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ORIGINAL PAPER

The Paleocene-Lower Eocene series of the Gafsa basin (South-Central Tunisia): integrated stratigraphy and paleoenvironments

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Abstract In the Gafsa basin, the Paleocene-Eocene interval is represented by the evaporite deposits of Thelja Formation, the phosphatic series of Chouabine Formation, and the carbonate bed of Kef Eddour Formation. The Thanetian-Ypresian transition lies within the lower unit (C1) of the Chouabine Formation. These different facies characterize circalittoral to margino-littoral paleoenvironments. Sedimentological analyzes of this interval allowed to define eleven genetic sequences. The comparison of these sequences with the global chart of Sneeden and Liu (2010) shows a good correlation with the third-order cycles. In the eastern part of the Gafsa basin (Jebel Chemsi), the Paleocene-Ypresian transition is characterized by a marly-carbonate series deposited in an isolated open marine environment not recording minor relative sea-level changes. The Selandian Pg10 major maximum flooding is detected within the S2 sequence of the Oued Thelja section. The Thanetian-Ypresian transition (55.8 Ma), identified in the S7 sequence of this section, coincides with a major sea-level rise at the origin of phosphate sedimentation onset in the Gafsa basin and around the Kasserine Island.

Keywords Paleocene-Lower Eocene · Sequence stratigraphy · Correlations · Gafsa basin · Tunisia

Introduction

During the Paleocene-Eocene transition, Tunisia was a part of the southern Tethys margin mainly characterized by phosphate deposits. These occurred chiefly in the southern part of central Tunisia, in the Gafsa shallow basin. Because of its position between the island of Kasserine, to the north (Burollet 1956), and the continental domain of the Saharan platform, to the south, this basin was the area of a diverse sedimentation,

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represented by argillaceous, carbonate, evaporite, and phosphatic facies. These different facies are represented by the Metlaoui group (Fournié 1978), the type section of which was logged in the Oued Thelja area (Fig. 1).

In 1978, Fournié subdivided this group into several distinct lithostratigraphic units: the Thelja Formation, mainly evaporitic at the base, and the phosphatic Chouabine Formation. The latter is overlain by the carbonate Kef Eddour Formation (Bel Haj Ali et al. 2002).

In the Gafsa basin, the sedimentary series of the Paleocene-Eocene transition was the subject of thematic studies, mainly stratigraphic (Burrollet 1956; Fournié 1978; Ben Ferjani 1984; Bolle et al. 1999; Bel Haj Ali et al. 2002), sedimentological (Sassi 1974; Chaabani 1995; Abdelli 2008), geochemical (Belayouni 1983; Chaabani 1995; El Ayachi 2011), and mineralogical (Sassi 1974; Chaabani 1995; Bolle et al. 1999; El Ayachi 2011).

In this work, these series will be the subject of a study in terms of sequence stratigraphy for the first time at the Paleocene-Eocene transition in the Gafsa basin. Correlation of third-order sequences will be effectuated with Sneeden and Liu chart's (2010) to record relative major, minor, and average sea-level changes that will be made at regional and global scales.

Geographic and geologic setting

The Gafsa Basin is bounded to the north by the Jebels Bou Ramli, the Ben Younes chain, and to the south by the north Chain of chotts. To the west, this basin extends into Algerian territory under Chott El Gharsa continental depressions. The type section of The Metlaoui group was logged in the Oued Thelja area, situated 5 km to the west of the Metlaoui village and cuts the southern flank of Jebel Alima (Fig. 1). In the eastern part of this Basin, the Paleocene and Eocene series outcrop in the northern flank of Jebel Chemsi, situated 30 km to the east of the Gafsa town (Fig. 1).

The Gafsa basin belongs to the southern Tunisian Atlas domain; it is a large structural domain that extends from the Gulf of Gabes, to the east to Algerian border to the west. This area extends along the northern edge of the Saharan platform and corresponds to the last folded structures of the Atlas domain. With a general East-West trending, these anticline structures correspond to asymmetric folds, often with faulted and uplifted southern flanks. These folds frequently show axes twists, truncated by the Gafsa major accident. The anticline structures of the southern Atlas are generally separated by wide plains and syncline depressions occupied by Neogene and Quaternary fillings.

Methods

Tow lithostratigraphic sections were logged in the Oued Thelja area (southern part of Jebel Alima) and the eastern part of the Chemsi anticline northern flank.

