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The Cenomanian–Turonian boundary on the Saharan Platform (Tunisia and Algeria)

Danièle Grosheny [a,*], Serge Ferry [b], Mohamed Jati [a], Mohamed Ouaja [c], Mustapha Bensalah [d], François Atrops [b], Fettouma Chikhi-Aouimeur [e], Fatiha Benkerouf-Kechid [e], Hedi Negra [f], Hamid Aït Salem [g]

[a] Université de Strasbourg, EOST, UMR 7359 GéoRessources - Nancy, 1 rue Blessig, 67084 Strasbourg cedex, France
[b] Laboratoire de Géologie de Lyon, Terre, planètes, environnement, UMR 5276, CNRS, ENS de Lyon, UCB Lyon 1, 2 rue Raphael Dubois, 69622 Villeurbanne, France
[c] Université de Gabès, Faculté des Sciences, Département des Sciences de la Terre, Cité Riadh, Zirig, 6072 Gabès, Tunisia
[d] Université Abou Bekr Belkaid, Faculté des Sciences de la Nature, Département de Géologie, Rocade 2, Tlemcen, Algeria
[e] Université des Sciences et de la Technologie Houari Boumédienne, Département de Géologie, Bab Ezzouar, Alger, Algeria
[f] Université de Tunis El manar, Faculté des Sciences, Unité de Recherche de Pétrologie cristalline et sédimentaire (05/UR/10), Campus universitaire Manar II, 2092 Tunis, Tunisia
[g] Algerian Petroleum Institute-Boumerdès, Algeria

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ABSTRACT

Several transects made of correlated stratigraphic sections and well logs have been constructed spanning southern Tunisia and the Algerian Sahara (Tinrhert) for comparison with earlier results obtained in the Saharan Atlas. The study is based on facies analysis, sedimentology, biostratigraphy focused on ammonites and foraminifers) as well as whole rock geochemistry ($\delta^{13}C$). These suggest that the entire northern Sahara Platform underwent marine flooding that commenced just prior to the onset of the global positive $\delta^{13}C$ shift documented for the Cenomanian–Turonian boundary. This flooding occurred in two phases. The first phase is expressed by the deposition of deeper-water, light-coloured bioturbated mudstones overlying the shallow-water deposits comprising the local Cenomanian successions. But in some places in the Central Sahara (Hassi Messaoud area, Tihemboka Arch) as well as in the Saharan Atlas, shallow-water carbonates kept up locally with the relative sea-level rise to build up isolated carbonate platforms. The topographic lows or saddles between these areas could have been formed through differential accumulation rates. During the second phase, flooding resumed and black shales were deposited over the mudstones in the saddles. The occurrence of black shales in these saddles is limited to the northern edge of the platform (Saharan Atlas of Algeria, Gafsa Trough in southern Tunisia). On the platform, this phase is represented by the same kind of mudstones deposited during the first phase of the flooding (southern Tunisia), or by ammonite-rich chalks in the intra-cratonic basin of the Tinrhert (southern Algeria). Black-shale deposition ceased in the early Turonian. Based on the $\delta^{13}C$ curve, the latest Cenomanian flooding of the Sahara Platform is roughly coeval with that documented for the US Western Interior.

During the first phase of the transgression, that is before the occurrence of the large *Whiteinella* of the *W. archeocretacea* Zone in the black shale unit, planktic foraminifers are dominated by small globulose forms of the *Hedbergella delrioensis* type, associated with Heterohelicidae. Keeled forms (rotaliporids, dicarinellids) are scarce and always very small when present. Perhaps these dwarfed forms were adapted to the restricted environments of the extensive intracratonic seaways crossing the Saharan Platform to the Benoué Trough in Nigeria.

1. Introduction

The Cenomanian–Turonian boundary event (CTBE) or Oceanic Anoxic Event 2 (OAE2) is one of the best-studied "anoxic" events in the geologic record (e.g. Schlanger and Jenkyns, 1976; Schlanger et al., 1987; Arthur and Schlanger, 1979; Jenkyns, 1980). Most authors have focused their studies on basinal sections which have been used for long-distance correlation, and include the Pueblo, CO, stratotype (Kennedy and Cobban, 1991; Keller and Pardo, 2004; Keller et al., 2004; Desmares et al., 2007), presently the Global Boundary Stratotype for the Cenomanian–Turonian (C/T) boundary (Kennedy et al., 2005; Sageman et al., 2006), or that of Eastbourne in England (Jeans et al., 1991; Hart et al., 1993; Paul et al., 1999;

* Corresponding author. Tel.: +33 368850450.
E-mail address: grosheny@unistra.fr (D. Grosheny).

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Keller et al., 2001; Gale et al., 2005). Other examples include: Wünstorf in Germany (Hilbrecht et al., 1986; Voigt et al., 2008; Hetzel et al., 2011), Kalaat Senan or Wadi Bahloul in Tunisia (Robazsynski et al., 1990; Burollet and Robasynski, 1991; Robaszynski et al., 1993a, 1993b; Amédro et al., 2005; Caron et al., 2006), Gubbio in Italy (Coccioni and Luciani, 2004, 2005), Pont d'Issole in southern France (Grosheny et al., 2006; Jarvis et al., 2011), as well as deep-oceanic sites (Kaiho and Hasegawa, 1994; Sinninghe-Damsté and Köster, 1998; Huber et al., 1999; Kuypers et al., 2004; Friedrich et al., 2006; Hardass and Mutterlose, 2007; Forster et al., 2008).

Our aim is to understand the relative sea-level changes around the CTBE, and to check for their relationship to the eustatic signal. Most authors have studied the CTBE in basinal sections dominated by black shale deposition favour a worldwide transgressive event, following the interpretations of Arthur and Schlanger (1979) and Jenkyns (1980). Such a transgressive event has been known for decades in the US Western Interior Basin, extending back to the work of Hancock and Kauffman (1979). But many other well-studied basinal sections outside this basin, such as those in England, Italy, Central Tunisia, or oceanic localities (see above), lack the direct correlation with the marginal deposits necessary to reconstruct directly sea-level changes. In SE France, the CTBE black shale of the Subalpine Basin hosts siliciclastic turbidites and is associated with the most pronounced Cretaceous regressive event on the western margin of the basin (Malartre and Ferry, 1993; Grosheny et al. work in progress). Something similar, although more complex, has been found on the Morroccan Atlantic margin (Jati et al., 2010), which does not correspond to what has been found eastward in the Tethys-oriented Errachidia Basin (Lezin et al., 2012) where the sea-level changes are quite similar to those recorded in the US Western Interior. Deciphering the superimposition of local tectonic effects on a possible eustatic signal would require detailed studies, such as that of Laurin and Sageman (2007), compared in a number of basins worldwide. Here, we presents the results of a study undertaken in both southern Tunisia (Gafsa area to the Dahar Plateau) and southern Algeria (Tademaït and Tinrhert). These results are compared with results previously obtained in the Saharan Atlas of Algeria, to better reconstruct relative sea-level changes during the CTBE for a broader part of the North African Craton.

2. Geological setting and sections studied

The Gafsa Trough in southern Tunisia (Fig. 1) is a narrow basin situated along the northern edge of the Saharan Platform. It was probably connected (Lüning et al., 2004) to the larger Mellegue Basin of northern Algeria and northern Tunisia ("sillon tunisien" of Robazsynski et al., 2000). Its eastern margin is delineated by the intersection of the W–E-oriented margin of the Saharan Platform and a major NW–SE-oriented lineament bordering the Kasserine Platform of Central Tunisia. Four sections were studied (Fig. 1, Table 1): Oued Beida within the Gafsa Trough, Jebel Asker from the Saharan Platform margin, and Foum Hassene and Chenini both positioned on the Saharan Platform. The Oued Beida section is located on the northeastern limit of the Jebel Berda anticline. The Jebel Asker section is situated on the northern border of the northern chain of the Chotts. The Foum Hassene section is situated a few kilometres south of the cliff formed by the upper Albian limestones in the southern chain of the Chotts, at the base of a second cliff made of the Turonian platformal limestones of the Gattar Fm. The Chenini section is situated close to the village of Chenini, at the base of the cliff overhanging the Sept Dormants necropolis. The sections represent a basin-to-platform transect, which is completed further to the south using well data (OS1) and field observations from the Briga area.

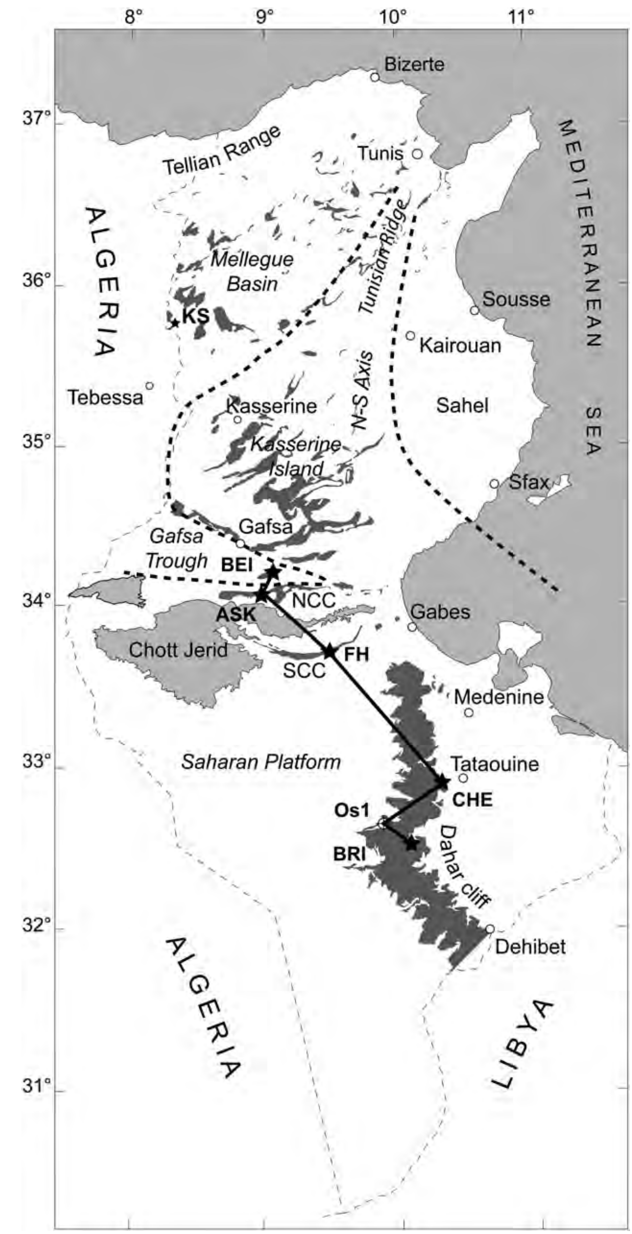

Fig. 1. Location of the transect studied in southern Tunisia. Sections: BEI, Oued Beida; ASK, Jebel Asker; FH, Foum Hassene; CHE, Chenini; Os1, Oued Siah Es Seraïa-1 well; BRI, Briga. NCC, Northern chain of the Chotts; SCC, Southern chain of the Chotts. KS, Kalaat Senan, reference area for C–T boundary sections in the Mellegue Basin. Words in italics on the map refer to palaeogeographic features after Lüning et al. (2004), modified. Dark-grey represents Cenomanian–Turonian outcrop areas.

The results obtained in southern Tunisia are compared with outcrop data from the central Sahara, further within the Saharan Craton. The sections studied in the present work are the sections of Bordj Omar Driss, Takouazet and Ohanet in the Tinrhert (Fig. 2, Table 1). The Bordj Omar Driss section (or "Fort Flatters", as it is also known in the literature and on geological maps, or "Temassinine" section in Amédro et al. 1996) has been logged along the paved road north of Bordj Omar Driss for its lower part, and completed with nearby outcrops for its upper part. The Takouazet and Ohanet sections have been logged in wadis cutting across the cuesta formed by the "Turonian bar" of Busson (1969, 1970), north of the main road from Bordj Omar Driss to In Amenas. The outcrop data were used to calibrate well logs from a number of locations.

