FOSSIL IMPRINT • vol. 80 • 2024 • no. 2 • pp. 319–328

NATIONAL MUSEUM

THE BIOSTRATIGRAPHIC PUZZLE OF BOU HANIFIA (LATEST MIOCENE, ALGERIA, TERRESTRIAL FAUNA)

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Pickford, M., Chaïd-Saoudi, Y. (2024): The biostratigraphic puzzle of Bou Hanifia (latest Miocene, Algeria, Terrestrial fauna). – Fossil Imprint, 80(2): 319–328, Praha. ISSN 2533-4050 (print), ISSN 2533-4069 (on-line).

Abstract: Studies during the 1970's and 1980's concluded that the continental Bou Hanifia Formation spanned the Vallesian and Turolian stages, the majority early opinion being that it was basal Vallesian and that it had yielded the oldest known remnants of the equid *Hipparion* from Africa. This opinion was taken to be backed-up by radio-isotopic age determinations of ca. 12.2 Ma obtained from volcanic tuffs that were originally mapped as being near the base of the formation. However, later suggestions in the literature indicated that some of the large mammals could be as young as late Turolian to Ventian (8–7 Ma). If so, then a major revision of North African biostratigraphy would be required. This paper focuses on the large mammals and avian eggshells recovered from the Bou Hanifia region, taking into account recent revisions of African faunas and a much augmented data base about their stratigraphic distribution, and it is concluded that the Bou Hanifia fossils have the closest relations to material from the late Turolian and Ventian Stages, and are thus likely to be of latest Miocene (Ventian) age (MN 13).

Key words: biostratigraphy, mammals, Northern Africa, Neogene, Miocene

Received: February 2, 2024 | Accepted: August 16, 2024 | Issued: December 20, 2024

Zoobank: http://zoobank.org/urn:lsid:zoobank.org:pub:D708399B-B1D4-4A8F-A43D-1F36A6BF01BB

Introduction

Bou Hanifia, Algeria, also known in the literature as Oued el Hammam (and for one locality, Dublineau (nowadays Hacine) and another as Sidi Salem) rose to prominence as a palaeontological resource when remains of *Hipparion* and other mammals were found during construction of the Bou Hanifia Dam (Suess 1932, Falconnier and Lombard 1942, Cornet 1952). The locality that yielded the original fossils was flooded when the dam construction was completed but other fossiliferous occurrences were subsequently discovered in the vicinity (Arambourg 1951a, b, 1958, 1959, 1963, 1968, Sen 1990) which yielded much additional material, including articulated remains of orycteropodids, equids, rhinocerotids and a hyaenid among other mammals as well as struthious eggshells (Pickford et al. 2023). Later field surveys in the region added micromammals to the faunal lists (Jaeger et al. 1973, Ameur 1984) notably *Progonomys cathalai* found in association with "*Hipparion*", from locality BH V in the Bou Hanifia Formation. Ameur (1984) described micromammals (the rodents *Zramys gueltae*, *Myocricetodon* cf. *parvus*, *Myocricetodon* cf. *ouedi*, *Senoussimys hanifiae*, *Progonomys cathalai*, *Africanomys kettarati*, *Atlantoxerus* sp., *Microdyromys* sp. and the erinaceid *Schizogalerix* sp.) concluding that BH V was younger than locality BH II which yielded *Zramys dubius*. The evidence was taken to confirm the Vallesian correlation of the Oued el Hammam (Bou Hanifia) deposits, as were radio-isotopic analyses of tuffs occurring near the base of the formation (Chabbar Ameur et al. 1976). However, no analytical details of the Bou Hanifia 'dated' tuffs have ever been published (Chabbar Ameur et al. 1976, Sen 1990), rendering the mentions of no scientific value.

Whilst the restricted microfaunal evidence generally supports correlation of the Bou Hanifia Formation to the Vallesian-Turolian (albeit with pertinent questions concerning the identification of the fossils), the large mammal remains suggest a late Turolian to Ventian correlation, several authors having noted that the hyaenids (Werdelin and Peigné 2010), suids (Cooke 1987), giraffoids (Harris et al. 2010), and equids (Bernor and White 2009, Bernor et al. 2010) are

DOI 10.37520/fi.2024.024

morphologically and metrically close to fossils collected at Marceau (Menacer) Algeria, and Sahabi, Libya, which are latest Turolian to Ventian in age. The large dimensions of the orycteropodid from Bou Hanifia suggest that it is close in age to Perpignan (Early Pliocene): if it is considered to be of Vallesian age (Lehmann 2009), then it gives rise to the unlikely scenario that the *Amphiorycteropus* LEHMANN, 2009 clade started out small (*A. browni* (COLBERT, 1933)), became large (*A. mauritanicus* (ARAMBOURG, 1959) the largest species of the genus), then smaller (*A. abundulafus* (LEHMANN et al. 2005) and *A. gaudryi* (MAJOR, 1888)) only to increase in dimensions again (*A. depereti* (HELBING, 1933)).