The study of the sedimentary series of the Paleocene-Eocene transition has been undertaken according to various methods of investigation including both field data and laboratory analyzes. In

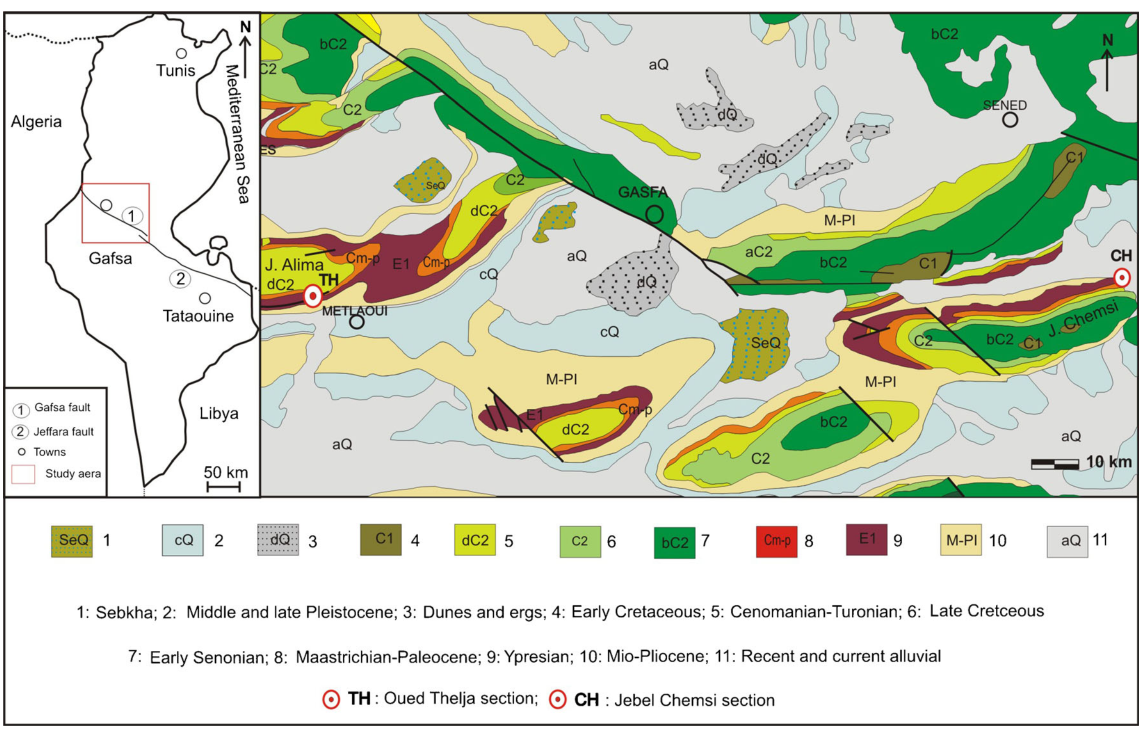

Fig. 1 Localization of the studied sections and geological map of Gafsa basin

the field, a first approach consists of a detailed study considering the geometrical characters of sedimentary bodies (extension, size, and morphology) sedimentary features including the nature of the components, structures, discontinuities and sequences, and faunal content. In the laboratory, petrographic analysis of more than 150 thin sections allowed the recognition of different skeletal and non-skeletal components as well as the determination of textures according to the terminology of Dunham (1962), a special attention being paid to diagenetic transformations. Marly samples were washed aiming the determination of the biophase chiefly composed of foraminifera and ostracods. These studies were complemented by a semiquantitative analysis of the abundance of various components.

All of these lithostratigraphic, sedimentological, and diagenetic data were used to reconstruct the depositional environments of the different facies. During the Paleocene-Eocene interval, the vertical evolution of the different facies was interpreted in terms of sequence stratigraphy as based on the concepts of Vail (1987); it allows identification of discontinuities and physical surfaces delimiting the systems tracts. A global correlation was conducted using the chart of Sneeden and Liu (2010).