Table 1
GPS coordinates of the sections studied.

Sections	GPS coordinates
Tunisia:	
Chenini	N 32°54'31.70", E 10°16'25.70"
Foum Hassene	N 33°43'28.80", E 9°30'20.90"
Jebel Asker	N 34°5'17.80", E 8°57'7.60"
Oued Beida	N 34°14'25.40", E 9°1'47.20"
Algeria:	
Bordj Omar Driss	N 28°10'36", E 6°48'06"
Ohanet	N 28°32'54", E 7°51'07"
Takouazet	N 28°46'39", E 8°45'22"

Previous work of Busson (1969, 1970) has shown that thick fluvial deposits were deposited in the Tinrhert during the Late Jurassic and the Lower Cretaceous. Marine sedimentation initiated in the Cenomanian with grey marlstones followed by green claystones hosting thick gypsum layers. Marine flooding occurred in the late Cenomanian represented by hard limestones (mudstones or wackestones), overlain by ammonite-rich, chalky limestones. The transgression lasted into the lower Turonian represented by grey marlstones. Evaporite sedimentation resumed in the "Senonian" (Coniacian?). A large number of ammonites have been collected from the Tinrhert sections and used to delineate the Cenomanian–Turonian boundary (Amédro et al., 1996), but the inception of the late Cenomanian deepening remains poorly defined biostratigraphically. The present study presents light-stable isotopic data to assist in constraining the timing.

Two perpendicular transects have been constructed. The W–E-oriented transect traces the lithological units on the western side of the El Biod Ridge, a Lower Cretaceous palaeogeographic high situated at the boundary between the Tinrhert and the Tademaït. The S–N-oriented transect allows correlations with previous results obtained (Grosheny et al., 2008) in the Saharan Atlas to the north. Only two of those previously studied sections in the Saharan Atlas are included here (Fig. 2), the platformal and basinal Djebel Mimouna and Khanguet Grouz sections, respectively.

3. Materials and methods

All the studied sections have been precisely logged, taking into account depositional facies and the nature of their vertical changes. A detailed sampling around the Cenomanian–Turonian boundary has been made to determine the changes in foraminiferal assemblages and obtaining $\delta^{13}C$ data.

Of the four sections studied in southern Tunisia, the Oued Beida and Jebel Asker sections have previously been described (Razgallah et al., 1994; Abdallah and Meister, 1997; Abdallah et al., 2000; Meister and Abdallah, 2005). They have been redescribed, and the

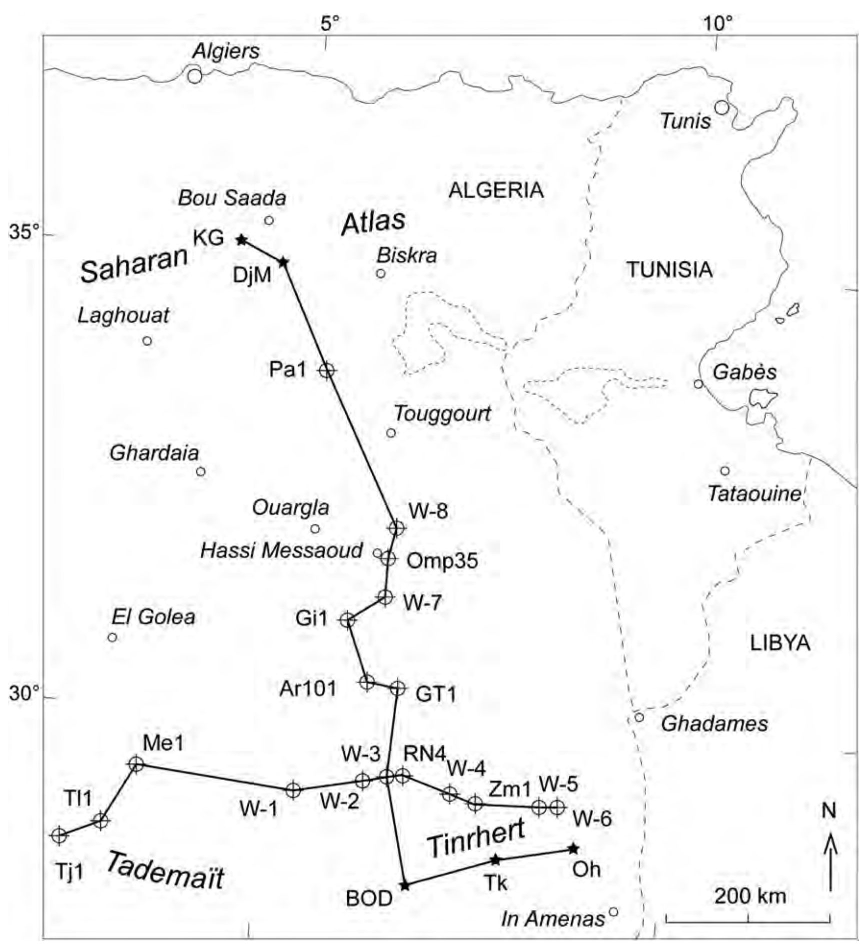

Fig. 2. Location map depicting the transects studied in Algeria. Black stars, outcrop sections: BOD, Bordj Omar Driss; DjM, Djebel Mimouna; KG, Khanguet Grouz; Oh, Ohanet; Tk, Takouazet. Circles, oil wells.

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ammonites cited by Meister and Abdallah (2005) have been approximately positioned on our log. Carbon isotope and foraminiferal data are now available for three of the sections (Oued Beida, Jebel Asker and Foum Hassene). Carbonates of the Chenini section further south are partly or strongly dolomitised, and, thus, have not been geochemically analysed.

This is the first isotope study and facies analysis undertaken in the Algerian Sahara. Detailed sampling has been made in the Bordj Omar Driss section around the CTB. The transition from the chalky limestones to the lower Turonian grey marls does not outcrop in this section. Sampling of the transition has been undertaken in the eastern Ohanet section where the facies change is visible and well constrained by ammonites (Amédro et al., 1996).

Due to the indurated quality of the samples, even of the black shales of the Gafsa Trough, the foraminiferal analysis was carried out using thin sections, two per sample, one parallel to bedding the other perpendicular to obtain planktic foraminifer sections suitable for taxonomic determination. Determinations were made using the systematics of Loeblich and Tappan (1988). The planktic zonal schemes used are those of Robaszynski et al. (1979), Caron (1985), and Robaszynski and Caron (1995).

Bulk carbonates were analysed for carbon stable isotope composition using an auto sampler MultiPrepTM 132 system coupled to a dual-inlet GV IsoprimeTM 133 isotope ratio mass spectrometer (IRMS). Mudstones and shales were preferably analysed. Results are expressed in permil deviation vs. PDB standard reference. The analytical error is lower than 0.06‰.

4. Palaeogeographic setting of the sections studied in Southern Tunisia

4.1. Oued Beida section

The CTBE (Fig. 3), is underlain by approximately 200-m-thick Cenomanian deposits consisting of numerous shallow-water transgressive–regressive depositional cycles (unit 1, Fig. 4A and B), although only the uppermost portion is presented in Fig. 3. These deposits comprise oyster-bearing marlstones, bioclastic beds, and

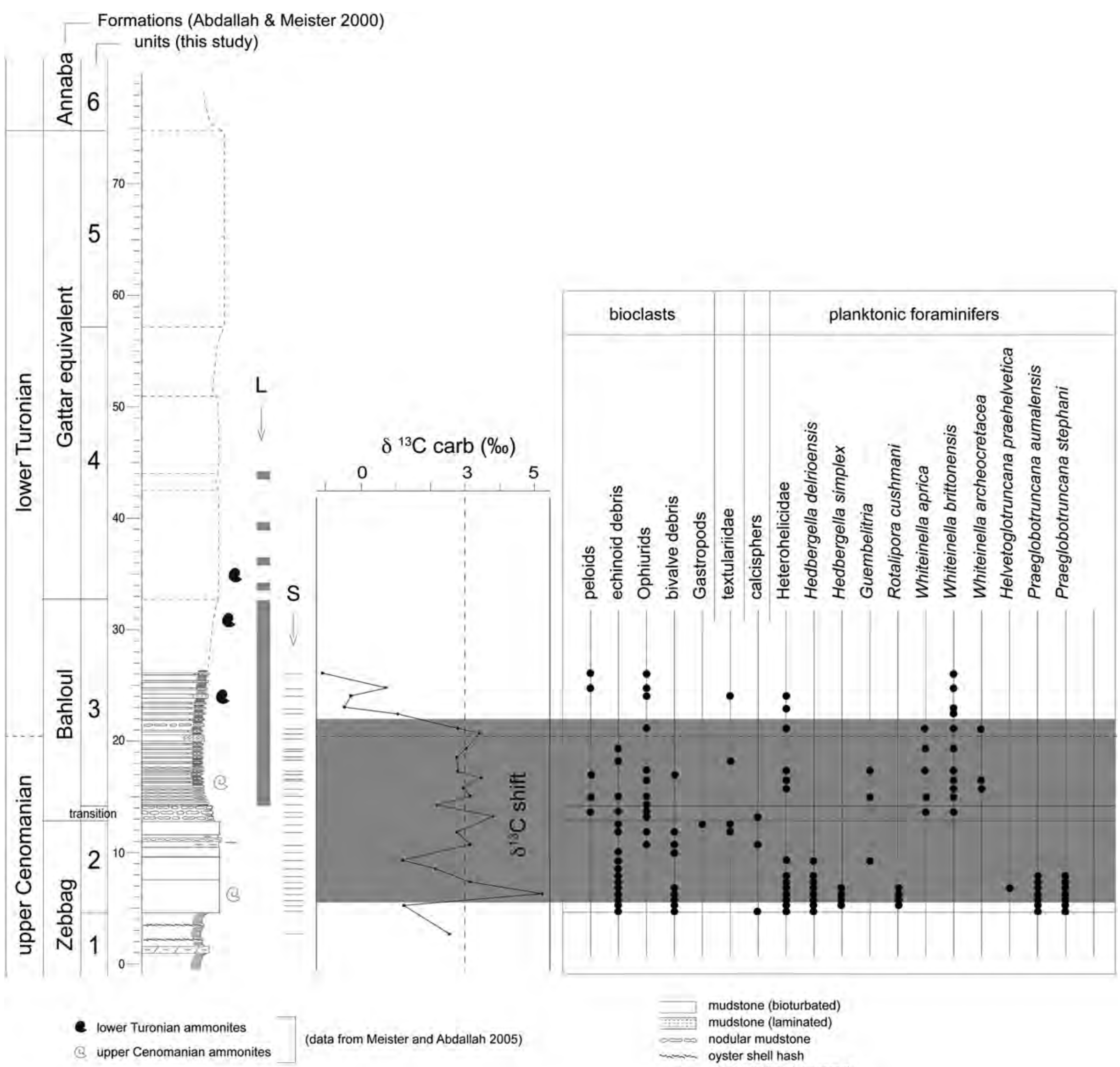

Fig. 3. The Oued Beida section. Informal units to the left of the lithologic column; L, laminated mudstone beds in the Bahloul equivalent; S, sampled levels.

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Fig. 4. The Oued Beida section. A, general view of the section denoting the units; B, closer view of massive white mudstones of unit 2, 8 m thick (note the coquina bed, denoted by the arrow, in the upper third); C, detailed view of the transition to the black shales of unit 3; D, close view of the laminated shales (weathered at outcrop) of unit 4. Numbers refer to the lithostratigraphic units of Fig. 3.

laminated dolomites. The overlying unit 2 is a massive fine-grained limestone (mudstone) bed, uniformly whitish-beige in colour, 8-m thick and contains a prominent bivalve-rich bed in the upper third (Fig. 4B). An interval with nodular mudstones alternating with greyish marlstones marks the transition to unit 3, a laminated black shale unit (Fig. 4C and D). Silicified shales form the more resistant beds alternating with the laminated shales (Fig. 4C). The whitish colour (Fig. 4D) is due to weathering at the outcrop; in cores, the unit is uniformly black. The transition to unit 4 is progressive. Units 4 and 5 are well-bedded light-coloured mudstones. Beds are thicker in unit 5. Unit 6 is more readily weathered due to its marlier lithology (middle Turonian "Annaba Marls", according to Abdallah et al., 2000). The section lacks *Watinoceras coloradoense* used to define the base of the Turonian (Kennedy et al., 2005), so the position of the Cenomanian–Turonian boundary was approximated by Meister and Abdallah (2005). By comparison between the section presented here and their ammonite data, the Cenomanian–Turonian boundary lies somewhere between 17 and 24 m (Fig. 3).

