

# Jurassic radiolarian-bearing series of Tunisia: biostratigraphy and significance to western Tethys correlations

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## ABSTRACT

Since the 1970s, radiolarians have been used extensively to study and characterize basin successions from the peri-Mediterranean regions. However, no data was ever produced in Tunisia in spite of the occurrence of Jurassic siliceous series previously described by many authors. Our study presents the biostratigraphical results obtained on sections from the Jédidi Formation, which characterizes the basinal series of the Tunisian Trough. We provide new direct age determinations from the base, the middle part and the top of the formation, which ranges from the latest Bajocian–middle Bathonian to the Oxfordian (Tethyan biozones UAZ 5-6 to 8-9). The onset of these radiolarian-bearing series of the Tunisian Trough, adjacent to partly coeval Ammonitico

Rosso successions, is interpreted as resulting from regional palaeotopographical gradient and palaeoceanographical conditions. Inaccurately interpreted as “true” radiolarites, these series are different from coeval radiolarites of the Maghrebian “Dorsale calcaire” and from more recent homologous deposits of the Flysch domain. They are instead correlative with series exposed in the Babors and the west-Numidian ranges of northern Algeria that belonged to the same Jurassic North African margin of western Tethys. During Alpine convergence s.l., this external domain was overthrust by nappe complexes of the Maghrebide inner zones and the Flysch domain units.

## Introduction

Over the last 50 years, Jurassic radiolarian-bearing siliceous successions from the circum-Mediterranean ranges have been well documented (see for instance synthesis by Bill et al. 2001). In northern Tunisia, the Jurassic series of the Jédidi Formation (Fm) considered as “radiolarites” or “pseudoradiolarites” by the authors (e.g. Alouani et al. 1990, Soussi 2002, respectively) have undergone various stratigraphic correlations, including controversial interpretations concerning the polarity of the Jurassic series to which they belong (see synthesis in Peybernès et al. 1994). Originally interpreted as lower Cretaceous in age (Solignac 1927; Castany 1951, 1955), they have carried various age attributions [Callovia–Oxfordian in Jebels (J.) Jédidi, Chaâbane and Tamrhoura (Pini & Salaj 1969), Kimmeridgian–Tithonian in the Ghardimaou area (Rouvier 1985), late Oxfordian–lower Kimmeridgian at J. Jédidi (Alouani et al. 1990), late Kimmeridgian–late Tithonian in J. Amar (Pey-

bernès et al. 1996) and late Bajocian–late Oxfordian in more recent syntheses (Soussi et al. 1998; Soussi 2002, 2003)]. Cordey et al. (2005) recently established the first preliminary direct age determination of the Jédidi Fm, questioning the previous sedimentological interpretations that these series were true radiolarites. We present here more complete results obtained at the type locality of the Jédidi Fm and other sections from the area (J. Chaâbane, Oued (O.) Tazega, Fig. 1). Direct radiolarian age determinations are established at the base, the middle part and the top of the siliceous series. In relation to these new results, we propose a palaeogeographical interpretation for the onset of these siliceous deposits and an attempt to focus on the main factors controlling deposition. Finally, regional correlations and comparisons to equivalent successions within the Maghrebides and northeastern Sicilian ranges place these deposits within their West-Tethyan context.

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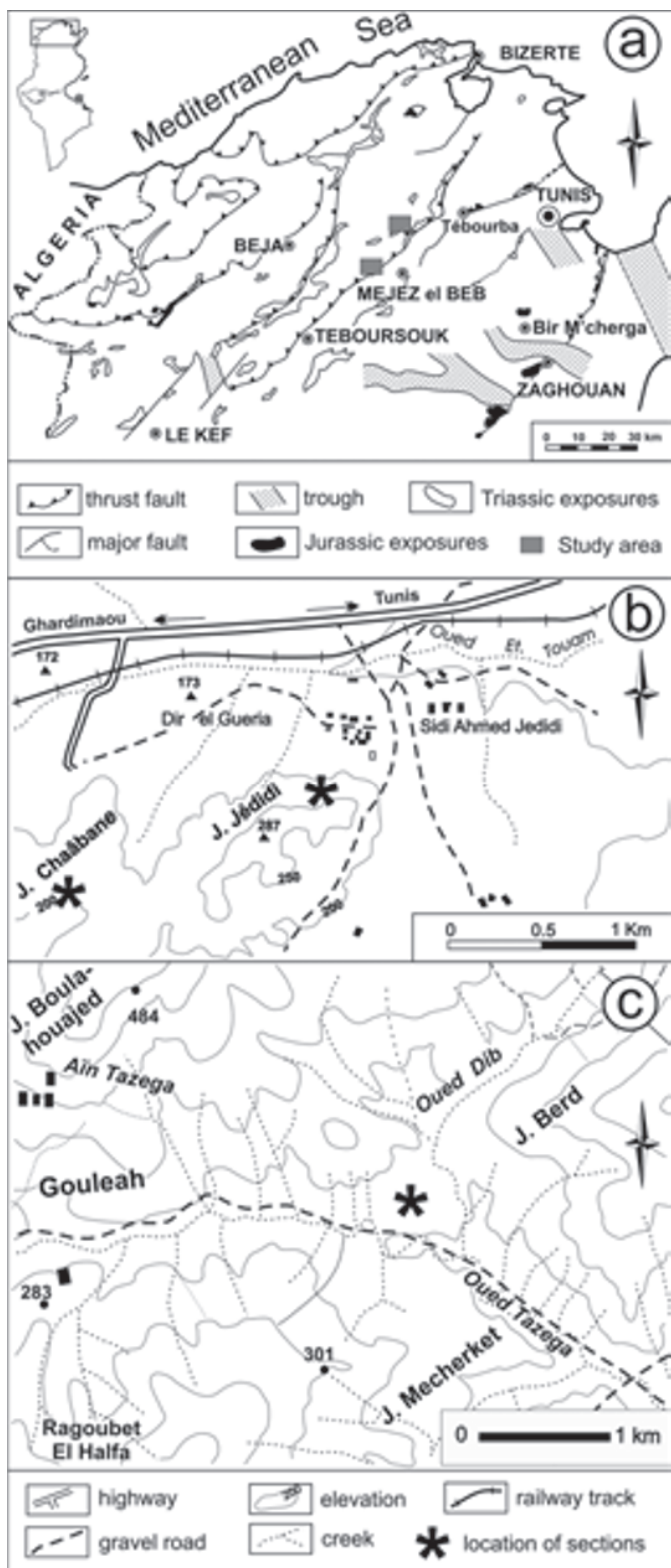


