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Journée thématique ASF. Diagenèse : avancées récentes et perspectives.
Orsay, 4 Juillet 2014 – Livre des résumés, Publications ASF, Paris, n°75, pp. 113-117.

Persistent paleosurfaces in the basement of French Massif Central: geodynamic implications

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Abstract: The post-orogenic evolution of crystalline massifs has always suffered from a lack of reliable geological data to constrain its history. With the advent of new techniques such as thermochronology and paleomagnetic age determinations, more robust constraints are available. However, their interpretations may still present contradictions. This is the case of the French Massif Central basement. The siderolithic paleoweathering surfaces have been dated to the Late Jurassic/Early Cretaceous, contrasting with previously accepted Tertiary age and implying that the Massif has never hosted a thick sedimentary cover. This contradicts with former thermochronological results. Herein, we expose the arguments for and against the proposed geodynamic evolution of the French Massif Central constrained by paleomagnetic age determinations. This said, thermochronological results should not be cast aside. Instead, the apparent contradiction should be addressed. Is there a, yet unknown, bias in these fission track records?

1 Dating of the siderolithic profiles

The red duricrusts, associated to the siderolithic formations overlying the French Massif Central basement have traditionally been assigned to the Eocene-Oligocene. Paleomagnetic results obtained on these duricrusts indicate that their ages range from 160 Ma (Late Jurassic) in the centre of the massif to 140 Ma (Early Cretaceous) in the northern parts (Ricordel-Prognon et al., 2010) (Figure 1). A second episode of remagnetization is recorded at around 50 Ma in two red duricrust sections: Le Rouget in the centre of the massif and St-Désiré near its northern edge. In the St-Désiré area, the younger age is recorded in the lower part of the profiles. This agrees with the weathering process which progress from the top to the base, by deepening of the profile.

The current geodynamic models for the Massif Central are anchored on a Tertiary age of the duricrusts. A revaluation of their ages to about 100 Myr (or more) older has major repercussions and demands that the geodynamic evolution of the Massif Central be revised, including its behaviour during the Mesozoic, its erosion, the development of the current landscapes, etc. In the past, the models were essentially constrained by a Tertiary age of the siderolithic formations. A significant portion of the continental evolution of the massif, the paleosurfaces and the current surface topography were considered as being of Tertiary age. Pushing the age of the siderolithic formations back to the Late Jurassic places back into question earlier geodynamic models. Moreover, if these evolutions are not of Tertiary age, how did the Massif evolve during the Tertiary? Lastly, the Late Jurassic ages of the siderolithic formations bring considerable constraints for interpreting the palaeogeographic evolution of the Massif Central during Mesozoic and Cenozoic.

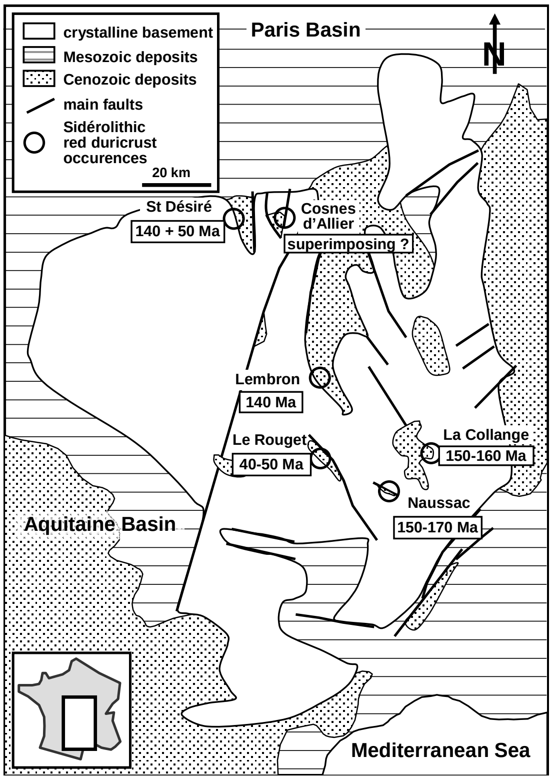

Figure 1 - Geological sketch of the French Massif Central showing the occurrences of the siderolithic red duricrusts setting on the basement and their paleomagnetic ages.