The δ^{13}C curve (Fig. 3) shows that the excursion associated with the CTBE begins $\approx$1 m above the base of unit 2 and ends 22 m above the base of the measured section. Various sections worldwide (Kennedy et al., 2005; Gale et al., 2005; Caron et al., 2006; Jarvis et al., 2011) have shown that the C–T boundary occurs just prior to the end of the δ^{13}C shift (Fig. 5). Therefore, the isotope curve helps to more accurately locate the position of the C–T boundary in the Oued Beida section (Fig. 3).

Planktic foraminifers appear suddenly at the base of unit 2, together with ammonites but they are absent in its upper part. They become more abundant again in the black shales of unit 4 where large *Whiteinella* are found. The main characteristic of the planktic fauna from the base of unit 2 is the very small size (three to four times smaller than normal) of the rare keeled rotaliporids and praeglobotruncanids present. The sudden occurrence of planktics and ammonites at the base of unit 2 suggests that the mudstone unit represents marine flooding. The disappearance of planktic foraminifers in the upper part of the unit is interpreted as the result of a shallowing trend, before a renewed deepening in the black shales unit, where the normal planktic fauna of the *Whiteinella archeocretacea* Zone (Robaszynski and Caron, 1995) with large *Whiteinella* is found. Such an interpretation would explain why the last occurrence of *Rotalipora cushmani* is so low within the δ^{13}C shift as compared with other sections in the world. The lower Turonian marker *Helvetoglobotruncana helvetica* (Robaszynski and Caron, 1995) has not been found in the sampled portion of the section. Lastly, the near constant occurrence of benthic remains like echinoid and ophiurid debris (Fig. 3) in the black shales suggests that the bottom waters of the Gafsa Trough were able, at least period. These bottom waters should be considered as generally suboxic rather than anoxic.

4.2. Jebel Asker section

The section (Fig. 6) records a thick Cenomanian series (Fig. 7B), but only the last few metres (unit 1) are included in Fig. 5. As with the Oued Beida section, the position of ammonites described by Meister and Abdallah (2005) are approximately located on our lithologic column by comparison with their log. Generally, the many short-term transgressive–regressive sequences that comprise the Asker Cenomanian succession are capped by laminated dolomitic beds (Fig. 7D) interpreted as tidal flat facies (or possibly

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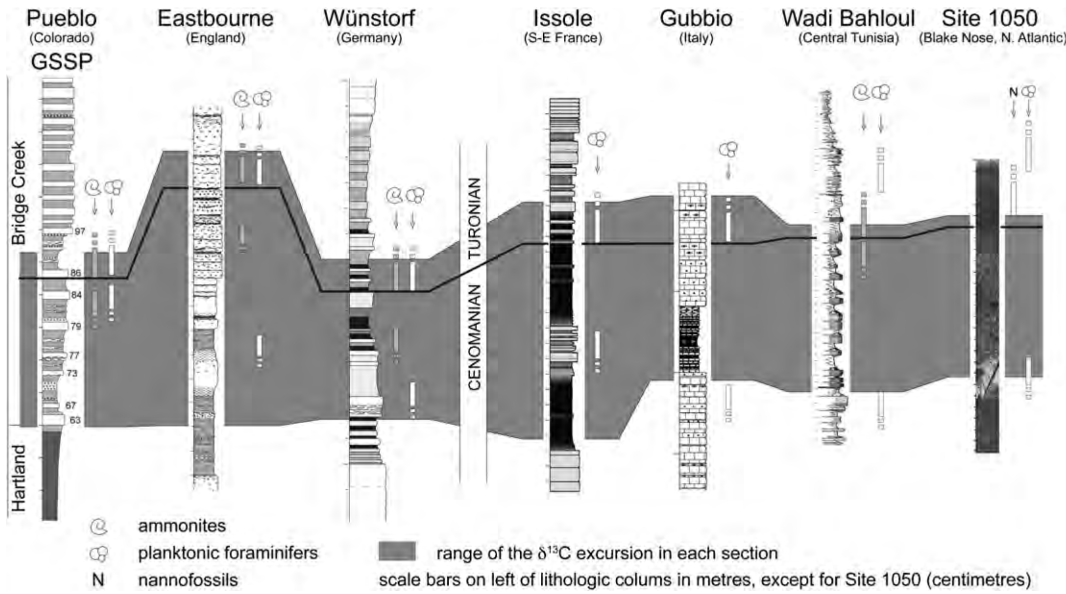

Fig. 5. Position of the Cenomanian–Turonian boundary in the upper part of the $\delta^{13}C$ anomaly as constrained by biostratigraphy in a number of key-sections. Origin of data: Pueblo section (Keller and Pardo, 2004; Kennedy et al., 2005; completed for foraminifers by Desmares et al., 2007, 2008), Eastbourne (Keller et al., 2001; Tsikos et al. 2004; Gale et al., 2005), Wünstorf (Hilbrecht et al. 1986; Hetzel et al., 2011; Grosheny et al. unpubl.; core data of Hetzel et al. reported on the quarry section of Ferry, unpubl.), Issole (Grosheny et al. 2006; Jarvis et al., 2011), Gubbio (Coccioni and Luciani, 2004Coccioni et al., 2004; Tsikos et al., 2004), Wadi Bahloul (Caron et al., 2006), Site 1050 (Huber et al., 1999). The stratigraphic range between the last occurrence of Cenomanian and the first occurrence of Turonian ammonites and planktic foraminifers (Cenomanian markers *R. cushmani*, Turonian markers: *H. helvetica*, marginotruncanids) is shown in each section. This range varies considerably from one section to another. It is the shortest in the GSSP Pueblo section.

stromatolitic where the lamination is undulated) capping deeper greenish marlstones or light-coloured, bioturbated mudstones (Fig. 7E). This suggests that overall this unit represents shallower facies than the Cenomanian sequence in the BEI section. Unit 2 consists of the same massive, light-couloured mudstones as in unit 2 of the Oued beida section. However this unit is thicker here (14 m as compared to 8 m at Oued Beida). The sequence also contains the same bivalve-rich bed in the upper third, that likely correlates to that in the Oued Beida section. In contrast to Oued Beida, black shales are absent. Instead, there is an alternation of bioturbated, whitish mudstones similar to those of unit 2 and whitish (weathered?) laminated mudstones (Fig. 6C, levels denoted as "L").

Analysis of panoramas (Fig. 7A) shows that unit 4, as drawn in the log of Fig. 6, is not laterally continuous. Its lower part represents the bottomsets of a huge bioclastic sand wave that thickens laterally. Unit 5 is a symmetrical huge sand wave (Fig. 7A), comprised of coarse-grained bioclastic debris (now dolomitised). Its lower part onlaps the underlying sand wave. Its crest is oriented about N–S, which is roughly perpendicular to the platform edge. In this respect, we interpret it as a longitudinal tidal sand wave, similar to those observed on satellite images of the margins of the Tongue of The Ocean in the Bahamas. Units 4 and 5 represent the platformal lower Turonian Gattar Fm., on the edge of the Gafsa Trough.

The characteristic $\delta^{13}C$ shift begins 4 m above the base of unit 2. It has a rather erratic pattern as compared to those more typical of the CTBE which could be due to diagenesis. Ammonite data of Meister and Abdallah (2005) position the C–T boundary between the 35 and 38 m on our log. This position falls within the upper part of the $\delta^{13}C$ shift, as in the basinal Oued Beida section.

Analysis of the microfauna shows a drastic change at the base of unit 2 where shallow-water components suddenly disappear. The small rotaliporids found in the basinal part of unit 2 at the Oued Beida section are not present here, suggesting a lower water depth. The temporary disappearance of planktic foraminifers in the middle of unit 2 likely represents the same shallowing seen in the Oued Beida section. The recurrence of a diverse planktic fauna at the base of unit 3 suggests renewed deepening, although facies change *vs.* unit 2 is minor and represented not by black shales as in the Oued beida section but by a few white laminated levels interbedded in the mudstones. The presence of Turonian keeled forms such as *H. cf helvetica* in the bottomsets of the giant bioclastic sand waves (unit 4) is surprising, as these forms are not found in shallow-water deposits, and are supposed to live at great depth during part of their life cycle (Caron, 1983; Hart, 1980, 1999) by comparison with living morphotypes of present-day planktic foraminifers (Bé, 1982; Arnold and Parker, 1999). This means either that the sand waves were deposited at a depth greater than expected on the platform edge, or that the keeled planktics were transported from the Gafsa Trough by storms or a combination of mechanisms.

4.3. Foum Hassene section

In this section (Fig. 8), as in the previous sections, the thick Cenomanian succession (Fig. 9A) comprises shallow-water, short-term, transgressive–regressive (T–R) cycles. Laminated dolomites (Fig. 9B) often cap the T–R sequences. The main difference here is the presence of tepee structures (Fig. 9C) and desiccation breccias at the top of some sequences indicative of more prolonged exposure. Unit 2 (Fig. 8) consists of the same massive light-coloured mudstones (Fig. 9A) as in the previous sections. There are no laminated levels in this section, as the homogenous mudstones of unit 2 are in sharp contact with the base of unit 3, a very-coarse-grained bioclastic unit with scattered, mostly unsorted rudist remains of the Gattar Fm. The unit is strongly dolomitised with planar bedding.

The ammonite *Neolobites* sp. aff. *vibrayeanus* has been found at the base of unit 2, at the same stratigraphic level as in the sections studied by Meister and Abdallah (2005) to the north. Thus, here unit 2 is also late Cenomanian (Wiese and Schultz, 2005). There are no biostratigraphic data to constrain the placement of the CTB in this section. The $\delta^{13}C$ shift (Fig. 8) begins within the lower part of unit 2 as in the two previous sections. The end of the excursion is more difficult to define likely due to dolomitisation. Based on the

