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Original article

Proposition of dating a Miocene Alpine tectonic event using mammal biochronology: example of the Four karst filling

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Abstract

Although the general tectonic history of the Ile Crémieu area (southern Jura) is known, establishing the chronology of events that have influenced the tectonic evolution seems to be much more difficult. A newly discovered layered karst filling in the Bajocian limestone, in the town of Four (Isère), is a synsedimentary evidence of a Tertiary tectonic activity. Actually, only the lower part of the filling has been folded by the movement of the fault in which the karstic network was made. Fossil mammals date the last movement on this fault plane, between 13.0 and 13.4 Ma. At a larger scale, the last activity of this fault could be correlated with a change in the paleo-stress field generated by the Alpine orogen, dating with precision an Alpine tectonic event. © 2002 Éditions scientifiques et médicales Elsevier SAS. All rights reserved.

Keywords: Tectonic; Alpine orogen; Paleokarst; Paleo-stress field; Neogene; Mammal dating; France; Ile Crémieu

1. Introduction

Since limestone quarrying started at the beginning of the 20th century, several karst fillings bearing Miocene fossil vertebrates are known in the Ile Crémieu Bajocian–Bathonian calcareous formations, near Bourgoin-Jallieu [1,2]. Whereas all other localities of this region are homogeneously filled with red clay, a new fissure filling discovered at Four is layered with three different fossiliferous layers. This new locality is the first stratified Miocene deposit in the Mesozoic calcareous formation of tabular southern Jura known to date [3].

The Ile Crémieu, located at the southern extremity of the Jura, is mainly constituted by limestone formations of Bajocian and Bathonian ages that belong to the "tabular Jura", so called because of its unfolded structure compared to the other Mesozoic Jura units [4]. The Jura strikes against the Ile Crémieu because of a steep, partly strike-slip, fault. This peculiar structural configuration is marked by local morphological and structural evolution disconnected from the folded Jura since the Cretaceous emergence [5].

Demarcq's studies [6,7] provide a good reconstitution of the paleobiogeography of the Rhône Valley. The location of the marine basin is interpreted from Tertiary formations near Bourgoin-Jallieu, Heyrieu and Chamagnieu on the structural map (Fig. 1): during the Miocene, two arms of the sea surrounded the Ile Crémieu area. Most of the Tertiary marine formations are Tortonian in age. Abundant fossil faunas were collected from karstic localities, allowing a precise dating of the regional karst fillings. The paleokarst filling in this region occurred during the Langhian–Serravalian interval, using the biochronological dating of main localities (La Grive M, La Grive L7, La Grive L3, Isle d'Abeau) [8]. Moreover, the karstic localities of the Ile Crémieu area are almost coeval. Such conditions allow a high-resolution biochronology.

The granitic crust emergence of Chamagnieu can be interpreted as a local effect of the collapse of the thickened Variscan crust on the Massif Central during the Late Carboniferous [9]. Two principal fault axes, sometimes conjugated, are observed in the Ile Crémieu area (Fig. 1): NE–SW and NW–SE [5], surrounding this granitic formation of Chamagnieu. So the fault network of Mesozoic limestone from the Ile Crémieu should be due to the reactivation of crustal faults, then made available to reactivation during the Cenozoic. This relation between crustal

