



UPPER TITHONIAN CALPIONELLID BIOZONATION AND REGIONAL CORRELATIONS OF THE TUBURNIC REFERENCE SECTION (GHAR DIMAOU AREA, NW TUNISIA)

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Abstract: In a complex tectonic setting, the Jurassic isolated outcrop of the Tuburnic area (Ghar Dimaou region, NW Tunisia) is considered to be the unique witness of Upper Jurassic successions from the Northern Tunisia-Algeria bordering area. The scarcity of seismic data and lack of direct datations along continuous and complete transects can allow only punctual comparisons and/or random correlations within the South-Tethyan Margin of Tunisia and Algeria. This paper aims to update the biostratigraphy of the Upper Tithonian series of this key section on the basis of a high resolution biozonation, using calpionellids as precise biomarkers. All the calpionellid zones and subzones are identified in two sections of the Tuburnic area (NW Tunisia), one of them being described here for the first time. In both sections, the genus *Chitinoidea* is mentioned and the accompanying and/or relaying hyaline calpionellid species are illustrated here for the first time. Neither the Kimmeridgian units of previous works nor their Middle-Upper Berriasian calpionellid-bearing sequences were identified. Within the whole Jurassic Tuburnic section, at least the upper part of the characteristic radiolarian-bearing biosiliceous levels, previously correlated with mimetic deposits from the Jedidi Formation of the “Tunisian Trough” (Bajocian-Callovian), are directly dated here by calpionellids as lowermost Upper Tithonian in age (Chitinoidea Zone). Long-distance correlations of the study sections with recently well-dated series from NE Algeria lead us to consider the Tuburnic area’s geodynamic setting as part of a pelagic resistant block’s southern edge. This extends from the Algerian Kabylia foreland of Northern Constantine to the Babors palaeogeographic domain. SE-NW correlations with coeval well-dated sections from Northern Tunisia allow us to consider the study section as part of the Northern Tunisia trough edge, progressively open to the Tethyan influences. A synthesis from both correlations transects, in Algeria and Tunisia, provide a basis from which to propose a regional geodynamic model.

Key words: NW Tunisia, NE Algeria, Upper Tithonian, Calpionellid biostratigraphy, correlations, geodynamic context

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Introduction

As part of the Jurassic South-Tethyan margin, Tunisia is considered an important Mediterranean domain for multidisciplinary investigations aiming at long-distance correlations within the Maghreb Range of North Africa. It consists of a hinge zone, where lower Mesozoic strata are weakly deformed and directly overlie the Saharan craton, allowing to realize N-S transects. In Northern Tunisia, the Jurassic series outcrop mainly in the “Tunisian Dorsale” (TD) and its satellite massifs, where most of these outcrops are bordered by the NE-SW-trending Zaghouan major fault. To the North and NW, the

Jurassic successions of Jebel Ammar (Sidi Thabet area) and Jedaida hills occupy a NE-SW band, which separates the TD from the Mejez El Bebb-Teboursouk regions of the “Tunisian Trough” (TT). In the TT, particular Dogger units consist of biosiliceous limestones regarded as “radiolarites” by Alouani et al. (1990) or “pseudo-radiolarites” by Soussi (2002). From further northward, in the Tellian domain of Northern Tunisia, only fragmentary data is available, leading to uncertain age attributions of the metamorphic limestone units of Jebel Hairech (Jendouba area) and Jebel Ichkeul in western Bizerte region.

In the same Tellian margin of North Africa, the NE Algeria Jurassic outcrops are rare, but outcrop well along a NE-SW

band from the Hodna Mounts (Setif area) to the Batna and Aïn Yaghout Mounts of Southern Constantine. Their first stratigraphic description is due to collaborative works by geologists in the frame of regional mapping. Nevertheless, the biostratigraphic interpretations of the Jurassic series by Guiraud (1973) and Vila (1980) had been useful as important references, although they were mainly dedicated to the structural geology and geological mapping of the area.

As far as the Jurassic-Cretaceous transitional units are concerned, the Northern Tunisia outcrops have been the object of many precise biozonations by means of ammonites and calpionellids during the last five decades (Memmi 1967, Bonnefous 1972, Busnardo et al. 1985, Boughdiri et al. 2005, 2006, 2009). However, in NE Algeria, pioneer calpionellid stratigraphy works by Colom et al. (1953), Donze et al. (1974) and Aissaoui (1979) have been the unique references, until recent works by Cherif et al. (2022) and Touansa et al. (2024) propose updated high-resolution calpionellid biozonations in the Batna, Aurès and Aïn Yaghout Mounts.

From this stratigraphic general overview, it appears that interregional correlations between Jurassic successions of NW Tunisia and NE Algeria are biased by the lack of complete outcrops favorable for precise stratigraphic investigations. The unique high-potential target may consist of the Tuburnic key section (Ghar Dimaou region, NW Tunisia), where ammonites collected by Soussi et al. (1998) reduced the degree of stratigraphic uncertainty, although some still persists. In fact, Glaçon and Rouvier (1970) and Rouvier (1985) attributed a Tithonian-Berriasian age to the upper part of this key section, by means of calpionellids (Zones A-C of Remane (1963, 1967), and Soussi et al. (1998) consider the base of this upper carbonate part to be of a Kimmeridgian age. Hence, this isolated section, located at ca. 100 km from its Jurassic lateral equivalents of NW Tunisia and NE Algeria, constitutes the unique witness of Upper Jurassic successions around the Tunisia-Algeria Northern border. Its particular interest resides in its potential contribution to filling our lack of knowledge on lateral facies evolution between NW Tunisia and the Northern Constantine area of Algeria.

In this work, a bed-by-bed sampling of the same Tuburnic section as well as a new complementary section from the neighboring Ouergech area aims at updating the calpionellid zonation of Upper Tithonian, and to revise the whole Jurassic stratigraphy and structural context in the light of new data presented here. Regional correlations with well-dated series from Northern Tunisia as well as those recently proposed for the Aurès Range, Batna and Aïn Yaghout Mounts allow us to place the study sections in their regional geodynamic context.

Location and structural context

The study section zone belongs to the Tell nappe domain of Northern Tunisia, a part of the western peri-mediterranean orogenic system (Text-fig. 1a). This formed during the Nubia-Eurasia convergence, initiated in the Late Cretaceous-Eocene. As a consequence, the Tell belt formations in Tunisia consist of overthrust Mesozoic to Cenozoic sheets, and overlying Oligo-Miocene Flyschs (Text-fig. 1b, c). These formations are considered to be the result of imbrication of allochthonous

units to the base of which Triassic evaporites have acted; either as autochthonous entities piercing the nappe structure (e.g., Perthuisot and Rouvier 1992, Rouvier 1993), or as part of the associated Tellian sequences (e.g., Booth-Rea et al. 2018, and references therein). To the South, the Tellian foreland and related external domain is represented by autochthonous Triassic to Miocene successions of the Atlasic Range that extend westwards to the Aurès Range and the Saharan Atlas of Algeria.

After successive rifting geodynamic events initiated since Triassic-Lower Jurassic times, a Late Cretaceous-Paleogene tectonic inversion led to relief uplifts associated with various discontinuities sealing the Tell and Atlas folds. The Upper Cretaceous-Eocene Atlasic shortening event and ensuing folding are considered as continuous during the Late Miocene (e.g., Frizon de Lamotte et al. 2000, 2006, 2009, Khomsi et al. 2009, 2016, and references therein). Recent works by Booth-Rea et al. (2018) and Gaidi et al. (2020) interpreted these related folds as fold-bend roll-over anticlines and hanging wall synclines in an extensional collapse setting of the nappe belt. According to these authors, a renewed shortening dated as Pliocene-Quaternary produced new basin depocenters over the footwall of reverse faults and oblique strike-slip fractures.