Fig. 1. Location of studied sections (Jurassic, Tunisia). a) northern Tunisia. b) Jebels Jédidi and Chaâbane. c) Oued Tazega.

### Stratigraphical and palaeogeographical setting

In this stratigraphical and palaeogeographical overview, we refer to the recent syntheses proposed by Soussi (2002, 2003). The Middle and Upper Jurassic successions of northern Tunisia are characterized by heterogeneous facies underlain by major discontinuities more or less marked from the Tunisian Dorsale to the Tunisian Trough (Fig. 2).

The nodular limestones with chert nodules and *Zoophycos* of Kef El Orma Fm (Aalenian–lower Bajocian) are overlain by marl/limestone alternations bearing thin-shelled bivalves (“filaments”) of the Bent Saïdane Fm (upper Bajocian–lower Callovian) of the Dorsale (Fig. 2). These facies are laterally equivalent to black filament-bearing limestones within the eastern flank of J. Zaghouan, to breccias-bearing marl/limestone alternations of J. Bou Kornine Hammam Lif, and to the Jédidi Fm in the Tunisian Trough. During the middle Callovian–Oxfordian time interval, the Ammonitico Rosso (A.R.) facies-like Zares Fm of the Dorsale corresponds to radiolarian-rich pelitic and carbonate units of the Fahs Fm (“faciès oclés” of Bonnefous, 1972) within the western Tunisian Trough which is laterally-equivalent to the Jédidi Fm. Sealing these successions, the Kimmeridgian–Berriasian carbonate series are mainly characterized by reefal and sub-reefal facies on risen blocks of the Dorsale (Ressas Fm) that grade into marls and pseudonodular limestones with *Saccocoma* and calpionellids of the Béni Kleb Fm, itself enriched in radiolarians and chert nodules within the Tunisian Trough.

The heterogeneity of Middle–Late Jurassic facies in northern Tunisia is the result of two main geodynamical and palaeogeographical events. The first corresponds to the fragmentation of the initial Early Jurassic platform linked to Tethyan rifting that led to a mosaic of raised and drowned blocks. The second event, coeval to radiolarian-bearing series of the Tunisian Trough, is expressed by a clear deepening in north-west Tunisian palaeoenvironments and, as a result, the partition of two major palaeogeographic realms: 1) a relatively resistant composite domain including the Tunisian Dorsale and 2) a deeper subsiding domain that differentiated from the Dorsale since the late Bajocian where the biosiliceous successions were deposited. The transition between these domains consists of a NE-SW intermediate area including the present range of J. Bou Kornine of Hammam Lif, Oust, Aziz, Bou Kornine of Pont du Fahs and Raouas-Béni Kleb.

### Location, structural setting and lithology of studied sections

The sections of J. Chaâbane and Jédidi are located 10 km west of the town of Mejez el Beb, near highway 6 linking Tunis to Ghardimaou (Figs. 1a, b). Between Mejez el Beb and O. Zarga, a gravel road heads south to Sidi Ahmed Jédidi then to the southeastern flank of J. Jédidi and Chaâbane (Fig. 1b). The studied area of O. Tazega is located 15 km to the NE of these sections and can be reached by gravel roads that bifurcate from highway 64 linking Tébourba to Mejez el Beb.