2 Role of eustatism

The paleomagnetic ages show that red duricrusts are older in the centre of the massif than to the north, near the edge of the Paris Basin (Figure 1). The spatial distributions of ages call for a progressive emergence of the massif over a 30 Myr period, coinciding with low eustacy levels at the end of the long regression period from the Triassic to the Lower Cretaceous. The second period of oxidation, leading to the paleomagnetic remagnetization ages of 50 Ma also coincides with a period of low sea level during the Eocene. Even if tectonic movements cannot be denied over this long period, the progressive emergence of the massif under the influence of falling sea level has played a decisive role for its evolution. Marine regression would have triggered the incision of the landscape and in turn lowering groundwater tables would have reactivated oxidation and weathering recorded by paleomagnetism.

3 Durability of the paleolandscapes

The red duricrusts are bound to contrasted paleolandscapes that are still imprinted in the current morphology of the massif. These paleolandscapes, formed of deep paleodrainages, pediments surrounding paleoreliefs, fault scarps, etc. are sealed by red duricrusts. Moreover, the red duricrusts locally seal paleovalleys filled with fluviatile sandstones and claystones.

What age are these ancient valley infill deposits? The sands beneath the red duricrust do not contain chert nodules at La Collange or St Désiré sites. We can deduce that their provenance is not the former Jurassic cover which contained chert layers. They may, however, be associated to Triassic fluviatile deposits known around the Massif Central and observed to infill paleovalleys cutting through the basement (Lougnon et al., 1974; Fogliérini et al., 1980; Soulé de Lafont and Lhégu, 1980).

The erosional history of the massif is complicated by successive marine transgression and regression. Albeit, it is likely that Jurassic and Cretaceous sediments covered the northern margin of the Massif and may have extended to its central parts. No matter the extent and history of the sedimentary cover, the fact that basement paleomorphologies inherited from the post-Hercynian evolution are preserved is most important; an unsuspected finding prior to the attribution of the red duricrust to a Jurassic age.

4 Grabens outset and Pangea break up

Often red duricrusts developed on thick fan deposits abutting fault scarps (St Désiré and Cher graben, Lembron area, Naussac graben and le Rouget site). Considering the previously accepted Tertiary age of the siderolithic formations, the red duricrusts were thought to have developed during the early stages of rifting. Field observations provide the evidence that the faults were active before development of the red duricrusts. With the new paleomagnetic ages, the sequence of events remain unchanged the timing of faulting along the Tertiary grabens began much earlier prior to 170-150 Ma (Late Jurassic).

By contrast, number of ore deposits connected to fracture opening in the basement have been dated back to Middle Jurassic by way of radiochronology. This is especially the case of various mineralizations in the Massif Central, the Vosges Massif and the Schwarzwald basements (Bonhomme et al., 1983; Brockamp et al., 2003; Edel et al., 2007).

In addition, extensive hydrothermal alterations occurred in Permian and Triassic age deposits along fault systems related to the Paleozoic crystalline basements. Their isotopic ages are concentrated between 190-140 Ma ago, around Middle-Late Jurassic (Bonhomme and Millot, 1987; Mendez Santizo et al., 1991; Clauer et al., 2008; Brockamp et al., 2011).

Authors agree to relate these hydrothermal activities, which are found extensively throughout Europe, with tectonic pulses during the break up of Pangea and the long-lasting opening of the North Atlantic Ocean and/or the nearby Tethys area. The onset of a pre-rift thermal uplift in the Aalenian has also been evidenced in Central and Northern North Sea (Rattey and Hayward, 1993). In the French Massif Central the red duricrusts that abut and seal the faults are direct evidence of pre-rifting faulting of the European craton and along which Oligocene rifting was reactivated.