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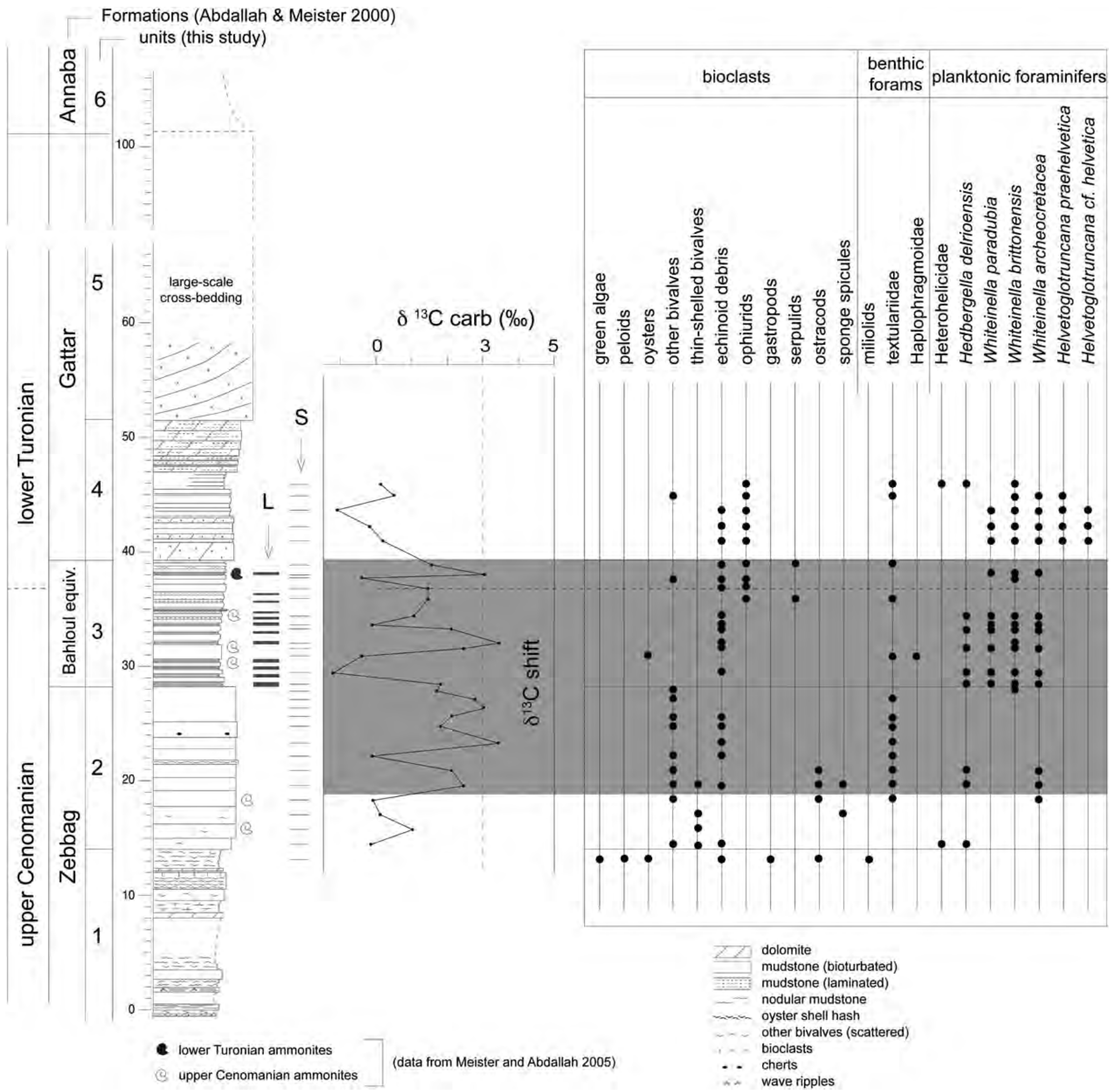

Fig. 6. The Jebel Asker section. Informal units on left of the lithologic column; L, laminated mudstone beds in the Bahloul equivalent; S, sampled levels.

results obtained in the previous sections, the C–T boundary likely can be placed between the 22 and 26 m, in the uppermost part of the $\delta^{13}C$ shift, above the bivalve-rich level in unit 2. This level (Fig. 8) could be the lateral equivalent of the coquina levels found in the northern sections, in the upper part of the mudstone bed of unit 2.

Planktic foraminifers appear suddenly at the base of unit 2, remain present until the mid-part of the $\delta^{13}C$ shift and then disappear. Despite the inner platform location of the section, keeled planktic foraminifers (*Thalmaninella*, *Dicarinella*) are present at the base of unit 2 but their size is very small, as in the basinal Oued Beida section; associated *Whiteinella* are of normal size. Another observation to be highlighted is the disappearance of planktics in the upper part of the $\delta^{13}C$ anomaly, under the platformal carbonates of the Gattar Fm. This stands in contrast to the northern sections where planktic foraminifers were abundant in the corresponding black shales or laminated mudstones, and will be discussed further below.

4.4. Chenini section

As in the other northern sections, unit 1 (Figs. 10 and 11A) is made of metre-scale T–R cycles of greenish claystone to marlstone at the base, and massive, bioturbated or laminated dolomite at the top. The flooding deposits (greenish marls) in these sequences lack the oysters commonly found in the northern sections. Apart from the dolomitisation, the mudstones of unit 2 (Fig. 11B and C) closely resemble the massive mudstones found in the correlative deposits of the more northern sections. Few planktic foraminifers were found in thin sections, and those that were present lacked biostratigraphic utility. Due to the dolomitisation, no isotope study was undertaken. The coarse-grained, planar-stratified, dolomitised calcarenites of unit 3 (Gattar platformal carbonates) are also similar to those found in the Foum Hassene section. Despite the few data available in this section, it displays the southward thinning of the mudstone units 2 (see Fig. 12).

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Fig. 7. Pictures of the Jebel Asker section. A, general view of the lower Turonian Gattar Fm. showing the internal geometry of a giant bioclastic sand wave whose crest is oriented about S–N, perpendicular to the outcrop; B, view of the section; C, closer view of units 2 and 3 showing the alternation of bioturbated and laminated (L) mudstones (Jacob staff = 1.5 m); D, view of the laminated dolomicrites at top of a transgressive–regressive sequence in unit 1; E, view of bioturbated mudstones at base of a transgressive regressive parasequence in unit 1. On all pictures, numbers refer to the lithostratigraphic units on Fig. 6.

4.5. Correlations and interpretation

Correlation of the four sections has been made by integrating both lithologic, biostratigraphic and isotopic data (Fig. 12). The first prominent feature is the marked change at the base of unit 2 in all the northern sections. Shallow-water, metre-scale T–R cycles are abruptly overlain everywhere by homogenous mudstones containing a more open-marine fauna (ammonites, planktic foraminifers). This lithological change can be followed in continuous outcrops all along the Dahar cliff (Fig. 1) from Chenini to Briga (Fig. 12) and to Dehibet in the south (Fig. 1), although the thickness of the homogenous mudstones diminishes to the south. This change is interpreted as resulting from a marine flooding (transgressive surface (TS) in Fig. 12). Nowhere along the 100-km long Dahar Cliff have we seen any evidence of backstepping at the transition between units 1 and 2, this suggesting the transgression was very quick. Because the $\delta^{13}C$ anomaly starts in all the three northern sections a few metres above the base of the mudstones, and because there is no evidence of backstepping, the facies change is considered to be relatively synchronous, not only in the north but also in the southern part of the transect (Fig. 12). The base of unit 3 represents deposition of the platformal Gattar carbonates. In the

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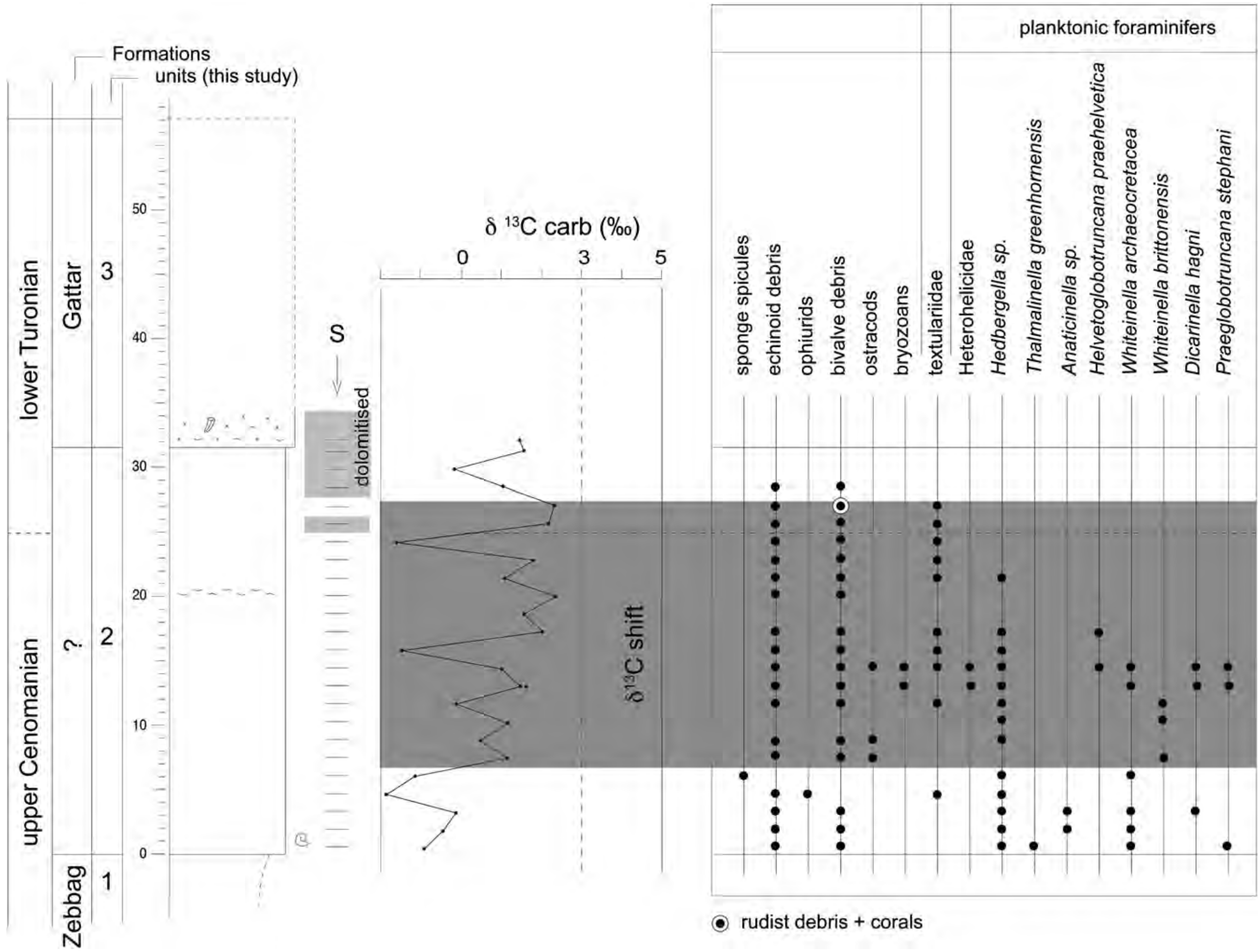

Fig. 8. The Foum Hassene section. Informal units on left of the lithologic column; S, sampled levels.

Chenini and Foum Hassene sections, as well as all along the Dahar Cliff to the south, the facies change is abrupt. There is no evidence of progradation, as seen on continuous outcrops in the Dahar Cliff, suggesting that the deposition of the Gattar carbonates was mainly driven by a drop in relative sea level on a flat depositional environment. The flatness of the depositional surface likely prevented the occurrence of a forced regressive wedge (Catuneanu et al., 2011) made of nested, erosion-based coastal prisms, because such a wedge requires a ramp profile to be expressed. In the Jebel Asker area, which was situated close to the platform edge, the Gattar carbonates have the particular pattern of large sand waves (Fig. 7A). These probably acted as barriers protecting the inner platform to the south. The development of these sand waves is also rather abrupt on the bioturbated and laminated mudstones of unit 3 (Fig. 7B). To the north, as already suggested by Abdallah et al. (2000), the shallow-water carbonates of the Gattar Fm. pass laterally into the fine-grained limestones of unit 5 in the Oued Beida section. Furthermore, they described an intermediate section (Jebel Bou Jarra) in which the uppermost part of the lateral equivalent of Oued Beida's unit 5 is comprised of shallow-water carbonates. Therefore, the progradational geometry of the Gattar Fm. is probably restricted to the platform edge. Everywhere in the south, its basal contact is sharp and the stratal pattern of the evenly-bedded, coarse-grained calcarenites is aggradational, except in the Briga area were rudist buildups are locally encountered (Fig. 12). The sharp basal contact of the Gattar Fm. can be thus interpreted as a sequence boundary (SB, Fig. 12). The thickening of the formation in the OS1 well (Fig. 12) is probably due to synsedimentary activity along the Briga Fault, which would also explain the particular location of the rudist buildups. Rudists are also found in the aggrading Gattar carbonates elsewhere but they are always isolated in a coarse-grained calcarenite. The fact that rudists were able to make buildups only along the Briga fault may be interpreted as resulting from a shallower location on the edge of a faulted block. The internal geometry of the buildups is also very complex (Ouaja et al., 2002), suggesting their top was close to the surface, and that they recorded minor changes in sea level. Such changes are not recorded laterally.