In this complex structural context, the Tuburnic study sections constitute the unique Jurassic outcrop of North-Westernmost Tunisia isolated at ca. 100 km lateral equivalents of Northern Tunisia and NE Algeria. To reach these sections from the Ghardimaou town, a recently amenaged N-S road leads to the El Galaa (= Ouergech = ancient roman Tuburnica site) village located at 7 km to the north (Text-fig. 1d). To the NW of El Galaa, another pathway bifurcates and bypasses the El Gouaress hill (379 m), parallel to the Tuburnic affluent. The Tuburnic and Ouergech study sections are respectively located at the GPS coordinates: 36° 32' 8.26" N, 8° 27' 2.19" E, and 36° 32' 5.93" N, 8° 27' 17.70" E.

Material and methods

These sections were sampled bed-by-bed, with particular attention paid to minor displacements of some beds due to frequent transverse faults. Classic field work methodology consists of following bed markers to sample encased successions that may be occasionally covered by dense vegetation. A total of 43 thin sections for the Tuburnic section, and 31 thin sections for the Ouergech section were observed and photographed under an optical Zeiss microscope equipped with a Canon camera. Calpionellid specimens were first determined independently and then checked by two of us (I. C. and M. B.), attempting to avoid random taxa assignments due to oblique sections, as recently stated by Boughdiri et al. (2020). The biozonation proposed here includes interval zones, on which limits are placed considering First and/or Last Occurrences (FO, LO) of index species. These delimitations are checked and occasionally reinforced by particular calpionellid association or abundance as marking bioevents. It refers to the standards of Alleman et al. (1970), as revised by Remane et al. (1986), but also considers the reference works on the North-Tethyan

Margin (Remane 1963, 1971 for SE France, Pop 1994, 1997a, b, 1998, Reháková and Michalík 1997, Michalík and Reháková 2011 for the Carpathians, Oloriz et al. 1995 for SE Spain, Lakova et al. 1999, Lakova and Petrova 2013, Petrova et al. 2019 for the Balkans). For North Africa, we mainly referred to works by Boughdiri et al. (2006, 2009) for Tunisia, Benzaggagh (2000, 2020) for the External Rif of Morocco, and Cherif et al. (2022) and Touansa et al. (2024) for Eastern Algeria.

Results

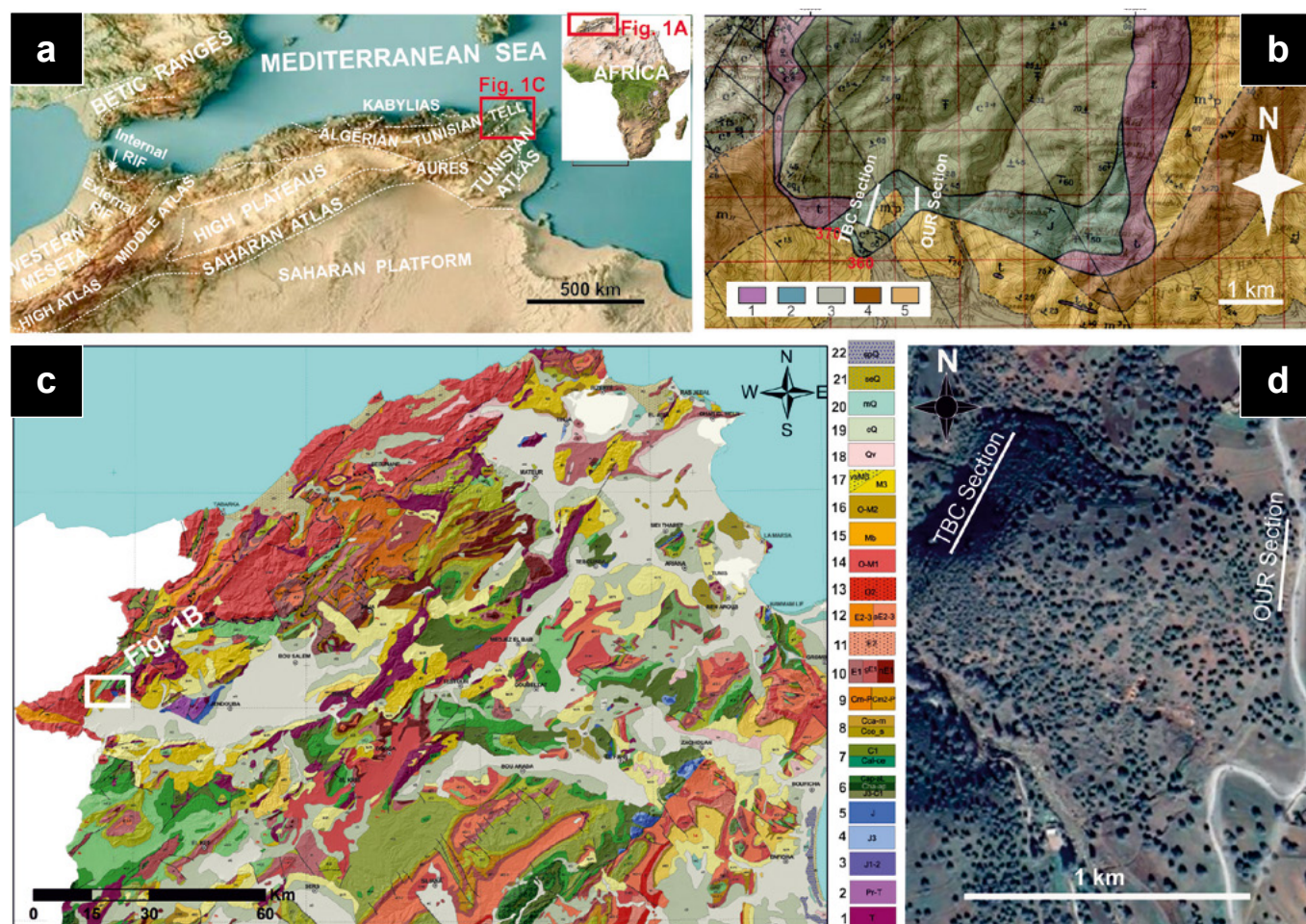
Calpionellid distribution and identified biozones

The Tuburnic area study sections (Text-figs 2, 3) are underlain by a Triassic blade-shaped lens, piercing the successions through the major tectonic fault of Cap Serrat-Ghardimaou (Text-fig. 1c). The oldest Jurassic units consist of 80-m-thick carbonate levels (Oust Formation), Hettangian-Lower Sinemurian (Soussi et al. 1998), overlain by the cherty limestones of the Zaghouan Fm (Upper Sinemurian-Lower Pliensbachian, 40 m, *ibid.*) (Text-fig. 3a).