The struthionid eggshells from excavated contexts at Bou Hanifia (Arambourg 1959) are herein identitifed as *Psammornis* sp. The oldest previously discovered in situ occurrences of this ootaxon were in the Segui Formation of Tunisia, which is younger than the Vallesian Beglia Formation (Choumowitch 1951, Sghari and Mercier 2011, Buffetaut 2022), being correlated to the Messinian Stage by Mannaï-Tayech (2006, 2009) which itself is largely equivalent to the Ventian Land Mammal Stage (Morales et al. 2013). This ootaxon is usually considered to be of latest Miocene to Plio-Pleistocene age, but most of the fossils attributed to it were not in situ when found, so there remains some doubt about its precise earliest and latest records but, on presently available evidence, an estimate as old as Vallesian seems highly unlikely.

Marine microfossils from subjacent strata have been employed to bracket the continental Bou Hanifia Formation within the Geological Time Scale – it is generally considered to equate to the Tortonian. In terms of land mammal ages, this would correspond to the Vallesian or Turolian (Chabbar Ameur et al. 1976), but some elements of the mammalian fauna indicate the possibility of a Ventian age for one or more of the sites (the locality of Dublineau (= Hacine) mentioned by Thomas and Petter 1986) and the possibility exists that there are even younger faunal elements from the deposits (this paper).

Taphonomic considerations

As currently understood, the Bou Hanifia Formation may include some deposits of Ventian age, which could have accumulated in gullies eroded into the Miocene sediments, in animal burrows excavated into the Miocene deposits, in pipes eroded into the pre-existing deposits, or in sediment traps close to slumped masses of the formation (see, for example, Falconnier and Lombard 1942, Cornet 1952). Only further surveys on the ground will resolve the contextual and stratigraphic issues.

In this context, it is noted that many palaeontological sites in Africa have yielded fossils of diverse ages due to a variety of processes, as described by Pickford (2018). Such processes include 1) reworking of fossils into younger strata (a common occurrence), 2) piping (on occasion, erroneously known as pseudo-karst), 3) erosional cut and fill, 4) infillings of animal burrows, 5) slumping and landslides of strata (see Pickford 2021) and 6) infilling of deep cracks developed in underlying sediments. Out of these six categories, pipe and burrow infillings often yield articulated skeletal remains, as did Bou Hanifia (Arambourg 1959). Cut and fill processes and reworking of fossils from older deposits into younger ones usually results in disarticulation, fragmentation, abrasion and scattering of fossils, so these processes are unlikely to have occurred at the Bou Hanifia sites where articulated and closely associated skeletal remains were excavated with no signs, such as abrasion, of having been reworked.