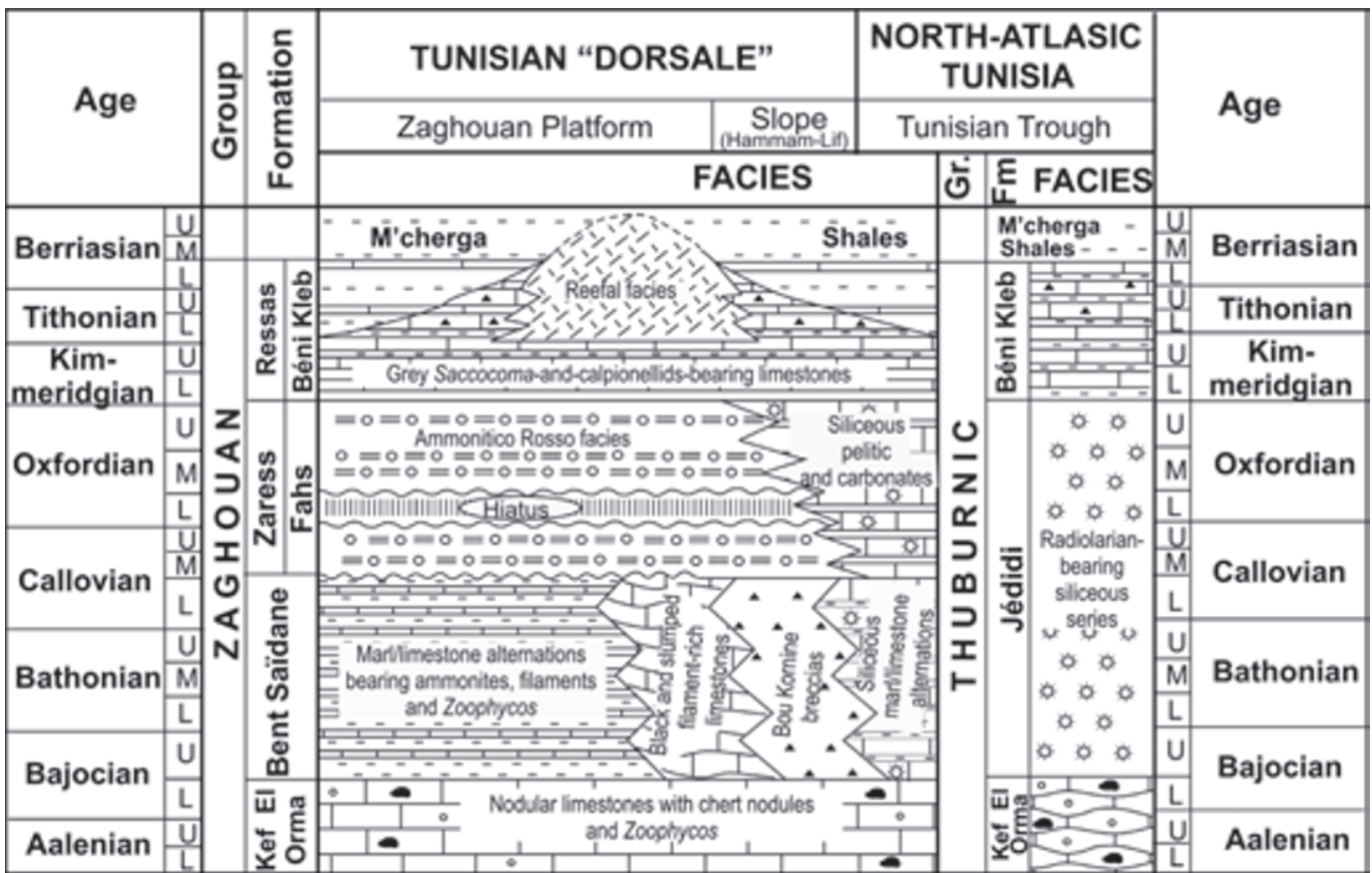


Fig. 2. Overview of Tunisian Jurassic stratigraphy, comprising Tunisian "Dorsale" and North Atlasic Tunisia (Tunisian Trough).

Jurassic units of the Jédidi-Chaâbane range are bounded to the south by the Téboursouk fault (Fig. 1a), cropping out along a NE-SW belt parallel to large exposures of Triassic salt formations. Lower Jurassic limestones, presently worked in a gravel quarry, bound the Jurassic southernmost exposures. Jurassic units extend to the north as the base of a wide syncline where sub-vertical to slightly reverse Middle and Late Jurassic strata are identified. These strata grade into Cretaceous and Eocene successions of Toukabeur and Chaouache that extend northward and northeastward within the Toukabeur-Hidou syncline. This syncline constitutes a back folding of the O. Zarga monocline generated by a strike slip faulting of J. Boulahouadjed (Fournet 2002). On the southeastern flank of J. Boulahouadjed, the studied Jurassic beds are sub-horizontal to northwestward dipping within a slice of terrane uplifted by the J. Berd diapir. As for the Jédidi and Chaâbane southern boundary of Jurassic units, the J. Berd diapir belongs to a wide NE-SW structure that crops out along the Téboursouk fault which separates the Tunisian overthrust structural zone to the west from the "Tunisois Domes" zone to the east (Jauzein 1967).

At J. Jédidi and Chaâbane, the sections are composed dominantly of thick red pelites alternating with thinly laminat-

ed siliceous limestone, dark brown to brick red with tints of yellow and green (Fig. 3). In their middle part, these sections exhibit a lesser amount of pelites and siliceous facies. Calcareous beds are dominant and are harder, thicker and darker than those of the base and the top of the series. At O. Tazega, the exposure is essentially composed of red to dark brown pelites with thin siliceous limestone beds at the base and the middle part (Figs. 4, 5). It is worth noting that through all studied successions, the siliceous facies vary along sections. Contrary to previous interpretations, Cordey et al. (2005) established that these successions are actually not "true" radiolarites s.s., as radiolarian-rich layers alternate with carbonates which are locally silicified. Carbonate proportions within siliceous limestone beds increase towards the top of the formation, grading into marl-limestone alternations of the Béni Kleb Fm.