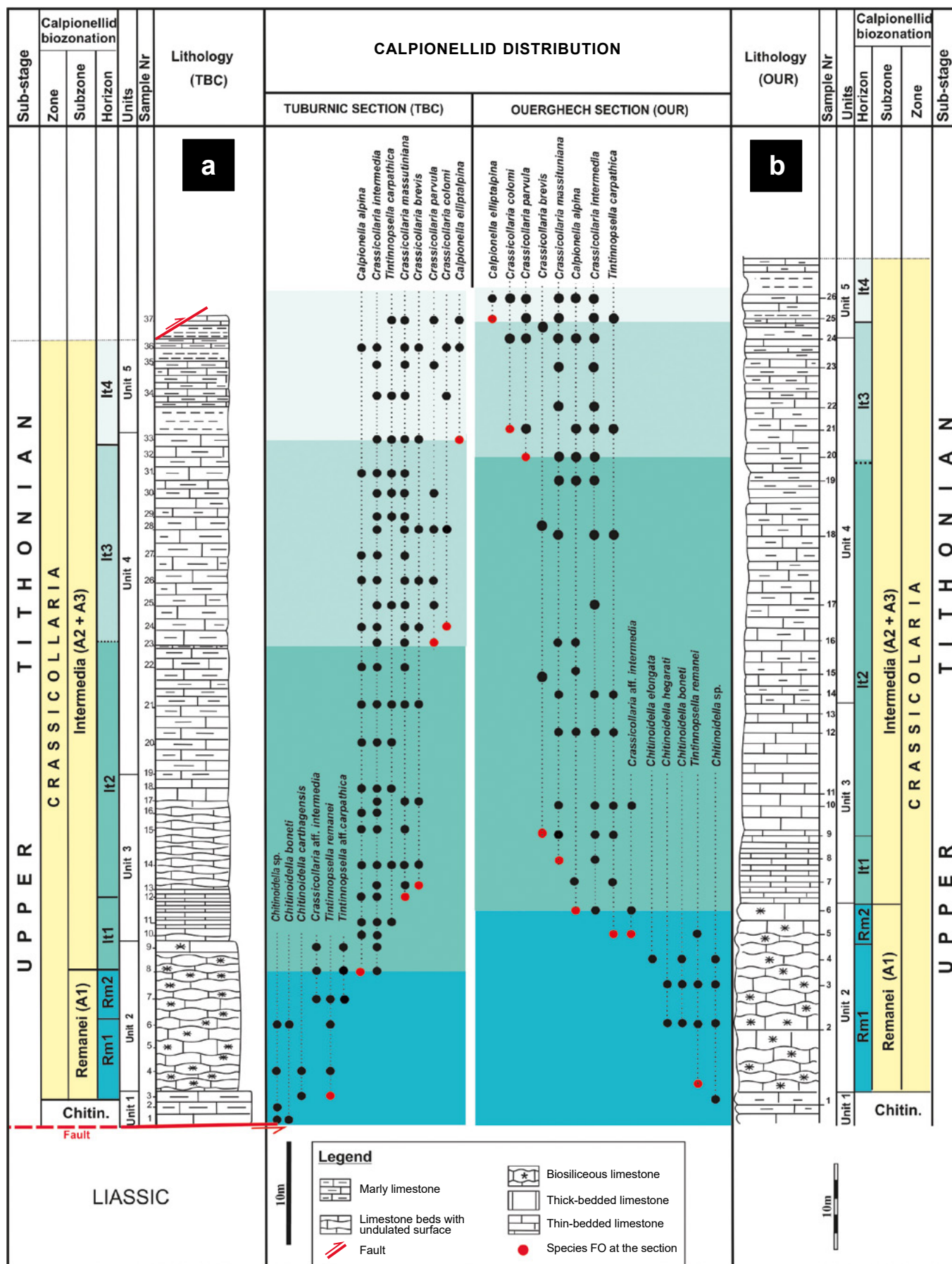
Higher, the marl-limestone alternation of the Stah Fm (Upper Pliensbachian-Toarcian) is followed by a nodular limestone unit (13 m) assigned by Soussi et al. (1998) to the Kef El Orma Fm (Aalenian-Bajocian), on the basis of ammonite faunas gathered at its base. Due to dense vegetation cover and tectonic disturbances, the Tuburnic (TBC) study section (Text-fig. 2a) starts with beds overlying the upper part of this nodular limestone unit, topped by an important fault (Text-fig. 3b). The lower and upper part of the new Ouerghéch (OUR) section (Text-fig. 2b) do not outcrop along the trail serving the El Galaa and El Ghorra villages.

Chitinoidea Zone, Boneti Subzone (beds TBC1–3: 2.5 m; OUR1: 3.6 m)

In the Tuburnic, the first marly limestone beds TBC1–TBC3 yield *Borziella slovenica* (BORZA) (Text-fig. 4a) and *Carpathella rumanica* POP (Text-fig. 4b). Only two specimens of *Chitinoidea* sp. were observed in the uppermost part of the bed OUR1 of the Ouerghéch section. This association allows us to trace the upper limit of the Chitinoidea Zone (Boneti Subzone) at the top of bed TBC3 and OUR1 of the respective study sections.



Text-fig. 1. Location and structural setting of study sections. a: Northern Tunisia structural domains within North Africa orogenic system. b: Extract of Geological map of study section areas; 1 – Triassic, 2 – Jurassic, 3 – Cretaceous, 4 – Lower Miocene, 5 – Upper Miocene-Pliocene c: Geological map of Northern Tunisia; 1–2 Permo-Triassic, 3–5 Jurassic, 6 Lower Cretaceous, 7–9 Upper Cretaceous, 10–12 Eocene, 13–16 Oligo-Miocene (Numidian Flyschs), 18–22 Quaternary. d: Google map view of study section location.



Text-fig. 2. Calpionellid distribution and biozonation of study section a: Tuburnic (TBC) section. b: Ouerghéch (OUR) section.

Crassicollaria Zone

(beds TBC4-37: 60.2 m; OUR2-21: 96.75 m)

Remanei Subzone

(TBC4-8: 9.9 m; OUR2-6: 21.6 m)

The first occurrence (FO) of the hyaline calpionellid species *Tintinnopsella remanei* BORZA is recorded in the radiolarian wakestone bed TBC4 of the Tuburnic section and OUR2 of the Ouerghéch section. This bioevent marks the lower limit of the Crassicollaria Zone of calpionellids (Zone A of Remane (1967) and that of the Remanei Subzone (Remane et al. 1986). In these radiolarian-bearing beds, *T. remanei* is still accompanied by chitinoideids (*Ch. hegarati* SALLOUHI, BOUGHDIRI et CORDEY, Text-fig. 4c; *Ch. carthagensis* SALLOUHI, BOUGHDIRI et CORDEY, Text-fig. 4d), the last occurrence (LO) of which is observed in beds TBC6 and OUR4. Following the recent biozonations for NE Algeria (Cherif 2022, Cherif et al. 2022, Touansa et al. 2024), the Remanei Subzone can be subdivided here into two horizons: the horizon Rm1 (beds TBC4-6, 6.2 m; OUR2-4, 17.2 m) and Rm2 (beds TBC7-8, 3.7 m; OUR5-6, 4.4 m), considering the LO of chitinoideids as a marking bioevent.

Intermedia Subzone

(Subzones A2 and A3 sensu Remane (1963, 1967)
(beds TBC9-37, 50.3 m; OUR7-6, 83.45 m)

The lower limit of this subzone is traced on the basis of the FO of medium sized *Calpionella alpina* LORENZ. It is placed below the mudstone beds TBC8 and OUR6 of the Tuburnic and Ouerghéch sections, respectively; just above are the first primitive forms of *Crassicollaria* aff. *intermedia* DURAND-DELGA (Text-fig. 4g, h, q) and *Tintinnopsella carpathica* MURGEANU et FILIPESCU (Text-fig. 4x, y). About 5 m higher, the quasi-simultaneous occurrences of *Cr. brevis* (Text-fig. 4l–n) and *Cr. massutiniana* COLOM (Text-fig. 4i–k) allow us to identify the base of the Brevis Zone of Reháková and Michalík (1997), and the Massutiniana Zone of Lakova et al. (1999). It coincides with the upper limit of the It1 Horizon of Cherif et al. (2022) and Touansa et al. (2024) (beds TBC9-12, 5.5 m; OUR7-9, 8.05 m). In beds TBC23 and OUR12 appear the first representatives of *Cr. parvula* Remane (Text-fig. 4o, p). This species is relayed, in bed TBC24, by *Cr. colomi* POP (Text-fig. 4u), which marks the base of the Colomi Zone of Reháková and Michalík (1997), which also corresponds here to that of the It3 Horizon of Cherif et al. (2022) and Touansa et al. (2024) (= beds TBC24-32, 15.3 m; OUR20-24, 16.3 m). Hence the It2 Horizon of these latter authors corresponds to the interval TBC9-12 (19.8 m) and OUR7-9 (43.6 m). Further upsection, the beds TBC33 and OUR25 bear the first *Calpionella elliptalpina* NAGY (Text-fig. 4r, s), defining the base of the Colomi Zone sensu and that of the IT4 Horizon of Cherif et al. (2022) and Touansa et al. (2024). In the topmost part of the section, rare small and spherical *C. alpina* (Text-fig. 4v, w) announce the Tithonian-Berriasian transitional interval, but their limited number does not allow tracing the Tithonian-Berriasian limit with certainty. However, the

decline of calpionellids, linked by some authors to a lowermost Berriasian sea level fall and arid climate conditions in other Mediterranean sections, may indicate the first beds of the Calpionella Zone of calpionellids (Alpina Subzone).

