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The continental French Massif Central during Late Jurassic and Early Cretaceous: paleoweatherings and paleolandforms

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Introduction

Geological records of the ancient continents are scarce, for some fully missing, and often blurred by successive and superimposed evolutions. For the best, the continents preserve only restricted testimonies of their evolution, displaying a patchwork of reliefs and weatherings discontinuous in time and space. However, the study of paleoweatherings and paleolandscapes is not useless: most of the basin deposits being of continental origin, it is necessary to reconstruct the weatherings, landscapes and environments that lead to their genesis. From this point of view, paleoweatherings are of prime importance: they supply the basins in soluble and solid compounds. Study of these scatterred continental testimonies allow to apprehend the paleoenvironments, paleoclimates and to reconstruct paleolandscapes and paleogeographies.

The Late Jurassic and Early Cretaceousperiods are suitable for such a "paleocontinental" exercice. A combined tectonic uprise, together with several sea level drops, lead to the emersion of wide areas of NW Europe and the development of thick "lateritic" profiles. Here in, we will focus on the French Massif Central and successively examine the nature of the paleosoils and describe the paleotopographies and paleolandscapes.

Geological framework

French Massif Central has only kept a patchwork of landforms and weathering profiles discontinous in space and time. The most important testimonies of the continental evolution of the Massif are formed of (1) red kaolinitic continental deposits and in situ paleoweathering profiles preserved at the base of the Tertiairy grabens and (2) paleoweathering products trapped in paleokarsts sinkholes developped on the Jurassic plateaus preserved in the hinge zones between the crystalline basement and the surounding sedimentary basins.

Kaolinitic and ferruginous paleoalterites on the basement

Above the basement occur significant blankets of red kaolinitic alterites, which, because of their geographic link with the Tertiary deposits, had classically been related to the Siderolithic *sensu lato* (Eocene-Oligocene). Detailed micromorphological studies allowed to show that these are in situ paleoweathering profiles, with catenas evolving in contrasted paleolandscapes. Without dated sedimentary cover, stratigraphic assignment of these alterites often has been speculative. Datings by paleomagmetism called into question these stratigraphic attributions and relate them to the Late Jurassic and Early Cretaceous periods, with ages of 160 to 140 MA (Thiry et al., 2004).

The "Siderolithic" in northern Massif Central

In the Cher graben and on its western edge, occur also red formations assigned to the "Siderolithic". The detailed study of the border of the graben allowed to show paleoreliefs buried by two sedimentary sequences, over 65 m thick, and crown by a red hardpan (Simon-Coinçon et al., 2000; Quesnel et al., in press). Several facies are distinguished.

1) Fluviatile deposits formed of coarse sandstone with blunt grains, centimetric quartz gravels, root traces, ferruginous nodules and greenish-yellow claystone with bioturbations and ferruginous pisolites.

2) Debris flow and sheet flow deposits with micaschist and quartz fragments. The micaschist fragments are either unweathered or argillised, the quartz clasts are little or not blunt.

3) A red hardpan is most often connected with the deposits bearing micaschist fragments.

4) Weathered micaschist, rubefied and argillised over nearly 20 m depth, often occurs at the edge of the deposit areas.

The red hardpans relate to paleosoils that mark out tight "glacis" anchored on the paleoreliefs. These paleosoils show pedogenic, macro and micromorphological organisations that allow to clarify their functioning and their evolution. The hardpans are

leached ferruginous soils, displaying differentiated toposequences, which secondly have been silicified by impregnation of the the clayey materials by opal (Thiry & Turland, 1985; Thiry, 1999). It forms contrasting catena with upstream nodular facies organized in rough columnar structure and downstream development of braided subhorizontal layering.

The "Siderolithic" in the centre of the Massif Central

In the southern Limagne Graben, the red formations of the Lembron crop out outstandingly at the "Les Mottes" section (Boudes) and shows 3 main units from the base to the top (Thiry et al., 2004).

1) Brick-red clayey sandstone, of massive structure and slightly indured.