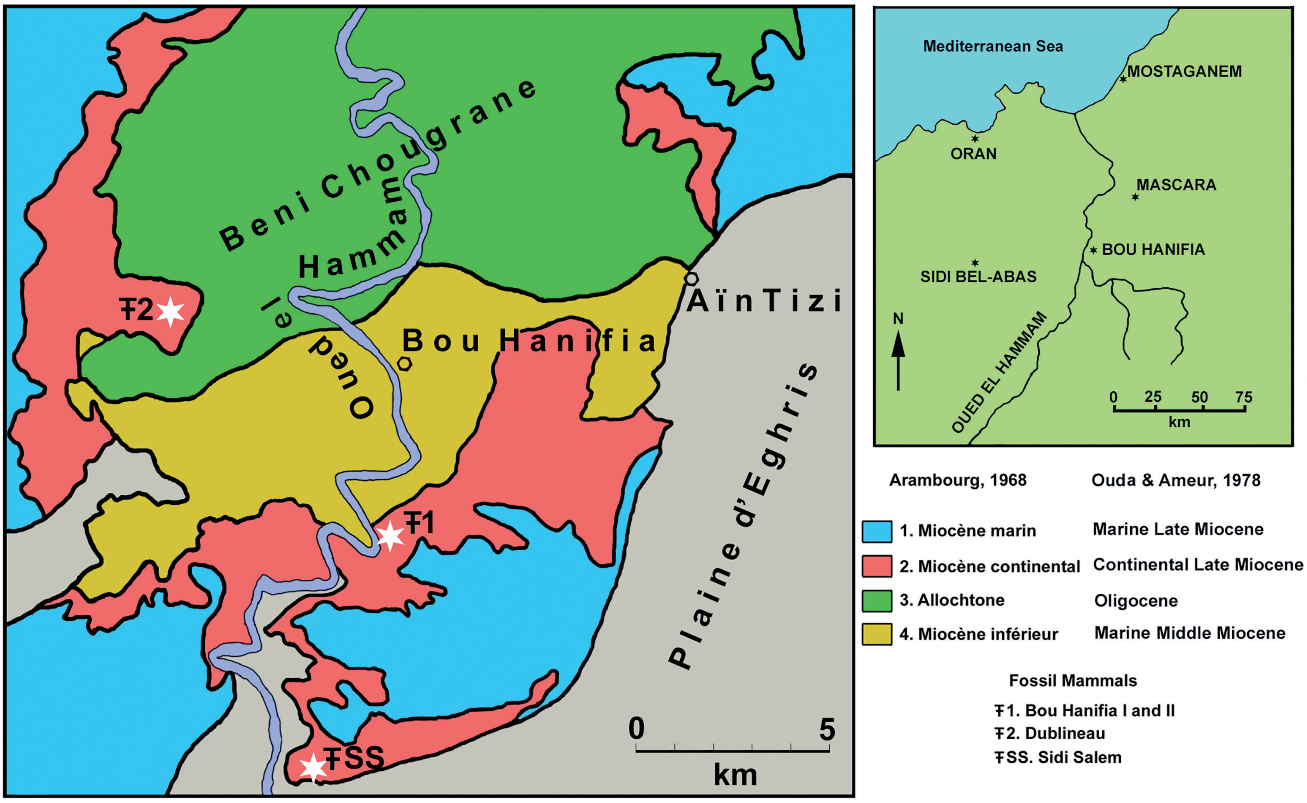
The fact that a mandible of *Amphiorycteropus* was preserved in the deposit sampled by Suess (1932; but first mentioned by Arambourg 1959 as *Orycteropus* in caption to planche V, fig. 10) and a partial skeleton of the same mammal was excavated from the distinct locality excavated by Arambourg (1959) along with articulated or associated remains of other large mammals (percrocutids, equids, rhinocerotids, giraffids, bovids) and birds (struthionid eggshell fragments) suggests that the occurrences could have been the infillings of a pipe (or pipes) eroded into the Miocene sediments or of an animal burrow (or burrows) (specifically those of aardvarks) excavated into them. Note that, at the present day, hyaenids, which are represented in the same Bou Hanifia I assemblage, often occupy aardvark burrows and frequently carry isolated bones and partial skeletons of mammals into them, where the young hyaenas are born and raised until they become independent. Paradoxically, many of the skeletal remains carried into caves by hyaenas remain in good condition. The co-occurrence of associated aardvark and hyaena remains (both adult and juvenile) along with partial skeletons of equids, bovids, giraffids and rhinocerotids is compatible with accumulation within an aardvark burrow system, as is the fine-grained nature of the sediments in which the entangled ("enchevêtrés") fossils were preserved (Arambourg 1959).

Such a scenario is compatible with Arambourg's (1959) description of the fossils encountered during the excavation that he undertook in 1951: "Mais, au point fouillé ils formaient un amas enchevêtré sur une surface de quelques mètres carrés et une epaisseur de 50 à 60 centimètres. Du fait de la plasticité du terrain, les spécimens, bien que fortement fossilisés, étaient souvent déformés, craquelés, et plus ou moins sectionnés."

If the 1951 excavations at Bou Hanifia were indeed into the infilling of a pipe or an animal burrow, then the fossiliferous deposits could be considerably younger than the surrounding sediments in which the infillings occur.

Geological context and age of the Bou Hanifia Formation

The continental Bou Hanifia Formation (Text-fig. 1) is underlain by the marine Anaseur Formation of early Middle Miocene age, and is overlain by un-named marine deposits of late Tortonian age (Ouda and Ameur 1978, Ameur-Chehbeur 1988). The continental deposits were originally correlated to the Oligocene (1: 50,000 Mascara map sheet of the Service géologique d'Algérie; see Arambourg 1959) but were correlated to the Pontian by Suess (1932) then successively to the "Sarmato-Pontien", "Pontien" and "pre-Pontian" by Arambourg (1951a, b, 1958, 1959, 1963). In more recent literature the Bou Hanifia Formation has generally been equated to the Vallesian land mammal



Text-fig. 1. Location, geological map and stratigraphy of the Bou Hanifia area, Algeria. Base map modified from Ouda and Ameur (1978) geological map modified from Arambourg (1968). Dublineau is now known as Hacine.

age (or to the marine Tortonian) with the *Hipparion* layers estimated to be ca. 10.5 Ma (Sen 1990, Bernor and White 2009, Bernor et al. 2010). Its precise position within the Vallesian was never made clear, however. Arambourg (1958, 1959) considered Bou Hanifia to be contemporary with Marceau (Menacer) which is of latest Miocene age (MN 13). In agreement with this Thomas et al. (1982), Petter and Thomas (1986), Thomas and Petter (1986) and Cooke (1987) considered that the locality from which the holotype of *Propotamochoerus devauxi* was collected (locality T2 in Arambourg 1968) was of the same age as Marceau which would make it of late Turolian or even Ventian age (Morales et al. 2013). For this reason, Thomas et al. (1982) referred to the locality as Dublineau in order to distinguish it from the other fossiliferous localities in the formation (Cooke 1987). The current name of the place is Hacine (also Hassine in the literature; Belkebir et al. 1996). Werdelin and Peigné (2010) included Marceau (also known as Menacer) in the Turolian, aged between 7.0 and 5.7 Ma. Subsequently, in the system of continental land mammal ages, the upper part of the Turolian ranging in age from 6.9–5.1 Ma, was defined as the Ventian mammal age (Morales et al. 2013), being more or less equivalent in geological time to the marine Messinian.