#### Radiolarian assemblages and age correlations

Previous attempts to extract radiolarians from the siliceous series of Tunisia were undertaken in the 1980s and 1990s by French and Italian teams, without success (R. Enay, pers. comm. 2004). We based our field study on thorough sample selection (Cordey & Krauss 1990) and specific laboratory

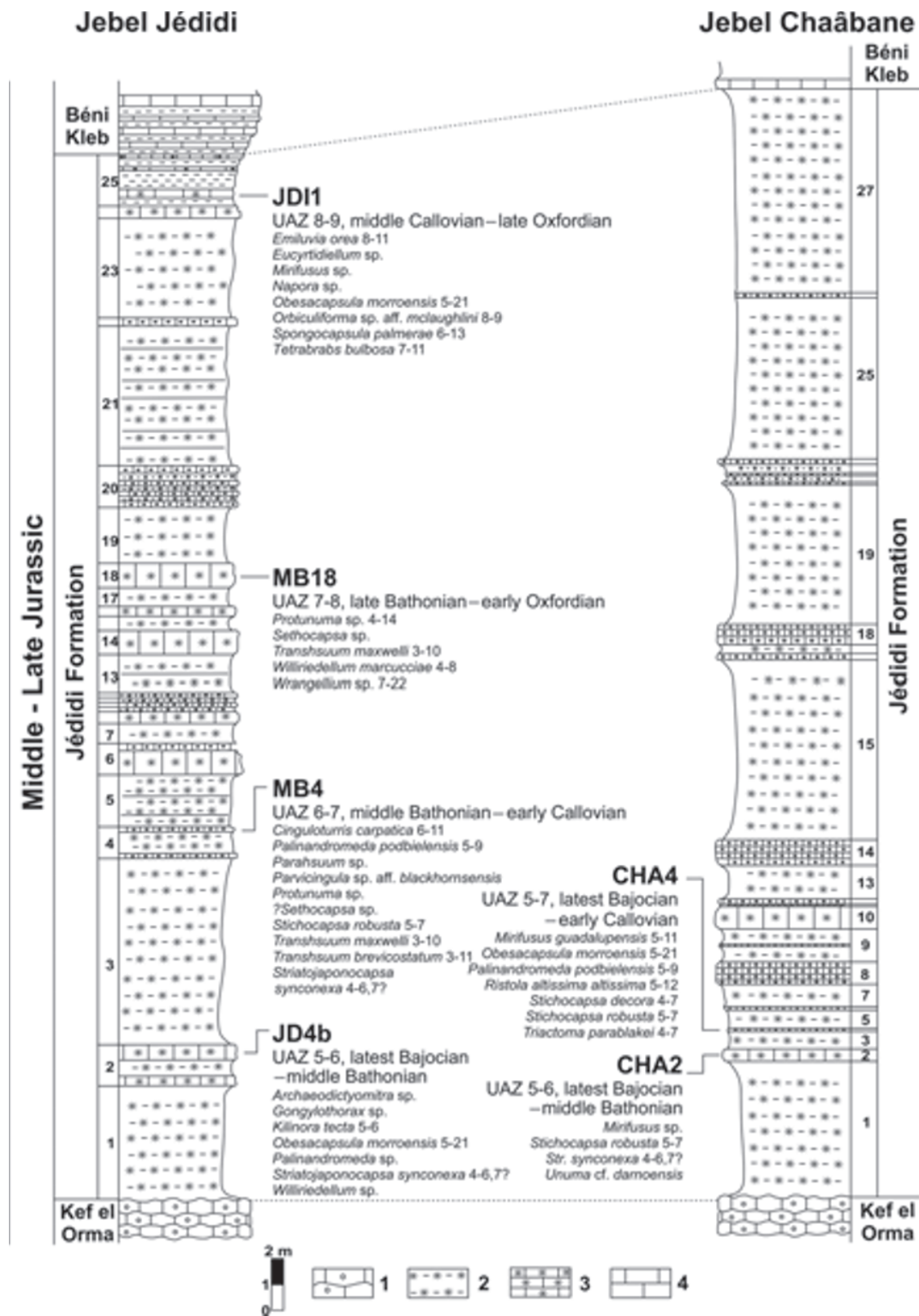


Fig. 3. Lithological sections from Jebels Jédidi and Chaâbane (Jurassic, Tunisia) with location of radiolarian samples, assemblages and ages (zonation by Baumgartner et al.1995, with additional information from O'Dogherty et al. 2006). 1: nodular limestone; 2: radiolarian-bearing pelites; 3: radiolarian chert or siliceous limestone; 4: limestone.