2) A succession of white clayey sandstone with red iron mottles, greenish-ochre sandy claystone, with iron-oxide pisolites and wholly bleached sandstone displaying purple-red iron oxide rhyzolithe-like pipes.

3) A red sandy claystone with pisolites whithin which is interbedded a typical pedogenic silcrete with capping and illuviation structures.

Micromorphological studies of the succession of iron mottled and bleached horizons show that they relate to a single and thick paleoweathering profile. From the top to the bottom there are: an upper leached horizon with ferruginous rhyzolithe-like pipes, in which the bleaching decreases with depth; a middle clayey, hydromorphic, illuviated horizon, with accumulation of iron oxides in pisolites; a lower mottled horizon which corresponds to a saprolite with partial leaching of the iron oxides near the water table. The massive brick-red horizon at the base of the section is a mature paleosoil on which superimposed the leaching of the above profile. The upper horizon with a silcrete relates to a younger ferruginous paleosoil on which superimposed the pedogenic silicification.

All the detrital elements of these formations are derived from the basement or eventually from the Permian-Carboniferous formations. In thin sections, there has never been brought out detrital elements which could proceed from Mesozoic cherts or sandstones. This implies that at time of deposition of the Lembron red formations, the basement was cropping out and devoid of any Mesozoic cover, nor residual formations coming from the weathering of such a cover.

The "Siderolithic" in southern Massif Central

Several small grabens in the southern Massif Central display also thick red kaolinitic duricrusts. In Naussac, such red kaolinitic paleosoils developped on a coarse alluvial fan leaned on a fault scarp. The paleosoils show well preserved pedogenic features

(termites burrows, illuviation and hydromorphic features, nodules...) but regarding the heterogeneity of the deposits they do not dispay clear pedogenic horizons. Thus it is not possible to state if they tally with one or several superimposed paleosoils.

0.0.1 Weathering mantles of the southwestern Massif Central

The existence of a weathered cover on the old basement in southwestern Massif Central is attested by the abundance of sandy clays with kaolinite in the transgressive Upper Cretaceous sediments of the nearby Aquitaine platform. Quartz grains derive from the basement and were removed with mica, tourmaline and heavy minerals. Without any weathering, Upper Cretaceous sediments show corroded quartz grains with cracks and holes filled with iron oxide. The Rouergue basement should have been outcropping since the end of the Jurassic and 10 m and more thick weathered mantles still exist on the plateaus (Simon-Coinçon, 1989). Those weathered covers are cut down by paleovalleys filled with fluviatile deposits of post-Jurassic age and are fossilized by continental Lower Tertiary sediments. Some profiles of more than 10 m thick show the transition from red-sandy kaolinite clay with goethite at the top to rubified coarse-grained granitic sand at the bottom. Those weatherings are probably contemporaneous with the lateritic paleoalterites known elsewhere on the Massif Central

The bauxitic weatherings on the Jurassic plateaus

The limestone plateaus outcropping on the hinge zones between the crystalline basement and the surounding sedimentary basins show also main weathering features dating back to Late Jurassic and Early Cretaceous. The emersion of these plateaus by the Late Jurassic withdrawal led to the development of deep and surficial karsts.

The bauxites of the Causses

Unknown until recently on the Grands Causses, the bauxite has been found on the Causse of Hospitalet, Causse of Campestre and Causse of Sauveterre (Bruxelles et al., 1999; Bruxelles, 2001, 2003). Almost twenty outcrops are localized at the edge of several karstic depressions. The footwall of the bauxite consists of Kimmeridgian to Bathonian karstified limestones. The roof is formed by marshland, mangrove and coastal sand deposits of Coniacian age.

Apart from numerous scattered blocks resting on surface and revealed by agricultural works, outcrops of bauxite appear, sometimes of several metres thick, as doline fillings. In those formations several levels display paleosoils with nodular structures and bioturbations, but the the most current facies is massive, formed of red clay, containing scattered dark red pisolites. Clear facies also exist. The upper part of the deposit is

often enriched by iron oxides. X-rays analyses have shown the abundance of kaolinite together with gibbsite and boehmite.