In conclusion, coming after the age revision of the Lower Jurassic – Middle Jurassic successions of the Tuburnic section by Soussi et al. (1998), our calpionellid biozonation of the Upper Jurassic carbonate series of the same section allows us to assign an Upper Tithonian- ? lowermost Berriasian age (Chitinoideida and Crassicollaria zones, and probably the lowermost part of the Calpionella Zone of calpionellids). These new data lead us to consider the absence of the Kimmeridgian-Lower Tithonian interval of Glaçon and Rouvier (1970), Rouvier (1985), Soussi et al. (1998), Soussi (2002) as well as the Berriasian successions of Rouvier (1985). No sedimentary arguments can plead in favor of a major discontinuity expressing a long-lasting hiatus; the cause of the missing interval is likely tectonic, since the study sections are encased between two reverse faults, more evident in the Tuburnic section (Text-fig. 2a). The whole Jurassic outcrop consists of tectonically imbricated units, likely rooted within the overthrusting Cretaceous and overlying Oligocene-Miocene flysch deposits of north-westernmost Tunisia, which may continue further northwest under the present Tunisia Mediterranean coast.

Interregional correlations

Correlation with coeval series from Northern Tunisia

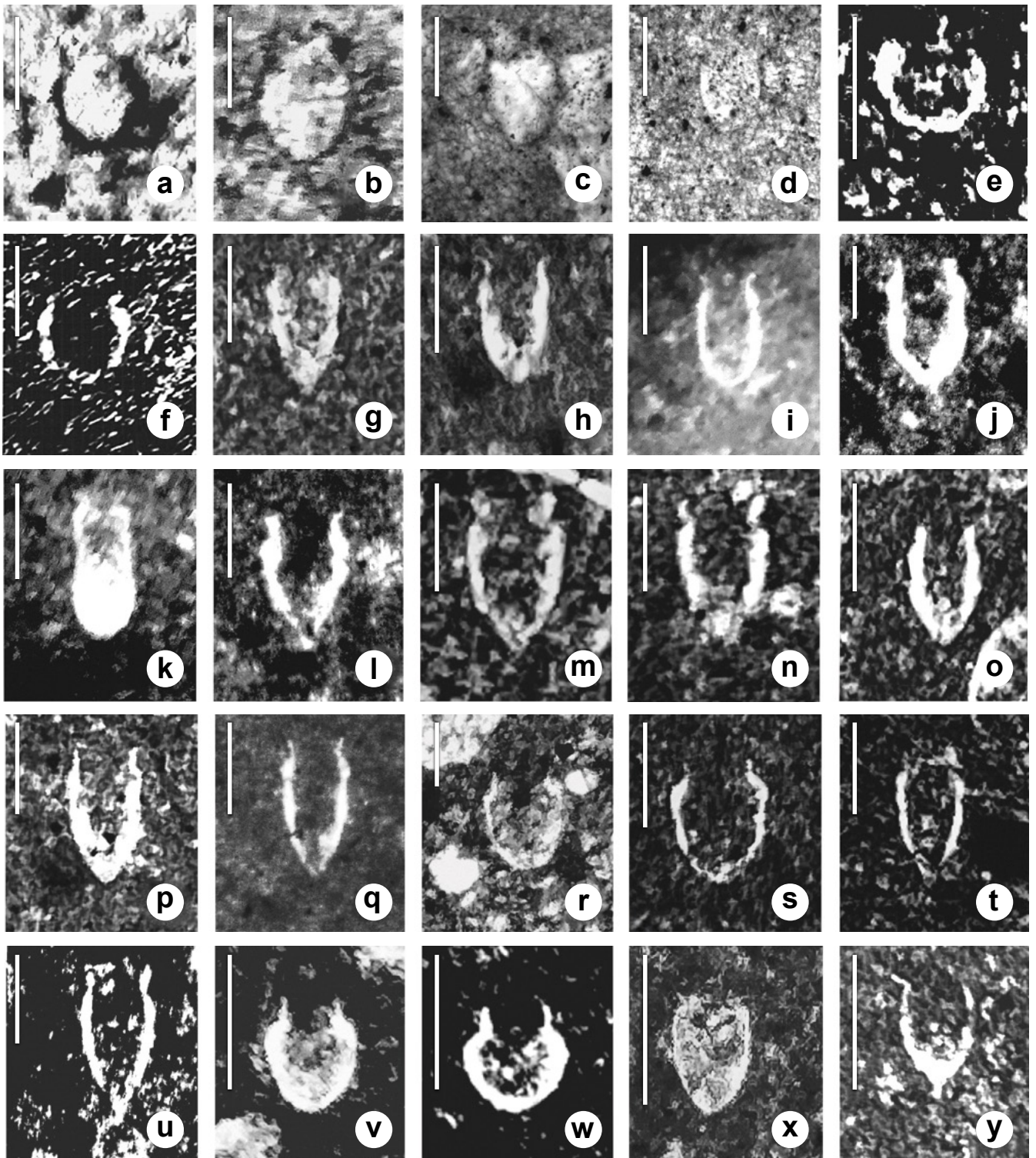
Text-fig. 5 illustrates SE-NW correlations of key sections from different palaeogeographic settings in Northern Tunisia. In J. Oust of the “Tunisian Dorsale” (TD), the Upper Tithonian reduced successions dated by ammonites and calpionellids (Boughdiri et al. 2005) are mainly characterized by debris-flows deposits and marl/limestone alternations. To the NW, in J. Amar, these facies pass laterally into thicker, more marly deposits, with limestone intercalations associated to calciturbidites, slumps and sliding structure.

Calpionellid associations borne by the upper part of these deposits allow us to date them as Upper Tithonian-Middle Berriasian (Boughdiri et al. 2006). The gravity-driven deposits of J. Amar pass northwestward into the J. Jedidi-Chaabane biosiliceous limestone unit (Jedidi Formation) underlying the Kimmeridgian-Tithonian Beni Klab carbonate formation. The upper part of this latter formation, assigned to Upper Tithonian-Middle Berriasian (Boughdiri et al. 2007) evolves laterally into the Tuburnic carbonate units of Tuburnic area studied here. This area is mainly characterized by the onset of a biosiliceous limestone unit at the base, overlain by the upper carbonate sequence of Upper Tithonian age.

The abrupt facies and thickness variations express a southeast-northwest deepening of the Upper Jurassic paleoenvironments of Northern Tunisia (Text-fig. 6). Before the onset of the Kimmeridgian-Tithonian platform, the Jurassic seafloor architecture of Northern Tunisia is characterized by a mosaic of high blocks and depressions, where Callovian-Oxfordian nodular red limestones of “Ammonitico Rosso” (AR) type facies are deposited (e.g.,