Vertical and lateral facies evolution and biostratigraphy

The sedimentary series of the Oued Thelja section includes carbonate, marly, evaporitic, and phosphatic facies (Fig. 2). The Paleocene-lower Eocene interval is represented from bottom to top by: the upper part of the marly El Haria Formation, the mainly evaporitic Thelja Formation, the phosphate-bearing Chouabine Formation and the limy Kef Eddour Formation. The 90-m-thick Thelja Formation is subdivided into four units (T1, T2, T3, and T4). The lower unit T1 starts with a rich ostreid and gastropod limestone topped by limestone-marl alternations. This is overlain by a lumachellic cross-bedded limestone and fine dolomitic limestones, capped by a metric gypseferous horizon. Units T2 and T3 consist of marly and lumachelic carbonates alternations, rich in glauconite and phosphate grains in T2. These units end with a plurimetric bed of solid gypsum locally capped by a stromatolitic dolostone with mudcracks.

The upper unit T4 starts with dolomites and bioclastic limestone/marl alternations and ends by phosphatic marl. Within the upper part of this unit, a plurimetric bed of bioclastic dolomite is characterized by cross-bedding features and an erosive base.

The Chouabine Formation, 45 m thick, is subdivided into five distinct lithological units (C1, C2, C3,C4, and C5). The basal unit C1 consists of gray marls with phosphates and phosphatic limestone intercalations rich in lamellibranch shells. The C2 Unit is mainly composed of phosphatic lamellibranch-bearing limestones and siliceous limestone beds. The C3 unit is represented by gray marl and phosphatic bed alternations. The upper units C4 and C5 are formed by bioturbated phosphate beds with fine limestone nodules. The Kef Eddour Formation, of a Ypresian age (Burollet, 1956. Bel Hadj Ali et al., 2002), is represented by a thick carbonated slab forming a prominent ridge in the landscape. It is composed of fossiliferous phosphated and bioturbated limestones which locally show flint nodules.

The uppermost limestone-marl alternations of the El Haria Formation yield planktonic foraminifera (Figs. 2 and 3): by *Chiloguembelina morsei* (Cushman) *Parvularugoglobigerine Eugubina Lutterbacher* and *Premoli Silva*, *Eoglobigerina fringa* (Subbotina) *Eoglobigerina trivialis* (Subbotina) *Preamurica taurica* (Morozona) and *Woodringina hornerstonensis* species. The occurence of *Parvularugoglobigerina Eugubina Lutterbacher Permoli Silva* indicates a lower Paleocene age (lower Danian, P1a biozone). The lowermost part of the T1 unit (Thelja Formation) is rich in planktonic foraminifera: *Eoglobigerina fringa* (Subbotina), *Eoglobigerina simplicissima* (Subbotina), *Subbotina triloculinoides* (Plummer) and *Globoconusa* spp. *Eoglobigerina fringe* (Subbotina) and *Subbotina Triloculinoides* (Plummer) indicate the lower Danian (P1b zone), or *Purassubbotina Pseudobulloides* (Plummer) zone. The rest of the Thelja Formation is devoid of palanktonic foraminifera.

Only benthic foraminifera, represented by the genus *Anomalinoides*, were identified. The marly lower C1 unit (Chouabine Formation) yields, in its lower part, an association of planktonic and benthic foraminifera (Figs. 2 and 4). The occurence of *Planorotalites pseudomenardii* indicates an upper Thanetian age (P4 biozone). Well-preserved and diverse planktonic foraminifera characterize the upper part of the C1 Unit. The occurence of *Morozovella subbotinae* and absence of *Morozovella velascoensis* indicate a Ypresian age (*Morozovella subbotinae* zone = top of P6 zone) (Fig. 2).

In the Jebel Chemsi section, the lateral equivalent of the Thelja Formation, 115 m thick, is represented by a succession of marls and carbonates (Fig. 5). It consists of four lithostratigraphic units with plano-concave lenticular bodies and cross-bedded and normal grading bioclastic limestones, at its base.

The upper parts of these units composed of argillaceous-limestone and indurated marl, sometimes admitting metrics to half-metric intercalations of phosphatic and bioturbated argillaceous limestone, containing pellets, shark teeth, lithoclast, and glauconite grains. In this section, the Chouabin Formation equivalent (25 m thick) is represented by marls with indurated marly and argillaceous-limestone intercalations some of which are phosphated and bioturbated. At Jebel Chemsi, the Kef Eddour Formation is composed of bioclastic and locally sandy limestone, admitting conglomerate intercalations with centimetric to pluricentimetric lithoclast, floating in a micritic matrix.