Falconnier and Lombard (1942) mapped the surroundings of the Bou Hanifia Dam in detail. They subdivided the rock sequence into three units, as follows:

"A. Soubassement marneux tertiaire.

B. Complexe gréso-marneux pontien.

C. Alluvions quaternaires anciennes et modernes.

L'épaisseur respective de ces divers terrains est de quelques centaines de mètres pour le soubassement marneux, de plus de 200 m pour le Pontien, et très variable pour les dépôts quaternaires."

The authors recognised six major sub-units within the "Pontian" complex, comprising interfingering layers and lenses of sands, grits, marls and conglomerates. They showed that the strata were prone to slumping and to landslides when undercut by erosion or by mechanical excavation. They also mapped Quaternary deposits upstream from the dam. Note that these authors described Quaternary deposits of variable thickness in the region.

Cornet (1952) mapped some Pliocene beds close to Bou Hanifia Dam and reported large slumped masses of sediment in the Bou Hanifia region (map reproduced in Neurdin-Trescartes 1992, 1995).

The Bou Hanifia Formation is one of the few North African sedimentary sequences to contain volcanic tuffs (Chabbar-Ameur et al. 1976, Sen, 1990) which yielded radio-isotopic dates of 12.18 ± 1.03 Ma and 12.03 ± 0.25 Ma. The presence of "*Hipparion*" in the same geological "formation" as volcanic tuffs dated to 12.18 Ma, was taken by some researchers to provide evidence concerning the age of the so-called *Hipparion* datum, soon estimated to be 12.5 Ma on the basis of the radio-isotopic dates at Bou Hanifia (Algeria) and Höwenegg (Germany) (Berggren and Van Couvering 1974, 1978, Van Couvering and Berggren 1977, Berggren et al. 1985). However, as was pointed out by Sen (1990) the tuff layers in the Bou Hanifia area occur in sediments that are well beneath the levels that yielded the equid fossils. On the basis of the radio-isotopic dates and palaeomagnetic stratigraphy, he concluded that "the small mammal locality BH 5, which also yielded *Progonomys cathalai* Schaub, 1938, should be as old as 10.3 Ma, and the age of the *Hipparion* locality BH 1 should be a little older than 10.5 Ma, but certainly younger than 12 Ma".

Neurdin-Trescartes (1992) wrote "La datation absolue des cinérites C2 à la base de Bou Hanifia, celle des cinérites C3 de Sidi Salem au sommet de Bou Hanifia, par rapport au gisement de l'Oued Zra ont permis de caler cette formation rouge continentale entre le Vallesien inférieur et le Turolien inférieur: étages continentaux correspondant à la fin du Serravallien et à une partie du Tortonien". No analyses were published so it is not possible to comment on the validity or otherwise of these "absolute" dates.

Bernor and White (2009) and Bernor et al. (2010) concluded that the equid fossils (P4/ and p/2) from Bou Hanifia ("*Cormohipparion*" *africanum* (Arambourg, 1959)) were morphometrically closest to material from Menacer, Algeria, and Sinap, Turkey, as well as to *Cremohipparion* Qiu et al., 1988 from Sahabi, Libya, with some resemblances to material from Langebaanweg, South Africa. All of these localities are of latest Miocene (Turolian-Ventian) age (equivalent to European land mammal zone MN 13). However, the authors retained a Vallesian correlation for the Bou Hanifia occurrences, as did Werdelin (2010). Rook et al. (2019) concurred with Bernor et al. (2010) that Bou Hanifia equids are aged ca. 10.5 Ma.