The main focus of this paper is centred on intermediate units 2 and 3. As shown in Fig. 5, the δ^{13}C anomaly of the CTB can be quite confidently used as a stratigraphic tool for correlations. In the two northernmost sections (Fig. 12), the uppermost part of the anomaly contains the CTB on the basis of ammonites. Within the homogenous mudstones of unit 2, the coquina bed is also laterally continuous within the range of the anomaly. The correlations thus suggest that the black shales of unit 3 of the Oued Beida section pass laterally upslope (Jebel Asker) into the alternation of bioturbated and laminated mudstones of unit 3. Although there is no biostratigraphic data available in the Foum Hassene section, the position of the δ^{13}C anomaly within the homogenous mudstones of this section suggests that the laminated mudstones of unit 3 in the Jebel Asker section correlate with the upper part of unit 2 in this

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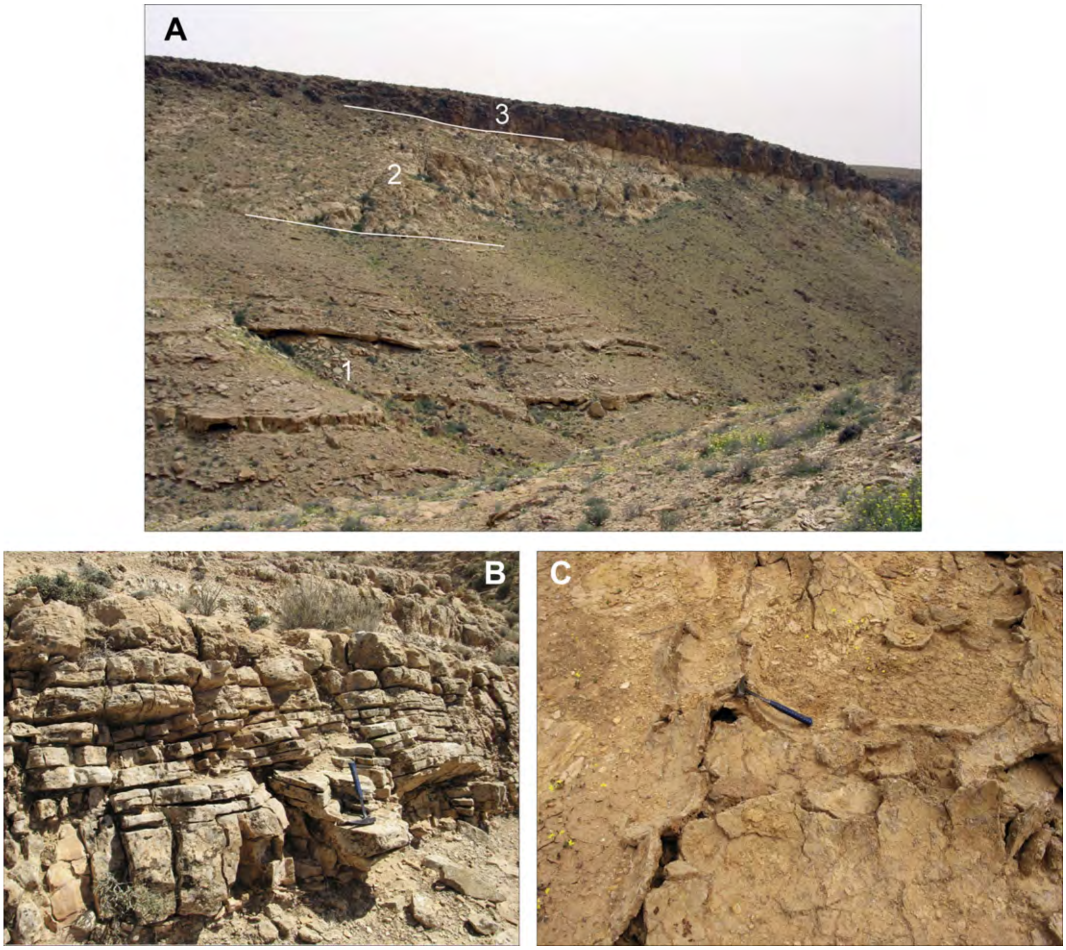

Fig. 9. Foum Hassene platformal section. A, general view of the section with unit numbers as in Fig. 8; B and C, examples of facies capping shallow-water Cenomanian parasequences: B, laminated dolomite; C, tepee structures.

section. Therefore, the laminated mudstones of unit 3 in the Jebel Asker section should thin and disappear to the south within the homogenous mudstones. The disappearance of the black shales to the south does not correspond to a simple pinching out onto a slope, but to an interfingering and progressive disappearance within an homogenous mudstone facies that blanketed the entire upper depositional profile, including the inner platform. As a consequence, the homogenous unit 2 of Foum Hassene has to correlate with the sum of units 2 and 3 in the two northernmost sections, except for the uppermost part of unit 3 in the Oued Beida section that should record the progradation of the Gattar Fm. on the platform edge.

Observations made along the Dahar Cliff south of Chenini show that the upper third (40 m thick in the measured Chenini section, but not fully represented in Fig. 10) of the Cenomanian succession, under the homogenous mudstones of unit 2, consists of metre-scale T–R sequences of green claystones and dolomites. These sequences are laterally continuous extending over ten of kilometres to the south. They thicken north of Chenini, when approaching the Chains of the Chotts and the Gafsa area (Fig. 1). Accordingly, the claystones are thicker in the T–R sequences and their top is no longer laminated dolomites but grainstones and/or oyster-bearing wackestones. Therefore, the S–N evolution of the facies, in the Cenomanian T–R sequences of unit 1 suggests a rather flat depositional profile, evolving to the north into a very gently inclined ramp, including the area that would later become the Gafsa Trough. The homogenous character of the mudstones at base of unit 2 suggests that the entire area was flooded during the transgression that slightly preceded the onset of the $\delta^{13}C$ excursion. A major change occurred during the second half of the $\delta^{13}C$ anomaly; as the mudstone deposition continued on the Saharan Platform (Chenini and Foum Hassene sections), a topographic low (the Gafsa Trough) was created in the Gafsa area where suboxic black shales, bearing some benthic fauna (bioturbation, benthic foraminifers), were deposited. According to Abdallah et al. (2000), the Gafsa Trough was limited to the north by a palaeogeographic high, referred to as the "Kasserine Island". We interpret the Gafsa Trough as resulting from flexure (accelerated subsidence) of the uppermost Cenomanian ramp along the Gafsa Fault bordering the Kasserine Island. This relatively minor tectonic event formed the Gafsa Trough during the second half of the $\delta^{13}C$ anomaly. Organic-rich shales then filled the Trough until the early Turonian, when the Gattar platformal carbonates began to prograde from the south to the platform edge. During Gattar deposition, suboxic conditions ceased in the Gafsa Trough, which was filled by light-coloured, bioturbated periplatform mudstones. The hypothesis of tectonically induced deformation around the CTB is also supported by a slight truncational uncorformity seen at outcrop in the southern reach (Briga area) where Cenomanian beds toplap onto the base of the Gattar Fm. (Fig. 13). The thickness change observed in Turonian carbonate deposits between well Os1 and the Briga section also suggests a synsedimentary movement of the Briga fault, creating

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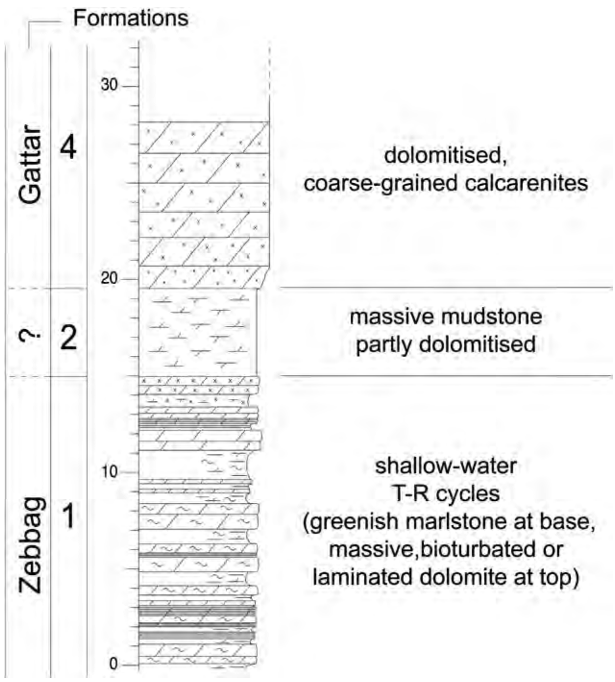

Fig. 10. The Chenini section.

locally more accommodation space during the deposition of the Gattar Fm.

5. Palaeogeographic setting of the sections and wells studied in Algeria

5.1. Outcrops of the Tinrhert (Central Sahara)

Cenomanian deposits of the Tinrhert predominantly consist of lagoonal marls consisting of an alternation of claystones and gypsum. These are overlain by cliff-forming limestones biostratigraphically constrained to the upper Cenomanian by ammonites (Amédro et al., 1996). Of the three sections studied (Fig. 14), the Bordj Omar Driss section (see Fig. 2 for location) is the most complete. In this section, the transition from the lagoonal, gypsiferous marls (Fig. 14, unit 1) to the upper Cenomanian limestones (unit 2) is sharp. The massive limestones (Fig. 15C) of unit 2 are light-greyish beige, strongly bioturbated marine micrites, which can be interpreted as forming as a result of a marine opening and deepening. Ammonites found by Amédro et al. (1996) throughout unit 2 belong to their zone 1, or "*Neolobites vibrayanus* alone". They indicate an upper Cenomanian age for the whole unit. The mudstones contain scattered shells, mostly oysters, suggesting a more normal marine environment following the earlier evaporite episode. The base of the mudstones is thus interpreted as a transgressive surface (TS, Fig. 14). The transition from the massive mudstones to the ammonite-bearing chalks of unit 3 is not visible in the Bordj Omar Driss section. As seen in the nearby Takouazet and Ohanet sections where this transition is visible (Figs. 14 and 15A), it occurs rapidly, although progressively. Ammonites found in the chalks are so numerous on some bedding surfaces that they may constitute a continuous pavement. Their sudden abundance in the chalks suggests a second phase of marine incursion and probable deepening. Ammonites become rare in the thin limestone beds occurring in the overlying grey marlstones. Although there is no particular surface indicative of a hiatus, the top of the chalks is interpreted as a maximum flooding surface (MFS, Fig. 14) because the overlying grey marlstones contains thin-bedded, fine-grained calcarenite layers interpreted as storm beds (stb, Fig. 14), and indicative of a shallowing-upward trend. The δ^{13}C shift begins within the lower part of unit 2 and continues into the overlying chalks of unit 3 (Fig. 14). It ends at the transition between the chalks and the overlying grey marlstones, as investigated in the Ohanet section where the facies change outcrops well. Ammonites found in different sections of the Tinrhert show that the deposition of the chalks began in the latest Cenomanian (Zone 2 of Amédro et al., 1996, with the assemblage *N. vibrayanus*, *Calycoceras naviculare*, *Eucalycoceras pentagonum*) and ends in the earliest Turonian (Zone 5 with *Pseudotissotia nigeriensis* alone, Amédro et al., 1996.).

In the Takouazet section (Fig. 14), limestones underlying the chalks are different from the fine-grained limestones of the Bordj Omar Driss section. These limestones alternate between hard and chalky, poorly sorted wackestones and packstones (Fig. 15B), bearing bioclastic fragments, including unbroken rudist shells. Therefore, during the first part of the δ^{13}C anomaly, the Takouazet area was shallower than the Bordj Omar Driss area where fine-grained limestones were deposited. Settings becomes shallower to the east, suggesting that an uppermost Cenomanian carbonate platform may have developed in the area of the Algeria-Libya border, a region which is known locally as the "Tihemboka Arch" (Acheche et al., 2001).