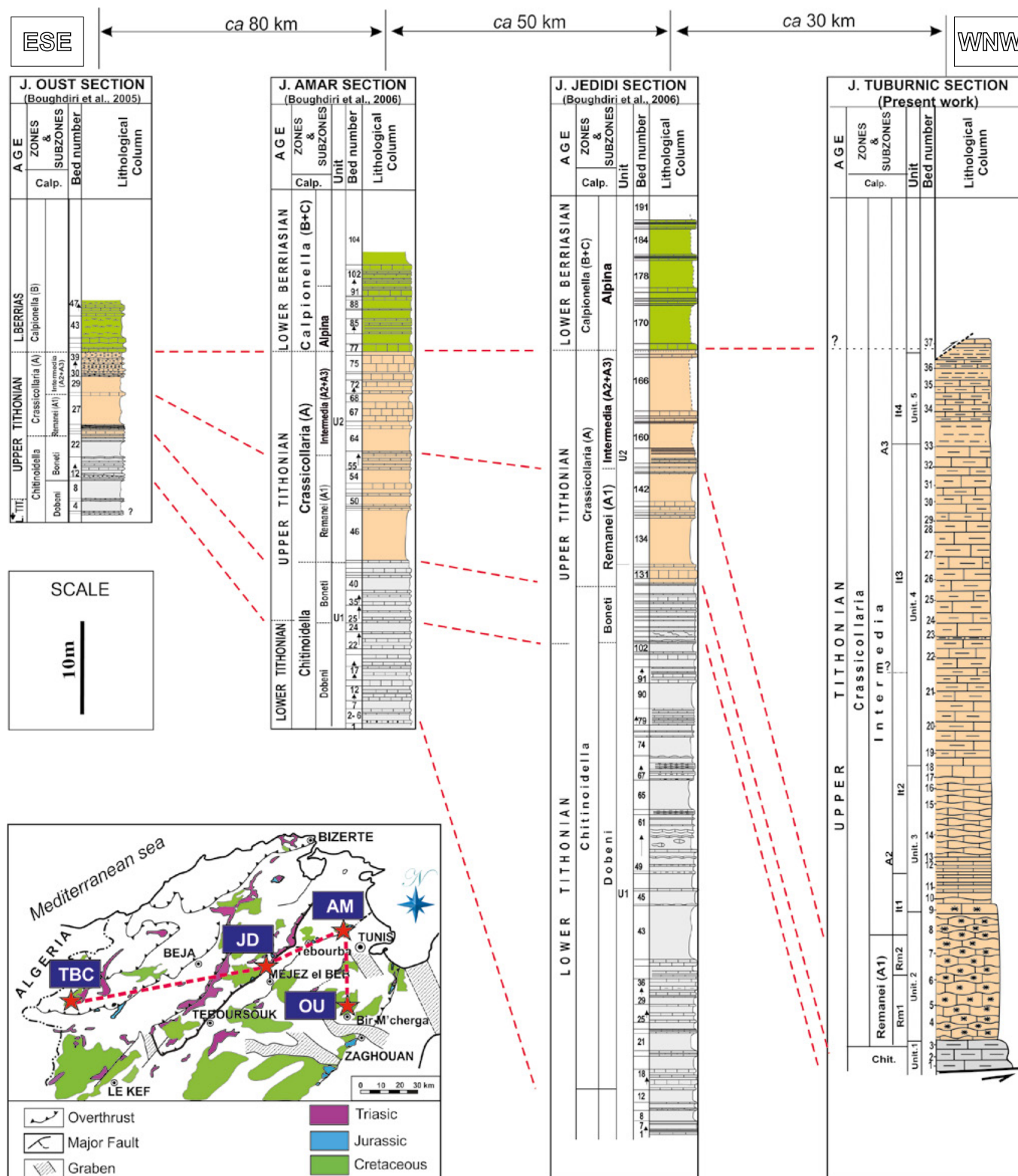
Text-fig. 3. Photos of main lithological units from study sections, a–d: Tuburnic (TBC) section. e–h: Ouerghech section (OUR).



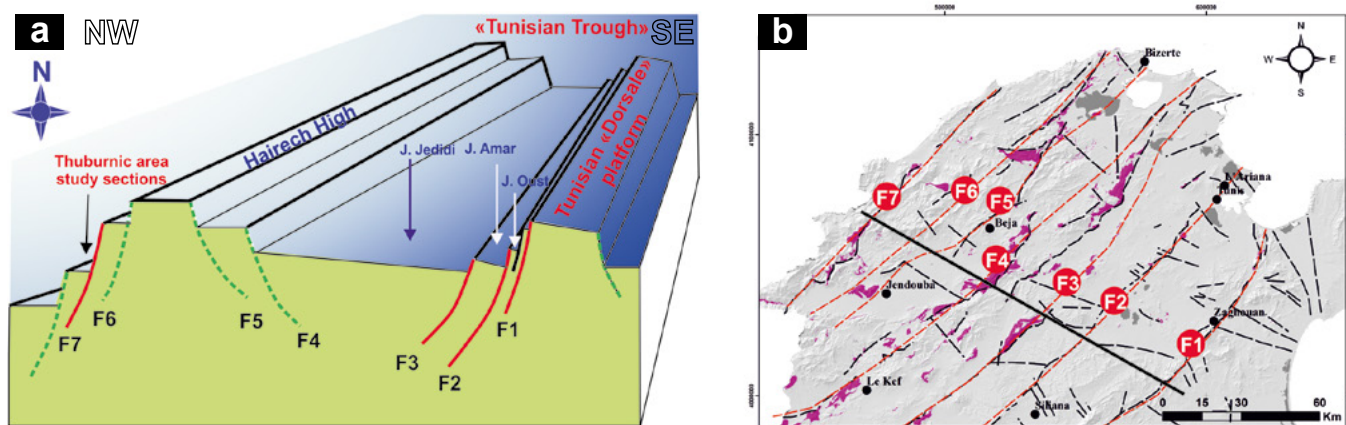
Text-fig. 4. Main Chitinoideid and Calpionellid species from study sections. Scale bar: 50µm. a: *Borziella slovenica* (BORZA), TBC1, Chitinoideidella Zone, Boneti Subzone, Upper Tithonian. b: *Carpathella rumanica* POP, TBC6, Chitinoideidella Zone, Boneti Subzone, Upper Tithonian. c: *Chitinoideidella hegarati* SALLOUHI et al., OUR2, Crassicollaria Zone, Remanei Subzone (Rm1 Horizon), Upper Tithonian. d: *Chitinoideidella carthagensis* SALLOUHI et al., TBC4, Crassicollaria Zone, Remanei Subzone (Rm1 Horizon), Upper Tithonian. e: *Tintinnopsella remanei* BORZA, TBC6, Crassicollaria Zone, Remanei Subzone (Rm1 Horizon), Upper Tithonian. f: *Tintinnopsella remanei* BORZA, OUR5, Crassicollaria Zone, Remanei Subzone (Rm2 Horizon), Upper Tithonian. g: *Crassicollaria intermedia* DURAND-DELGA, TBC9; Crassicollaria Zone, Intermedia Subzone (It1 Horizon), Upper Tithonian. h, i, q: *Crassicollaria intermedia* DURAND-DELGA, OUR6, OUR9, OUR25 Crassicollaria Zone, Intermedia Subzone, Rm2, base of It2, It4 Horizons, respectively, Upper Tithonian. j, k: *Crassicollaria massutiniana* COLOM, TBC17, TBC 27, Crassicollaria Zone, Intermedia Subzone, It2, It3 Horizons, respectively, Upper Tithonian. l–n: *Crassicollaria brevis* REMANEI, TBC14, TBC23, OUR 16, Crassicollaria Zone, Intermedia Subzone, It2 Horizon, Upper Tithonian. o, p: *Crassicollaria parvula* REMANEI, TBC25, OUR22 Crassicollaria Zone, Intermedia Subzone, It3 Horizon, Upper Tithonian. r, s: Elongated forms of *Calpionella alpina* LORENZ (= *Calpionella elliptalpina* NAGY), TBC 36, OUR26, Crassicollaria Zone, Intermedia Subzone, It4 Horizon, Upper Tithonian. t, u: *Crassicollaria colomi* POP, TBC36, OUR24, *Crassicollaria* Zone, Intermedia Subzone, It4 Horizon, Upper Tithonian. v, w: Spherical forms of *Calpionella alpina* LORENZ, TBC37, OUR23, Crassicollaria Zone, Intermedia Subzone, It4 Horizon, Upper Tithonian. x, y: *Tintinnopsella carpathica* MURGEANU et FILIPESCU, TBC36, OUR25, Crassicollaria Zone, Intermedia Subzone, It4 Horizon, Upper Tithonian.

Peybernès et al. 1994, 1996, Soussi 2002, Boughdiri et al. 2006, 2007, and references therein). This structuring isolates the TD, to the SE, from more subsiding basins of the TT to the NW. In these latter settings, the AR facies are laterally relayed by biosiliceous carbonates (Bajocian-Oxfordian; Cordey et al. 2005, Boughdiri et al. 2006), considered as “radiolarites” (Alouani et al. 1990) or “pseudo-radiolarites” (Soussi 2002). This leads us to consider the individualization of two significant palaeogeographic domains bordered to

the southeast by the major NE-SW Zaghouan fault. The first comprises the relatively resistant area of the TD, where debris flow deposits from J. Oust accumulated; the second consists of a deeper subsiding region (TT) distinct from the Dorsale, characterized by the biosiliceous limestone and marly series with slumps, and calciturbidites observed in J. Amar. The transition between these regions includes an intermediate zone extended NE-SW and bounded by the “Tunis-Elles” fault. (Text-fig. 6, Fault F2).