5 Mesozoic cover of the Paleozoic massif

Dating of the red duricrusts resting on crystalline basement raises the question of the Mesozoic cover of the Massif Central. Geologists considered classically that the Massif Central formed a high throughout the Mesozoic era. It was generally admitted that even if the basement was not outcropping the Jurassic series were reduced and the Upper Cretaceous transgression did not cover the massif. This paleogeographic outline was argued by the presence of proximal facies in the peripheral deposits (dinosaurian footprints in continental borderlands, exondation traces, thickness reduction, sandy deposits coming with the Cretaceous transgression and absence of residual flintstones) (Vignaud et al., 1994 ; le Lœuff et al., 1999 ; Gand *et al.,* 2007). This "accepted" outline was questioned during the 1990s by the results from apatite fission tracks analyses. These results led to propose that the Massif Central was covered by a thick Mesozoic series, up to 1500 m, and which would have been eroded quickly at the end of the Upper Cretaceous and the beginning of the Tertiary, before the development of the siderolithic duricrusts that rest on the basement. (Barbarand *et al.*, 2001; Peyaud, 2005). Both proposals corresponded to conflicting geodynamic evolutions (Figure 2).

The dating of the red duricrusts calls into question the eventuality of such a thick Mesozoic cover on the Massif Central. Indeed, if the crystalline basement was uncovered during the Lower Cretaceous it is not possible to cumulate Jurassic and Cretaceous sedimentary series. Only an Upper Cretaceous cover is plausible yet it is unconceivable that it was thicker on the massif than in the peripheral sedimentary basins. It then follows that the Cretaceous (post-Sidérolithic) sedimentary cover never reached 500 m of thickness.

Moreover, Mesozoic material, in particular chert, is not observed within the red duricrusts in the centre of the Massif Central. Cherts stemming from the Jurassic cover are observed in duricrusts in the northern Massif Central, along the Paris basin margin. The Jurassic chert cobles known in the centre of the massif are restricted to alluvium coming from Jurassic deposits that line the massif to the South and to the East (Fernandes, 2012). It is thus likely that the centre of the Massif never hosted a Mesozoic cover and that the sands underneath the red duricrust in La Collange section are fluviatile sands related to the major Triassic discharge. In addition, there are no known residual Cretaceous flints in the centre of the Massif or in the alluvium connected to the large valleys cut in the basement. Therefore, one cannot exclude that a portion of the Massif Central remained emerged also during the Upper Cretaceous. The arguments of the classic geological hypotheses based on facies of the peripheral deposits are therefore sound. However, why do fission track analyses support a scenario with a thick sedimentary cover?

