Paleosurfaces and residual deposits in Ardenne-Eifel: historical overview and perspectives

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Historical overview of paleosurface research in Ardenne-Eifel

Already in 1899 Davis mentioned the possibility that the Ardennian 'peneplain' could be of a younger age than the base surface of the Jurassic cover, to which it connects to the south of the massif. He also recognized that the Rhine and Mosel troughs testified to a multistage uplift and denudation history of the Rhenish shield (1896). Ten years earlier, Gosselet (1888) had given a fairly modern overview of the nature and age of the residual deposits associated with the Ardennian surface and had discussed the tectonic deformations implied by their distribution. So, the main ideas involved in deciphering long-term landform development in the Ardenne-Eifel date well back to the 19th century.

First detailed geomorphological studies devoted to this topic appeared in the beginning of the 20th century for the Eifel (Philippson, 1903) and two decades later for the Ardenne (Baulig and his multifaceted Ardennian platform, in 1926). In 1922 and especially 1927, Stickel developed the ideas of Philippson and recognized two higher 'pre-Oligocene' surfaces R2 and R1 in the Eifel, plus two levels within a Mosel trough of assumed upper Miocene age. In the Ardenne, in contrast with some more unrealistic views (e.g., Baeckeroot, 1936; Lefèvre, 1938; Stevens, 1938), Macar proposed in 1938 a detailed morphological scheme emphasizing two stepped main surfaces within the massif, a pre-Maastrichtian 'upper' surface and a pre-Eocene 'lower' surface, thus being already very similar to the Stickel's system in the Eifel. In this period, some more local studies also deserve attention (Breddin, 1932).

Generally based on a refined presentation of the Macar's system (Macar, 1954), several important studies of Ardennian paleosurfaces were published in the '50s and the beginning of the '60s. For instance, Pissart (1962) carefully described the Eocene surface of W Ardenne and the associated sediments. This was also the time when the Macar's team in Liège extensively investigated the so-called 'Neogene planation levels' of the Ardenne massif (e.g. Goossens, 1955; Alexandre, 1958; Pissart, 1962). More than 10 such stepped levels of more or less limited extent were recognized below the main planation surfaces! In the Eifel, Richter (1962) was also contaminated by this idea of too many intricate planation levels. On the contrary, Lucius (1950) considered that the 400 m level in the Gutland and the 500 m level in the Oesling belong to a single, tectonically deformed surface of Pliocene age (but exhuming the pre-Triassic surface in the Oesling).

More importantly, Gullentops (1954) insisted on the indications provided by the paleosoils and weathering products associated with the various surfaces he described in W central Ardenne. Alexandre (1958) also dedicated much work to the study of paleoweathering in central Ardenne. But while Gullentops proposed a synthetic view of the successive Ardennian paleolandscapes, Alexandre went into elusive details of an excessive number of successive surfaces.

In the Eifel, a particular concept was developed by Louis (1953). Basing on the observation of *in situ* deposits of assumed Oligocene age at altitudes as low as 280 m in the Mosel trough, this author claimed that up to 200-m-thick Miocene fluvial gravels filled up a Paleogene hydrographic network within the trough. This concept was developed later to an excessive point by Birkenhauer (1965).

Quitzow (1969, 1982) and Voisin (1981) opened the last period of paleosurface research respectively in the Eifel and the Ardenne. Refining on the surface reconstruction of Stickel, Quitzow namely suggested that the Mosel trough could be of tectonic origin, therefore implying that it would be of the same age as the R1 surface. Voisin addressed the question of the morphological evolution of W Ardenne. Putting special emphasis on the weatherable bedrock and the existing correlative deposits, he described an upper Triassic peneplain, a 'Wealdian' surface finally going into a 'Landenian' surface (still somewhat uneven within the W Ardenne) and finally proposed for the whole Ardenne an

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Oligocene-Miocene peneplanized landscape characterized by a thick weathering mantle whose material was exported north- and eastward in foreland basins. Finally, while several paleosurface studies were still conducted in the Eifel by researchers of the Cologne University (Pfeffer, 1978; Zenses, 1980; Junge, 1987), Demoulin (1995) proposed the first comprehensive synthesis linking the surfaces of Ardenne, Eifel and their surroundings. In the last ten years, Löhnertz (1994), Le Roux (2000) and Pierre (2000) also reconsidered some aspects of the long-term landscape evolution along the southern edge of the Ardenne-Eifel massif.

