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Stratigraphy of the Hameima and lower Fahdene Formations in the Tadjerouine area (Northern Tunisia)

Abir Chihaoui [a], Etienne Jaillard [b,*], Jean-Louis Latil [c], Ihsen Zghal [d], Anne-Sophie Susperregui [a], Jamel Touir [e], Jamel Ouali [d]

[a] Université de Grenoble, LGCA UMR 5025, Maison des Géosciences, BP 53, 38041 Grenoble Cedex 9, France
[b] Université de Grenoble, IRD – LGCA UMR 5025, Maison des Géosciences, BP 53, 38 041 Grenoble Cedex 9, France
[c] Le Maupas, 05300 Lazer par Laragne, France
[d] Ecole Nationale d'Ingénieurs de Sfax, Route de Soukra, BP W, 3038 Sfax, Tunisia
[e] Faculté des Sciences de Sfax, Département des Sciences de la Terre, Route de la Soukra, km 3.5, Sfax 3018, Tunisia

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ABSTRACT

In the Tadjerouine area of north-western central Tunisia, the Albian transgression is characterized by deposition of alternating marls, limestones and sandstones (Hameima Fm) that overly massive platform carbonate rocks (Serdj Fm). The continuing transgression results in deposition of a thick series of marls and shales with subordinate carbonate beds (Fahdene Fm). A detailed study of the Hameima Fm, previously ascribed to the Late Aptian, shows that this formation can be subdivided into three members, all of earliest Albian age (*Leymeriella tardefurcata* Zone). The top of the Hameima Fm is slightly diachronous in the study area. A similar study of the Lower Shales of the Fahdene Fm demonstrates that they belong to the *L. tardefurcata* Zone and to the lower part of the *Douvilleiceras mammillatum* superzone. The overlying Allam limestones, formerly considered Middle Albian in age, are mainly of late Early Albian age (upper part of the *D. mammillatum* Superzone and *Lyelliceras pseudolyelli* Zone), although an extension into the lower Middle Albian cannot be ruled out. The Allam limestones are abruptly overlain by a diachronous series of Late Albian shales (Middle Shales of the Fahdene Fm), thus evidencing a stratigraphic hiatus of most of the Middle Albian and part of the early Late Albian. Our new data will lead to revision of the range of some Aptian/Albian orbitolinids and Albian planktic foraminifera.

1. Introduction

Changes between platform and basin facies have long caused problems to stratigraphers because of lithologic lateral changes and of difficult biostratigraphic correlations between shelf and basin faunas. As an example, the transition between the central Tunisian platform and the Northern Tunisian basin is marked by both complete argillaceous successions and lateral facies changes, which make a coherent use of the current stratigraphic nomenclature difficult. Although ammonite successions are known for a long time from the Aptian–Albian interval in north-western Tunisia (Pervinquière, 1907; Dubourdieu, 1956; Burollet, 1956; Memmi, 1999), the ammonite biostratigraphy, the transition between platform and basin facies, and the chronology of the Albian transgression are still poorly understood.

The Aptian–Albian boundary is still a matter of debate, because the ammonite faunas are commonly endemic, the sedimentary environments are marked by abrupt changes related to widespread anoxic events or to sharp regressions followed by major eustatic transgressions (*e.g.* Erba, 1996; Hart et al., 1996; Kennedy et al., 2000; Hancock, 2001; Owen, 2002; Mutterlose et al., 2003). In addition, significant synsedimentary tectonic events obscure the sedimentary or eustatic signals, provoking hiatuses, erosions and unconformities (*e.g.* Cotillon, 1989; Guiraud and Maurin, 1992; Chaabani and Razgallah, 2006).

The aim of this paper is to present a detailed stratigraphic study of the Hameima Formation and of the lower part of the Fahdene Formation, and a reassessment of the age and nature of the stratigraphic successions deposited during the Lower to Middle Albian. In this study we refine the stratigraphic nomenclature in the transition zone between the platform and basin in central and northern Tunisia. We improve the age constraints of the lithologic units, and provide a more reliable chronology of the tectonic and eustatic

* Corresponding author. Fax: +33 476 51 40 58.
E-mail addresses: Abir.Echihaoui@ujf-grenoble.fr (A. Chihaoui), Etienne.Jaillard@ujf-grenoble.fr (E. Jaillard), g.r.e.g.b@wanadoo.fr (J.-L. Latil), Ihsen_zghal@yahoo.fr (I. Zghal), Anne-Sophie.Susperregui@insa-rennes.fr (A.-S. Susperregui), Jamel.Touir@fss.rnu.tn (J. Touir), Ouali_j@yahoo.fr (J. Ouali).

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events that affected Tunisia during the latest Aptian–lower Upper Albian. For this purpose, we studied several selected sections located around the city of Tadjerouine (36°6′N, 8°30′E) by means of field observations and extensive collection of ammonites.

2. Geological setting

The Cretaceous deposits of Tunisia are classically divided into three main paleogeographic zones (Fournié and Pacaud, 1973; Zghal and Arnaud, 2005), which are from south to north (Fig. 1):

- the Saharian epicratonic platform, covered by thin, mainly clastic, continental to shallow marine deposits;
- the Central Tunisian platform, marked by shallow marine, first siliciclastic, then calcareous deposits. The platform is bounded to the north by the present-day NE–SW trending thrust and fold belt that characterizes northern Tunisia; central Tunisia includes the southern Chott depression that separates the Saharian and Central Tunisian platforms;
- the North Tunisian basin, which received thick marly deposits during most of the Cretaceous (Fig. 1).

During Albian times, the regional tectonic regime is thought to be dominated by NE–SW to E–W extension, although a short termed, intra-Albian transpressional regime has been reported locally (Bouaziz et al., 2002). Extension is characterized by normal faults enhancing block tilting and evaporite diapirism, both controlled by inherited structures (*e.g.* Ouali et al., 1986; Burollet and Ellouz, 1986; Martinez et al., 1991; Ladeb et al., 1995; Zouari et al., 1999).

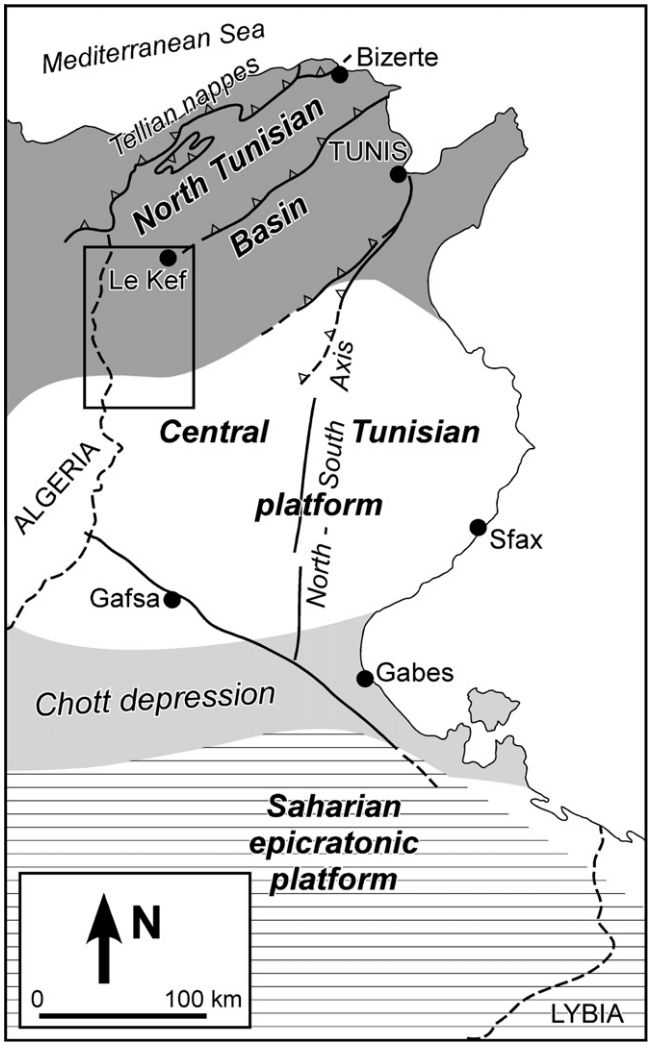

Fig. 1. Paleogeographic sketch of Tunisia during Aptian–Albian times and location of the study area.

Tertiary deformation is more common toward the north; marked in central Tunisia by open folds affecting previously faulted series and in northern Tunisia by tighter folds associated with salt diapirs. The latter area is overthrusted by the south verging Tellian nappes, which crop out along the coast.

