzes et al. (2004) interpret most of the volcanism as originating from a deep mantle plume which developed at the K–T transition, and the inversion periods and the formation of the ECRIS as the consequence of compressive stresses which have affected the European foreland. As shown above, essential geological data do not support this view. Our main objection concerning the paper of Dèzes et al. (2004) can be summarized as follows:

1. The graben area did not suffer a Late Eocene compression but a Late Cretaceous–Early Paleocene one.
2. The URG and MCG did not develop under N–S compression during Late Eocene and Oligocene. These grabens were affected by constant E–W (in the MCG) and WNW–ESE/NW–SE (in the URG) extension direction at that time, with a vertical σ_1 principal stress axis.
3. Sedimentation at sea-level in the MCG and URG shows that a local influence of upward gravitational forces to explain the Oligocene extension cannot be proposed.
4. There is no evidence to assume a mantle plume-related volcanism since the K–T transition: (i) Oligocene time lacks volcanism; (ii) The plume-like anomalies inferred from tomographic studies can be dated from the Late Miocene in the Massif Central and the Pleistocene in the Rhenish Massif. In this province, geological data suggest that an earlier Miocene mantle upwelling likely occurred.

During Late Eocene and Oligocene, pure extension occurred in the MCG and the URG, extension direction being parallel or sub-parallel to the crustal shortening directions in the Alps (Lickorish et al., 2002). This extension in the Alpine foreland contemporaneous to a period of a strong compression in the Alps was interpreted by Merle and Michon (2001) and Michon et al. (2003) as resulting from a slab pull exerted by the Alpine lithospheric root. The stop of extension in the MCG and the northward abrupt shift of the depocentres in the URG and the Roer Valley Graben around the Oligocene–Miocene transition reveal a sudden change of the ECRIS dynamics at that time. This evolution was interpreted by Michon et al. (2003) as the consequence of a slab detachment below the Western Alps, stopping the pure extension in ECRIS.

Dèzes et al. (2004) reject these interpretations for two main reasons: (1) A slab breakoff occurred in the Central Alps at the Eocene–Oligocene transition (Von Blanckenburg and Davies, 1995) making wrong the slab pull model. (2) No slab breakoff affected the Western Alps at the Oligocene–Miocene transition but at the Miocene–Pliocene transition (Sue and Tricart, 2002). It is interesting to note that Von Blanckenburg and Davies (1995) never proposed a slab breakoff at the Eocene–Oligocene transition but at 45 Ma (i.e. Middle Eocene). Consequently, the postulated change of deformation in ECRIS between Late Eocene and Oligocene as described by Dèzes et al. (2004) cannot originate from a slab breakoff-related change of stress. Conversely, a slab pull model occurring at Late Eocene (i.e., 10 Ma after the slab breakoff below the Central Alps) cannot be rejected. For the Western Alps, contrary to what is written in the paper of Dèzes et al. (2004), Sue and Tricart (2002) do not propose a slab detachment at the Miocene–Pliocene transition. In their paper, the authors discuss the origin of the extension in the internal Alps since the end of the Oligocene. Several hypotheses are proposed to explain the transition from compression to extension around the Oligocene–Miocene transition (i.e., back-arc extension, collapse and spreading of an overthickened crust, slab breakoff or lithospheric root detachment,...). The authors consider that the slab breakoff hypothesis can hardly be applied to explain the transition from compression to extension, since rapid regional uplift and heating were not observed. However, it can be objected that exhumation of the external crystalline massifs started around the Oligocene–Miocene transition (Tricart et al., 2001) and that this uplift was accompanied by circulation of hot fluids (Corsini et al., 2004). For these reasons, we believe that the slab breakoff hypothesis cannot be rejected to explain the evolution of the Western Alps around the Oligocene–Miocene transition.

5. Conclusion

The model of Dèzes et al. fails to explain most field data of the ECRIS, even those which are acknowledged by the whole geological community. We do not claim that our model is the right one, but we do believe that it is the one which takes into account most available data known nowadays, especially those which make the model of Dèzes et al. incorrect, that is, the stress orientation during graben formation and evolution, the Oligocene sedimentation at sea level lacking volcanism and the Miocene age of plume-like structures.

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