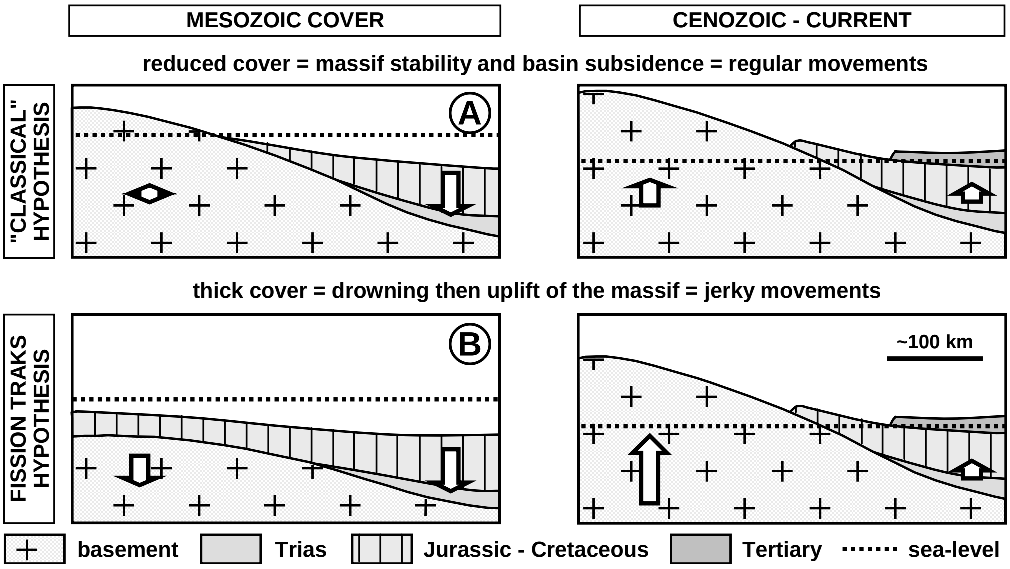

Figure 2 – Sketch of the conflicting hypotheses for the geodynamic evolution of the French Massif Central during the Mesozoic. In the "Classical" hypothesis (A) the massif remained bare or hosted a reduced sedimentary cover. The tectonic constraints are more or less continuous with a relatively stable zone of flexure. In the fission track hypothesis (B) the massif supported a thick cover. Here, differential movements and important erosion intervenes after the Upper Cretaceous.

6 Persistence of the paleosurfaces

In addition to the Jurassic paleosurfaces marked by the red duricrust and dated by paleomagnetism, other paleosurfaces related to the continental evolution of the Massif Central are known and help constrain its geodynamic evolution. These are namely Triassic paleosurfaces characterized by specific weathering of the basement and Tertiary paleosurfaces underlying Oligocene deposits in grabens.

Basement rocks (granites, gneiss, rhyolites and even Permo-Carboniferous sedimentary rocks) show often pinkish/reddened facies throughout the Massif Central. It has been shown that these reddened facies are albitised (mainly pseudomorphic replacement of the primary plagioclases into albite and alteration of the biotite into chlorite) and hematized (Schmitt, 1992; Parcerisa et al., 2009). These reddened and albitised facies, up to 200 m thick, are arranged in a clear succession against the Triassic unconformity that gives significant constraints to their connection with the Triassic palaeosurface. Moreover, altered facies have been dated back to the Triassic by using radiochronological methods (Bonhomme et al., 1980; Schmitt et al., 1984) and more recently by paleomagnetic methods(Ricordel et al., 2007).

Given that the alterations are of the same age as the unconformity, it follows that the albitized facies are related to the Triassic paleosurface and can be used to trace the Triassic paleosurface through wide crystalline areas, even areas far removed from the Mesozoic cover.

Spatial and temporal distributions of the paleoweathering features and related unconformities provide key arguments to unravel the geodynamic evolution of the Massif Central. Triassic, Late Jurassic and Tertiary unconformities are superimposed on large areas of the Massif Central. This implies very little erosion of the crystalline basement since Triassic time, as shown by the widespread preservation of the Triassic albitized facies. These paleosurface ages provide important constraints to Mesozoic/Cenozoic crustal dynamics modelling. Identification and dating of the successive continental unconformities are evidence for long lasting continental evolution and landscape stability of large areas of the Massif Central during the Mesozoic.

The remarkable persistence of the Triassic paleosurface has been highlighted by geomorphologists. The consistency and in particular the resistance to erosion emerges as a major feature of this paleosurface and seems to be mainly related to the albitization. The albitized granites are entirely free of anorthitic plagioclases that are much more sensitive to chemo-mechanical weathering. The development of albite and additional chloritization of the primary biotite crystals render the rocks much more resistant to weathering and erosion.

7 Conclusion

The results presented herein show the importance of determining the age of paleoweathering profiles and focus interests on the history of continental areas and in particular the geodynamics of Paleozoic crystalline basements. The results obtained over more than 30 years of investigation of the paleosurfaces of the French Massif Central and its bordering geological formations highlight how interpretations “ripen” and evolve through time and the necessity and benefit of nurturing a research program over several decades. This said, an unresolved question remains in explaining the inconsistency between the scenarios constrained by paleoweathering profiles ages versus fission track analyses. A possible research path to be explored is the crystallization of apatite during Triassic albitization of granites.

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