Text-fig. 5. Correlation of TBC section with lateral equivalents from Northern Tunisia.



Text-fig. 6. a: Schematic block-diagram illustrating sea-floor structuring of Northern Tunisia during Upper Tithonian. Main controlling faults: F1 – Zaghuan, F2 – Sidi Thabet, F3 – Teboursouk, F4 – Thibar, F5 – Jendouba-Beja, F6 – Haïrech-Ras Korane, F7 – Cap Serrat-Ghar Dimaou. **b:** Simplified map of Northern Tunisia showing main controlling faults.

Further northwest in the Mejez El Bebb area (J. Jedidi-Chaabane) and Teboursouk region (J. Lansarine), another subsiding area gives rise to an elongated sub-basin oriented northeast-southwest, characterized by biosiliceous successions (“radiolarites” or “pseudo-radiolarites” of the authors), interpreted as the deeper Jurassic domain of northern Tunisia (Soussi 2002). This sub-basin is bounded by the F3 Fault of Teboursouk (Text-fig. 6). The Tuburnic area represents a resistant but still pelagic high block within the TT, delimited to the SW by the Cap Serrat-Ghar Dimaou fault. Text-fig. 6a illustrates a block-diagram scheme of the sea floor structure of Northern Tunisia. This highlights the controlling major faults in NW Tunisia.

In all these adjacent regions, former troughs have evolved into carbonate platforms where the rate of sedimentation matched or exceeded the rate of subsidence, leading to the complete filling of available space with Upper Tithonian carbonate deposits.

Correlation with NE Algeria

Recently, Cherif et al. (2022) propose a precise calpionellid biozonation in the Upper Tithonian–Upper Berriasian of J. Kasserou (Ravin Bleu site, Batna Mountains, NE Algeria). By means of the same biomarkers, Touansa et al. (2024: fig. 5) propose SW-NE correlations of the J. Kasserou section and the J. Toumbaït series of Aïn Yaghout Mountains. These authors evidence notable variations in thickness between the lateral Upper Tithonian equivalents, interpreted as the consequence of a synsedimentary tectonic control that structured the background basement topography in a depression at the Ravin Bleu latitude, to the SW, followed by a swell in the Jebel Toumbaït, to the NE; both are bordered by ancient NW-SE-trending faults reactivated during Late Jurassic times.

In NE Algeria, another N-S correlation transect proposed by Touansa et al. (2024) links the Ravin bleu site and J. Toumbaït sections, to the north, with the reference section of J. Azreg of the Aurès Range, to the south. This transect shows important thickness variations and facies contrasts between correlated section groups. In fact, the relatively constant marl/limestone alternations of the northern area are opposed to the more marly

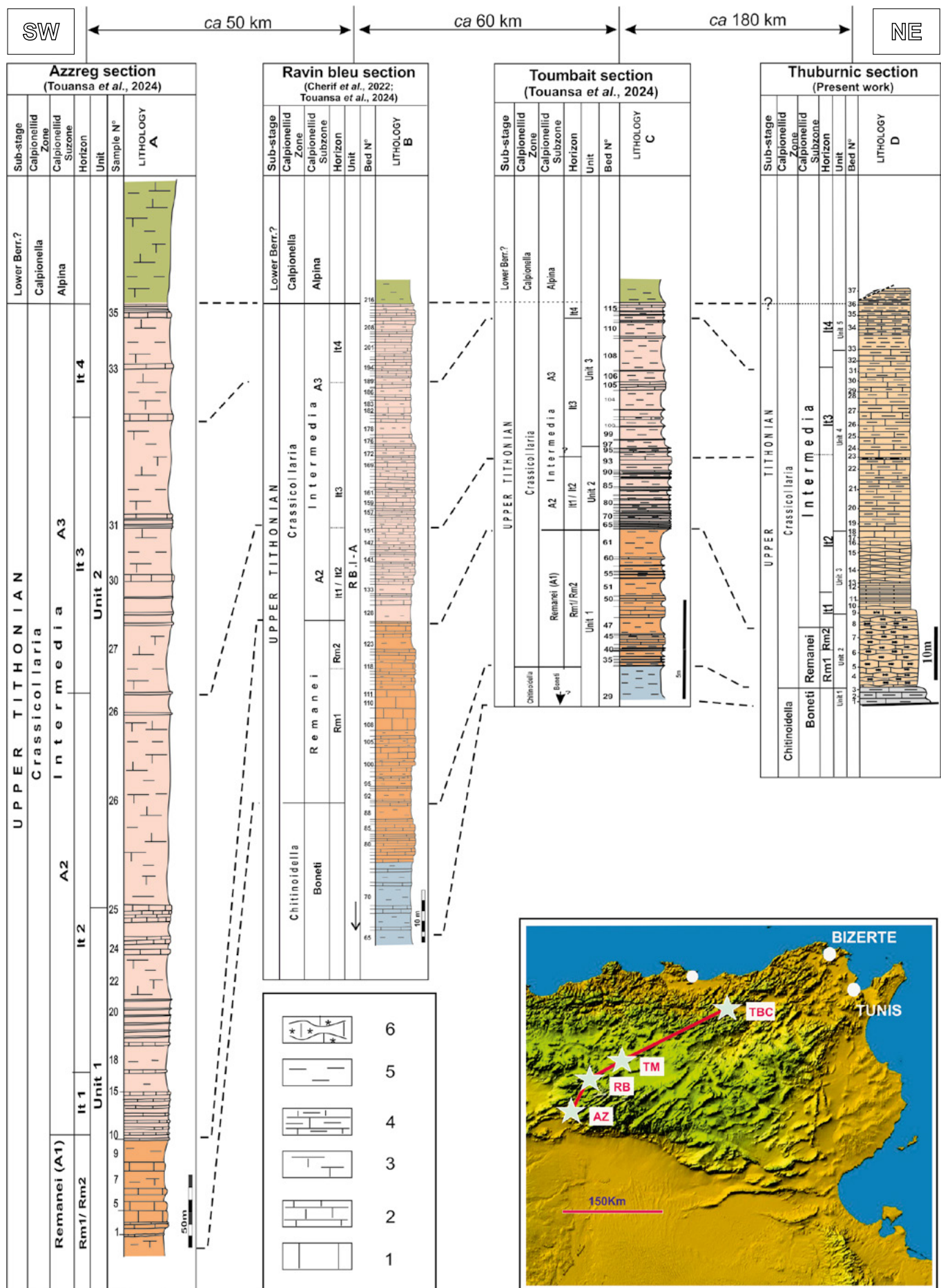
deposits with gravity-driven facies of J. Azreg, to the south. Touansa et al. (2024) attributed this contrast to a regional geodynamic context, where both depositional environments are separated by a major south-verging slope, as the result of a tectonic control, which involves the E-W- trending North-Atlantic major fault.

For interregional correlation purposes, the same sections dated by Touansa et al. (2024) are linked here to the Tuburnic section of NW Tunisia within a SW-NE correlation transect (Text-fig. 7). This shows that, during the Upper Tithonian, series thicknesses tend to be reduced towards the NE (Tuburnic of NW Tunisia), with notable facies contrasts in this latter area. This contrast singularizes the Tuburnic section by its limestone facies, biosiliceous component, and lesser marly intercalations. This leads to separate three different depositional environments: to the SW, the J. Azreg section (Aurès Range) represents the Aurès basin of the Saharan Atlas Trough of Algeria; the Ravin bleu site and J. Toumbaït sections, as part of the Pre-Atlassic zone, and the Tuburnic section, to the NE. As in NW Tunisia, the Tuburnic section belongs to an uplifted resistant block from the Algerian Tellian domain, clearly different from its deeper coeval successions in NE Algeria. This resistant block seems to be the continuity (or a part) of the same high swell NW Tunisia, as interpreted from our correlations in Text-fig. 5.