The bauxites of the Paris Basin

In the Paris Basin, bauxitic formations, with about 10 to 25% of gibbsite, have recently been recognised, coming with the Clay-with-Jurassic-cherts that cover extensive surfaces at the southeastern border of the Paris Basin (Nivernais) (Thiry et al., in press). The gibbsite is connected to red formations that are true in situ paleoprofiles over the Callovian-Oxfordian limestone. Locally the gibbsite bearing formations are blanketed by rounded chert conglomerates and lenses of sand with quartz gravels; elsewhere, they are covered by Clay-with-flints resulting from the weathering of the Late Cretaceous chalk. Pedogenic silcretes, with typical titania-rich illuviation features, crown these chert and flint bearing formations.

The thick weathering mantle of Clay-with-Jurassic-cherts, containing gibbsite locally, may have developed after the withdrawal of the sea during Late Tithonian and before the Albian transgression, to which are assigned the rounded chert conglomerates and sand with quartz gravels. Probably these bauxitic formations have been much more extensive that presently, amounts of them may have been "resilicified", with alteration of gibbsite into kaolinite at the time of the silicification of the "Siderolithic" glacis during Middle/Late Eocene. The old minings of Siderolithic iron ores are related to these Clay-with-Jurassic-cherts. Thereby, the Siderolithic iron deposits, typical of the southern borders of the Paris Basin (de Grossouvre, 1886), may also be of Early Cretaceous age and correlative with the bauxite deposits in southern France.

The paleotopographies

Recognition and characterisation of some paleoweatherings imply directly the being of specific landscapes and/or paleotopographies: it is obvious for the paleoweatherings developed on the Jurassic limestones, they correspond to karstlands. Nevertheless, here in we will less try to infer the landscapes from the weathering types than to recognise geometric elements of the paleolandscapes, in order to specify their nature and their extent in the Massif Central. We will successively examine how looked the wide limestone platforms and then the basement.

Paleokarsts on the limestone platforms

Paleokarsts were well-developed on large and massive emerged limestone platforms in the Grands Causses and Quercy (Astruc, 1988; Simon-Coinçon & Astruc, 1991; Bruxelles et al., 1999). They often are only known by dissolution forms without contemporaneous filling. It would mean that karstic surfaces did not include an appreciable cover of weathering formations.

In Quercy, on the edge of the Aquitain Basin, the reconstitution of paleolandscapes is allowed by the recognition of paleomorphologies buried by Cenomanian deposits that cast large karstic depressions with flat bottom and with conical hills which evoke tropical karsts, but also high cliffs and incised by paleovalleys (Astruc, 1988). Those paleovalleys have been invaded during the onset of the transgression by coastal marshes and mangroves with deposition of lignite (near Sarlat).

In the Grands Causses, the presence of autochthonous bauxite reveals a long period of continental weathering during which the first landscapes were formed (Bruxelles, 2001). Several dolines called "grands sotchs", initiated almost certainly during the Early Cretaceous, constitute the wall of the bauxite. Bauxite subsists as veneers against the sides of the doline and fossilises lapies. Some ferruginised Upper Cretaceous limestone and calcareous sandstone seal the “grands sotchs” filling, indicating that these paleolandscapes predate the Upper Cretaceous (Coniacian) transgression.

In the Grands Causses, the large depressions with flat bottom present many karstic hills up to 20 m high and are punched by 40 m deep “grands sotchs”. Nevertheless, no indication of ancient endokarst exists in the Grands Causses nor in Quercy, this may point out a relative high water table that limited vertical development of the karstification.

The paleolandscapes on the basements

On the basement, the paleolandscape amplitude may have been significant. Probably there have been high scarps (often fault scarps) which might have reached or exceeded 100 m of elevation. There were also wide areas with inselbergs, similar to the present day African and Brasilian tropical landscapes.