A factor complicating the history of Bou Hanifia biostratigraphy was a publication by Chabbar Ameur et al. (1976) who erroneously listed *Propotamochoerus devauxi* in the faunal list for Bou Hanifia I. The only described material of this species came from site T2 (not to be confused with BH II) ca. 8 km northwest of Bou Hanifia I and II (Arambourg 1968; locality named Dublineau in Thomas and Petter 1986). Harris and White (1979) mistakenly wrote that Bou Hanifia is in Chad, but more plausibly proposed that *Propotamochoerus devauxi* Arambourg, 1968, is a synonym of *Nyanzachoerus tulotos* Cooke et Ewer, 1972 writing that, "The specimen described by Arambourg (1968) has very obvious affinities with *Nyanzachoerus tulotos* material from East African localities, suggesting that sediments of the Oued el Hamman are of similar or greater age than those of Lothagam 1B and 1C". However, should *P. devauxi* and *N. tulotos* be synonyms, then the senior name would be *N. devauxi*. In their fig. 134, Harris and White (1979) positioned Bou Hanifia in column A, along with Lukeino and Lothagam. This placement suggests correlation to the late Turolian (MN 12) (or even to the Ventian MN 13). These Lothagam levels are of latest Miocene age, between 5.1 and 7 Ma. In contrast, Cooke (1978) and Cooke and Wilkinson (1978) initially accepted an age of 12 Ma for the Bou Hanifia suid fossils but subsequently Cooke (1987) changed his mind, noting that "the type locality of *devauxi* should be designated Dublineau and the age is most probably Turolian, or very late Miocene (Thomas et al. 1982)". It is noted that the suids from the Beglia Formation (Vallesian, Tunisia) probably belong to a different species from *N. devauxi*, as proposed by Van der Made (2004).

Lehmann (2009) accepted an age of ca. 10.85 Ma for the Bou Hanifia orycteropodid, but remarked that its large dimensions flowed against the general trend of increase in size through the Miocene that occurred in this group of mammals. He deduced that "*Amphiorycteropus browni* was the smallest species of its genus. Although their phylogenetical relationships are not yet resolved, this species is chronologically followed by *A. mauritanicus*, the largest taxa (sic) of the genus. The size decreased again with *A. abundulafus* and *A. gaudryi*, but eventually, *A. depereti* showed a large general size again". A more parsimonious hypothesis would be to consider the dating of the Bou Hanifia species as being too old, and to move it upwards in time into the Ventian (7–5 Ma) closer in time to *A. depereti* (Perpignan, MN 15, ca. 5 Ma; Van der Made 2003), as this would remove the necessity of having to postulate an evolutionary yo-yo in body size (smallest to largest to smaller to larger) in the genus *Amphiorycteropus*.

In his review of the fossil rhinocerotids from Africa, Geraads (2010) estimated that the age of *Ceratotherium*(?) *primaevum* (Arambourg, 1959) from Bou Hanifia was 10 Ma. If the generic identification is correct, then this would make Bou Hanifia the oldest known occurrence of the genus, the next oldest from Africa being the doubtfuly referred material from Chorora (Ethiopia) and Namurungule (Kenya). It would even be older than the Eurasian species *Ceratotherium neumayri*, best known from Turolian sites at Pikermi (MN 12), Samos (MN 11), Pentalophos (MN 10–11) and Maragha (MN 12, the type locality of the species) (Geraads 2005, Geraads and Spassov 2009). According to Geraads (2010) *Ceratotherium douariense* (Guérin, 1966) from Tunisia is the only other species from the Miocene of Africa that is reasonably attributed to the genus (but even in this case there are doubts, the genus being considered paraphyletic by Geraads 2010), all other records from the continent being from Pliocene or younger deposits. As such, an early Vallesian age for *Ceratotherium* Gray, 1868 from Bou Hanifia stands out as being potentially anomalous.

Harris et al. (2010) reported the giraffoid *Palaeotragus germaini* Arambourg, 1959 at Bou Hanifia (Oued el Hammam), Menacer (ca. 7 Ma) and Smendou (Late Miocene to Pleistocene) in Algeria, and *Palaeotragus* cf. *germaini* from Ahl-al-Oughlam (Pliocene, Morocco) and Langebaanweg (Early Pliocene, South Africa) as well as other sites in North Africa (Morocco and Tunisia).

Gentry (2010) estimated that the Bou Hanifia bovids described by Arambourg (1959) (*Gazella praegaudryi* Arambourg, 1959 and *Damalavus boroccoi* Arambourg, 1959) spanned the period 10.0–9.0 Ma. Bishop (2010) considered that the Bou Hanifia suid remains (which came from Hacine, formerly Dublineau) described by Arambourg (1968) as *Propotamochoerus devauxi* were of a primitive nyanzachoere close to material from Lothagam, Kenya, and thus of Late Miocene age. She agreed that it belongs to the genus *Nyanzachoerus*. On the basis of the list of rodents reported from Bou Hanifia sites, Winkler et al. (2010) correlated the formation to the Late Miocene, but without entering into detail. Werdelin and Peigné (2010) studied the hyaenid *Dinocrocuta algeriensis* (Arambourg, 1959) from Bou Hanifia, concluding that it belonged to the same species as that from Menacer, which is late Turolian or Ventian in age.