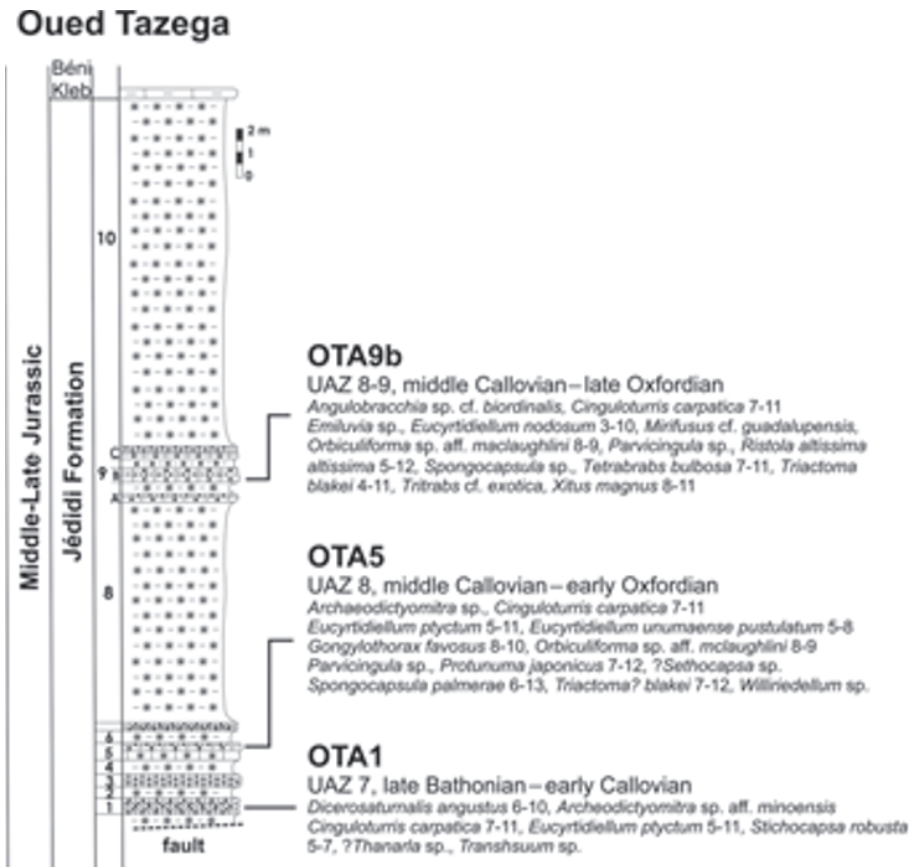


Fig. 4. Lithological section from Oued Tazega (Jurassic, Tunisia) with location of radiolarian samples, assemblages and ages (zonation by Baumgartner et al. 1995 with additional information from by O'Dogherty et al. 2006). Lithology: see Figure 3.

processing (low concentration acids). The three sections described yielded radiolarian fauna of fairly good preservation (Plate I). Nine productive horizons and their faunal content are presented in this paper (Figs. 3, 4). We used the unitary association-based biozonation from Baumgartner et al. (1995) for age correlations, along with new taxonomical and biochronological information from O'Dogherty et al. (2006).

At the J. Jédidi type-section (Fig. 3), preliminary data reported the occurrence of two diagnostic associations within the lower and middle part of the succession (Cordey et al. 2005). Sample MB4 (Fig. 3) contained an association corresponding to UAZ 6; we have extended this correlation to UAZ 6-7 (middle Bathonian–early Callovian age) due to recent revisions (see paragraph above). Sample MB18 (Fig. 3) is correlative with UAZ 7-8 of late Bathonian–early Oxfordian age. New data documented in this paper provide age determinations near the base and the top of the Jédidi Fm. Sample JD4b from sequence 2 at 5.5 m from the base bears an association corresponding to the UAZ 5-6 of latest Bajocian–middle Bathonian age. Sample JDI-1 collected 2 m below the top of the type-section released an assemblage correlative to UAZ 8-9 of middle Callovian–late Oxfordian age.

The J. Chaâbane section (Figs. 1, 3) was chosen as complementing the J. Jédidi type-section. So far, two samples from sequences 2 and 4 (Fig. 3) released diagnostic radiolarians.

Sample CHA2 corresponds to UAZ 5-6 of latest Bajocian–middle Bathonian age, a chronological correlation identical to JD4b at J. Jédidi. One meter above, sample CHA4 released an association attributed to UAZ 5-7 of latest Bajocian–early Callovian age. No radiolarian has yet been successfully extracted from the middle and top parts of the J. Chaâbane section.

The O. Tazega section (Figs. 1, 4) provided three diagnostic samples. In the lower part of the section, sample OTA1 (Fig. 4: sequence 1) has an assemblage correlative with UAZ 7 of late Bathonian or early Callovian age; sample OTA5 (Fig. 4: sequence 5) released an association attributed to UAZ 8 of middle Callovian–early Oxfordian age. In the middle part of the section, sample OTA9b (Fig. 4: sequence 9b) contains an assemblage attributed to UAZ 8-9 of middle Callovian–late Oxfordian age.

In summary, the oldest radiolarian assemblage obtained from the Jédidi Fm is correlative with UAZ 5-6 of latest Bajocian–middle Bathonian age (J. Jédidi and Chaâbane). At O. Tazega, the oldest assemblage is late Bathonian or early Callovian age (UAZ 7). These results show that the O. Tazega section probably does not expose the very base of the formation, as suggested by the presence of a fault (Fig. 4). The occurrence of UAZ 5-6 (latest Bajocian–middle Bathonian in age) about 6 m from the base of the Jédidi Fm type-section is