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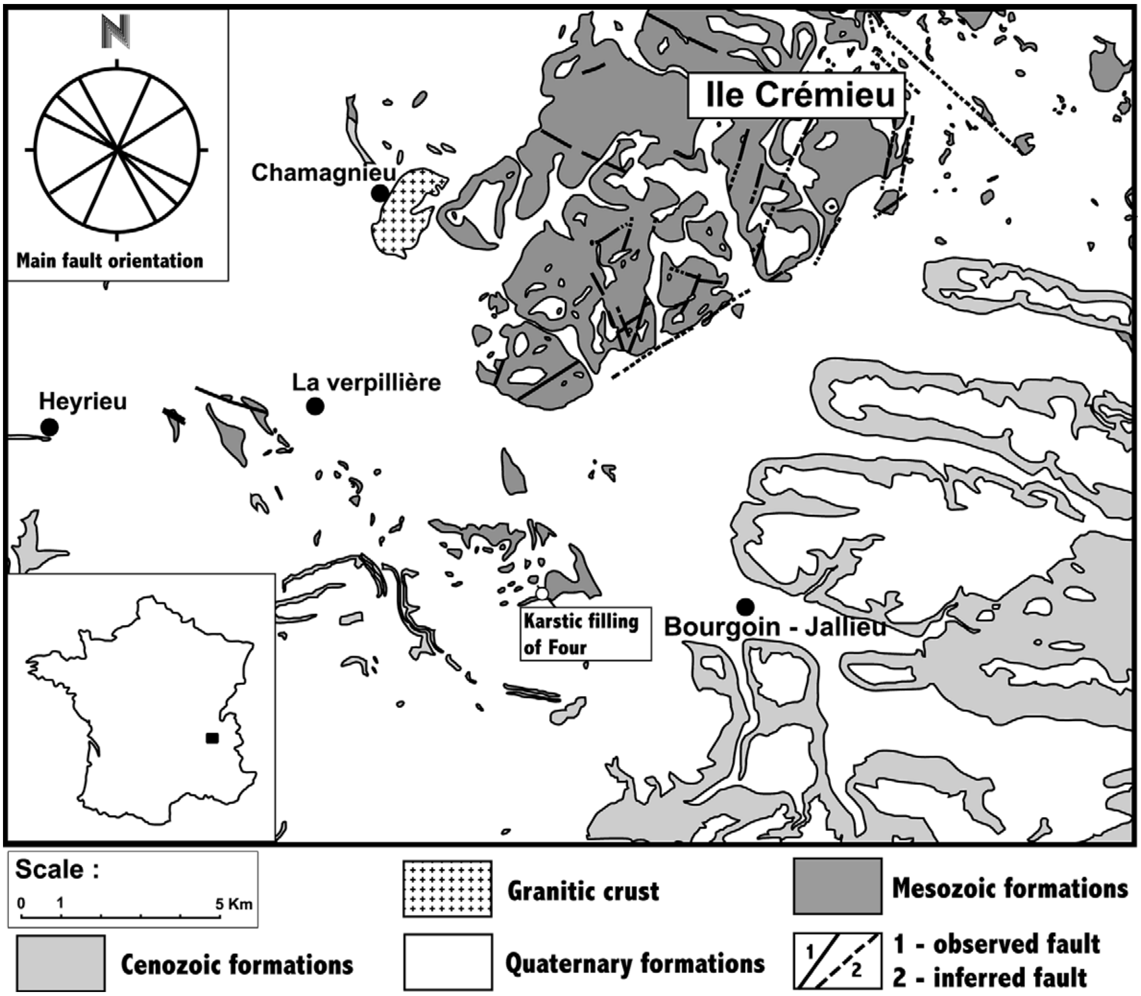

Fig. 1. Structural map of the Bourgoin-Jallieu area and orientation of main faults (from the geological map of Bourgoin-Jallieu: 1:50 000 [4]).

structure and Meso–Cenozoic tectonic activity is well known through structural and tectonic studies in different regions, for instance Bourgogne [10,11] and the Paris Basin [12,13]. A question concerning the Ile Crémieu area is to know if the Tertiary Alpine orogen has reactivated the Mesozoic faults network.

Bergerat [14] provides a chronology of the tectonic phase succession during the Cenozoic (Fig. 2). For the most recent period, the Alpine paleo-stress fields were oriented NE–SW at the beginning of the Miocene. A drastic change in the paleo-stress field occurs in the Upper Miocene, when its orientation becomes globally NWN–SES, without information on what occurs between both events. Effects of those paleo-stress fields can be observed far away from the Alpine chain, in the Paris basin, demonstrating the large-scale influence of synorogenic tectonics [14].