Our study area is located in north-western Tunisia, at the transition between the central and northern Tunisian paleogeographic domains (Souquet et al., 1997). The little town of Tadjerouine is located south of Le Kef, close to the Algerian border. Tadjerouine is surrounded by scattered, faulted and folded massifs (jebels), which morphologically dominate the less deformed Late Cretaceous to Quaternary sedimentary cover (Fig. 2). The jebels consist to the most part of massive Aptian carbonate rocks (Serdj Formation), overlain by limestones, shales and marls of the Hameima and Fahdene formations. Six sections have been studied around these jebels, which are from northwest to southeast (Fig. 2): (1) Jebel Harraba on the Algerian border; (2) Henchir El Goussa area (north of the El Gara section of Burollet 1956, p. 71), (3) north of Jebel Hameima (Dubourdieu, 1956, pp. 160–161 and 197–201; Burollet, 1956, p. 66 and pp. 71–75), (4) northwest of Jebel Slata (Burollet, 1956, pp. 75–77; Charens section of Vila et al., 1995), (5) south of Jebel Djerissa (Burollet, 1956, p. 77), and (6) across Jebel Bou el Haneche (Burollet, 1956, p. 71) located north of Thala (Fig. 2).

3. Previous work

Following several scientific explorations during the late 19th century, the Cretaceous stratigraphy of northern and central Tunisia was first studied by Pervinquière (1907), who attempted to determine the succession of stratigraphic stages through lithological and fossil collections. However, it was not before the 1950s that the biostratigraphy and lithostratigraphy of the Cretaceous series of Tunisia were studied and described in detail. Castany (1951) published a geological synthesis and a geological map of the area, while Sainfeld (1952) studied lead–zinc mineralizations, mainly hosted in Aptian–Albian strata. Dubourdieu (1956) published a detailed description of numerous sections in western Algeria and Eastern Tunisia, associated with numerous fossil determinations. Burollet (1956) established the stratigraphic nomenclature of the Cretaceous succession of Tunisia, which is still in use today, by means of several detailed field sections (see M'Rabet, 1981; Burollet et al., 1983; M'Rabet et al., 1995; Zghal and Arnaud, 2005).

Since then, Bismuth (1973) compiled a helpful synthesis of the Aptian–Albian stratigraphy, refining the location of faunas formerly quoted in the Hameima section, and correlating the latter with southern areas. Short syntheses on the stratigraphy and ammonite paleontology of the Lower Cretaceous of Tunisia were published by Burollet et al. (1983) and Memmi (1999), respectively. Robaszynski et al. (1993a,b, 2008) published detailed stratigraphic and sedimentological studies focused on the Albian–Cenomanian boundary, and on the Late Cretaceous, along sections located southwest of Tadjerouine. Previously published biostratigraphic ages from Burollet (1956) and Bismuth (1973) were confirmed through microfossil analysis along the Hameima section in the Tadjerouine area (Zghal, 1994; Zghal et al., 1997). Finally, Vila et al. (1994, 1995, 2001) and Ghanmi et al. (2001) provided numerous, although scattered, biostratigraphic data on the Aptian–Albian interval, and showed the presence of Lower Albian

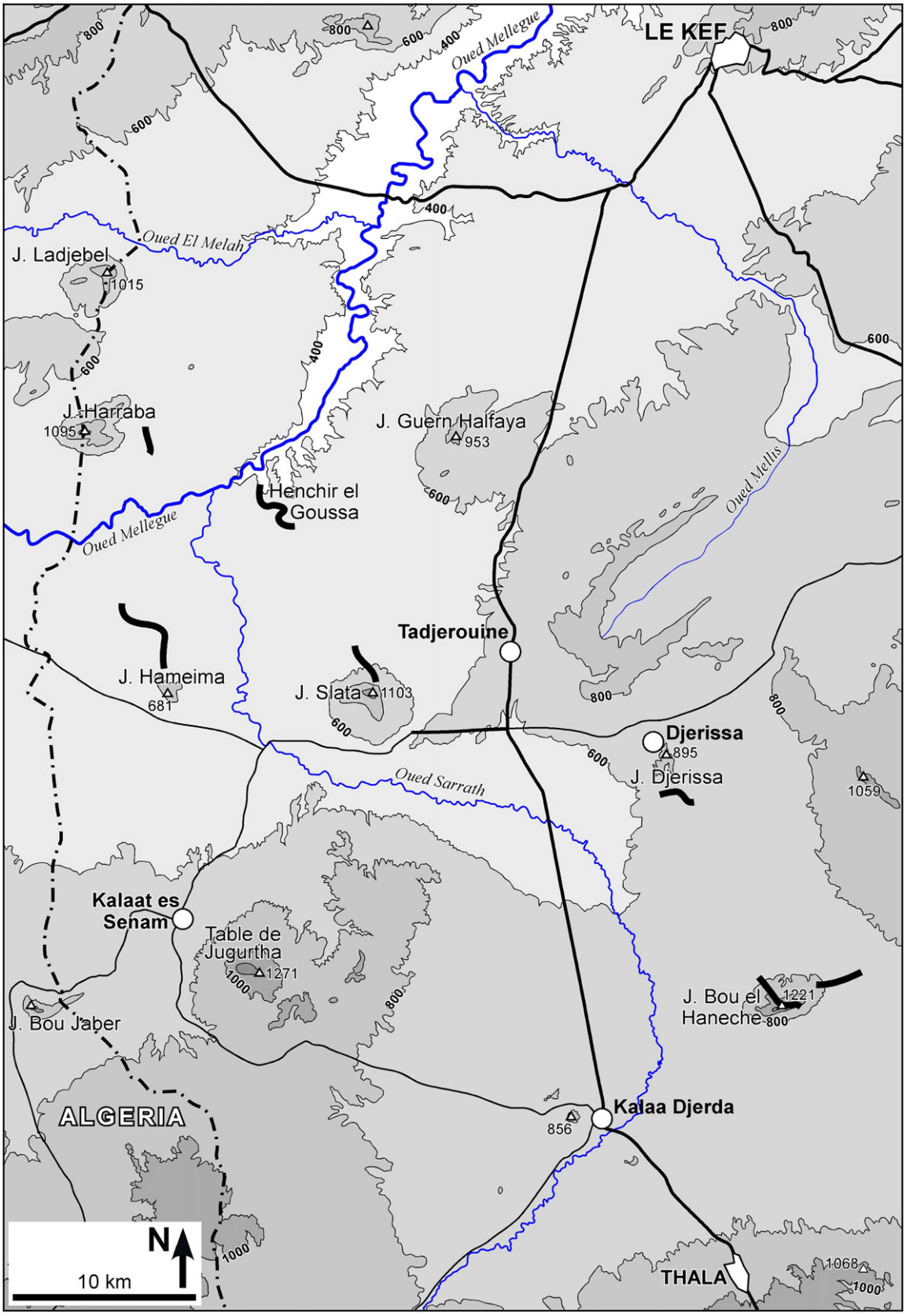

Fig. 2. Location map of the main studied sections (location on Fig. 1). From northwest to southeast: Jebel Harraba, Sidi Embarka section; Henchir el Goussa, El Goussa section; Jebel Hameima section; Jebel Slata, Charens section; Jebel Djerissa, Djerissa section; Jebel Bou el Haneche, Bou el Haneche section.

strata in the Hameima Formation, as did El Euchi (1993) further south. More recently, Zghal and Arnaud-Vanneau (2005) and Jaillard et al. (2005) presented preliminary results on the Aptian–Albian succession in the Tadjerouine area, and the paleontological

study of our ammonite collection is currently being published by Latil (2010).

In the Tadjerouine area, Burollet (1956) divided the Aptian–Albian interval into: (1) The Serdj reefal massive limestones of probable Aptian age, the top of this limestone may locally be of Albian age (Burollet 1956, p. 66); (2) The Hameima Formation (≈300 m thickness), made of shales, dolomites, limestones and sandstones of approximately Late Aptian age; and (3) the Fahdene Formation, mainly made of dark marls and shales, which comprises several informal units:

- *Lower Shale (300 m)*: dark shales and marls, which include a noticeable "ammonite-rich horizon" ascribed to the "Clansayes zone", considered by Burollet (1956, p. 72) as earliest Albian, but now referred to the latest Aptian (Flandrin, 1965; Burollet et al., 1983).
- *Allam limestones (180 m)*: black massive limestones and dark marls, ascribed to the Middle Albian.
- *Middle Shale (280 m)*: black shales and marls, dated as Late Albian.
- *Mouelha limestones (50 m)*: black laminated limestones of Late Albian age, and
- *Upper Shale (more than 1200 m)*: black shales with some marly intercalations, of uppermost Albian ("Vraconnian", ≈400 m) and Cenomanian age (≈800 m).