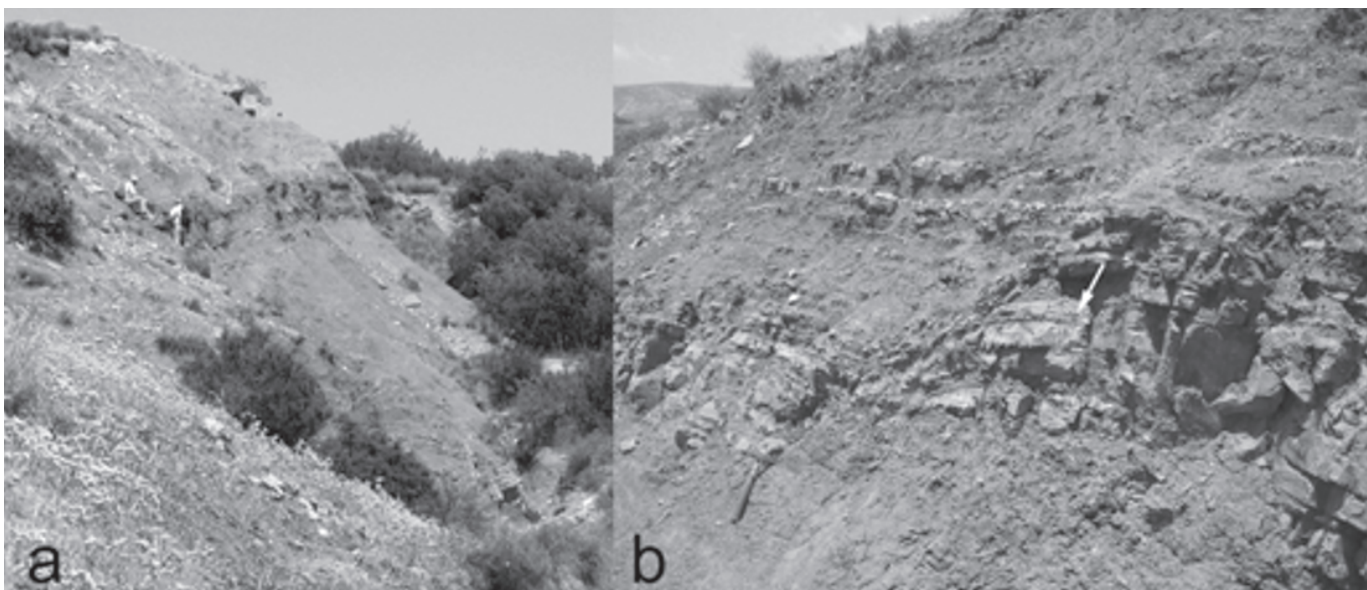


Fig. 5. Exposures from Oued Tazega section. a) General view, from bottom to top. Geologists on chert sequence 9 (see Figure 4). b) Close-up of sequence 9 (to the right of fault); arrow: location of sample OTA9b (see text).

consistent with the occurrence of late Bajocian ammonite data from the underlying Kel el Orma Fm (Soussi et al. 1998). The youngest age obtained so far on these siliceous series of the Tunisian Trough is middle Callovian–late Oxfordian, as shown by both J. Jédidi and O. Tazega sections. Although the corresponding radiolarian association UAZ 8-9 is found only 1.6 m from the top of the formation in J. Jédidi, it is found about 18 m below the overlying Béni Kleb Fm in O. Tazega. This apparent discrepancy could be explained by either tectonic duplication affecting part of sequence 10 at O. Tazega, or significant differences in sedimentation rates, or else the occurrence of diachronism between the two areas. We cannot differentiate between these hypotheses as we have not yet found any diagnostic radiolarians above OTA9b at O. Tazega. However, a tentative Oxfordian age for the top of the Jédidi Fm seems consistent with the late Oxfordian data obtained on the Béni Kleb Fm by Boughdiri et al. (2006).

Biostratigraphical data obtained on the J. Jédidi type-section can be applied to assess sedimentation rates for Tunisian siliceous series and compare it with ‘true’ radiolarite successions. If a tentative latest Bajocian–early Bathonian to middle–late Oxfordian interval seems consistent for J. Jédidi section, it represents a time span of approximately 10 m.y. (Gradstein et al. 2004). Given the 40 m overall average thickness of the formation, the average sedimentation rate of these siliceous series would be  $\sim 4$  m per m.y.. In comparison, the average rate for ‘true’ Tethyan radiolarites s.s. of the same time interval is usually around 1 or 2 m per m.y. (De Wever et al. 1994). This confirms the preliminary assessment by Cordey et al. (2005) that the Jurassic siliceous series of northwest Tunisia are indeed a mixture of siliceous and carbonate sedi-

mentation whose sedimentation rates are commonly higher than those of true radiolarites.

#### The onset of siliceous deposition in northwest Tunisia

Rapid lateral changes of upper Bajocian–lower Callovian facies in northwest Tunisia (Fig. 2) indicate an increase in Tethyan-rift-related structuring of the ‘Tunisian Trough’ initiated in the Lower Jurassic. The earliest radiolarian-bearing successions (lower part of the Jédidi Fm) of the Trough correspond to the partially silica-free deposits of Bent Saïdane Fm within the subsiding domain of the ‘Tunisian Dorsale’. Both domains are separated by coeval transitional slope facies. Then, the A.R. deposits of the Tunisian Dorsale occurred on the same tilted-block topography during Middle Callovian–Oxfordian time. Their onset coincides with the first siliceous argillites and limestones of the Fahs Fm (Dorsale) and the upper part of the Jédidi Fm (Trough).

The association of radiolarian-bearing siliceous successions and A.R. facies have recently been outlined by Beccaro (2006) in the southern Alps and Sicily.