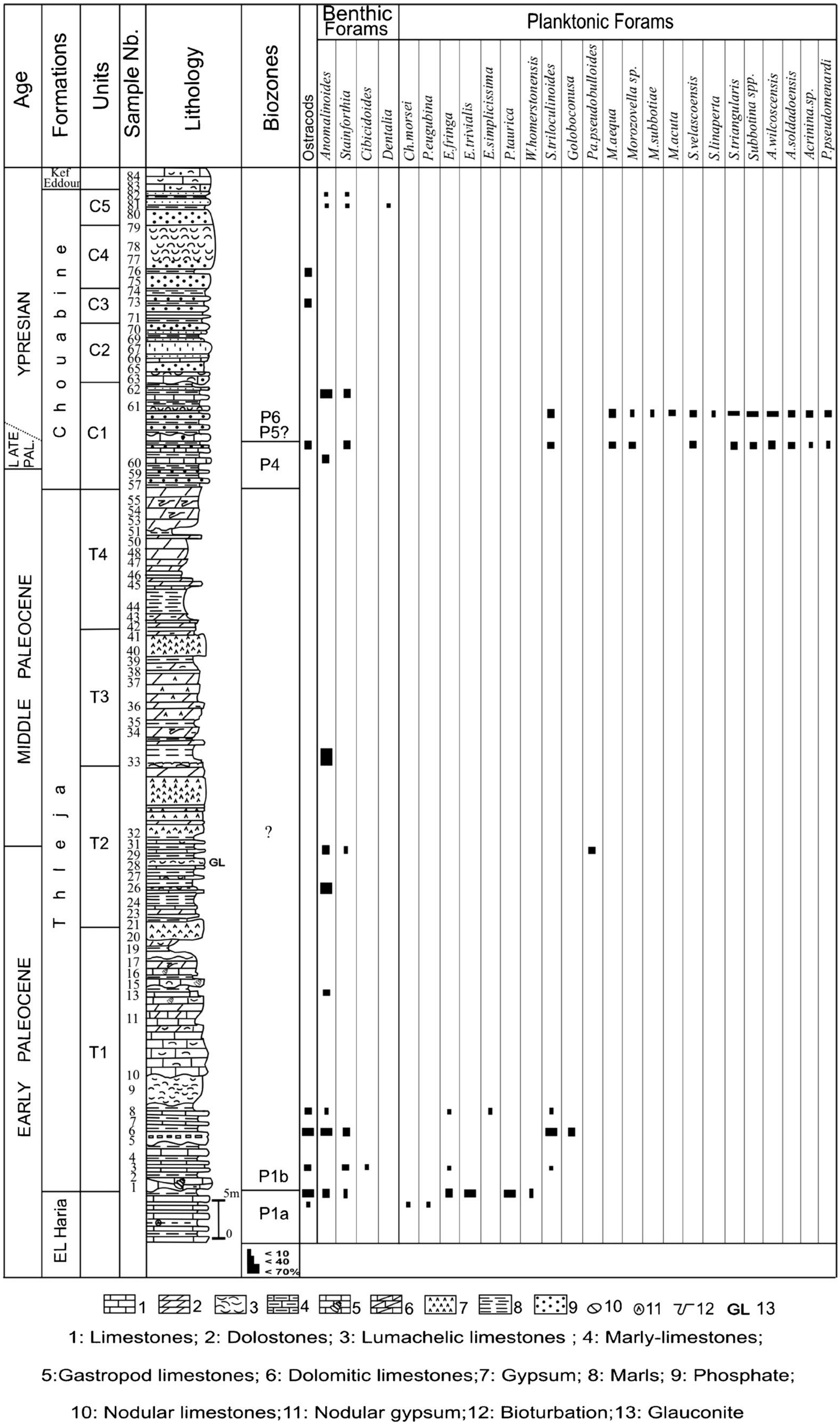

Fig. 2 Distribution of benthic, planktonic forams, and biozones at Oued Thelja section