The studied sections allowed us to examine the Hameima Formation, and the Lower Shales and Allam limestone units of the Fahdene Formation.

4. Lithostratigraphy and fauna

4.1. Serdj Formation

Burollet (1956) defined the "Serdj Limestones" as massive limestones and dolomites, rich in reefal to peri-reefal faunas such as rudistids, corals and benthic foraminifera. The Serdj Formation (M'Rabet, 1981), mainly of Aptian *p.p.* age is assumed to be diachronous, and its top may reach the Albian (Burollet, 1956). This assumption has been supported by a detailed study of the formation in its type location (Jebel Serdj, northeastern Tunisia) by Tlatli (1980).

In Jebel Harraba, 30 m below the top of the Serdj Formation, we found several specimens of *Acanthohoplitinae*, and two *Epicheloniceras* sp. of Late Aptian age (Jacobi Zone). However, the latter seem to be reworked, because they show signs of transport and bio abrasion, and they are phosphatised. This latter lithology does not correspond to that of the surrounding shaly succession.

4.2. Hameima Formation

Burollet (1956) defined the "shales with sandy interbeds of Hameima" (now known as the Hameima Formation, *e.g.* M'Rabet et al., 1995) as a "black to dark green shale succession, with numerous thick interbeds of sandstone, dolomite and biogenic limestone".

In the Tadjerouine area, the 150–230 m thick Hameima Formation directly overlies the Serdj Formation (Fig. 3). The Hameima Formation is not exposed in El Goussa (Fig. 2), where the section begins at the top of the Hameima Formation. The basal contact of the Hameima Formation is at the top of the uppermost thick, massive, rudistids and chondrodonts bearing limestone (or dolomite) bed of the Serdj Formation. The upper contact is at the top of the uppermost thick bed of sandstone (El Goussa and Hameima areas) or limestone (other sections), and at the base of the lowermost thick argillaceous marly interval of the Fahdene Formation. The Hameima Formation is mainly made of massive limestone layers, locally rich in orbitolinids, separated by thick marl intervals, and usually comprises quartz arenite intercalations. A laterally constant sandstone interval ("Clansayes Sandstones" of Vila et al., 1995) allows us to subdivide the Hameima Formation into three lithologic members (Fig. 3).

4.3.1. The Lower Member

The Lower Member is 70–120 m thick and rests on the massive carbonate bed of the top of the Serdj Formation. The top of this unit is marked in all sections by a thick limestone bed, usually caved by deep karsts, locally filled with iron-rich mineralizations. This member mainly consists of marls and limestones, rich in orbitolinids at the base, with few beds of calcareous sandstones in the lower and upper parts. Marly beds are rich in echinoids (sea urchins), bivalves, but also contain some brachiopods and gastropods, and scarce ammonites. The limestone beds display orbitolinids, pectinids and oysters. The Hameima section exhibits a dominantly marly succession, while limestone beds are more numerous in the Slata and Djerissa sections (Fig. 3). In the same way, the Djerissa and Bou el Haneche sections commonly exhibit crinoid-rich calcarenitic beds.

In the nearby section of Jebel Ouenza (Eastern Algeria), Dubourdieu (1956, p. 56) collected from this member *Knemiceras compressum* and *Douvilleiceras* gr. *albense-monile*, and concluded surprisingly a latest Aptian age (Dubourdieu, 1956, pp. 90–92). During our work, the Lower Member yielded few ammonites, identified as *Acanthohoplitinae*, *Parengonoceras* sp. and *Douvilleiceras* sp. nov.? from the Djerissa section. In the Slata section, the top of this Member yielded "*Hypacanthoplites*" *paucicostatus*, and *Parengonoceras* sp.

4.3.2. The Middle Member

The Middle Member, 35–70 m thick, of the Hameima Formation is marked by the occurrence of abundant sandstone beds ("Clansayes Sandstones" of Vila et al., 1995). The lower part of the unit is usually made of marls and sandstones, with limestone beds in the Djerissa and Bou el Haneche sections (Fig. 3). The middle part is dominated by sandy marls, which grades upward into cross laminated sandstones. The top of the unit is made of thick, orbitolinid-rich limestones, which are thicker toward the southeast (Djerissa and Bou el Haneche sections). The macrofossils in marls and sandstones mainly consist of oysters and pectinids, associated with surbordinate echinoids, annelids, trigonids and other scarce bivalves, corals, gastropods and plant remains. In the Slata, Djerissa and Bou el Haneche sections, the uppermost orbitolinid limestones exhibit scarce annelids, oysters and corals. In the El Goussa and Hameima sections, the Hameima Formation ends up with thick sandstone beds, whereas in the Slata, Djerissa and Bou el Haneche sections, the top is marked by massive orbitolinid-rich limestones (Fig. 3).

The Middle Member yielded scarce, poorly preserved ammonites (Djerissa section), identified as Acanthohoplitinae. In the Hameima section, the top of the Middle Member yielded *Orbitolina* (*Mesorbitolina*) *parva* and *O.* (*M.*) *minuta* (Zghal, 1994; Zghal et al., 1997). However, Zghal and Arnaud-Vanneau (2005) quoted *Mesorbitolina parva* and *Praeorbitolina wienandsi*, the association of which is classically ascribed to the lower part of the Upper Aptian.

4.3.3. The Upper Member

The Upper Member is 0–55 m thick and exhibits various successions. It mainly comprises marls and limestones, with subordinate sandy limestone beds (Djerissa section, Fig. 3), and includes glauconitic/phosphatic, or clast rich layers. The fauna consists of oysters, pectinids, pinnids, brachiopods (Bou el Haneche) and scarce ammonites. However, some massive limestone beds are still rich