The structural evolution of the southern Jura thrust belt during the Tertiary was described with an evidence of thrust transfer zone, but without any evidence of a real influence on the Ile Crémieu autochthonous Mesozoic cover. Through thrust propagation, tectonic stress due to Alpine orogen extends its influence to foreland basins [15,16]. So we can expect that evolution in the paleo-stress fields in the Tertiary [14] occurs in the Mesozoic limestone cover of the Ile Crémieu. As the synorogenic sedimentation in the Tertiary Molasse basin demonstrates the influence of tectonic propagation on the foreland basins [15], one way to show tectonic events during the Tertiary in the Ile Crémieu massif is the occurrence of Neogene syntectonic deposits within its limestone Bajocian formation.

2. The karst filling at Four

The Four karst filling has been discovered in a quarry within the Bajocian limestone of the Ile Crémieu area (Fig. 3). Like the other Bajocian limestone of the area, the formation is an Alpine carbonated ramp presenting an entrochal calcarenitic shoreface facies. No folded structure can be seen in the enclosing limestone.

This karst filling is the first layered fissure known in Tertiary fossiliferous fillings of the region. This filling contains four fossiliferous red clay layers (n1 to n4; Fig. 3) separated by three yellow clay layers without fossil remains (i1 to i3; Fig. 3). The latter are similar to a non-fossiliferous yellow clay filling (near la Grive M), and were analyzed as

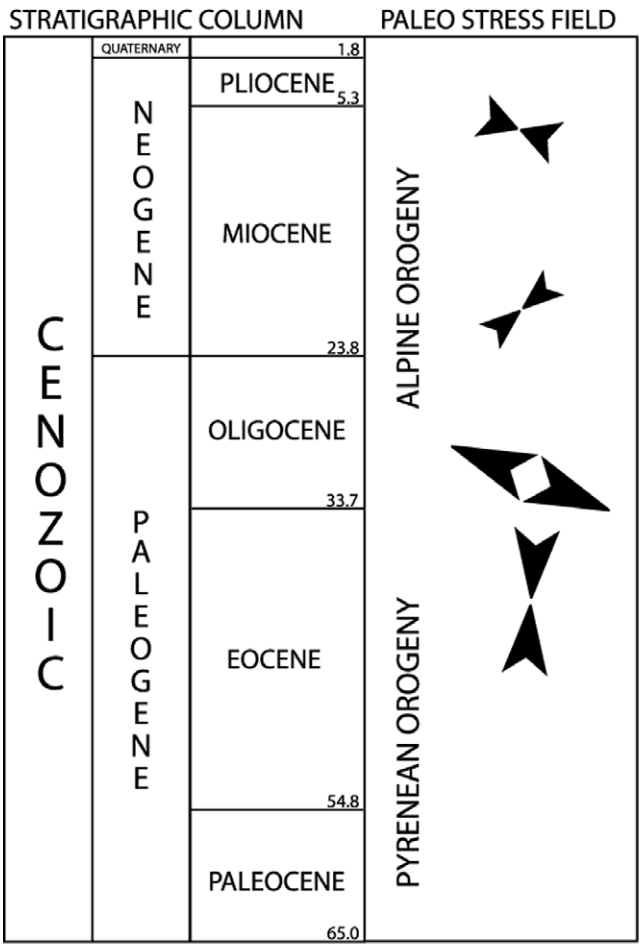

Fig. 2. Chronology of Cenozoic Alpine tectonic phase succession, from [14].

siliceous clay layers. They are principally composed of illite for the clay fraction, and quartz and muscovite for the sandy fraction (unpublished analysis by P. Ballmann, pers. comm. P. Mein). In this context, the three siliceous clay layers of Four can be interpreted as settling phases occurring between two surface clay flow arrivals, thus explaining the absence of fossils. The karstic cavity is formed along a sub-vertical normal fault oriented 140° N. An offsetting can be observed on the enclosing Bajocian, between the left and right sides of the quarry, around the karst, whereas the fault plane is not striated. A second normal fault is observed 3 m on the left side of the karst, showing the same orientation and dip (Fig. 3). As a matter of fact, the fault offsetting orientation of the enclosing limestone is not observable due to bad preservation in the quarry, but a total offsetting of over 10 m between the two extremities of the quarry can be seen.