In Tunisia, we note a tendency towards progressive lime-free conditions either upsection or from the southeast (Dorsale) to the northwest (Tunisian Trough) which could result from this regional palaeotopographical gradient. Although the environmental conditions of radiolarian-rich deposition are still a matter of debate, we preliminarily consider that the relatively unfavourable conditions for carbonate productivity (i.e. the onset of A.R. condensed units and the A.R./siliceous series heteropy) could be related to paleoceanographical conditions. As formulated by Baumgartner (1987) for other Tethyan

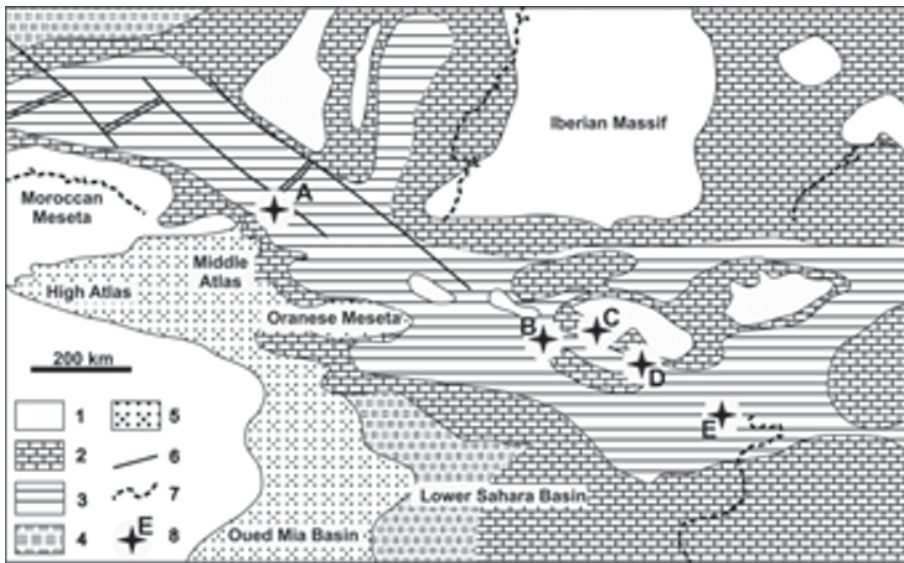


Fig. 6. Middle Callovian palaeogeography of North Africa (after Thierry 2000) and location of radiolarian-bearing siliceous series. 1: land; 2: marine carbonate platform; 3: deep marine deposits; 4: coastal marine (terrigenous); 5: fluvio-lacustrine facies; 6: fault; 7: present-day coast line; 8: location of Maghrebian biosiliceous series; A: Moroccan flysch substratum remnant (Tisirène Fm); B: Babors; C: Great Kabylia; D: Lesser Kabylia (Achaïches); E: “Tunisian Trough”.

basins in different palaeogeographical settings, it is possible that bottom currents may have caused high surface fertility in the Tunisian Trough basin and winnowed light radiolarian tests from swells by resuspension and transport into the adjacent current-protected basin.

Since the Kimmeridgian, the last occurrence of A.R. facies of the Dorsale and coeval biosiliceous successions within the adjacent Tunisian Trough and nearby exposures are overlain by the carbonate series of Béni Kleb Fm (Enay et al. 2005, Boughdiri et al. 2005). Peybernès et al. (1996) interpreted this dramatic facies change as linked to a drastic sea level fall. As formulated by Cecca et al. (1992) for the disappearance of the A.R., an eustatic cause of the onset or disappearance of radiolarian-rich successions is not likely because 1) the stratigraphical and geographical distribution of these successions do not depend on sea level fluctuation, and 2) the broadly homogenous and constant radiolarian-bearing deposits within the Jéjidi Fm encompass different stratigraphical intervals that correspond to various sea level fluctuations as illustrated in charts (e.g. Haq et al. 1987, Hardenbol et al. 1998). Our point of view favours the interpretation of a return to higher rates of carbonate sedimentation due to a marked change in the palaeocirculation regime (Cecca et al. 2001, Savary et al. 2003, among others). In fact, by the end of the Jurassic, the tectonically-related change in Mediterranean Tethys position exposes this realm to weak surface circulation controlled by subtropical gyres rather than to prevailing equatorial current systems (Hsu 1976, Weissert 1979, Baumgartner 1987, Savary et al. 2003).

#### Comparison with radiolarian-rich deposits of the Maghrebian-Sicilian Range and geodynamical context

To our knowledge, only the Jurassic biosiliceous successions described in the Babors (Ehrmann 1942, Leikine 1971, Obert 1981) and the northwest Constantinois region of northern

Algeria (Durand-Delga 1951, 1955) can be compared with the Jéjidi Fm of Tunisia (Fig. 6). Although direct age determination is still lacking, a Middle Jurassic age was previously assigned to these similar series. Middle Jurassic facies from the Mesorif (Morocco) may also be associated to this former group of radiolarian-bearing successions of the external segments of the Maghrebides (Atrops, pers. comm. 2006).

In the Maghrebian flysch area (Fig. 6), Jurassic sections include more “true” radiolarites that clearly differ from Tunisian deposits. For example, red radiolarites with embedded breccias and oolitic limestones (Bajocian–Tithonian) are exposed within the Ouareg Fm of Targuist area (Rif, Morocco) (Olivier et al. 1996). These overlay calcareous turbidites and cherty limestone of late Aalenian–late Bajocian age. Homologous successions can be found eastward over long distances similar to those in the Lesser Kabylia (northern Algeria) where the Achaïches series also contain radiolarites with limestone microbreccias (Bouillin 1979, Durand-Delga 1979). In the Sicily-Calabrian Arc, Tithonian radiolarites of the Contarada Lanzeri Fm (Bouillin et al. 1995) and the Caloveto-type series (Santantonio & Teale 1987) are considered to be lateral equivalents of the flysch substratum remnants.