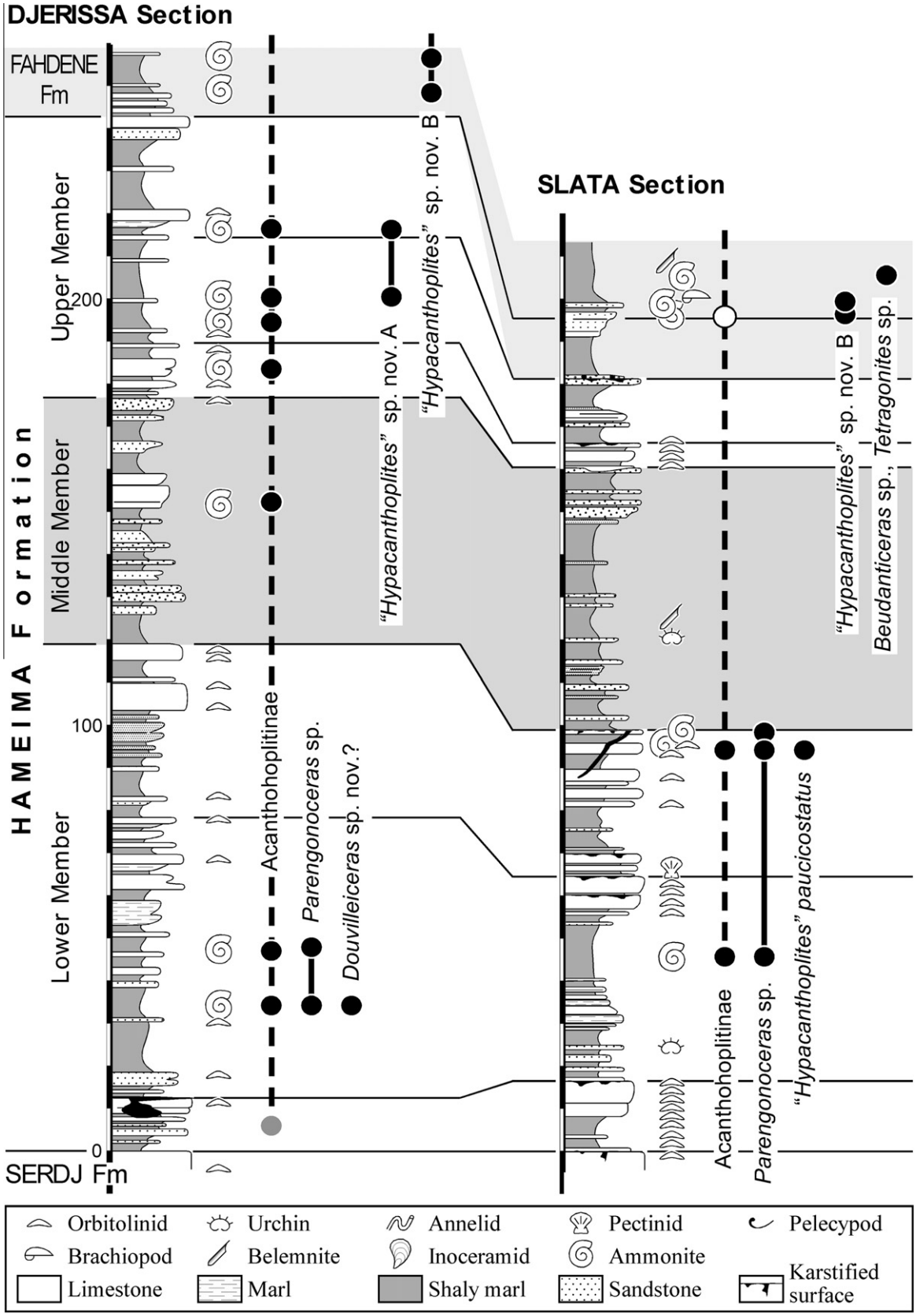

Fig. 3. Distribution of ammonites in the Hameima Formation along the Djerissa and Slata sections. Grey dots: location of ammonites from the Harraba section. White dots: reworked ammonites.

in orbitolinids, and locally in red algae and annelids. This unit seems to be thinner and richer in marls toward the Northwest (Slata section). Shallow karsts are visible on top of some beds of the south-eastern sections (Djerissa and Bou el Haneche, Fig. 3).

In a faulted outcrop located southwest of Jebel Bou el Haneche, the Upper Member of the Hameima Formation yielded a *Douvilleiceras* sp. (determination Arnould-Saget, in Burollet, 1956, p. 71), indicating a Lower Albian age. Our ammonite fauna is made of Acanthohoplitinae. In Jebel Djerissa, we collected "*Hypacanthoplites*" sp. nov. A in the middle part of this member (Fig. 3).

4.4. Fahdene Formation

Burollet (1956) defined the "Fahdene marls and shales" (usually named Fahdene Formation, M'Rabet, 1981; Burollet et al., 1983; M'Rabet et al., 1995) as "a very thick series of marine, grey to black marls and shales, with a few beds of limestones or marly limestones", which "rest on the Serdj limestones, where present". The type locality of the Fahdene Formation is located in the centre of the Oued Bahloul anticline, southeast of Makthar (Burollet, 1956). In this paper, we examine the lower part of the Fahdene Formation, *i.e.* the Lower Shales, the Allam Limestones, and the base of the Middle Shales (Fig. 4).

4.4.1. The Lower Shale Member

The Lower Shale Member is 180 m (Bou el Haneche) to 400 m thick (El Goussa). Although it consists mainly of monotonous marl and shale accumulations, the unit exhibits calcareous to marly intercalations, thus defining a basal, median and upper shaly unit. This member has not been studied in the Djerissa section. The base of the Lower Shale Member is defined as the first thick shaly level overlying the uppermost massive sandstone or limestone bed of the Hameima Formation.

4.4.1.1. The basal shale unit. The basal shale unit is mainly known in the El Goussa and Hameima section, where it is 55–60 m thick (Fig. 4). It consists mainly of dark green shales, with few thin calcareous interbeds, and locally phosphatic nodules. In the Hameima section, the lower part of this unit is marked by a thickening upward series of bioturbated, sandy limestones, exhibiting storm laminations near the top. There, the fauna associated with the sandy limestones consists of ammonites, oysters, pectinids, trigonids, sea urchins, and scarce plant remains. This sandy interval seems to be lacking in the El Goussa section, where large scale slump structures can be observed. The upper shaly part of the unit yielded only ammonites, with scarce oysters and gastropods. In the Slata section, this unit may be represented by a 15 m thick, undated shaly interval.

Ammonites collected from the basal shale unit were determined as "*Hypacanthoplites*" *paucicostatus*, *Parengonoceras* sp. and Acanthohoplitinae indet. in the lower part, and "*Hypacanthoplites*" *ouenzaensis*, *Douvilleiceras* sp. nov.?, *Parengonoceras* sp. and "*Hypacanthoplites*" sp. in the upper part (Fig. 4). The occurrence of both "*H.*" *paucicostatus* and "*H.*" *ouenzaensis* indicates that the basal shale unit is at least in part coeval with the Upper Member of the Hameima Formation of the south-eastern sections, thus indicating a lateral facies change from the northwest to the southeast.

4.4.1.2. The first carbonated interval. The first carbonated interval is 45–60 m thick, and corresponds to the "Ammonite-rich horizon" of Burollet (1956). In the Djerissa and Bou el Haneche sections, the Fahdene Formation seems to begin directly with the "Ammonite-rich horizon". In contrast to the underlying shales, the "Ammonite-rich horizon" consists of alternating limestones and dark bioturbated, argillaceous marls, locally rich in pyrite. In the Slata section, this unit is represented by a 1–20 m thick series of coarse grained, bioclastic limestones, locally sandy. In the Hameima, Slata and Bou el Haneche sections, it contains ammonites, associated with belemnites, sea urchin fragments, brachiopods, pectinids, oysters and other bivalves (Fig. 4), whereas in the El Goussa section it only yielded ammonites and scarce belemnites.

From these layers, Burollet (1956, p. 74) and Dubourdieu (1956, p. 152, 160, 163) mentioned ammonite faunas made of *Douvilleiceras* and *Acanthohoplitinae*, ascribed to the "Clansayes zone". In the "Ammonite-rich horizon", we collected numerous specimens of "*Hypacanthoplites*" nov. sp., associated with *Douvilleiceras* sp. and desmoceratids (Fig. 4). This horizon has been recognized in all the studied sections.

4.4.1.3. The intermediate shale unit. The intermediate shale unit is 70–130 m thick (Fig. 4). It consists of dark shales, with scarce thin beds of marly limestones, containing abundant pyrite concretions, and locally dark green phosphatic nodules. No fauna but ammonites have been observed in the Hameima and El Goussa sections, while echinoids, oysters, pectinids and other bivalves occur in the Bou el Haneche section. Bioturbation is rare and horizontal laminations are commonly observed. In the Slata section, the intermediate shaly unit is represented by a 35 m thick series of dark shales, yielding few poorly preserved pyritous ammonites.

The base of this unit is marked by the first local occurrence of *Prolyelliceras gevreyi*. The other collected ammonites consist of desmoceratids, *P. gevreyi*, *Mirapelia advena* and scarce reworked *Acanthohoplitinae* (Fig. 4).

4.4.1.4. The second carbonated interval. The second carbonated interval is 20–70 m thick (Fig. 4). In the El Goussa and Hameima sections it consists of alternating shales with pyrite concretions, and bioturbated marly limestones. The base is commonly marked by a calcareous bed containing phosphatized clasts, which forms a conspicuous correlation bed (Dubourdieu, 1956; Zghal, 1994; Zghal et al., 1997). The faunal content is dominated by belemnites, irregular echinoids and ammonites to the northwest, and by pectinids, ammonites and subordinate brachiopods to the southeast. Oysters and gastropods are also present. This unit seems to be reduced in the Bou el Haneche section (20 m). In the Slata section, the second carbonate interval is made of a 25 m thick succession of phosphatic, coarse grained bioclastic limestones, with few shaly layers.

In this unit, we collected the following ammonites: *P. gevreyi* (only in the lower part), *Mirapelia* cf. *alticarinata*, *Beudanticeras* sp. and *Desmoceras* (*Desmoceras*) *latidorsatum*.

4.4.1.5. The upper shale unit. The upper shale unit is 20–70 m thick, and is chiefly made of dark shales, rich in pyrite concretions, locally bioturbated, with few thin beds of marl (Fig. 4). Macrofossils are dominated by pyritous ammonites localised in few layers, and belemnites associated with subordinate brachiopods, pectinids and other bivalves. In the Slata section, it is 55 m thick and contains a few sea urchins. This unit thickens toward the northwest.

The pyritous ammonite levels have been recognized by Pervinquière (1907), Dubourdieu (1956) and Burollet (1956). In this unit, we collected the following ammonites: *Prolyelliceras radenaci*, *D. mammillatum*, *Beudanticeras revoili*, *B. dupinianum africanum*, *Phylloceras* (*Hypophylloceras*) *velledae*, *Ptychoceras hamaimensis*, *Pictetia astieriana*, *Silesitoides thos*, *Desmoceras* sp., *Protanisoceras* (*Protanisoceras*) cf. *acteon*, *Anisoceras* sp. and *Puzosiinae* (Fig. 4). In the Bou el Haneche section the top of the unit yielded *Tegoceras mosense* (Fig. 5).