Inside the karst, the two lower red clay layers (n1 and n2) and the lower siliceous bed (i1) indicate an offsetting of 30 cm downward on the left side of the karst. Even if no inner structure is visible in clay layers, various observations provide information on the filling constitution. On the one hand, no evidence in the enclosing cavity can lead to envisaging a different sedimentary dynamics for those three first beds. Moreover, observation of the layer interface does not show any erosive features, demonstrating that the deposits occurred with low energy dynamics. It explains the conservation of all the previous deposits and the tabular pattern of the last clay layers. On the other hand, the hypothesis of a differential packing between the two sides of the filling can be as well overruled on a meter scale. Concerning the structure of the lower layers, the deformation observed can be described as slight folds on the left side of the filling. The deformation observed is due to the quantity of movement applied on sediments; in the present case, the drag fold slight stretching structure along the fault can be explained by a short offsetting applied on the karst filling at a meter scale. Thus, all these observations lead one to consider the folded structure of n1, i1 and n2 phases as a drag fold only linked to the activity of the fault.

Hence, as the last beds are not folded, the fault's last movement is recorded by the karst filling. It means that the last tectonic activity of this fault occurred between the deposit of the second (n2) and third (n3) fossiliferous layers. Before the third red clay layer deposit (n3; Fig. 3), the decantation phase of the second siliceous clay bed (i2; Fig. 3) filled up the available space created by the drag fold, thus explaining the last beds' horizontality. The first layer (n1) bears a specific fauna dated from the end of the biochronological zone MN6 from the European mammalian time scale [17,18] and calibrated with high-resolution magnetostratigraphic data [19]; the other layers (n2 to n4) are attributed to the MN7–8 zone. The evolution of a new cricetid species rodent (*Democricetodon fourensis* Maridet et al., 2000) occurring in all fossiliferous beds shows that the time span between n1 and n4 is short [3]. The tooth size difference of *D. fourensis* between n1 and n4 is not statistically significant [3], so the time span from the beginning of the filling to the end is too short to be recorded by rodent evolution. Using the resolving power of rodent evolutionary lineages [20], we can estimate the time span of this filling as between 250 000 and 750 000 years.

The presence of a taxon (*M. gregarius*) in the higher layers of the filling (n2 to n4) indicates that the last movement of this fault occurred at the end of the Serravalian, during the biochronological zone MN7–8. Moreover, by comparing to other local karst fillings bearing the same taxa, we can give a more accurate dating of the last movement of this fault at the beginning of MN7–8. Using marine–continental correlation [21] and the biochronological syntheses [22], this local tectonic reactivation occurred between 13.0 ± 0.15 Ma (n2) and 13.4 ± 0.20 Ma (n3–n4) according to the Swiss Molasse calibration with global MPTS [23,24].

3. Interpretation

If we suppose that karsts fill when the base level is high enough to provide an accommodation space in the network, the most likely hypothesis to explain the rapid filling of