In an inner structural setting, the Middle Jurassic successions of the Maghrebian “Dorsale calcaire” include thin radiolarite beds devoid of detrital intercalations. Among these series are those of the Internal Rif (J. Moussa, Haouz Chain), where red-to-green radiolarite layers and argillites were dated Middle Jurassic. Radiolaritic argillites and radiolarites (Callovian–Oxfordian) are known in the Medium Dorsale of Great Kabylia (Fig. 6; El Hatimi & Duée 1989, El Hatimi et al. 1991, Durand-Delga et al. 2005). Lateral equivalent series described in the Peloritani dorsale of northeast Sicily (Toarmina-Montesano Pietro area) include filament-rich and cherty limestones, upper Callovian radiolarites and calpionellid-bearing limestones (Bouillin et al. 1992).

This review suggests that three categories of Jurassic radiolarian-bearing successions can be distinguished in this region, characterizing three nappe complexes originating from three main palaeogeographical domains: Internal units, Flysch basin and External units (Durand-Delga 1980, Durand-Delga & Fontboté 1980). The Tunisian series analysed here belong to the latter domain and were deposited on the north-African margin of western Tethys. Replaced in their broader geodynamic setting, we consider that some elements of the Maghrebian inner zones were part of the Alkapeca microcontinent (Bouillin et al. 1986) that also included present-day Calabrese and Peloritan overthrusts. The western part of this microcontinent consisted of the Alboran terrane. During Upper Eocene–Oligocene times, the collision Alkapeca-Iberia generated back-thrust tectonics that evolved in a northwest-dipping subduction of the African Margin beneath Alkapeca. As recently formulated by Chalouan et al. (2001), Tertiary Alpine s.l. general convergence led to docking of the extending Alkapeca segments (present-day thrust sheets of north-African inner margin) along with closure of the Maghrebian Flysch oceanic trough (Fig. 6), and took place onto the ancient African margins that were formed by the present day Tello-Rifan external zones.

## Conclusion

Radiolarian assemblages extracted from the siliceous series of the Jédidi Fm (Tunisian Trough) led to direct age determinations of the succession ranging from latest Bajocian–middle Bathonian to middle Callovian–late Oxfordian age. Our study also establishes an age reference for the top of the Kef El Orma Fm and the base of Béni Kleb Fm, where biostratigraphical markers are scarce or absent. These new data offer a good argument to seal the debate concerning the polarity of the Jurassic sequence of the Tunisian Trough that lasted for several decades.

In perspective, radiolarian dating may still offer some potential for future palaeoecological and palaeogeographical reconstructions in Tunisia, some radiolarian-bearing carbonate and siliceous beds in other localities of the Jédidi Fm or the Fahs Fm being still undated. At the scale of the south-Tethyan margin, these may also be useful for larger correlations between the Maghrebian external segments, the Algerian northern Aures mountains, the Babors, the Numidian chains and Mesorif (Morocco).

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### Plate I

Jurassic radiolarians from the Jédidi Fm (Tunisia). Scanning Electron Microscope. Figures: taxon, sample number, picture number, scale length.

1) *Ristola altissima altissima* (RÜST), CH4, specimen 7, 550 µm; 2) *Palinandromeda podbielensis* (OZVOLDOVA), MB4, specimen 15, 200 µm; 3) *Orbiculiforma* sp. aff. *mclaughlini* PESSAGNO, OTA5, specimen 1, 400 µm; 4) *Podobursa* sp., OTA1, specimen 2, 600 µm; 5) *Stichocapsa decora* RÜST, CH4, specimen 16, 350 µm; 6) *Striatojaponocapsa synconexa* O'DOHERTY, GORICAN & DUMITRICA, JD4b, specimen 6, 350 µm; 7) *Striatojaponocapsa synconexa* O'DOHERTY, GORICAN & DUMITRICA, MB4, specimen 9, 350 µm; 8) *Gongylothorax* sp., JD4b, specimen 10, 400 µm; 9) *Williriedellum* sp., OTA5, specimen 33, 300 µm; 10) *Gongylothorax favosus* DUMITRICA, OTA5, specimen 19, 300 µm; 11) *Protunuma japonicus* MATSUOKA & YAO, OTA5, specimen 17, 300 µm; 12) *Unuma* cf. *darnoensis* KOZUR, CH4, specimen 19, 700 µm; 13) *Stichocapsa robusta* MATSUOKA, MB4, specimen 1, 125 µm; 14) *Kilinora tecta* (MATSUOKA), JD4b, specimen 15, 300 µm; 15) *Eucyrtidiellum ptyctum* (RIEDEL & SANFILIPPO), OTA1, specimen 20, 350 µm; 16) ?*Sethocapsa* sp., OTA5, specimen 15, 400 µm; 17) ?*Archaeodictyomitra* sp., OTA1, specimen 27, 300 µm; 18) *Cinguloturris carpatica* DUMITRICA, MB4, specimen 23, 100 µm; 19) *Spongocapsula palmerae* PESSAGNO, OTA5, specimen 3, 550 µm; 20) *Obesacapsula morroensis* PESSAGNO, CH4, specimen 3, 700 µm; 21) *Mirifusus guadalupensis* PESSAGNO, CH4, specimen 1, 650 µm; 22) *Transsuum* sp., OTA1, specimen 7, 450 µm; 23) *Transsuum brevicostatum* (OZVOLDOVA), MB4, specimen 27, 150 µm; 24–26) *Archaeodictyomitra* spp., OTA5, specimens 12-7-9, 500 µm; 27) *Archeodictyomitra* sp. aff. *minoensis* (MIZUTANI) OTA1, specimen 28, 275 µm.