4.4.2. The Allam Limestone Member

The Allam Limestone Member is 110 m (Hameima, Djerissa) to 180 m thick (El Goussa, Bou el Haneche) (Fig. 4 and 5). Burollet (1956) described the "Allam Limestones" as hard, fine-grained black limestones, which alternate with dark shales and marls, containing belemnites and poorly preserved ammonites (*Puzosia* sp.).

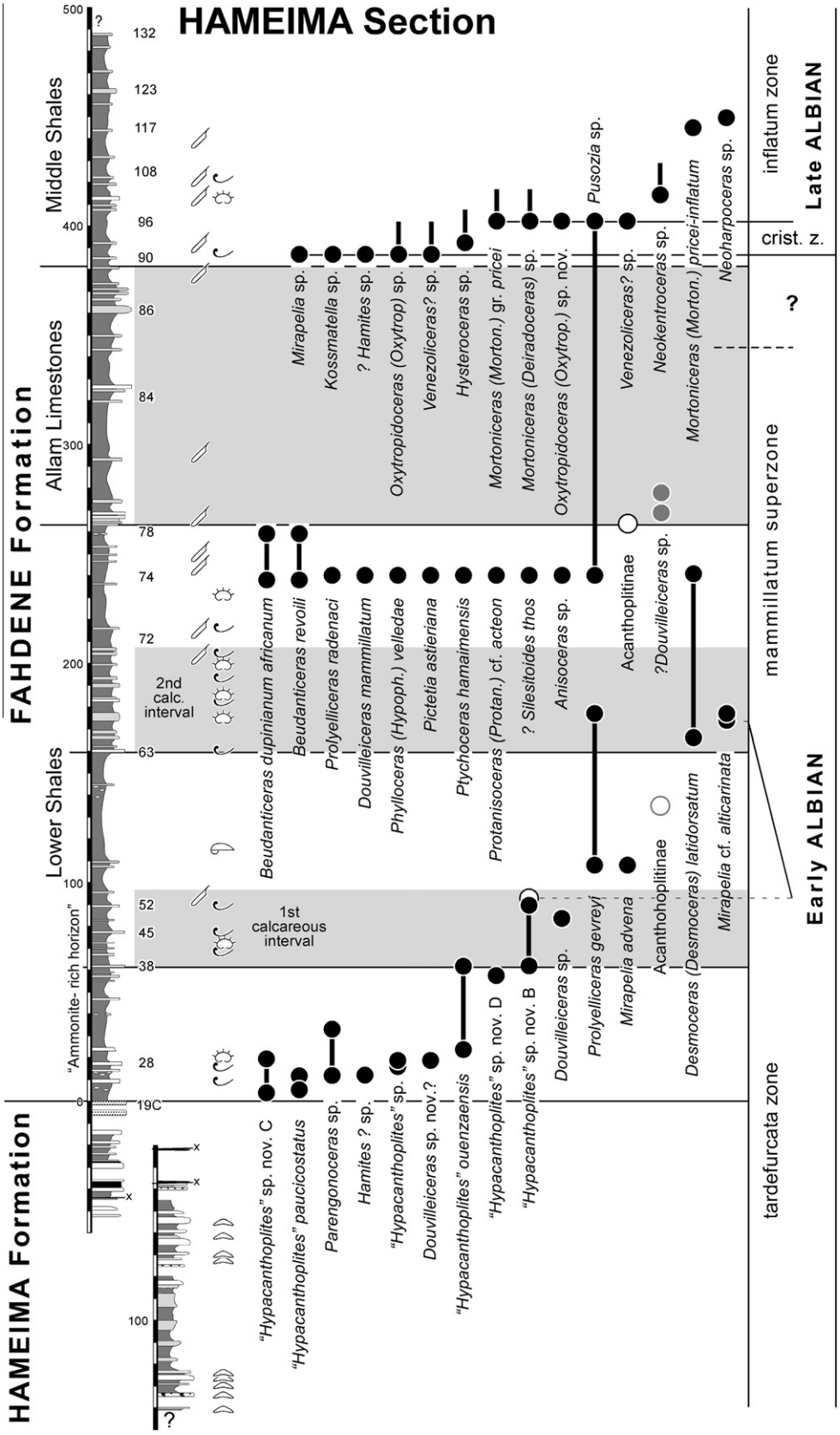

Fig. 4. Distribution of ammonites in the Fahdene Formation along the Hameima section. Black dots: ammonites from the Hameima section. White dots: reworked ammonites. Shaded areas: carbonate intervals. For caption, see Fig. 3.

He ascribed the Allam Limestones to "approximately the Middle Albian". Dubourdieu (1956) also ascribed this non-fossiliferous unit to the Middle Albian.

According to our observations, the Allam Member is made of fine-grained black laminated limestones, interbedded within dark grey shales rich in pyrite, and containing locally small scale oil

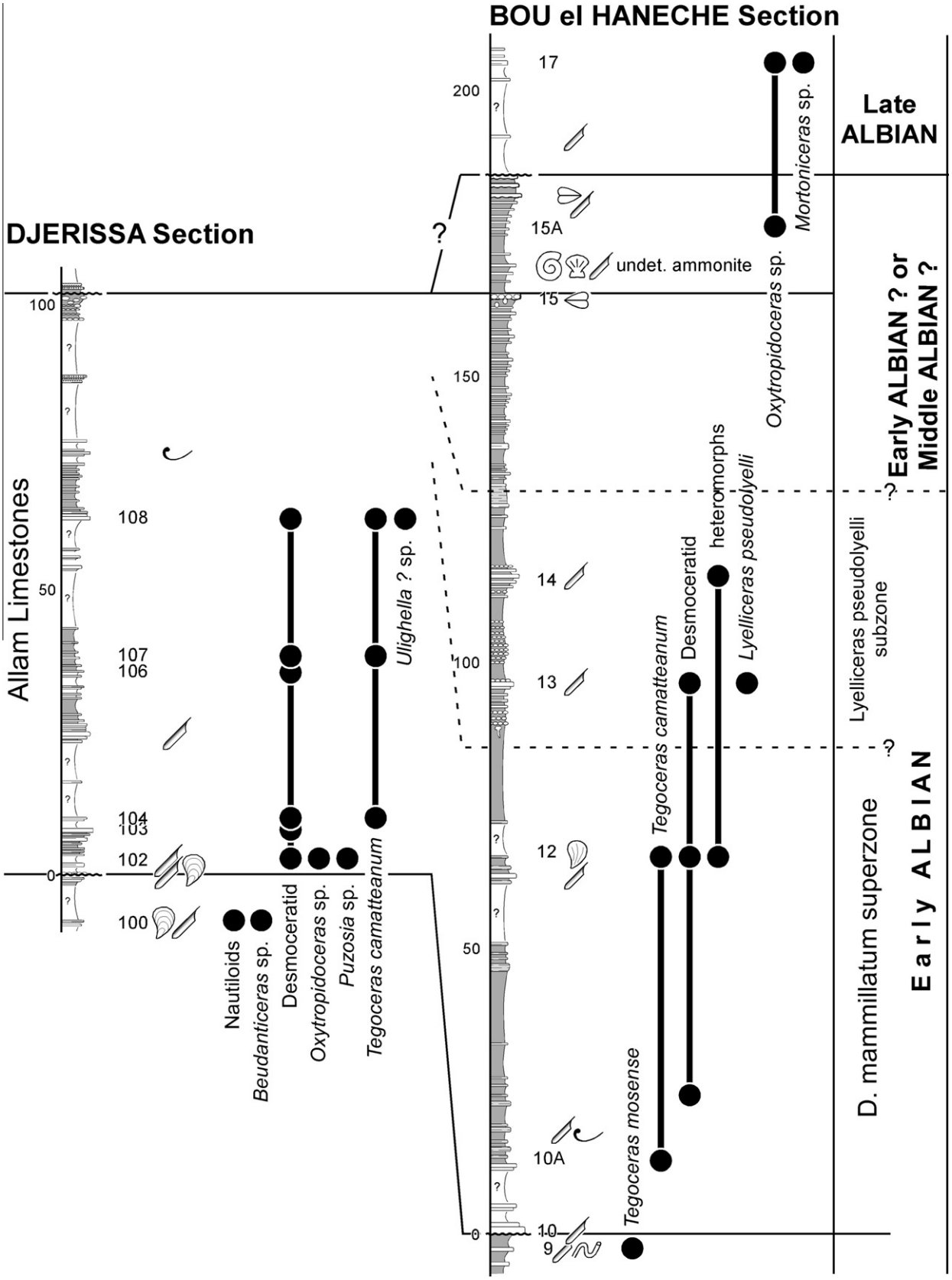

Fig. 5. Distribution of ammonites in the Allam Limestones (Fahdene Formation), along the Djerissa and Bou el Haneche sections. For caption, see Fig. 3.

seeps. In the Djerissa section, the base of the unit is locally marked by a limestone bed containing phosphatized clasts, whereas in the Slata section it is marked by bioclastic and finely sandy limestones, rich in phosphate and glauconite (Fig. 5). The uppermost part of the

unit is commonly silicified (El Goussa, Hameima, Djerissa, Bou el Haneche), and commonly contains abundant, large limestone nodules. The fauna mainly consists of belemnites, associated with scarce ammonites, costulated or inoceramid-like small bivalves, and fish remains.