Correlative residual deposits in Ardenne-Eifel

The geometrical reconstruction of the Ardenne-Eifel paleolandscapes would be highly speculative if it could not be supported by the careful examination of correlative residual deposits of various types scattered on the erosion surfaces. Most important are of course the remnants of marine deposits accumulated when parts of the massif were drowned at different epochs. However, while the Triassic-Liassic and Cretaceous marine sediments preserved on the southern and northern margins of the massif are easily identified and dated, the exact age of assumed Oligocene non-fossiliferous marine sands in N Ardenne and Eifel is still debated and the distinction between Eocene and Oligocene marine deposits remains delicate in the 'Entre-Sambre-et-Meuse' area.

Continental deposits are also often most useful, especially when they belong to an extended cover formerly burying a particular surface. For instance, Weald deposits are landmarks of the pre-Cretaceous surface along the SW margin of the Ardenne, and Landenian (Thanetian) fine sands characteristically cover the Eocene topography of the massif to the west of the Meuse river. In other areas, continental sediments, though of uncertain age and origin, may be indicative of particular denudational episodes. This is the case of pre-Liassic gravels trapped in the hollows of the Triassic topography in S Ardenne. In the Eifel, the Vallendar fluviatile gravels of Eocene/Oligocene age also provide insight into the Tertiary paleodrainage history of the area. Moreover, paleobotanical findings within lacustrine clays and clay layers included in gravel deposits shed light on the age and the complex history of the Mosel trough (Löhnertz, 1978; Kadolsky *et al*., 1983).

Finally, *in situ* and reworked weathering products have also been used to distinguish different paleosurfaces, and recent attempts to date them look very promising. One namely will note the thick kaolinitic saprolites associated with the base surface of the Cretaceous in the N Ardenne-Eifel and on the nearby Brabant massif (Legrand, 1968), and with the pre-Landenian surface of W Ardenne on both sides of the Meuse river (Voisin, 1995; Dupuis *et al*., 1996). In this respect, the pre-Oligocene surfaces of N and NW Ardenne and the Mosel trough appear largely devoid of such a deep weathering mantle, but their lower position within the Tertiary landscape allowed reworked weathering products derived from the higher surfaces to accumulate and to be preserved in favourables sites (e.g. the Andenne lacustrine clays of Miocene age trapped in solution pockets of the Dinantian limestones of the Condroz and Entre-Sambre-et-Meuse). Silcretes, and to a lesser extent ferricretes, especially when they are of pedogenic origin, are weathered material of special interest. In particular, silicified boulders are widespread over large parts of N and SW Ardenne (the so-called 'pierres de Stonne'), Eifel and their foreland areas (Limburg, NE Paris basin, Lower Rhine Embayment).

Paleosurfaces in their evolutionary framework (fig. 1)

During Mesozoic and Cenozoic times, the Ardenne-Eifel underwent almost permanently subaerial denudation, only interrupted by limited marine transgressions. The seas drowned the margins of the massif, coming from E and SE in Triassic and Liassic times, from W during the Eocene and from N in the Early Oligocene. Only the Upper Cretaceous sea could have submerged larger parts of central Ardenne.

Seven generations of surfaces may be recognized. A pre-Triassic surface is conserved in W Eifel, west of the N-S Eifel Zone and along the SE border of the massif. It is continued westwards by the so-called post-Hercynian peneplain, which constitutes the southern margin of the massif, with a S-dipping of 1 to 3%. In NE Ardenne, the oldest paleosurface dates back to the Upper Cretaceous. Some remnants of this pre-Senonian surface are also preserved on the highest summits of the massif at 650-700 m elevation (Baraque Michel, Baraque Fraiture, Weisser Stein, Schneifel). A more extensive Dano-Montian surface covers the eastern part of central Ardenne and Eifel at altitudes above 500 m. In contrast with the other surfaces, the latter developed independently of any marine ingression. Its age is therefore inferred only from geometrical considerations.