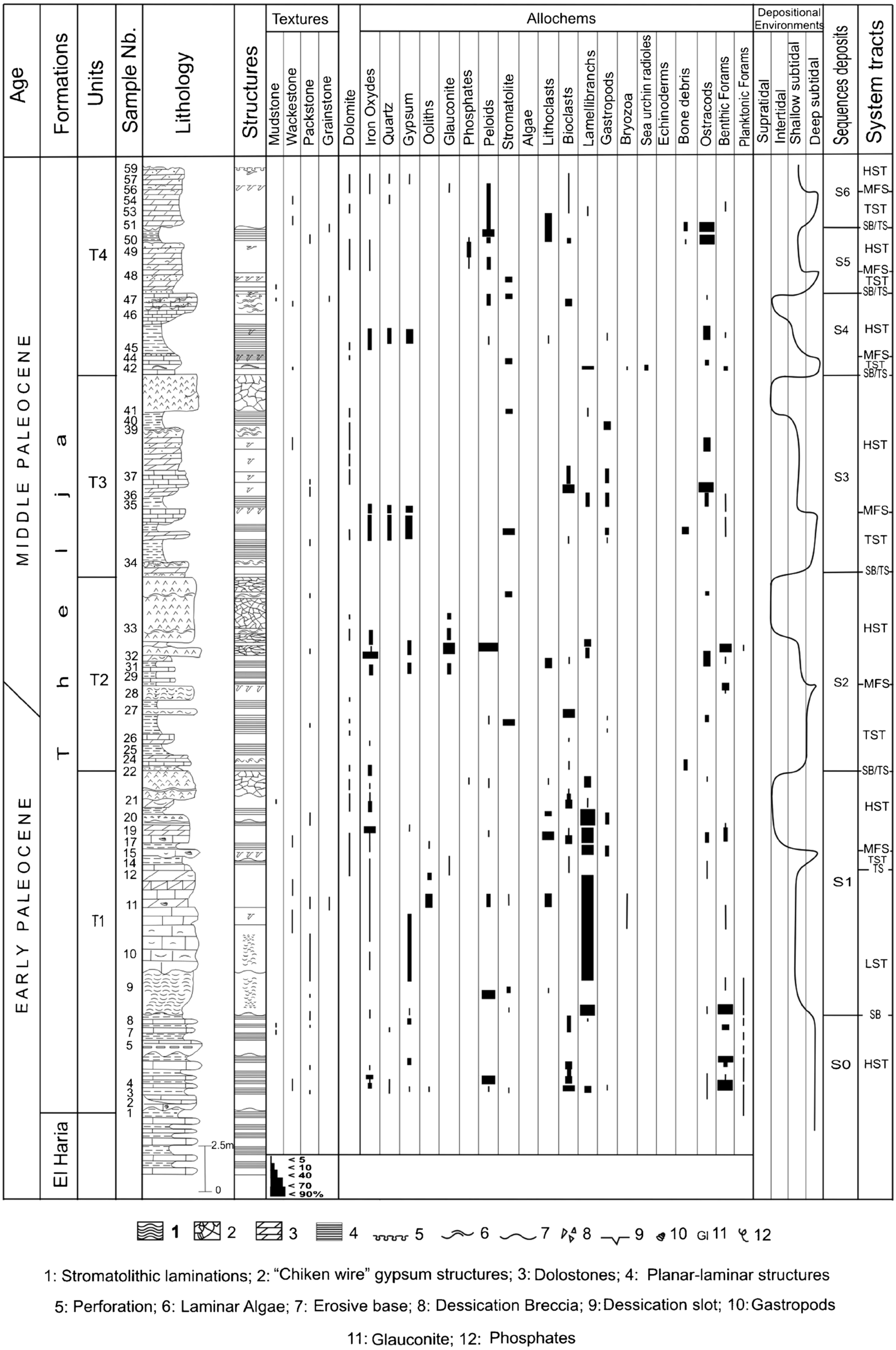

Fig. 3 Log of the Thelja Formation, displaying sedimentary features, major facies elements, depositional environments, and sequence-stratigraphic interpretation