From the Allam Limestone Member, we collected at the base: *Beudanticeras* sp., *Ulighella* sp., *Douvilleiceras* sp., *Oxytropidoceras* sp., *Pusozia* sp. and *Desmoceratids* (Fig. 4 and 5). In the Djerissa and Bou el Haneche sections, the lower part (60–70 m) of the Allam Limestone Member yielded *Tegoceras camatteanum*, while its middle part yielded one specimen of *L. pseudolyelli* in Bou el Haneche (Fig. 5). The upper part is barren of ammonites.

4.4.3. The Middle Shale Member

The Middle Shale Member of the Fahdene Formation rests conformably on the commonly silicified top of the Allam Limestone Member. Only the base of this member has been studied in detail, because good outcrops are scarce.

The Middle Shale Member is not silicified, and consists of dark shales with few thin beds of bioturbated marl. The macrofauna consists of numerous crushed ammonites, associated with less common belemnites, and scarce echinoids and bivalves. The very base of the unit is locally rich in glauconitic grains (El Goussa) or fine-grained sandstone (Hameima, Slata).

In the Hameima section, the very base (5 m) of the Middle Shale Member yielded *Hamites* sp., *Kosmatella* sp. and *Mirapelia* sp., together with *Venezoliceras* sp. and *Oxytropidoceras* (*Oxytropidoceras*) sp. (Fig. 4). Higher up in the Hameima section, and in other sections, the ammonite association consists of *Mortoniceras* (*Deiradoceras*) sp., *Mortoniceras* (*Mortoniceras*) sp., *Oxytropidoceras* sp., *Venezoliceras* sp., *Hysteroceras* sp., *Neokentroceras* sp., *Puzosia* sp., indicative of a Late Albian age (Mortoniceras pricei Zone).

5. Biostratigraphy

5.1. Top of the Serdj Formation

The occurrence of reworked *Epicheloniceras* sp. at Jebel Harraba, 40 m below the top of the Serdj Formation, indicates that the age of the top of the Serdj Formation must be considered as latest Aptian or younger, *i.e.* close to the Aptian–Albian boundary, because *Epicheloniceras* sp. indicates the Late Aptian.

In various places of eastern Algeria and central Tunisia, and especially in Jebel Hameima, the top of the Serdj Formation yielded the following association of benthic foraminifera: *Archaealveolina reicheli*, *Paracoskinolina tunesiana*, *Mesorbitolina texana*, *M. minuta*, as well as calpionellids: *Colomiella mexicana* and *C. recta* (Bismuth, 1973; Fourcade and Raoult, 1973; Tlatli, 1980; Cherchi and Schroeder, 1982; Zghal, 1994; Zghal et al., 1997). Although *A. reicheli* is locally mentioned in earliest Albian deposits (Dinarides; Husinec et al., 2000; Velic, 2007), *A. reicheli* and *P. tunesiana* are usually regarded as early Late Aptian in age (Bismuth, 1973; Peybernès, 1982; Zghal, 1994; Arnaud-Vanneau, 1998). On the other hand, the association of *M. texana* and *M. minuta* would indicate a Late Aptian age in northern and western Africa, although it reaches the Early Albian in eastern Africa (Peybernès, 1982). However, because *C. recta* first occurs soon after the base of the Albian, the association of *C. mexicana* and *C. recta* indicates an earliest Albian age (Reháková and Michalik, 1997; Días-Brito, 1999 *in* Días-Brito and Ferré, 2001). This, combined with our ammonite findings, suggests that the age of the top of the Serdj Formation is close to the Aptian–Albian boundary. As a consequence, *A. reicheli* and *P. tunesiana*, as well as the *M. texana–M. minuta* association should be considered as reaching the latest Aptian, or even the earliest Albian (see discussion below).

5.2. Hameima Formation

The Lower Member of the Hameima Formation yielded *Acanthohoplitinae*, *Parengonoceras* sp., *Douvilleiceras* sp. nov.? (Plate 1, Fig. 1 and 2) and "*Hypacanthoplites*" *paucicostatus* (at the top). The Middle Member of the Hameima Formation did not yield diagnostic fauna, while the Upper Member of the Hameima Formation contains *Douvilleiceras* sp. (Burollet, 1956) and Acanthohoplitinae.

Douvilleiceras of the group of *D. leightonense* are known from the middle part of the *L. tardefurcata* Zone (sensu Owen, 2002) to the lower part of the *D. mammillatum* Zone (Owen, 1988; Kennedy et al., 2000), while parahoplitids (among which Acanthohoplitinae) became extinct before the end of the *L. tardefurcata* Zone (Kennedy et al., 2000). Therefore, the Hameima Formation is ascribed to the *L. tardefurcata* Zone (first ammonite zone of the Early Albian, Fig. 6), except the very base that may be of latest Aptian age, because it yielded only Acanthohoplitinae. Note that the *Douvilleiceras* specimens found in the Lower Member of the Hameima Formation (Dubourdieu, 1956; this work; Pl. 1) are the oldest

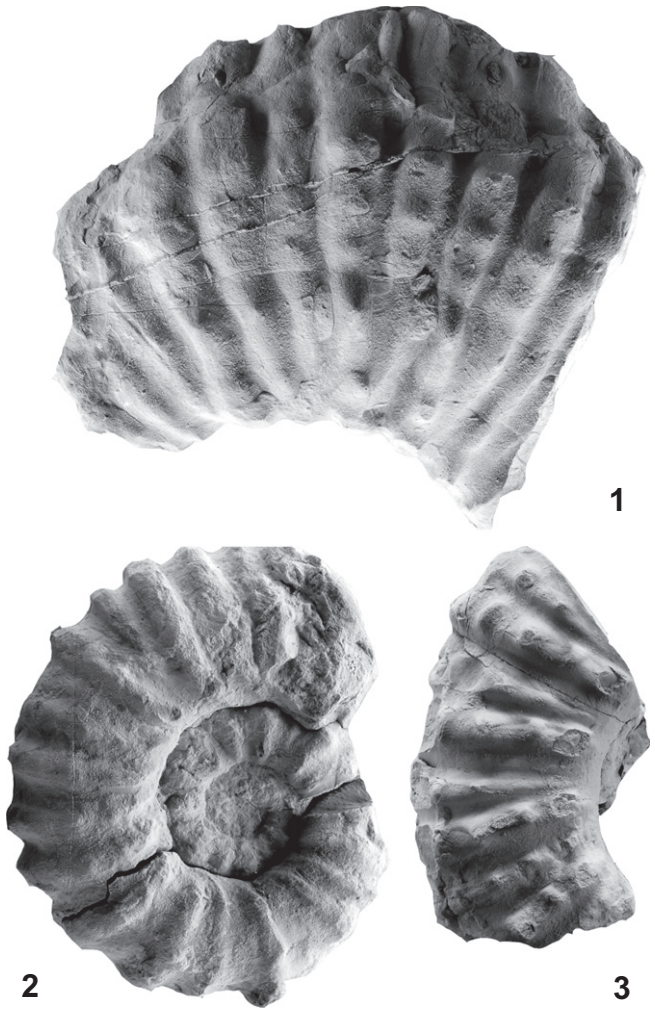

Plate 1. Albian ammonites from the Hameima Formation and from the Lower Shales of the Fahdene Formation. 1: *Douvilleiceras* sp. nov. ?, FSL.596316, Level 4b of SW Ouenza section, Algeria (Dubourdieu, 1956, p. 56). Lower part of *Leymeriella tardefurcata* zone, early Lower Albian. (x 0.8). 2: *Douvilleiceras* sp. nov. ?, UJF-ID. 10715, bed J.O, Jebel Jerissa section, Tunisia. Lower Member of Hameima Fm, *Leymeriella tardefurcata* zone, early Lower Albian. (x 0.8). 3: *Douvilleiceras* sp. nov. ?, UJF-ID. 10716, bed 28 of Hameima section, Jebel Hameima, Tunisia. Lower Shales of Fahdene Fm (Lower part), *Leymeriella tardefurcata* zone, early Lower Albian. (x 0.8). Specimen repository: FSL, Université Claude Bernard Lyon 1, France; UJF-ID, Université Joseph Fourier, Institut Dolomieu, Grenoble.

known representatives of the genus *Douvilleiceras* in North Africa, providing, however, an unequivocal Lower Albian age for these beds. The ontogeny of the Tunisian specimen with persistent primitive morphology on early whorls, clearly differentiates this specimen from all other known *Douvilleiceras* (Latil, 2010). It probably deserves a species status, but our material is not sufficiently well preserved for that.