In the northern Massif Central, on the edge of the Cher graben, the red hardpans are linked to graded piedmonts anchored either on paleoreliefs armed by the basement quartzites or on fault scarps apparently active at that time (Simon-Coinçon et al., 2000). The coarse deposits at the upper part of the sequence, without sorting nor marked sedimentological organisation, are most probably linked to sheet flow deposits, ie without hierarchised hydrographic network, which shape such piedmonts under contrasted pluviometric regims with long dry periods broken by heavy rains. The paleolandscape may be compared to Sahelian landscapes in Africa with encased plateaux and piedmonts.

These piedmont paleolandscapes superimpose and intersect older paleolandscapes formed of deep meandering paleovalleys with steep slopes, incised in the basement. These paleovalleys are filled with well sorted fluviatile deposits, including thick clayey layers which remind wide fluviatile systems, stable and long-lasting, ordered on a re-

gional scale. It may not be excluded that these large paleovalleys are actually inherited from Triassic paleovalleys, even Permian ones, exhumed and reshaped during the end of the Jurassic.

Some paleovalleys crowned by the red hardpan are about 80 m below the top of the basement hill and the whole difference of elevation between the paleoreliefs and the paleovalley floors is at least of 150 to 200 m.

In the Lembron area, centre of Massif Central, three topographical units are distinguished: (1) the western plateau which corresponds to a flat granite surface sparsely covered by Tertiary sediments up to 50-60 m thick with basalt flows on top ; (2) a scarp which is the transition unit between the plateaus and the plain, the scarp is complex, i.e. it is stepped and shows large embayments infilled with "Siderolithic" sediments ; (3) the eastern plain which is formed by Tertiary sediments and sparse outcrops of bedrock rocks where the sedimentary cover has been eroded. The geometry of the basal red formations is complex. It can be summarized into two main arrangements: (1) crowning around basement heights such as dome structures or inselbergs or (2) as infills of paleovalleys that incise the basement at the scarp foot.

A flat basement surface with inselbergs is observed near the base of the scarp. This surface is likely the result of the denudation of its former thick alterite cover. Erosion also affected the scarp where it formed valleys, steps and large embayments. The resulting landscape has subsequently been preserved by multi-phased sediment deposits. This paleolandscape may be compared to the present day wide stepped surfaces with inselbergs from Africa and South America.

Conclusion

Early Cretaceous ages obtained on in situ paleoweathering that were up to now widely attributed to the Siderolithic $s.l.$, mainly to the Late Eocene–Oligocene period, lead to greatly revise the importance of the post-Cretaceous weathering relative to its Lower Cretaceous counterpart which is contemporaneous to bauxite development.

Deciphering the informations from the paleomorphologies linked to these paleoweatherings also allows to list diverse paleolandscapes with scarps, wide plateaus, inselbergs, paleovalleys on crystalline basement, karstic landscapes on the limestone plateaus, also cuestas and fluvial channels.

The preserved paleoweathering profiles may be envisioned as "screenshots" of a longlasting continental evolution, the aspects concerning erosion phases being more difficult to handle and quantifiy. Relative elevations can be assessed from both the residual testimonies and subsequent transgressions. In contrast, there are no reliable tools which can be used to evaluate absolute paleoelevations whereas such tools exist for

paleobathymetry assessing in marine realm.

Preservation of such very old landforms poses problems. Have they never been buried or have they been buried for a while (upper Cretaceous possibly) and then re-exposed ? These hypothysis having implications in terms of weathering and denudation rates, geodynamics and changes in base levels. There is no argument indicating that the siderolithic paleoprofiles in central or southern Massif Centrals have one been buried, whereas the paleokarsts in the Grands Causses have been burried by upper Cretaceous deposits and cleared of their sandy cover during the Tertiary.

The next challenge is to make substantial progress in paleoweathering profile dating, especially in the scope of improving time resolution which is a necessary step before attempting efficient correlation between the continental records, i.e. the paleoweatherings, and the diverse processes involved in their development (eustatism, climate, global and regional tectonics). The goal is to set up a "continental stratigraphy of climatic and geodynamic events" which is expected to be compared to the "sequence stratigraphy" used in marine realm.

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