The remainder of the Turonian succession (Fig. 15A) also shows an interesting feature, unnoticed until now the terminal "Turonian bar" of Busson, which has a sharp basal contact (Fig. 15D) clearly truncates the uppermost part of the undifferentiated "Turonian marls" as shown in our correlations (Fig. 14). Its lithology, laminated carbonates (Fig. 15E) bearing desiccation cracks, is also in sharp contrast with the underlying marlstones.

5.2. Subsurface data

Constrained by the field observations made in Tinrhert, the C–T transition has been studied in the subsurface through a series of selected oil wells, in order to correlate both with southern Tunisia to the east and with the edge of the Saharan Platform to the north. To better convey the spatial relationships, two transects have been constructed (Fig. 2). The W–E-oriented transect (Fig. 16) parallels the outcrops of the Tinrhert. It cuts across the N–S-oriented palaeogeographic high termed the El Biod Ridge (Busson, 1970) between the Tademaït and Tinrhert basins. This structural high strongly influenced the deposition of poorly-dated Hauterivian(?) to Barremian sandstones found in oil wells. During the Cenomanian and Turonian, its influence was diminished. In both the Tinrhert and the Tademaït basins, uppermost Cenomanian limestones sharply rest on Cenomanian gypsum or anhydrite bearing marls ("Marnes à gypse" of Busson). Lower Turonian marls are also equally represented in both basins, as well as on the El Biod Ridge. Based on outcrop data from the Tinrhert studied above, the limestones between the "Marnes à gypse" and the lower Turonian grey marls represent the CTBE, including the hard mudstones and platformal carnonates at the base and the white chalks in the upper part. In the subsurface (i.e., well logs), it is not possible to differentiate between the various units 2 and 3 as can be done with outcrop exposures (see above). Thus, they appear as a single, undifferentiated unit in subsurface correlations. But the sharp basal contact of this limestone package (Fig. 16) is identical to that observed in outcrop (Fig. 14). The W–E variability (Fig. 16) in this limestone unit is informative. In the Tademaït, the unit is thin and it is assumed that it is coeval with the fine-grained limestones and chalks found in outcrops south of the transect (not represented in Fig. 14), that is similar to those observed at Bordj Omar Driss, but thinner. To the east, the thickness increases in well W1, remains

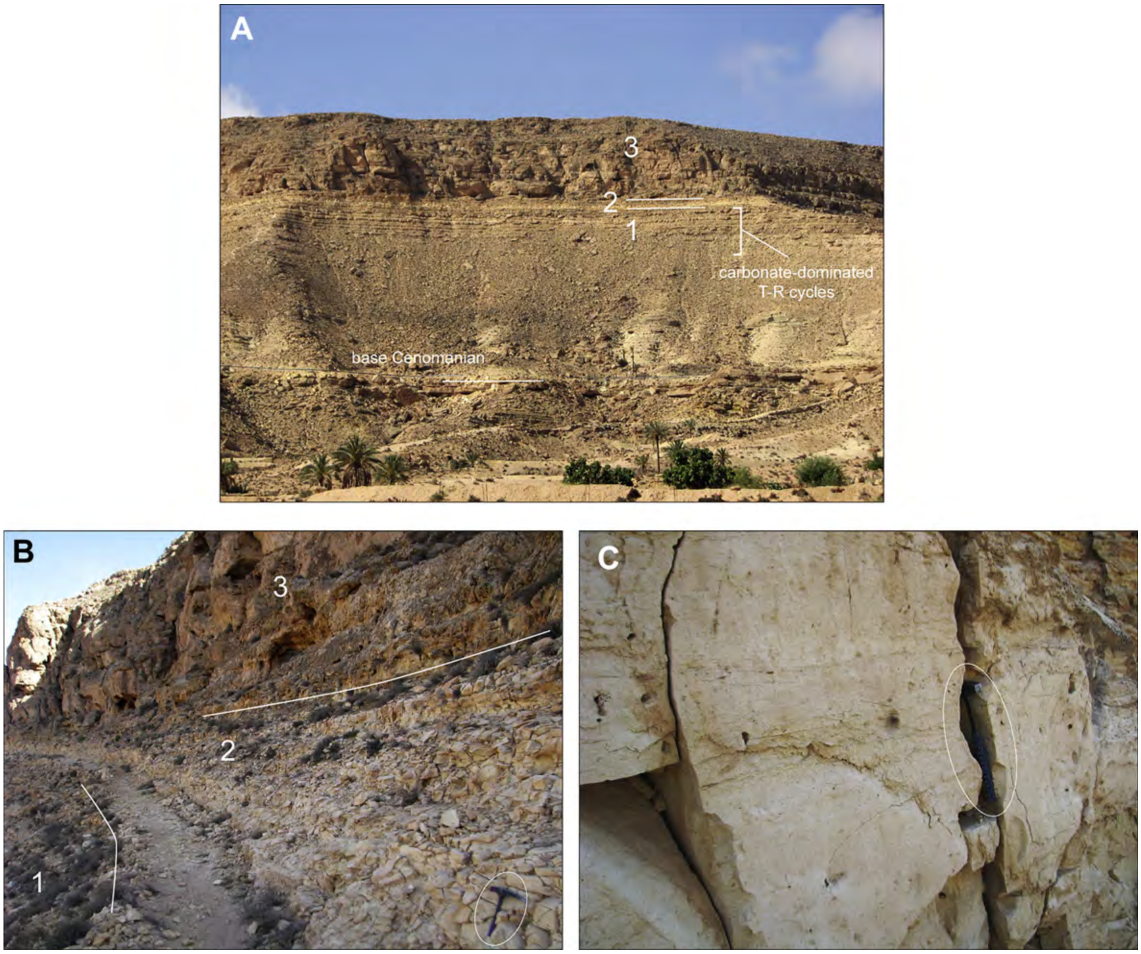

Fig. 11. Chenini section. A, general view of the section with units as in Fig. 10; B, view of the dolomitised mudstones of unit 2; C, closer view of the mudstones of unit 2 showing faint, even lamination. On pictures B and C, hammer (circled) for scale.

constant from W2 to W5, and then dramatically increases again when approaching the Algeria–Libya border, between wells W5 and W6 (Fig. 16). On the basis of the facies changes from the fine-grained limestones of the Bordj Omar Driss section to the coarse-grained wackestones of the Takouazet section seen a few kilometres to the south and which parallel the transect, the increase in thickness between wells W5 and W6 is interpreted as lithologic and thickness changes expected when approaching a carbonate platform. This inferred carbonate platform would have been located on the Tihemboka Arch. Because it developed above the basal surface of the unit, interpreted as a transgression surface in the Bordj Omar Driss section, the growth of this carbonate platform was coeval with the C–T transgression. At that time, the El Biod Ridge seems to have had no palaeogeographic influence. As in correlations of sections (Fig. 14), the terminal “Turonian bar” slightly truncates the underlying marlstone succession (Fig. 16).

The S–N transect (Fig. 17) allows a connection of the outcrop sections of the Tinrhert with those already studied in the Saharan Atlas (Grosheny et al., 2008). This has been made through examination of a number of oil wells crossing the Hassi Messaoud area on the northern termination of the El Biod Ridge. All logs were aligned (Fig. 17) using the basal surface of Senonian carbonates and evaporites as datum. On the northern part of the transect (Saharan Atlas), the distinction between the uppermost Cenomanian platformal carbonates and the Turonian ones has been established using ammonites, the microfauna and isotope data (Grosheny et al., 2008). The study showed that a marine flooding began in the latest Cenomanian, just prior the $\delta^{13}C$ shift. During the first part of the $\delta^{13}C$ anomaly, isolated carbonate platforms occurred and kept up with the sea-level rise. The intervening corridors or saddles were created as a result of differential accumulation rates between the coarse-grained bioclastics on the growing carbonate platforms and the fine-grained periplatform limestones in the intervening lows. Therefore, as a result of the keep-up mechanism, the first part of the CTBE $\delta^{13}C$ shift is represented either by up to 80 m of shallow-water carbonates or by a mere 20 m of fine-grained mudstones in the saddles. It is thus likely that the depositional depth of the periplatform mudstones would have been no more than 60 m, assuming that the top of the platforms was close to sea-level. The carbonate platforms were flooded during the second part of the $\delta^{13}C$ shift. CTBE black shales were deposited continuously in the corridors from the uppermost Cenomanian well into the lower Turonian (*Mammites nodosoides* ammonite zone), as is shown in Fig. 17 (Khanguet Grouz section, KG). In the Turonian, the Tu1 carbonate sequence (*sensu* Grosheny et al., 2008) ends with rudist-bearing limestones in the Djebel Mimouna section (DjM). These pass laterally into offshore storm beds in the Khanguet Grouz section (Fig. 17). The transgressive surface (TS, Fig. 17), identified in the Saharan Atlas on the upper Cenomanian shallow-water deposits, correlates with that found in the outcrop sections of the Tinrhert (Bordj Omar Driss section, Figs. 14 and 17), because occurring in both areas just prior to the $\delta^{13}C$ shift. These shallow-water deposits are

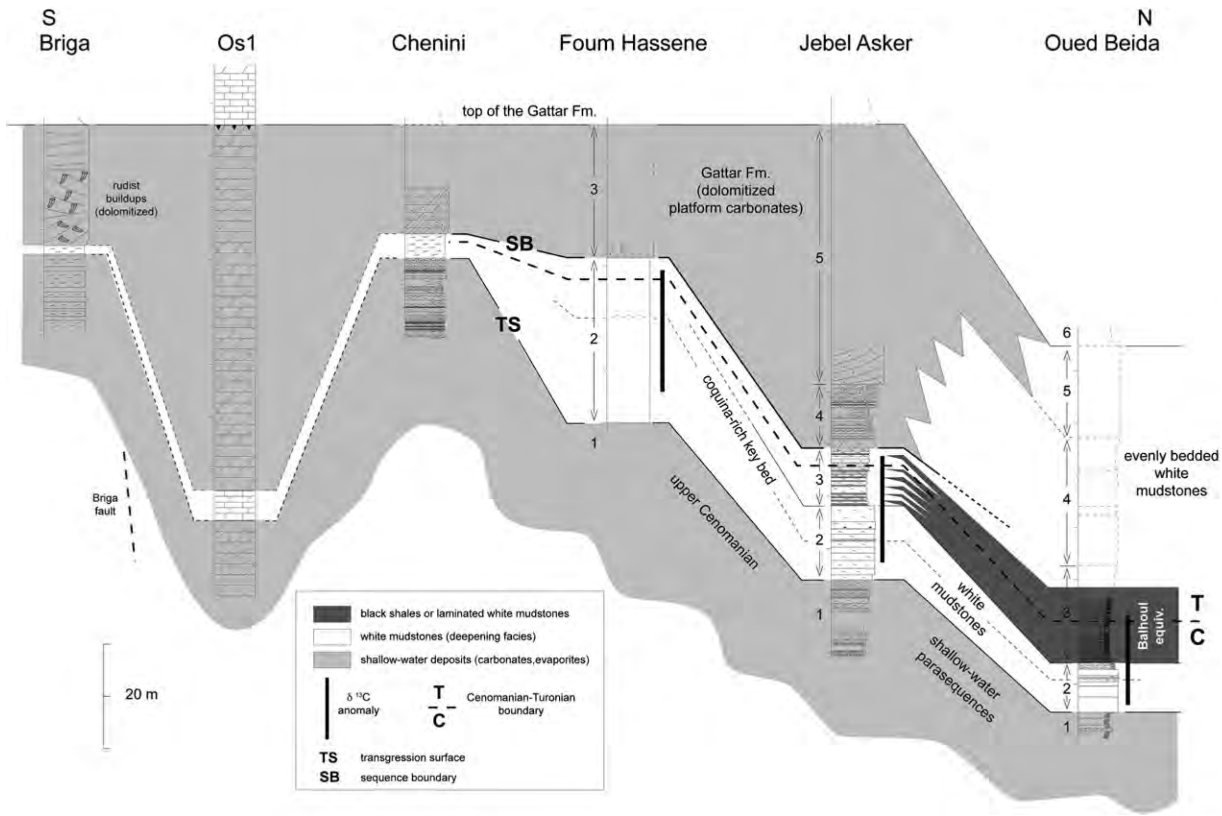

Fig. 12. Correlations of the sections along the S–N Tunisian transect. 1 to 6, lithologic units defined in the three northernmost sections.

overlain, depending on places, either by open-marine mudstones, or rudist-bearing carbonates, as in the Tinrhert or in southern Tunisia. South of the Hassi Messaoud area (Fig. 17), correlations between Bordj Omar Driss and well Ar101 show that the limestone unit resting on the Cenomanian “Marnes à gypse” (ev., Fig. 17) rapidly thickens to the north in wells Ar101 to W8. We interpret it the same way as the response seen in the southern transect (Fig. 16) when approaching the Tihemboka Arch. Therefore, the fine-grained limestones deposited at Bordj Omar Driss during the first half of the δ^{13}C shift are hypothesised to pass into the north to an upper Cenomanian carbonate platform more than 100-m thick, a thickness similar to that of the isolated carbonate platforms of the same age found in the Saharan Atlas (Grosheny et al., 2008). Correlations also show the pinching of Turonian marls between wells GT1 and Ar101. The upper “Turonian bar” of Busson clearly truncates the Turonian marls in wells GT1 and Ar101, and seems to be lacking in the Hassi Messaoud area. If correct, Turonian deposits should be lacking in the Hassi Messaoud area.