Comprehensive stratigraphic and biostratigraphic studies were carried out in the Bou Hanifia region by Ouda and Ameur (1978) who concluded that the continental beds attributed to the Bou Hanifia Formation were underlain by the Anaseur Formation of Serravallian age, citing abundant marine microfossils. They correlated the *Hipparion*-bearing band at Bou Hanifia to the Tortonian, or specifically post Zone N15 age. This would mean that the deposits are younger than 11.2 Ma, the currently accepted age of the Serravallian-Tortonian boundary (Legoinha 2008).

Belkebir et al. (1996) noted that the Bou Hanifia Formation is underlain by marine strata yielding microfossils attributable to the *Globorotalia mayeri* biozone (N13/N14 of Blow 1969; Serravallian in that publication; but according to Gradstein et al. 2004, who correlated these zones to the base of the Tortonian, younger than Zone N14 which ends at ca. 10.8 Ma) and are overlain by late Tortonian-Messinian deposits (N17 of Blow 1969; the zone starting at ca. 8.8 Ma according to Gradstein et al. 2004). These correlations, if correct, imply that the Bou Hanifia Formation accumulated between 10.8 and 8.8 Ma, which runs counter to the presence of a volcanic tuff near the base of the formation dated to 12.18 ± 1.03 Ma (Chabbar Ameur et al. 1976). The latter authors concluded that "the Bou Hanifia Formation spans a time span of around 12.0–9.7 Myr BP".

In summary, the literature indicates that interpretation of the continental deposits in the neighbourhood of Bou Hanifia has not been straight-forward. Considered by most authors to represent a single long-term phase of continental deposition preceded and followed by periods of marine deposition, the unit was interpreted to comprise several distinct depositional phases by authors such as Falconnier and Lombard (1942), Thomas et al. (1982) and Thomas and Petter (1986). The latter authors correlated some localities to the Vallesian (Bou Hanifia (BH I, BH II, BH V) close to the dam) and some, 8 km to the northwest of the dam, to the Turolian (called by them Dublineau). Cooke (1987) agreed with this, correlating the type locality of *Nyanzachoerus devauxi* to the Turolian or very Late Miocene. The locality of Sidi Salem, reported to be near the top of the section six kilometres south of Bou Hanifia Dam, was correlated to the lower Turolian by Chabbar Ameur et al. (1976).

However, if the large mammal remains accumulated in aardvark burrows excavated into Bou Hanifia Formation or in pipes or gullies eroded into it, then much of the discrepancy between stratigraphy and biochronology would be resolved. The deposition of the continental Bou Hanifia Formation would have occurred during the interval between zones N13/14 and N17 of Blow (1969) as interpreted by the researchers who focussed on the marine strata, whereas the burrowing, piping or gullying would have occurred any time afterwards, on condition that the sediments were exposed at the surface and were not under water or deeply buried. Such was the case during the so-called Messinian Crisis (Mannaï-Tayech 2006, 2009) and for much of the Plio-Pleistocene. Such a scenario is compatible with comments in the literature concerning the taxonomic affinities of the hyaenids, equids, nyanzachoeres, rhinocerotids, giraffids and orycteropodids, as noted above. The conclusion that flows from this discussion, is that most of the large mammals from "Bou Hanifia" are likely to be of latest Turolian to Ventian affinities rather than Vallesian as has been assumed by most authors for the past three decades.

Struthious eggshells found in excavations at Bou Hanifia by Arambourg (1959) alongside the articulated mammal skeletons, represent a species of *Psammornis*, a widespread ootaxon the geographic distribution of which ranges from Algeria in the west to the Arabian Peninsula in the east (Pickford et al. 2024). Arambourg (1959) considered that, at 2.5–3 mm thick, the shells were too thin to belong to *Psammornis rothschildi* Andrews, 1912, so he attributed them to *Struthio* sp. Remeasurement of the eggshells from Bou Hanifia indicates that he overestimated the thickness, it being from 2.0 to 2.7 mm. The type material of the species is reported to be 3.2–3.4 mm thick (Andrews 1912), which is appreciably thicker than the specimens from Bou Hanifia, but other specimens from diverse localities in North Africa and the Arabian Peninsula are thinner (Lowe 1933, Pickford et al. 2023). The morphology of the pore complexes and the inner and outer layers of the Bou Hanifia eggshells with the relatively thick spongy layer between them is similar to the type material of *Psammornis rothschildi*, but the lesser thickness indicates that the Bou Hanifia fossils represent a smaller species of the oogenus.

Some fossils of *Psammornis* were recently described from Oman, but were attributed to *Diamantornis laini* Pickford et al., 1995 by Pickford et al. (2023). This is a Late Miocene ootaxon but detailed study of additional material in Oman (attributed to *Struthio kakesiensis* Harrison et Msuya, 2005 by Rosén et al. 2021) indicates that it is more likely to represent *Psammornis* than *Struthio* or *Diamantornis*, the superficial resemblances between the eggs of these taxa being due to the post-mortem modification of their surfaces due to the subaerial exposure that they underwent long after being fossilised. Most specimens of *Psammornis rothschildi* were surface finds, and are thus of little reliability for biostratigraphic purposes, but some material was collected from in situ contexts in the Segui Formation of Tunisia (Choumowitch 1951, Sghari and Mercier 2011) which is of late Turolian to Ventian age (sometimes correlated to the Messinian) and it is common in Oman in situations that indicate its derivation from the latest Miocene Marsawdad Formation and younger deposits in the region (Rosén et al. 2021).