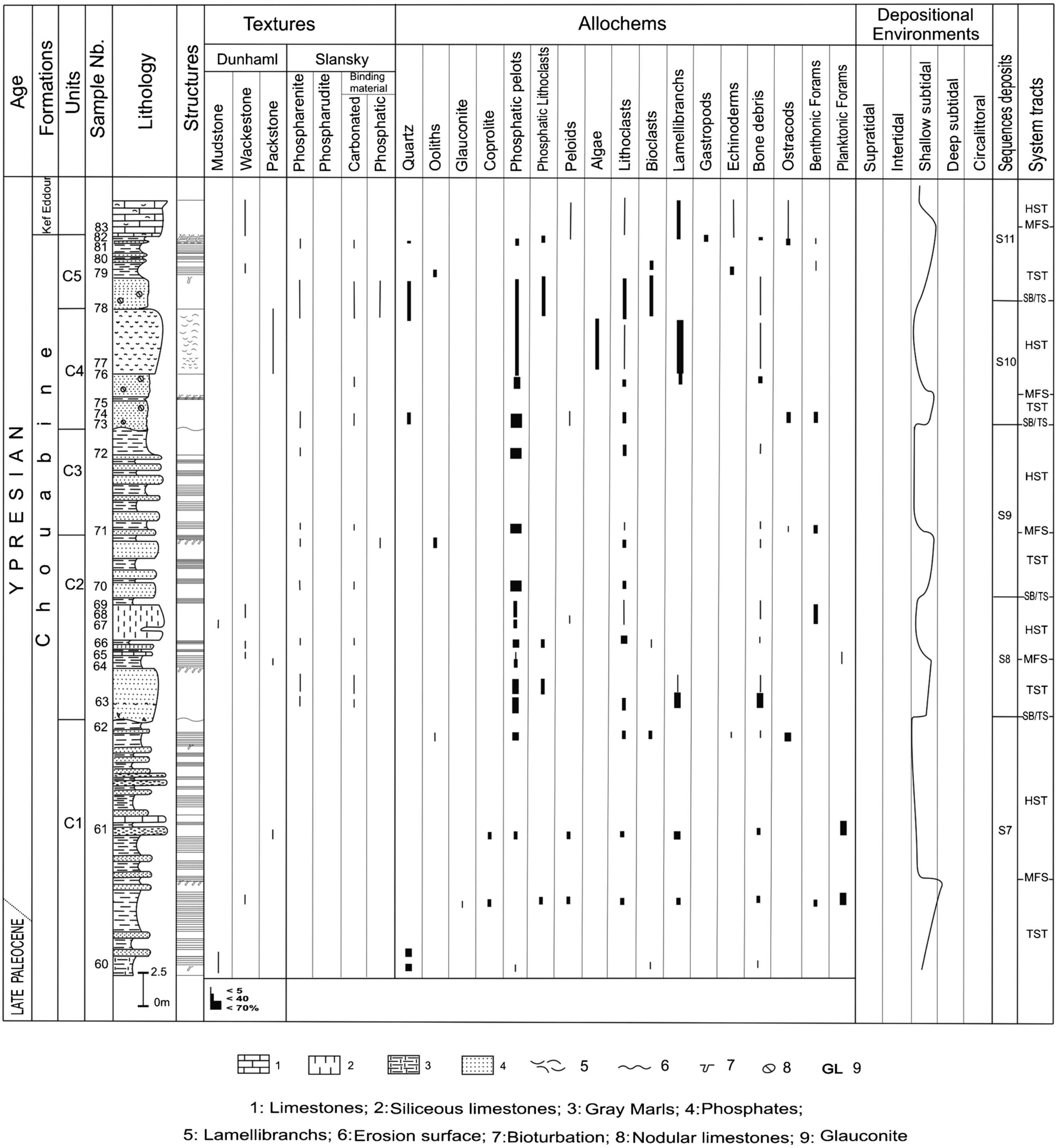

Fig. 4 Log of the Chouabine Formation at Oued Thelja section, displaying sedimentary features, major facies elements, depositional environments, and sequence-stratigraphic interpretation

Depositional environments

In its reference locality, the Thelja Formation is subdivided into four lithostratigraphic units (T1, T2, T3, and T4). The lower part of the T1 unit is formed by marl-limestone alternations with diversified microfaunas (Fig. 3) represented by ostracods, benthic, and planktonic foraminifera. This lithological unit is interpreted as a deep subtidal open marine environment. The middle part of T1 unit is represented by locally dolomitic and fossiliferous limestones, showing cross-bedding structures. This carbonate facies was deposited in an agitated shallow subtidal marine environment. The uppermost of T1 unit corresponds to a massive gypsum bed. This evaporitic facies characterizes a confined lagoon environment.