6. Discussion

The comparison of Tinrhert and southern Tunisia, using both the δ^{13}C shift and ammonites as correlation tools suggests that the oyster-bearing mudstones of the Bordj Omar Driss section are a lateral equivalent of the massive mudstones underlying the black shales of southern Tunisia (unit 2 in the Oued Beida and Jebel Asker sections, Figs. 3 and 6). Accordingly, only the first half of the black shales of the Gafsa Trough (Oued Beida section, Fig. 3) would be the lateral equivalent of the chalks of the Tinrhert, given that they cover the second half of the isotope shift in both sections. Therefore, the

Fig. 13. Angular unconformity between upper Cenomanian deposits and cliff-forming lower Turonian platformal carbonates of the Gattar Fm. in the Briga area (BRI, Fig. 1).

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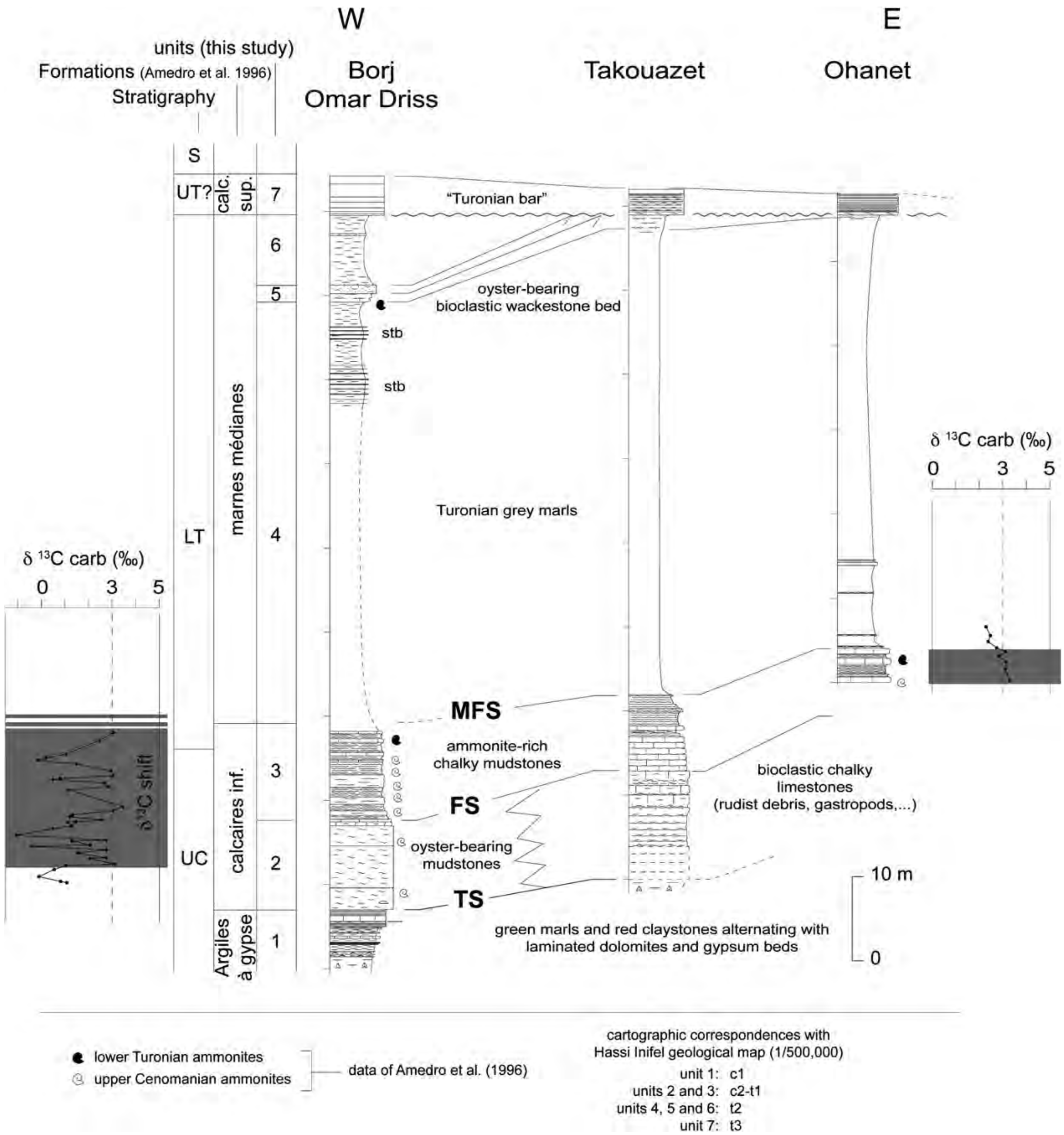

Fig. 14. Correlation of the Tinrhert sections. 1 to 7, informal stratigraphic units; TS, transgression surface; FS, flooding surface. UC, upper Cenomanian; LT, lower Turonian; UT, upper Turonian; S, Senonian.

isotope study confirms previous, paleontology-based interpretations (Busson et al., 1999).

Comparison of southern Tunisia and the Saharan Atlas of Algeria (Grosheny et al., 2008, and Fig. 17, this study) shows the same coeval facies change from shallow-water high-frequency parasequences, to deeper-water mudstones just before the beginning of the $\delta^{13}C$ shift. It is now clear that: (1) large parts of the Saharan Platform underwent a marine flooding in the latest Cenomanian as has been already documented in other areas of the world; and (2) that the flooding started everywhere on the platform just prior to the CTBE $\delta^{13}C$ anomaly. What our study also suggests is the potential use of the $\delta^{13}C$ excursion for long-distance correlations around the Cenomanian–Turonian boundary in the absence of palaeontological data because our data are consistent with what has been found in many other sections worldwide (Fig. 5, and references therein).

All available data have been used to construct a palaeogeographic map for the CTBE in Tunisia and Algeria (Fig. 18). North of the transect, in central Tunisia, the data of Lüning et al. (2004) have been used. Isolated carbonate platforms separated by deeper seaways or corridors are encountered mostly in Algeria. In southern Tunisia, there is no evidence of any carbonate build-up of this age. The palaeogeographic picture is that of a drowned plateau, where the deposition of planktic-rich mudstones spanned the CTBE. Shallow-water carbonates are inferred further south on the Tihemboka Arch, based on the well log correlations in the Tinrhert (Fig. 16). Black shales were deposited later in the corridors of the Saharan Atlas, not in the Tinrhert and Tademaït basins where

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Fig. 15. Pictures of the Tinrhert sections. A, General view of the Takouazet section, with the upper part of the white chalks of unit 3 (see log on Fig. 14) in the foreground, overlain by lower Turonian grey marls (unit 4) and the limestones of unit 7 (units 5 and 6 lacking) at the top of the hill; B, General view of the Ohanet section (see log on Fig. 14 for unit numbers), people (circled) for scale; C, closer view of the massive, bioturbated mudstones of unit 2 in the Bordj Omar Driss section (Jacob staff in the foreground is 1.5 m long); D, closer view of the sharp contact (unconformity) of the limestones of unit 7 on grey marls of unit 4 in the Takouazet section (unit 7 is about 4 m thick); E, close view of the evenly laminated limestone forming unit 7 in the Takouazet section (Jacob staff, for scale is 1.5 m long).

ammonite-rich chalks replace them. Later, in the early Turonian, a topographic low occurred in the Tinrhert and Tademaït where grey marls are encountered. The relationships between the Tademaït–Tinrhert area and the Saharan Atlas of Algeria in the lower Turonian are difficult to understand because of the unconformity at the base of the upper Turonian and/or Senonian deposits that truncate the successions in the Hassi Messaoud area (Fig. 17). To the NE, the successions of the Mellegue Basin are overally deeper and continuous throughout the Cenomanian and the Turonian (Robaszynski et al., 1993b, 2000); they also bear CTBE black shales.

The corridors that appeared between the carbonate platforms during the CTBE were explained as accompanying, through a deficit of carbonate production, the keep-up mechanism of the "carbonate factory" that took place at some places during the latest Cenomanian flooding (Grosheny et al., 2008). Nevertheless, the idea of a passive functioning of the corridors should not be overinterpreted The data from southern Tunisia suggest that tectonics may have overprinted the morphological changes of the sea bottom, such as the inferred asymmetrical deepening of the Gafsa Trough during the second part of the $\delta^{13}C$ anomaly, due to a possible movement along the Gafsa Fault. The idea of slight tectonic deformation, especially occurring around the Cenomanian–Turonian boundary, is also supported by the results obtained on the Moroccan Atlantic margin (Jati et al., 2010). Along the Agadir transect, at the top of an

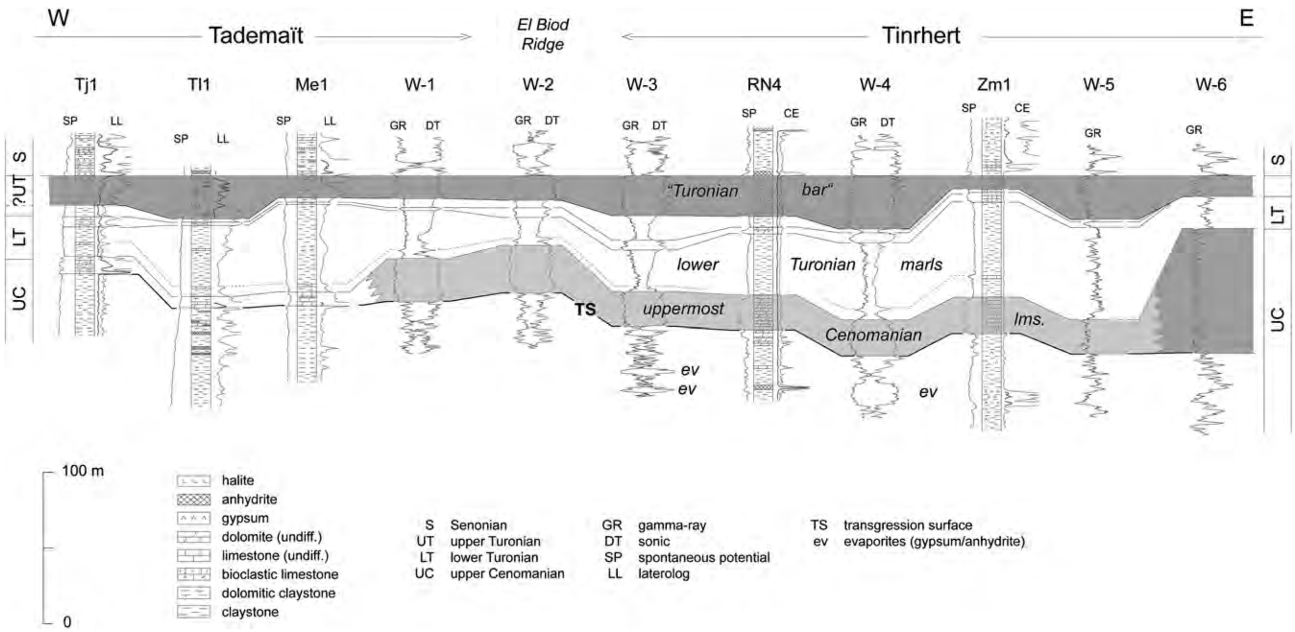

Fig. 16. Correlation of well logs along the Tinrhert W–E transect. Significance of UC, LT, UT and S, see Fig. 14.

otherwise regularly subsiding Cenomanian succession comprised of T–R sequences lacking any evidence for subaerial exposure, two quick forced regressions are recorded just before and just after the $\delta^{13}C$ anomaly. Work in progress on an additional transect north of the Agadir transect has not yet revealed any evidence of such forced regressions. This could support the idea of a short-lived tectonic "pulse" by the CTBE, responsible for some heterogeneity in the sequence stratigraphic record on a large scale.