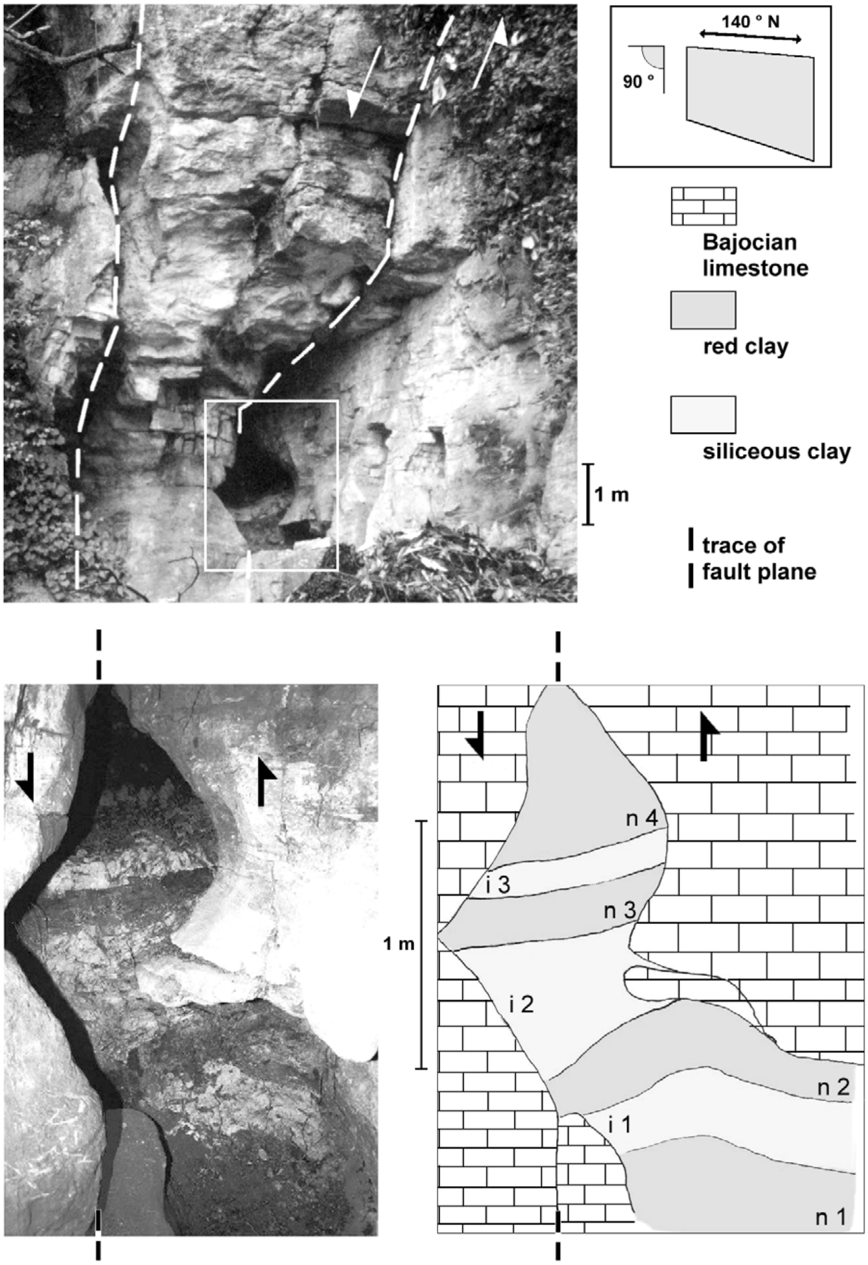

Fig. 3. Karstic locality from Four, with its different layers and the fault plane. Two faults can be observed, with the same orientation: 140° N, and dip: 90°. The karst filling is formed on the second fault, on the right side of the picture. The faults are represented by dotted lines. On the schematic view of the filling, the red clay layers are named n1 to n4 and the yellow siliceous clay layers i1 to i3. Red clay layers are the only fossiliferous beds. The enclosing limestone is formed by a Bajocian entrochal calcarenitic shoreface facies. On the lower part of the filling, the limestone underlies the n1 layer.

paleokarsts is a fast increase of relative sea level, probably due to a general subsidence of Mesozoic limestone formations, already implying a significant tectonic activity at the Langhian–Serravalian. However, in a more regional context, fault movement can be linked to the Alpine orogen.

This karst filling is located in a network of faults, almost all oriented 140° N, with a dip close to 90° (as the second fault; Fig. 3). For the fault of the karst filling, as well as for the other faults of this network, no observation indicates a consolidation. If we consider a tectonic stress applied on all this network, all the faults should have been reactivated. So the last activity of the faults, as shown by the karst filling, could be linked to a general change of the paleo-stress field at this period, between Lower Miocene and Upper Miocene. As explained earlier, we can expect that, through thrust propagation, orogenic tectonic stress was extended to the Ile Crémieu limestone cover. The idea of a differential reactivation depending on each stress field orientation was already proposed to explain the juxtaposition of horst and accumulating zone [5].