Discussion

The literature on the Bou Hanifia Formation is extensive and a high diversity of opinions has been written about its age. Part of the debate is due to the usage of various biostratigraphic concepts by different authors. Arambourg (1951b) for example, initially correlated the strata to the late Vindobonian because the continental Bou Hanifia deposits overlie marine beds at the time correlated to the Burdigalian (but subsequently correlated to the Cartennian by Chabbar Ameur et al. 1976, or to the Serravallian by Ouda and Ameur 1978 or to Foraminiferal zone N14 of Blow 1969, by Belkebir et al. 1996) and they underlie what, at the time, were called Vindobonian marine beds (but which were later correlated to the Tortonian by Ouda and Ameur 1978). He later (Arambourg 1958) equated the Bou Hanifia *Hipparion* beds to the Pontian, equivalent to Marceau (the latter site is more correctly correlated to the Turolian (Thomas et al. 1982) or even to the Ventian (Morales et al. 2013). At this period of his career Arambourg was employing the term Pontian for the continental equivalent of the marine Pliocene, including in it classic mammal-bearing localities such as Pikermi (Greece) and Maragheh (Iran). For the past half century these continental deposits have been included in the Late Miocene (Turolian) following the biostratigraphic revisions of Crusafont-Pairo (1950) (Berggren and Van Couvering 1974) and the term Pontian is no longer used for continental beds, having been replaced by more precisely defined terms such as Vallesian, Turolian and Ventian (Morales et al. 2013).

In the literature, majority opinion has correlated the Bou Hanifia *Hipparion* levels to the Vallesian (usually estimated to be ca. 10.5 Ma; Sen 1990) but some authors (Delfaud et al. 1973, Chabbar Ameur et al. 1976, Ameur-Chehbeur 1992) positioned BH I at ca. 12 Ma and BH II at ca. 11.7 Ma. As such, the *Hipparion* fossils from the formation were frequently interpreted as being among the oldest known from Africa (Bernor and White 2009, Bernor et al. 2010). Indeed, for a while the age of the *Hipparion* datum (or its FAD – First Appearance Datum) was based on the fossils from two localities where radio-isotopic dating had been carried out, Bou Hanifia in Africa and Höwenneg in Europe, from which basis the datum was estimated to be 12.5 Ma. However, as Sen (1990) pointed out, the Bou Hanifia *Hipparion* fossils are from beds much higher in the stratigraphic column than the tuffs upon which the age determination was made, and he estimated that the equids were in the vicinity of 10.5 million years old on the basis of their topographic position within the formation.

Several papers have been published on rodents from the Bou Hanifia Formation (Ameur 1984, Ameur-Chehbeur 1988, Mein et al. 1993, Mahboubi 2014, López-Antoñanzas et al. 2019, Zebbar 2022). It is notable that none of the rodents were derived from the same precise localities as the large mammals. Delfaud et al. (1973) correlated localities BH I and BH II to the base of the Vallesian, and estimated an age of just under 12 Ma for the Bou Hanifia Formation *Hipparion* fauna (citing *Progonomys* cf. *cathalai*, *Zramys* sp., *Myocricetodon* sp.). From the point of view of biostratigraphy, a potential problem with the citation of *Progonomys* cf. *cathalai* at Bou Hanifia, is that the fossils likely do not belong to this species (López-Antoñanzas et al. 2019) even if they might belong to the genus *Progonomys*. Mein et al. (1993) already pointed out that the attribution of the Bou Hanifia specimens to *Progonomys cathalai* was not correct. They listed Sinap Tepe I, Anatolia, Turkey (MN 9), as the earliest known record of the genus. The other two rodent genera from Bou Hanifia are represented by indeterminate species, meaning that little if any information can be drawn from them concerning the age of the deposits. Sidi Salem, which was described as being close to the top of the Bou Hanifia Formation, was correlated by Delfaud et al. (1973) to the Turolian (ca. 8.5 Ma) on the basis that it yielded remains of *Galerix* sp., *Zramys* sp., *Myocricetodon* sp., *Paraethomys* sp. and Ctenodactylidae indet. As with the BH II microfauna, none of the Sidi Salem micromammals were identified to the species level, which undermines their utility for biostratigraphy. The *Zramys* from the site was later included in *Zramys salemi* Jaeger, 1977 by Coiffait (1991).