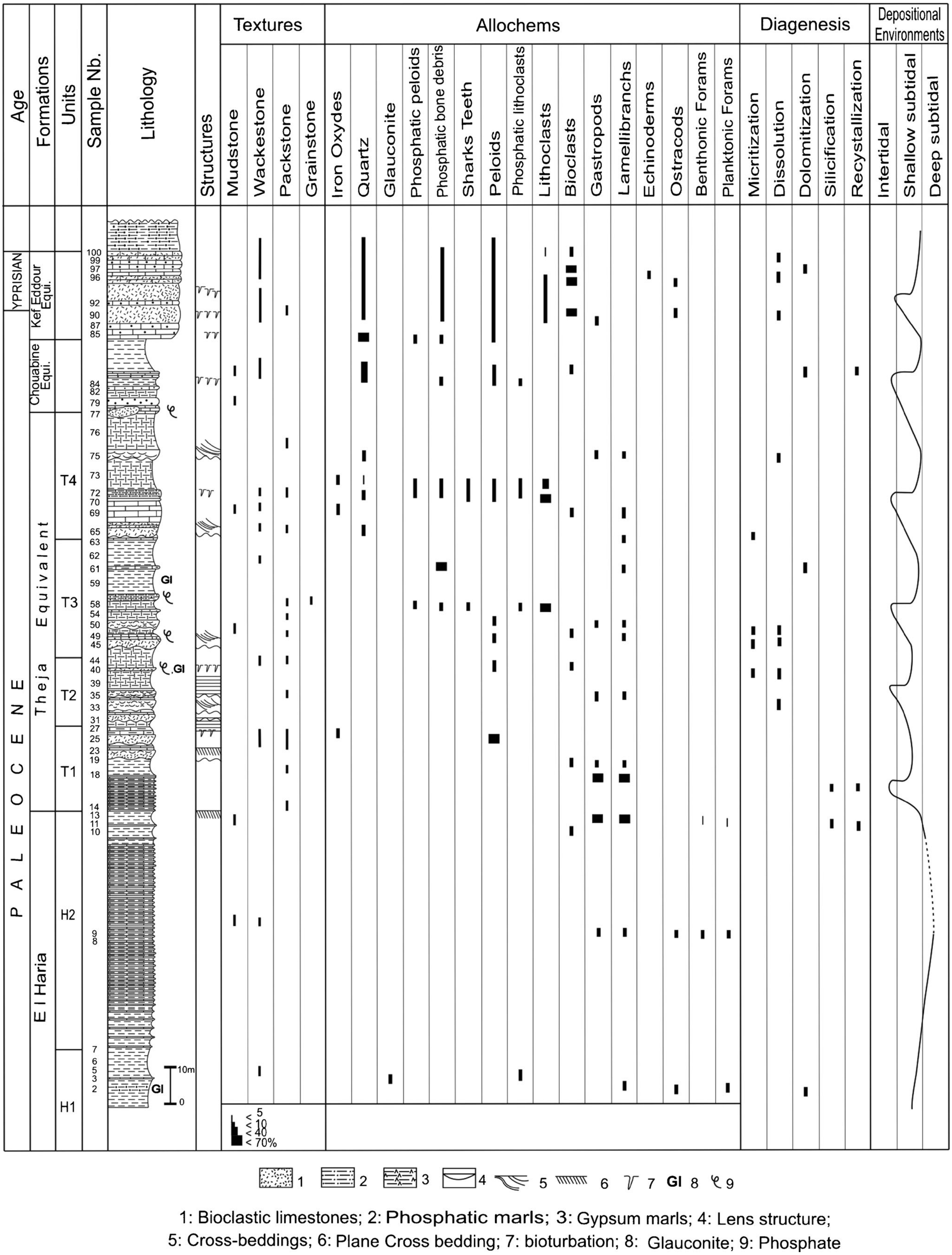

Fig. 5 Log of the Jebel Chemsi section, displaying sedimentary features, major facies elements, diagenesis, and depositional environments

The T2 unit starts with marl and lumachelic limestone alternations rich in glauconite grains and fossilizes a poorly diversified neritic and planktonic fauna. The faunal content and the richness in glauconite grains suggest a deepening upward environment, probably related to a marine transgression. The top of the T2 unit is composed of a massive gypsum layer, overlain by laminated stromatolitic dolomites with dessication cracks. This facies succession indicates a shallowing upward environment, illustrated by the transition from a confined lagoon to a supratidal environment.

The base of The T3 unit shows azoic marl overlain by dolomites rich in gypsum nodules, and its uppermost part is represented by a massive gypsum bed. This facies evolution pleased in favor of a marine regression and a confined depositional environment.

The T4 unit is composed of azoic marl and fossiliferous carbonates, which characterize a calm shallow subtidal marine environment. In this unit, the interbedded algal-laminated carbonates indicate a temporary emergence of the depositional environment (intertidal to supratidal).