The paleo-stress field was oriented NE–SW at the beginning of the Miocene (22–20 Ma). In this period, Alpine

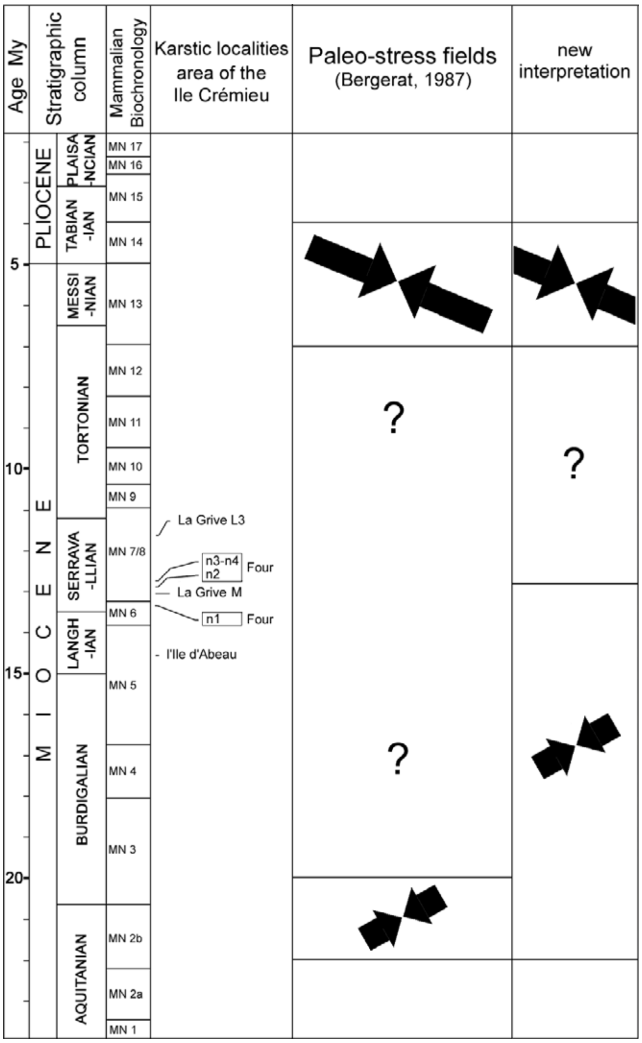

Fig. 4. Stratigraphic position of karstic localities and correlation with Alpine paleo-stress field changes (from [14,22,24]).

stress can affect in compression the fault networks oriented NW–SE determining a horst–graben system [5]. In this case, the karst filling fault could be activated. A change in the paleo-stress fields occurs at the Upper Miocene (7–4 Ma), and the orientation of stress becomes NWN–SES and could stop activation of the NW–SE fault networks. The tectonic event recorded in the karst filling could have a more general signification, giving a more precise age for the paleo-stress field orientation change, near 13 Ma, attesting that the NE–SW stress orientation of the Lower Miocene is still available for the Middle Miocene. This explanation could suggest a more rapid change of paleo-stress field than expected before [14] (Fig. 4).

4. Conclusions

This proposition of tectonic event dating using mammalian faunas is not an isolated case. Indeed, the sedimentation of fossiliferous localities is constrained by tectonic context. Moreover, mammalian faunas are often the only way to have precise dating, when other methods are not available anymore.

In a way similar than for the karst filling of Four, using a faulted karst filling in the phosphorite formations of Quercy (SW France), a Middle Eocene floor-age has been established for a tectonic paroxysm of the Pyrenean orogen [25]. Moreover, mammals of the Clermont–Ferrand basin's locality of la Roche-Blanche–Gergovie (Puy-de-Dôme, France) were used to show the activity of the Limagne rift during the Aquitanian period [26], whereas no other arguments in the sedimentation can be used to provide a dating of the residual tectonic activity.

All fossiliferous localities' sedimentation processes, including fossils deposits, are linked to the geological context. For this reason, mammal evolution can provide more information than usually expected, not only for interpreting the ages of beds or for level dating, but also to answer questions not reachable before, with usual sedimentary and tectonic approaches. From this point of view, the locality of Four is a rare one, providing high-quality data for paleontology and tectonics.

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