5.3. Biostratigraphic discussion

Zghal (1994) and Zghal et al. (1997) reported *M. parva* and *M. minuta* from the upper part of the Lower Member of the Hameima Formation, and ascribed this unit to the Late Aptian. More recently, Zghal and Arnaud-Vanneau (2005) mentioned *M. parva* and *P. wienandsi* from the same beds, suggesting an age close to the Early to Late Aptian boundary. The currently admitted age of benthic foraminifers such as *A. reicheli*, *P. tunesiana*, *M. texana*, *M. minuta*, and *M. parva* has been mainly determined using stratigraphic sections bearing both foraminifers and ammonites in Algeria and Tunisia (*e.g.* Fourcade and Raoult, 1973; Bismuth, 1973; Cherchi and Schroeder, 1982). The conflicting ages indicated by ammonites and benthic foraminifers in the studied sections seem to arise mainly from two facts.

First, the ammonite fauna reported from these sections is mainly made up of species of Acanthohoplitinae, which are highly endemic forms, only rarely associated with cosmopolitan species. In the Ouenza massif (Algeria, about 30 km west of the Tajerouine area), Dubourdieu (1956) found, associated with numerous Acanthohoplitinae, a species determined as *Douvilleiceras* gr. *albense-monile* (Pl. 1, Fig. 1) near the base of what is now called the Hameima Formation (40–80 m above the massive limestones equivalent to the Serdj Fm; Dubourdieu, 1956, p. 56). Although he acknowledged that this ammonite usually indicates a late Early Albian to earliest Middle Albian age, he ascribed this unit to the Late (not latest) Aptian because of the admitted range of the associated Acanthohoplitinae ammonites (Dubourdieu, 1956, p. 92). Conversely, near the base of the Fahdene Formation of the Hameima section, Burollet (1956) quoted in his "ammonite-rich horizon", several Acanthohoplitinae and a *Douvilleiceras bigoureti*. He ascribed, therefore, this level to the Early Albian "Clansayes zone included" (*e.g.* Burollet, 1956, p. 72). However, following the conclusions of the colloquium of Lyon, 1963, the "Clansayesian stage" has been included into the Late Aptian (Flandrin, 1965), thus adding confusion to the age assignments of these Acanthohoplitinae faunas.

Second, in the sections described in the Constantine area, ammonites and benthic foraminifera have not been found in the same beds, and therefore, age assignments of the foraminifera remained speculative. In Kef Hahouner (NE of Constantine, Fourcade and Raoult, 1973), the upper part of a 200-m thick series of massive limestones ("terme E"), contains *A. reicheli*, *P. tunesiana* and *M. tex-*

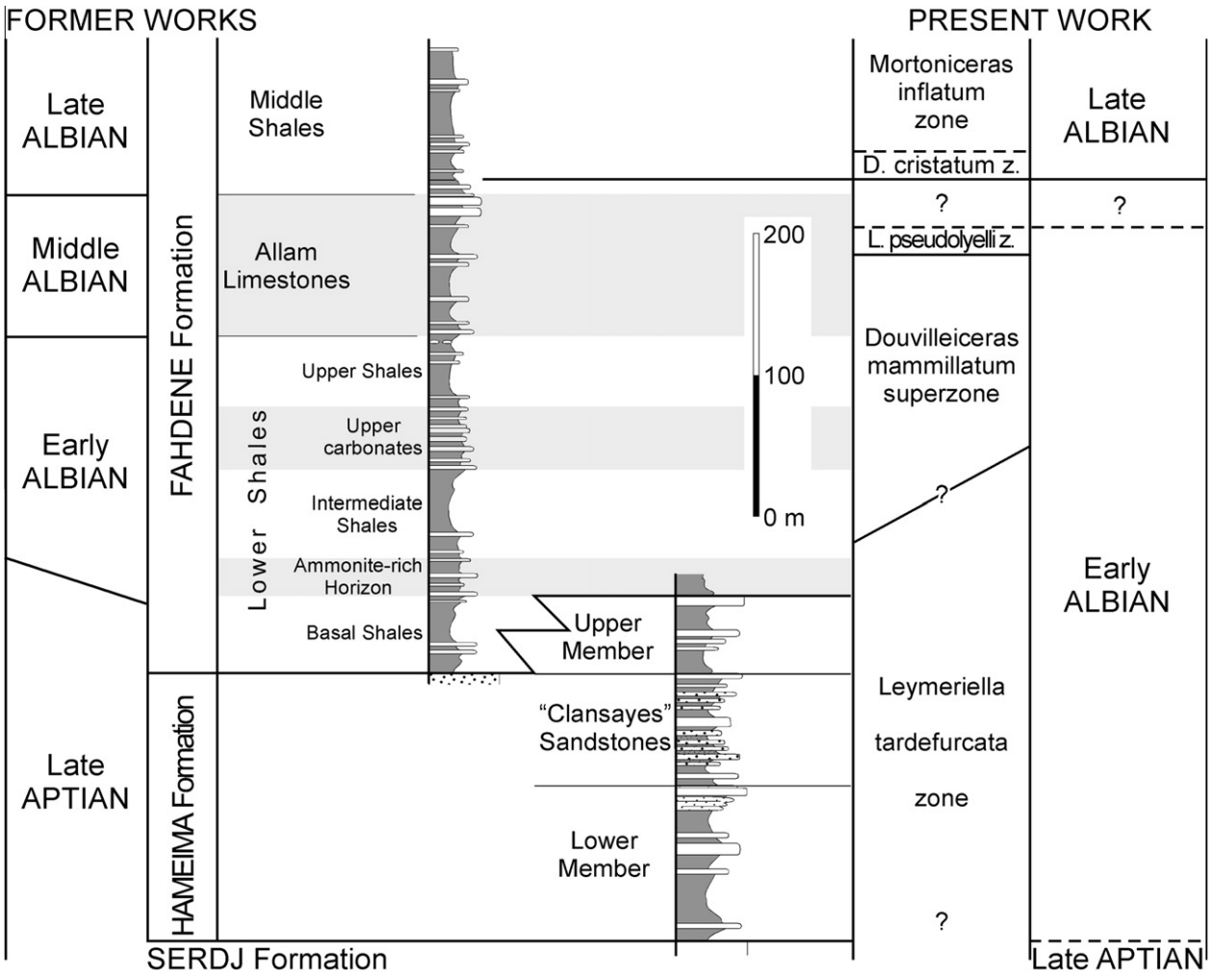

Fig. 6. Synthetic stratigraphic column of the Albian series in the Tadjerouine area, and comparisons between former, and proposed age attributions. For caption, see Fig. 3.

ana, and is overlain by a 40 m-thick series of thinly bedded limestones, and then by nodular, ammonite-bearing limestones (“terme F” of Fourcade and Raoult, 1973). The ammonite fauna from the “terme F” was examined by Breistroffer (*in* Fourcade and Raoult, 1973, p. 233), who mentioned that “all these ammonites are too big and poorly preserved and do not allow reliable determinations”, and concluded nevertheless that the fauna is most probably of Late Aptian (Gargasian) age. After quoting that some ammonite identifications suggest an older age (p. 233), Fourcade and Raoult (1973) concluded that *A. reicheli* and *P. tunesiana* are of Late Aptian (Gargasian) age.