Instead of progressively regrading the older surfaces and cutting them at low angle like during Mesozoic times, the Tertiary paleosurfaces developed at their expense by developing 50-200 m high scarps at their inner margin. The Eocene surface did so on the western side of the massif, the pre-Tongrian surface on the northern one and the Upper Eocene to Miocene surface of the NE Paris basin at the southern margin (although some authors question the erosional nature of the slope between the latter and the Dano-Montian surface). In a last period of extensive

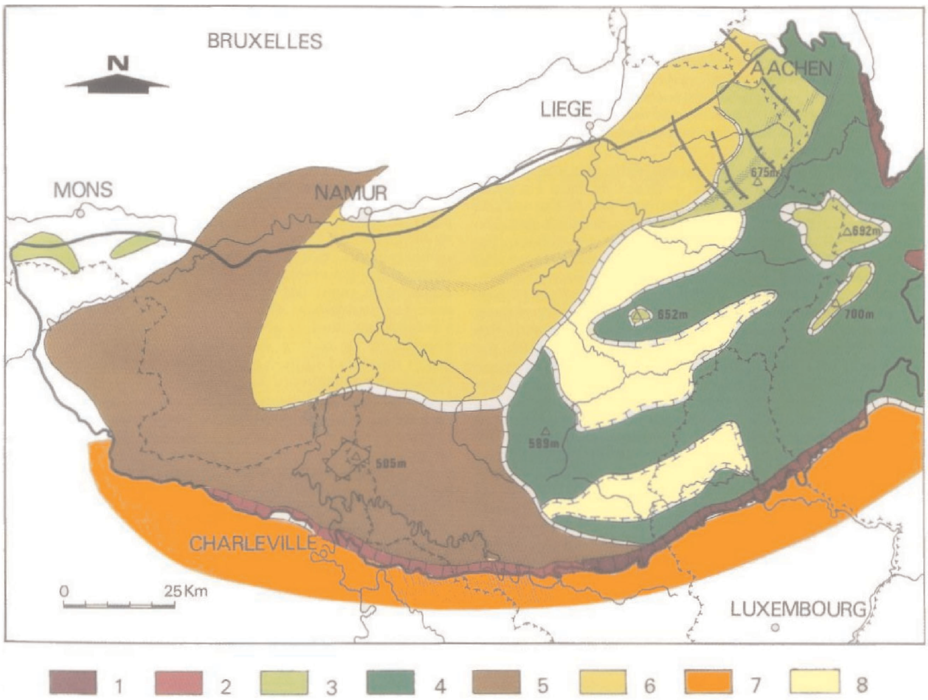

Fig. 1.- Paleosurfaces in the Ardenne-Eifel before the Plio-Pleistocene downcutting (taken from Demoulin, 1995). 1. pre-Triassic surface. 2. post-Hercynian surface. 3. pre-Senonian surface. 4. Dano-Montian surface. 5. Eocene surface. 6. Pre-Tongrian surface. 7. Eocene/Oligocene surface of the NE Paris basin. 8. Oligo-Miocene planation basins. - Hatched zones between the surfaces: erosion scarps. - Stippled band: flexure zone.

planation, some 'intramontane basins' still developed in the central part of the massif within the Dano-Montian surface.