Mahboubi (2014) following Jaeger et al. (1977) positioned Bou Hanifia at ca. 12 Ma, and Sidi Salem at ca. 8.4 Ma, with the immigration of *Hipparion* and *Progonomys* at 12.5 Ma. The latter estimate would make Bou Hanifia by far the oldest occurrence of the genus *Progonomys* in Europe or Africa, long predating the oldest occurrence in Europe (Sinap I, Turkey), which is an unlikely scenario. Coiffait (1991) estimated the ages of Bou Hanifia sites as follows: Bou Hanifia 1 – ca. 10.8 Ma, Bou Hanifia 2 – ca. 10.7 Ma, Bou Hanifia 5 – ca. 10.3 Ma, and Sidi Salem at ca. 8.5 Ma. Stoetzel (2013) included Bou Hanifia 2 in her Biozone 3 (Vallesian) and Sidi Salem in her Biozone 4 (Turolian). Bessedik et al. (1997) estimated the age of Bou Hanifia 5 as 10.3 ± 0.5 Ma, and Sidi Salem as ca. 8 Ma mentioning that the latter site is located immediately below the boundary between N16-N17 (Turolian). In summary, the fossil rodents from Bou Hanifia sites do not provide a robust argument in support of a Vallesian age for some of the deposits.

If the Bou Hanifia *Hipparion* sites are close in age to Marceau (= Menacer) as postulated by Arambourg (1958) then they would be Turolian or even Ventian (Morales et al. 2013) rather than Vallesian (Thomas and Petter 1986).

Finally, the struthious eggshell fragments excavated at Bou Hanifia by Arambourg (1959) are herein attributed to *Psammornis* sp., the specimens being similar to abundant material from latest Miocene deposits in Oman (Pickford et al. 2023). The oldest known in situ occurrence of this ootaxon is from the Segui Formation, Tunisia (Choumowitch 1951, Sghari and Mercier 2011), equivalent in age to the Messinian Stage (Mannaï-Tayech 2006, 2009), of which the terrestrial equivalent is the Ventian Land Mammal Age (MN 13; Morales et al. 2013).

Conclusion

This article reassesses the palaeontological content of the Bou Hanifia Formation, Algeria, and proposes a revision of the age of the large mammal and avian faunal remains excavated by Arambourg in 1951 (Arambourg 1959).

Firstly, diverse authors of several scientific papers concerning the Bou Hanifia large mammals (equids, hyaenids, tetraconodont suids, giraffoids, rhinocerotids) have stressed similarities that the fossils share with material from Menacer (Algeria), Sahabi (Libya) and Lothagam (Kenya), all of which are latest Miocene in age (late Turolian to Ventian). In addition, the orycteropodid fossils from Bou Hanifia are closest in dimensions to specimens from Perpignan, France (Early Pliocene) and the fossil struthious eggshells are compatible in thickness and morphology with specimens of *Psammornis* sp., a latest Miocene to Plio-Pleistocene ootaxon from northern Africa and the Arabian Peninsula. From this it is proposed that the large mammal and avian fauna from Bou Hanifia described by Arambourg (1959) is likely to be of late Turolian (MN 12) to Ventian (MN 13) age, rather than Vallesian (MN 9) as commonly assumed. The most plausible correlation, taking into account all the faunal remains from Arambourg's excavations, is considered to be to the Ventian (MN 13).

In conclusion, it is inferred that the Bou Hanifia Formation, which was long considered to comprise only early Late Miocene deposits ranging in age from ca. 12 Ma (Vallesian) at the base (Thomas et al. 1982) to late Turolian at Dublineau (now Hacine) (Petter and Thomas 1986, Thomas and Petter 1986) and ca. 8.7 Ma at Sidi Salem near the top of the succession (Chabbar Ameur et al. 1976) may also include deposits of Ventian (MN 13) age (possibly as infillings of tubulidentate burrows or pipes). In order to resolve the biostratigraphic issues evoked during this study, it is essential to undertake further investigations in the field.

Acknowledgements

MP would like to thank the Muséum National d'Histoire Naturelle, Paris, for administrative and logistic aid and for according him the status of Affilié honoraire. Thanks are also due to the Centre de Recherche en Paléontologie – Paris (CR2P), the CNRS, and Sorbonne Université. YS-C thanks the French Embassy, Oran for financial support for a study tour in France. We thank Guillaume Billet and his curatorial team (Muséum National d'Histoire Naturelle, Paris), as well as Mike Day (Natural History Museum of the United Kingdom, London) for access to fossils in their care. We thank Lahcene Belkebir (Laboratoire de Paléontologie stratigraphique d'Oran) and Salamet Mahboubi (Laboratoire de Recherche, 24, Tlemcen) for interesting discussions. Denis Geraads, Sevket Sen and Jorge Morales are thanked for their constructive criticisms of the manuscript.

The authors are pleased to contribute to this special issue in memory of Oldřich Fejfar whose studies in northern Africa clarified biostratigraphic issues, especially those in Libya.

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