Regarding the planktic foraminifers, the outstanding characteristic is the very small size of keeled forms found in the basal transgressive mudstone unit of the CTBE, as compared to the normal size of the large *Whiteinella*, when present. This observation can be made in southern Tunisia as well as very far onto the craton in the Tinrhert sections. These small forms may either be juveniles or dwarfed forms adapted to the relative shallowness of the intra-cratonic corridors. According to Hart and Bailey (1979); Hart (1980, 1999); Bé (1982); Caron and Homewood (1982); Caron (1983), among others, Cretaceous keeled forms are supposed to need a water column sufficient deep to sustain their life cycle, a depth greater than for globulose forms (*Hedbergella*, *Whiteinella*) or biseriate forms (Heterohelicidae) which are both surface dwellers during their entire life cycle as documented for living

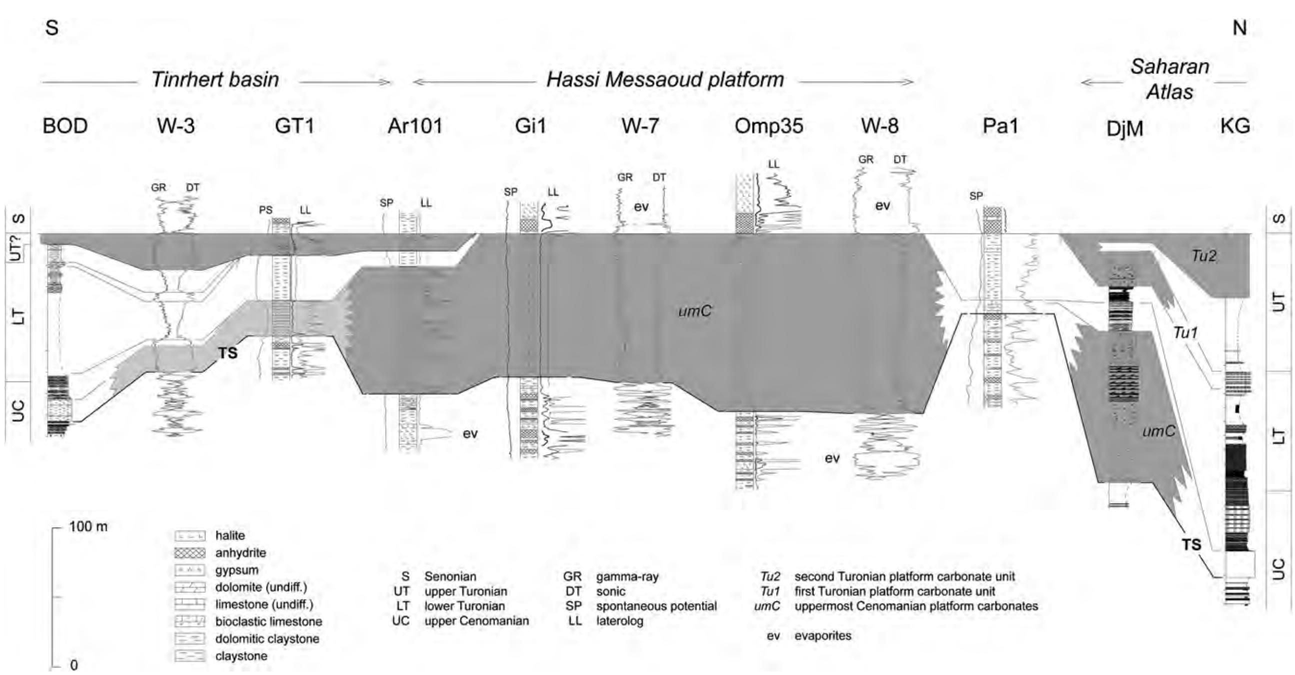

Fig. 17. Correlation of well logs along the S–N transect from the Tinrhert to the outcrop sections of the Saharan Atlas. Significance of UC, LT, UT and S, see Fig. 14. BOD, Bordj Omar Driss section; DjM, Djebel Mimouna section; KG, Khanguet Grouz section. TS, transgression surface.

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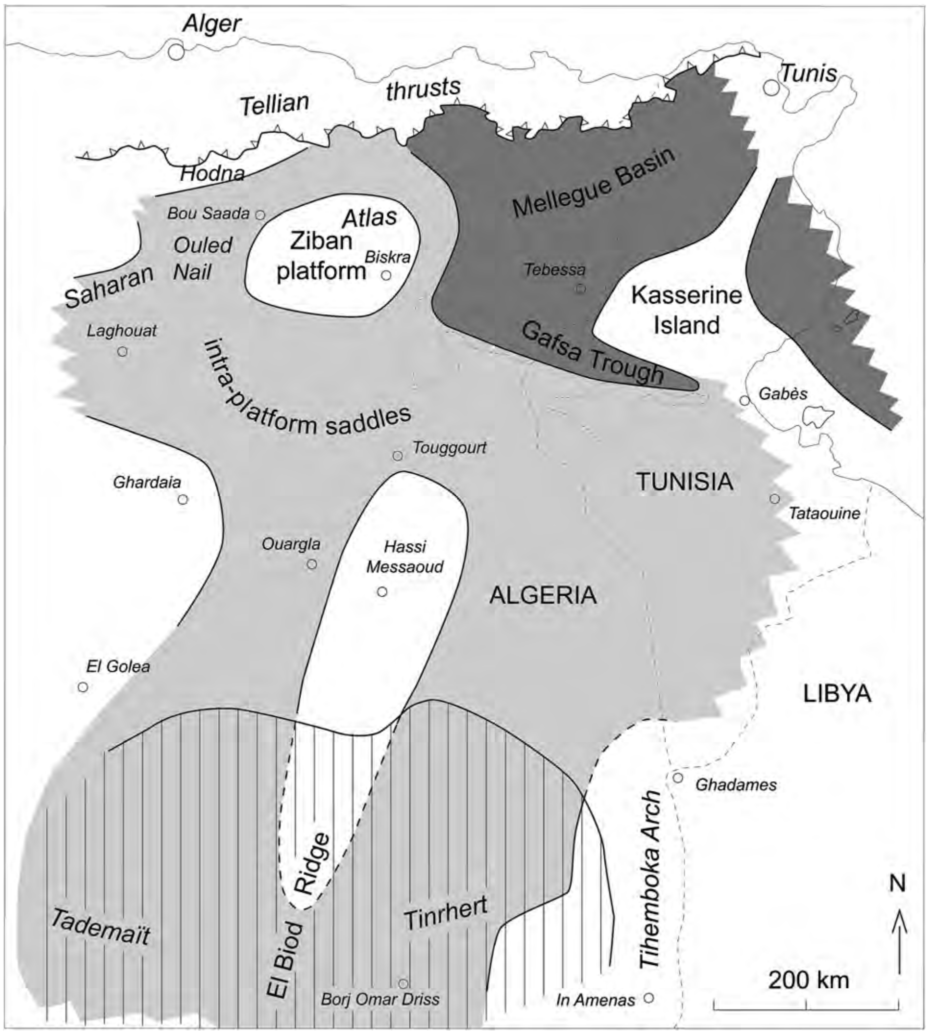

Fig. 18. Palaeogeography of the Saharan craton during the Cenomanian–Turonian Boundary Event. Light-grey, mudstone-filled corridors between uppermost Cenomanian carbonate platforms (in white); dark-grey, Mellegue basin with deeper Cenomanian to Turonian facies successions; hatched, the Tademaït/Tinrhert intra-cratonic basin marked by the deposition of lower Turonian grey marls above the CTBE chalks. Modified from Lüning et al. (2004) based on data of Grosheny et al. (2008), work in progress in the Tebessa area, and the analysis of a number of well logs.

planktic foraminifers (Bé, 1982; Hemleben and Spindler, 1983; Hemleben et al., 1989; Arnold and Parker, 1999). Regarding the Cenomanian keeled forms, most key-sections studied worldwide for the CTBE are situated in settings that are moderately deep (foreland basins, epicontinental seas), but probably deep enough to sustain their life cycle according to the above hypothesis, as they are found in great numbers in the lower CTBE beds. In the Sahara, the marine connection between the Tethys and the South Atlantic Ocean through the Benoué Basin in Nigeria during the Cenomanian has been documented by several workers (Collignon and Lefranc, 1974, Courville et al., 1991, 1998; Meister et al., 1992, 1994). The very large concentration of ammonites in some beds of the CTBE chalks of the Tinrhert also suggests that surface currents may have flowed through the seaways created by the latest Cenomanian rise in relative sea level, to carry the shells and accumulate them in some places like a Tinrhert “pool” (Fig. 18). The absence of large, keeled planktics in the sections studied cannot be explained by the “sorting” of juveniles by these currents which would also have transported large keeled adults as well. Therefore, we hypothesise that the whole life cycle of the keeled forms was affected, and that they were probably able to adapt to an unfavourable environment.

7. Conclusions

Based on both new faunal and isotope data, we show that the Cenomanian–Turonian boundary black shales of the Gafsa Trough, in southern Tunisia, pinch out to the south into the upper part of homogenous bioturbated mudstones that represent the latest Cenomanian flooding of the Saharan Platform. Comparison with the Saharan Atlas of Algeria shows that similar mudstones were deposited during the first part of the Cenomanian–Turonian boundary $\delta^{13}C$ shift. However, in Algeria shallow-water open-marine carbonates nucleated at some places, keeping up with the sea-level rise and creating a particular palaeogeography made of corridors and isolated carbonate platforms. Black shales were deposited in the Gafsa Trough during the second part of the $\delta^{13}C$ shift, as well as in the corridors of the Saharan Atlas of Algeria, which were connected to the deeper Mellegue basin. The deposition of black shales more or less ceased late in the early Turonian, well after the $\delta^{13}C$ shift. In the Tinrhert Basin (Central Sahara), we find the same sequence of events: the Cenomanian lagoonal gypsum-bearing marls are overlain by open-marine mudstones contemporaneous with the first part of the $\delta^{13}C$ shift. These mudstones also pass laterally into platformal carbonates in the Hassi

Messaoud area and "Tihemboka Arch" close to the Algeria–Libya border. The primary lithologic difference between South Tunisia and the Saharan Atlas is the absence of black shales, which are replaced by ammonite-rich chalks during the second part of the $\delta^{13}C$ shift. Thus, this study confirms that the CTBE is marked by a rise in relative sea level across the Algerian and Tunisian parts of the African craton. It also confirms that the $\delta^{13}C$ shift can be a reliable stratigraphic tool for long-distance correlations, controlled by faunal data in all sections studied.

The planktic foraminifera fauna found in the mudstones at the beginning of the flooding contains carenate forms (*Rotalipora* and *Dicarinella*) of abnormally small size. These were probably adapted to the relative shallowness of the seaway(s), which at that time connected the Tethys and the South Atlantic through the Bénoué Trough.

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