Revising the same section, Cherchi and Schroeder (1982) questioned this age, and ascribed the “terme F” of Kef Hahouner to the latest Aptian (“Clansayesian”). On the other hand, Cherchi and Schroeder (1982) mentioned that in Jebel Dahar the *A. reicheli–P. tunesiana* association has been ascribed to the Albian. Finally, Cherchi and Schroeder (1982) mentioned that in Jebel Sidi Rehris (Constantine area), the *A. reicheli–P. tunesiana* association is found in the 50 m-thick upper part of a massive limestone series. These beds are located 20 m above a marly bed with *Hypacanthoplites* species of latest Aptian age (Late Clansayesian), and 10 m below a marl series that yielded *Desmoceras* species, of Early to Middle Albian age. Cherchi and Schroeder (1982) concluded that the *A. reicheli–P. tunesiana* association is of latest Aptian age, although the presented data only indicate a latest Aptian to Early Albian age for the *A. reicheli–P. tunesiana* association.

In the same work, Cherchi and Schroeder (1982) ascribed the microfauna found at the top of the Serdj Formation (*A. reicheli–P. tunesiana* and *C. mexicana–C. recta*) in the Hameima section to the early Late Aptian (Gargasian), based on the fact that they are located 300 m below the “ammonite-rich horizon” of Burollet (1956), which they ascribed to the latest Aptian (“Clansayesian”). The same reasoning has been applied by Bismuth (1973), who ascribed to the early Late Aptian (Gargasian), the *A. reicheli* found at the top of the Serdj Formation, because they are located “*much below a fossiliferous horizon bearing ammonites of the Clansayes zone*” (Bismuth, 1973, p. 184). However, we already mentioned that the “ammonite-rich horizon” yielded a specimen of the *Douvilleiceras* genus (Burollet, 1956), that ensures an Early Abian age for this level.

This succession of misinterpretations of French-speaking workers probably explains why the *M. parva–M. texana–M. minuta* association has been assigned to the early Late Aptian in the French-speaking African countries (Tunisia, Algeria, Morocco, Senegal), whereas it is considered of Late Aptian and earliest Albian age in English-speaking African countries (Tanzania, Somalia) (Peybernès, 1982). Whatever the case, our ammonite collections (Latil, 2010) indicate that the *A. reicheli–P. tunesiana* association, found at the top of the Serdj Formation, reaches the latest Aptian, and that *M. parva* and *M. minuta*, determined from the Hameima Formation, reach the earliest Albian (*L. tardefurcata* Zone). The mention of *P. wienandsi* in the Hameima Formation probably results from a wrong identification.

5.4. Fahdene Formation: Lower Shale Member

In the basal shales unit and for most of the first carbonate interval, the association of *Douvilleiceras* sp. nov.? (Plate 1, Fig. 3) and Acanthohoplitinae indicates an age included in the *L. tardefurcata* Zone. The upper part of the first carbonate interval records the last local occurrence of Acanthohoplitinae (bed 52), followed by the first local occurrence of *P. gevreyi* (Fig. 4). Because *P. gevreyi* is known elsewhere in the *L. tardefurcata* Zone (Kennedy et al., 2000), the first carbonate interval is ascribed to this time-span (Fig. 6).

The intermediate shale unit of the Lower Shale Member yielded *P. gevreyi* and *M. advena*. Because of the known range of these two species (Kennedy et al., 2000), the intermediate shales can be ascribed to the late part of the *L. tardefurcata* Zone (Fig. 6).

The second carbonate interval records the first local occurrence of *M.* cf. *alticarinata* (bed 67) and the last local occurrence of *P. gevreyi* (bed 68, Fig. 4). Since *M. alticarinata* is only known from the *D. mammillatum* Zone (Owen, 1988), *P. gevreyi* does not seem to be restricted to the *L. tardefurcata* Zone, as previously assumed (Kennedy et al., 2000). Whatever the case, the co-occurrence of these two species suggests an age comprised within the *D. mammillatum* Zone (middle and upper part of the Lower Albian; Fig. 6). The occurrence of *T. mosense* at the top of the Lower Shale Member suggests an age close to the *L. pseudolyelli* Subzone (last ammonite subzone of Lower Albian age) for this level.

Zghal (1994) and Zghal et al. (1997) quoted the first local occurrence of *Hedbergella rischi* and *Ticinella primula* a few meters above the base of the second carbonate interval. This has been taken as indicative of a Middle Albian age (Zghal, 1994; Zghal et al., 1997), as assumed by several workers (*e.g.* Premoli-Silva and Sliter, 1995; Bellier and Moullade, 2002). However, this association has been reported from Early Albian (Luciani et al., 2004) or even Late Aptian strata (Cobianchi et al., 1997). Our data suggest that *T. primula* and *H. rischi* co-occur in Tunisia within the *D. mammillatum* superzone and before the beginning of the *L. pseudolyelli* Zone, of late Early Albian age.

5.5. Fahdene Formation: Allam Limestone Member

Beside non-diagnostic ammonites collected near the base of the unit, the Allam Limestones yielded several *T. camatteanum* in the lower part of the succession, while *L. pseudolyelli* was found in the middle part of the Allam Limestone Member (Fig. 5). Therefore, the lower part of the member can be ascribed to the upper part of the *D. mammillatum* superzone, while its middle part is of upper Lower Albian age (*L. pseudolyelli* zone; Latil, 1995). However, the undated upper part of the section (40–60 m in the Jerissa and Bou el Haneche sections) may reach the base of the Middle Albian (Fig. 6). Therefore, in the Tadjerouine area, at least part of the Middle Albian substage seems to be lacking, because Upper Albian strata directly overly the Allam Limestone Member (see below).

5.6. Fahdene Formation: Middle Shale Member

At the base of the Middle Shale Member of the Hameima section, evolved forms of *Venezoliceras* sp. and *Oxytropidoceras* (*Oxytropidoceras*) sp. suggest an age within the Dipoloceras cristatum Zone (first ammonite zone of the Upper Albian; Fig. 6). This ammonite association has not been found in the other sections of the Tadjerouine area. A few meters above, the occurrence of *Mortoniceras* (*M.*) gr. *pricei* and *Mortoniceras* (*Deiradoceras*) sp. indicates the Mortoniceras pricei Zone (second ammonite zone of the Upper Albian). At the base of the Middle Shale Member of the Hameima section, the first occurrence of planktic foraminifera such as *Ticinella roberti*, *T.* gr. *raynaudi* and *Biticinella breggiensis* support a Late Albian age (Zghal, 1994; Zghal et al., 1997).

Therefore, the stratigraphic hiatus of Middle Albian age seems to be followed by a diachronous transgressive series, since the base of the Upper Albian Middle Shale Member of the Fahdene Formation would belong to the Dipoloceras cristatum Zone or to the Mortoniceras pricei Zone, according to the sections.

6. Conclusions

In the Tajerouine area, the latest Aptian–early Late Albian interval presents a rather constant lithological succession (except in Je-

bel Slata), the age of which, however, may vary according to location.

In all sections, the Hameima Formation is of Early Albian age (middle part of the *L. tardefurcata* Zone). However, the upper Member of the Hameima Formation, made of marls and orbitolinid limestones in the south-eastern sections (Fig. 3), is coeval with ammonite bearing shales, marls and subordinate sandstones deposited in the north-western sections (base of the Lower Shale Member of Fahdene Fm, Fig. 4). The boundary between the Hameima and Fahdene Formations is therefore diachronous (older in the northwest than in the southeast; Fig. 6).

Although its base is heterochronous, the Lower Shale Member of the Fahdene Formation is of Early Albian age (*L. tardefurcata* Zone, and *D. mammillatum* Zone). This lithological unit thickens toward the northwest, illustrating the paleogeographic transition between the Central Tunisian platform and the North Tunisian basin.

Finally, the Allam Limestone Member is mainly of late Early Albian age (late *D. mammillatum* Zone and *L. pseudolyelli* Zone), although its upper part may belong in part to the early Middle Albian (Fig. 5 and 6). It is directly overlain by early Late Albian shales (Middle Shale Member of Fahdene Fm), the base of which seems to be slightly diachronous. This, together with the probable hiatus of most of the Middle Albian substage (Fig. 6), suggests a major tectonic and/or sedimentary event during the Middle Albian.

These new biostratigraphic data allow revision of the stratigraphic range of some foraminifera. The benthic foraminifera *A. reicheli* and *P. tunesiana* seem to reach the latest Aptian (late "Clansayesian"), while *M. texana* and *M. minuta* reach the earliest Albian (*L. tardefurcata* Zone). In the same way, the planktonic foraminifera *H. rischi* and *T. primula* appear in the late Early Albian in Tunisia.

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