A plausible morphogenic evolution of the Ardenne-Eifel may be outlined as follows. From the Variscan orogeny onwards, a long period (~230 My) of tectonic quiescence and predominantly humid tropical climates (at least during the Cretaceous) allowed a broad faceted surface to be progressively elaborated, whose marginal segments are more or less inclined with respect to its central part depending on the age of their burial by marine sediments and on local tectonics. This acyclic evolution ended with the first significant tectonic tilting and uplift of the massif in the Palaeocene. It seems thus that the Tertiary cyclic morphogenic evolution of the Ardenne-Eifel began earlier than what has been recorded in other Variscan massifs of NW Europe by Klein (1990), i.e. in the Thanetian instead of the Lutetian. The Tertiary uplift of the massif, whose step-like character is linked to successive tiltings in different directions (westwards during the Eocene, then, from the Oligocene onwards, northwards and gradually northeastwards in connection with the subsidence of the Lower Rhine Embayment), induced then the development of stepped surfaces from the borders of the massif to its centre. The particular location of the intramontane' Mosel trough could be linked to additional slight flexuring. With the acceleration of the uplift and the progressive climatic cooling during the Neogene, only planation basins of local importance could still develop.

Tectonic indications of deformed paleosurfaces

The large-scale deformation of even the youngest extended paleosurface of Ardenne-Eifel bears witness to the Neogene to recent uplift of the massif. Moreover, the uniform tilting of every individual surface within the massif and in the surrounding areas shows that the uplifted region also includes the SE part of the Brabant massif in the north, and parts of the NE Paris basin in the south, thus corresponding to a ~100-km-wide, WSW-striking band centred on the massif. The deformation generally appears as a broad upwarping, with an en-bloc uplift and a more localized flexure developing only along the northern flank of the Ardenne, and en-échelon faults marking the contact between N Eifel and the Lower Rhine Embayment. Transversally, the present-day maximum uplift is located in NE Ardenne and NW Eifel.

Differential tilting between successive surfaces suggests that every particular uplift episode did not exceed some 200-300 m with respect to the forelands, these amounts being accommodated partly by subsidence of the surrounding areas, partly by a true uplift of the massif, with the development of 100-120 m-high erosion scarps. Despite their various tilt orientations, the successive uplift episodes may be tentatively analysed within the frame of the hypothesis of lithospheric buckling induced in the front of the developing Alpine orogen (Nikishin *et al.*, 1997). However, it is probable that another driving force of the recent Ardenne-Eifel uplift has to be searched in the Eifel plume activity (Ritter *et al.*, 2001).

Beyond large-scale geodynamic considerations, the deformed paleosurfaces of Ardenne-Eifel also provide some hints on the local tectonic history of the massif. In the best documented case of the Baraque Michel high of NE Ardenne, it is possible not only to identify the active tectonic structures but also to get some ideas of several periods of activity during the Mesozoic and the Cenozoic. Unfortunately, in most other cases (Croix Scaille high of W Ardenne, Mosel trough, transition from S Ardenne to NE Paris basin and Luxemburg Embayment), the tectonic origin of paleosurface peculiarities is much more difficult to assess.

Perspectives

Although we have got now a fairly consistent view of the long-term landform evolution in the Ardenne-Eifel, some questions have been so far hazily addressed and deserve deeper investigations. First of all, the study of the weathering products, *in situ* or reworked, associated with the paleosurfaces should greatly benefit from renewed attention aiming at improving their geochemical characterization, understanding their mode of formation (silcretes) and getting some ages. Various dating techniques (paleomagnetism, K/Ar) have started to be applied successfully on weathered material coming from the massif (Yans *et al*., 2002) or nearby areas (Théveniaut *et al*., 2002), and AFT analyses certainly would yield complementary information on denudation amounts and rates (Vercoutere & Van den Haute, 1993).

Another largely neglected point is that of the relationships between production of weathered material in the massif and its syn- or post-weathering accumulation in various nearby sedimentation areas.

Finally, there is a need for a more documented and comprehensive analysis of the interplay between paleosurface development, paleoweathering and tectonics. This is true at the regional and continental scales. Locally, we should look for further evidence to support the non-tectonic nature of the contact between S Ardenne and the NE Paris basin. On a larger scale, the consistency of Ardennian and Eifelian paleosurface data with the assumed buckling of the NW European lithosphere in connection with the Alpine tectonic phases is not yet fully ascertained, and the Wyns' hypothesis of a tectonic control of paleoweathering (Wyns, 2002) should also be tested for the Ardenne-Eifel massif within the geodynamical frame of W Europe.

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