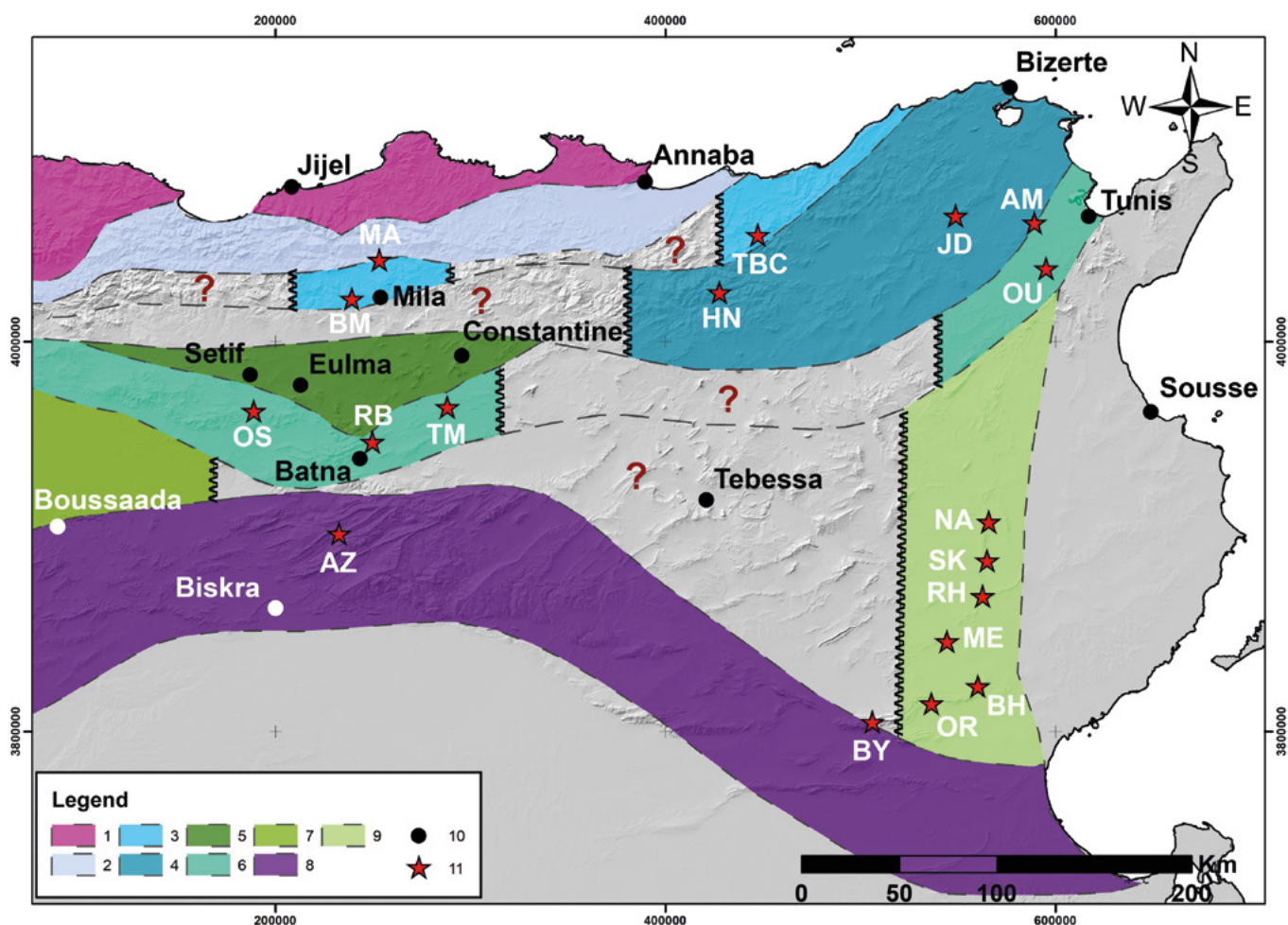
Synthesis and discussions: Upper Tithonian correlatives from NW Tunisia and NE Algeria, towards a regional geodynamic model (Text-fig. 8)

In Northern Tunisia and NE Algeria Tunisia, the South-Tethyan margin of North Africa mainly comprises, from south to north:

- The Saharan platform with reduced Jurassic facies of proximal character that pass into the subsiding basin of the Chotts area of Southern Tunisia (Soussi 2002). Bordered to the south by the South-Atlassic fault corridor, this Tunisia Chotts basin extends westwards to the south-eastern segment of the Saharan Atlas Trough in Algeria where coeval facies were identified in the Biskra region by Guiraud (1973).
- The “North-South Axis” (NOSA) high block in central



Text-fig. 7. Correlation of TBC section with lateral equivalents from NE Algeria. 1 – Massive limestones, 2 – Thin-bedded limestones, 3 – Weathered limestones, 4 – Marly limestone beds, 5 – Marls, 6 – Biosiliceous limestones.



Text-fig. 8. Upper Tithonian facies distribution and main facies zones: 1– Kabylia, 2 – Facies zone of Internal Tell, 3 – Facies zone of External Tell, 4 – “Tunisian Trough” facies zone and its extension in Babors foreland of Algeria, 5 – Isolated platform of Constantine mole; 6 – Tunisian Dorsale and its extension to Pre-Atlasic zone of NE Algeria, 7 – North–South Axis platform of Central Tunisia and its high plateau equivalent zone from western Algeria, 8 – Saharan Atlas Trough (Algeria) and Chotts basin (Southern Tunisia) correlative facies zone, 9 – Tunisian North–South Axis (NOSA), 10 – Town location, 11 – Location of compared sections from NE Algeria and Tunisia (AZ – Azreg, OS – Oued Soubella, RB – Ravin Bleu, TM – Toumbaït, BM – Bou Maarouf, MA – M’cid Aïcha, HN – Hammam N’bails, TBC – Tuburnic, JD – Jédidi, AM – Amar, OU – Oust, NA – Nara, SK – Sidi Khalif, RH – Rhéouis, ME – Meloussi, BH – Bouhedma, OR – Orbata, BY – Ben Younes).

Tunisia and, at a lesser degree, the isolated Zaghuan platform of the TD of NE Tunisia that can be easily correlated to the High plateaus of western Algeria, where comparable limestone/dolostone sequences are observed, together with the onset deltaic sequences, since of the Oxfordian–Lower Tithonian, in W Algeria (Elmi et al. 1998), and during the Berriasian, in central Tunisia (M’rabet 1987, Soussi 2002, Boughdiri et al. 1999, Ben Nsir 2017, Ben Nsir et al. 2019).

- The platform-basin transitional facies of the peri-Dorsalien sections of NE Tunisia (e.g., J. Staa, J. Zaress, J. Bent Saidane, J. Oust) show tight similarities with correlatives in the Pre-Atlasic zone of NE Algeria (Hodna and Batna Mountains, Aïn Yaghout Ranges).

In both domains, the Upper Jurassic sequences are mainly characterized by the onset of Ammonitico-Rosso facies (Middle–Upper Oxfordian), overlain by Kimmeridgian–Middle Berriasian carbonates. This common-facies areas can be delimited within a curved band, oriented NE–SW in northern Tunisia, E–W to NE–SW around the Aïn Yaghout Range zone, and NW–SE in the Hodna Mountains region of NE Algeria (Text-fig. 8). This facies band bypasses, to the south, east and

west, a sub-triangular Upper Jurassic “Constantine mole” as an isolated platform, characterized by its reduced inner shelf deposits. This isolated platform and adjacent transitional facies of the South–Setifian Ranges pass into the bordering pelagic facies of the Hodna, Batna and Aïn Yaghout Mountains. They clearly contrast with their deeper correlatives from the Northern Aurès Range (J. Azreg section) with their characteristic gravity-driven deposits (Guiraud 1973, Aissaoui 1979, Vila 1980, Touansa et al. 2024). This N–S abrupt facies and thickness variation along adjacent facies in NE Algeria pleads in favor of a tectonic control, where the E–W fault corridor of the North Saharan Atlas, NW–SE and NE–SW respective bordering faults of Hodna–M’sila and Chebket Sellaoua would have played an important role. At least, during Upper Jurassic times, the Sellaoua Trough of NE Algeria, usually admitted as the continuity of the TT, would have been rather a subsiding block within a band covering the present pre-Atlasic zone. Worthy of note is the fact that, if Upper Jurassic outcrops are still unknown from the intermediate area between the Batna Mountains and Aurès Range, their potential equivalent has to be followed in SE Tunisia, around the Gafsa Basin. In this key

zone, the Jebel Ben Younes section of Gafsa area is made of marl/limestone alternations and grey nodular limestones that differ from their dolomitic Upper Nara Formation equivalents and marly Sidi Khalif Formation in the NOSA. It was recently revised by ammonites and calpionellids (Ferchichi 2021): an Upper Tithonian-Lower Berriasian age was assigned to this section, and SE-verging synsedimentary faults were evidenced within Upper Tithonian units. In this same Gafsa region, Jurassic outcrops were recently discovered by Bahrouni et al. (2016) in J. Bouhedma; their upper part being recently dated by calpionellids as Upper Tithonian by Ferchichi et al. (2019) and Ferchichi (2021). These sections would have belonged to a transitional zone assuring the link with the Northern edge of the Chotts basin, which also includes the still-unknown section representatives of the zone between the Batna and Aurès Ranges in NE Algeria.

- In NW Tunisia, the Jurassic TT deposits and their characteristic radiolarian-bearing biosiliceous are recognized in Jebel Amar and Jedeida hills, more distinctive further north, in the J. Jedidi-Chaabane (Mejez El Beb) and J. Lansarine (Teboursouk), where they are directly dated by radiolarians as Bajocian-Oxfordian (Cordey et al. 2005, Boughdiri et al. 2007). These biosiliceous sediments are considered as partly equivalent to the Ammonitico Rosso facies of the TD. According to Soussi (2002), the TT and its siliceous facies passes, in Algeria, to the present M'sila-Batna area that seems to correspond, after Guiraud (1973), to a relatively deep zone open to pelagic influences. The same author added that the Upper Jurassic facies (Saccocomid-limestones and calpionellid-bearing marl/limestone alternations) of the TT are comparable to those described in the Hodna and Batna Mounts. Our recent investigations in the Aurès Range (Touansa et al. 2024) and the Batna Mounts (Cherif et al. 2022, Touansa et al. 2024) as well as our work in progress in the Oued Soubella and Boutaleb areas of the Hodna Mounts do not agree with Soussi's interpretations. In these investigated areas, the Upper Jurassic AR facies are rather analogous to those of the TD and Aïn Yaghout Mountains, but do not include the radiolarian-bearing biosiliceous limestone units of the TT. In fact, these TT facies are rather comparable to those discovered by Peybernes et al. (1994, 1996) in the Souk Ahras area of NE Algeria. They also show tight affinities to the South-Tellian domain of Algeria, mentioned in the Babors ("phtanites" units of Ehrmann 1942, Leikine 1971, Obert 1981) and the northwest Constantinois region (Durand-Delga 1951, 1955). This facies correlation, previously proposed by Boughdiri et al. (2007), leads to link the TT and the South Tellian zone within another facies band that trends NE-SW in NW Tunisia and continues W-E in Northern Algeria, passing through the vicinity of the "Constantine mole's" isolated platform's northern edge.

- To the North of the TT, in NW Tunisia, the Tuburnic and Ouerghéch sections studied here are revealed to be a precious milestone for Tunisia-Algeria interregional correlations. The Tuburnic section is characterized by its reduced Dogger sequences (Soussi et al. 1998). It is considered here as part of a high pelagic resistant block within the TT, delimited to the south by the Cap Serrat-Ghardimaou fault, which would have played an important synsedimentary controlling role. In Northern Algeria, co-eval successions should be

searched around the El Milia area where the Bou Maarouf (BM) and M'cid Aïcha (MA) sections (Text-fig. 8) show tight affinities. In addition, the current location of the Tuburnic sections to the northwest of the Haïrech metamorphic Liassic outcrop (Jendouba area) may support this palaeogeographic interpretation, considering the Haïrech section as part of a NE-SW elongated band called the Haïrech-Ichkeul ridge (Rouvier 1985). This ridge may partly extend westwards to the El Milia-Texana area, where similar metamorphic series were described by Durand-Delga (1979). Hence, the Tuburnic area resistant block would have belonged to the northern part of this wide resistant edge that has been tilted northwards and progressively open to the Tethyan ocean. This latter tilted zone would be followed under the Mediterranean Sea, where the Tunisia Tellian succession continuity cannot be observed.

Finally, the palaeo reconstructions proposed here aim at replacing the Tunisia-Algeria Upper Jurassic northernmost successions in their regional geodynamic context. These confirm that, in Algeria and Tunisia, the Upper Jurassic sedimentary record shows a S-N polarity, from a continental to proximal domain in the south, to a deeper pelagic domain to the north. Our proposed model (Text-fig. 8) is clearly still in need of further precisions or modifications, depending on new datings and/or the availability of complete seismic profiles crossing the proposed tectono-sedimentary zones. Of a particular relevance are two important remarks:

- 1) The zone limits proposed in Text-fig. 8 attempted to follow the current fault routes; only structural restoration based on balanced sections can bring a certain light to the "true" tracing of this facies' zone limits and their Tunisia-Algeria transborder extension. As a particular consequence, the curvature of facies zones delimited here by major faults, from E-W in Algeria to NE-SW in Tunisia, is unlikely to have been prefigured during Upper Tithonian sedimentation. It would have resulted from superimposed more recent palaeogeographic and corresponding structural contexts.

- 2) Each of the defined facies zones is far from being homogeneous; but should be traversed by a mosaic of highs and sub-basins with differential bathymetry, while maintaining the same general facies characteristics.

Conclusion

The calpionellid biozonation of two sections from the Tuburnic area (Ghardimaou region, NW Tunisia) allows us to distinguish two Upper Tithonian calpionellid zones (Chitinoïdella and Crassicolllaria), including three subzones (Boneti, Remanei and Intermedia), and five horizons (Rm1, Rm2, It1, It2, It3 and It4). The proposed biozonation fits the standards used elsewhere in the South- and West-Tethyan domain. In the Crassicolllaria Zone, the Rm2 Horizon of the Remanei Subzone, and the It1, It2, It3 and It4 horizons of the Intermedia Subzone have been recently proposed for co-eval sections in NE Algeria, and are confirmed here. The study sections from the Tuburnic area; as the unique witness of the Upper Tithonian, within a hinge zone between the easternmost segments of the Algeria Saharan Atlas and Tell belts of Northern Tunisia, are shown here to be of great interest for interregional correlations. These led to replace

the Upper Jurassic series of Northern Tunisia and NE Algeria in their regional geodynamic context, allowing us to propose a model associating both countries facies zones.

Future works are to be oriented, in the short term, to the eastern part of the Tuburnic outcrops, which is indeed densely covered by vegetation and intensely disturbed by minor faults. However, rigorous field work may lead to a synthetic complementary section composed of successive sub-sections, where bed-by-bed following of markers, assisted by calpionellid biostratigraphy would be of a great interest towards settling the long-running stratigraphic debate. In addition, as shown in the geodynamic model proposed in this work, the lack of data concerning unknown (or not outcropping) Upper Tithonian sections in Northern Tunisia and NE Algeria seriously biases the continuity and precision of the plotted facies zones. This handicap may be overcome by seismic profiles crossing the concerned gap areas, whose interpretation is supported by the recently published high resolution biostratigraphy in both countries. Furthermore, long-distance correlations of these available sections with their correlatives in Western Algeria and Morocco will be of a great interest in replacing the whole Maghrebien successions in their broad western Tethys context.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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