In the Oued Thelja section, the phosphatic Chouabine Formation was divided into five distinct units (C1, C2, C3, C4, and C5). The marls of the C1 base, overlying the neritic fauna carbonates of Thelja Formation, are rich in diversified planktonic and benthic foraminifera (Fig. 4). These microfaunas indicate a deepening upward environment (deep subtidal to circalittoral) related to a major marine transgression.

The C2 unit is composed of a bioturbed phosphatic limestone bed which is topped by siliceous limestone bearing benthic foraminifera. The uppermost of this unit consists of phosphate layers. Facies of the C2 unit characterize a shallowing marine environment, more or less anoxic, with a low sedimentation rate.

The C3 unit is composed of alternations of benthic foraminifera-rich marls and phosphatic layers with hummocky cross stratifications. These alternations indicate a shallow marine environment, occasionally influenced by storm effects.

The C4 unit is formed of bioturbated phosphates, topped by lumachelic limestone of a packstone texture containing bioclasts and lithoclasts. These limestones show an inverse gradding of phosphatic grains and bioclasts indicating transport and reworking of sediments in a shallow agitated marine environment.

The upper part of C5 unit, composed mainly of phosphates, shows intercalations of azoic marls. These phosphates rich in glauconite grains and phosphatic lithoclasts, fossilize burrows, small ripple marks and hummocky cross stratifications. This phosphatic facies was deposited in a shallow, slightly open marine environment, occasionally influenced by storm effects.

At the Oued Thelja section, the Kef Eddour Formation is composed mainly limestones of a packstone texture rich in lamellibranch shells. This limestone facies suggests a shallow marine environment occasionally agitated characterizing an inner platform facies.

Within the Jebel Chemsi section, the marly-limestone unit of the upper part of El Haria Formation is represented by wackestones and mudstones (Fig. 5). These limestones contain planktonic and benthic foraminifera with mollusk-shell debris. These microfauna indicate a calm deep subtidal marine environment. Subazoic mudstones of the uppermost part of this unit record an evolution to a lagoon environment unfavorable to the biomass development.

In its lower part, the Jebel Chemsi lateral equivalent of Thelja Formation show lenticular bodies of bioclastic limestone with an erosive base and concavo-planar morphology. This bioclastic facies has a packstone texture, with debris and fragments of lamellibranch partly dissolved shells as well as some sections of gastropod shells. Within these carbonate bodies, a stacking of lenticular bodies was distinguished. These bodies consist of metric to plurimetric lenses with concavo-planar morphology, cross bedding, and vertically graded bioclasts. These characterize a shallow marine subtidal environment with high to moderate energy conditions where littoral currents erode and transport non-lithified bioclastic material generating a coastal progradation.

The lenticular bodies of bioclastic limestones, corresponding to coastal megachannels, are topped by a marly carbonate and phosphatic facies which fossilize pellets, lithoclasts, shark teeth remains, bone debris, and ostracods. This facies, capped by bioturbated surfaces with glauconite grains, characterizes a shallow, slightly oxygenated subtidal marine environment with low to moderate energy conditions. The presence of burrows indicates a slowdown in the sedimentation rate. The tops of the lithologic units of the Thelja lateral equivalent are composed of azoic marls and clay reflecting unfavorable life condition.

At Jebel Chemsi, the Chouabine Formation lateral equivalent consists of marls yielding scarce lamellibranch and ostracod shell debris. This marly unit, with phosphatic argillaceous limestone intercalations in its lower part, characterizes a sheltered lagoon environment. At Jebel Chemsi, the carbonate deposits of Kef Eddour Formation, represented by wackestones with dissolved lamellibrach debris, quartz grains, and lithoclast, suggest a calm proximal shallow marine environment, close to the exposed land (Island of Kasserine, Saharan Platform).

Sequence stratigraphy

At the Oued Thelja section, the sedimentary series of the Paleocene-Eocene transition was subdivided into ten depositional type 2 sequences and only one type 1 sequence.

S1 sequence covers the middle and upper parts of the T1 unit of Thelja Formation (Lower Paleocene). Its lower limit corresponds to an erosive base and is characterized by an abrupt vertical facies change (Fig. 3). This facies change coincides with a sea-level fall. The lowstand system tracts (LST), represented by plano-concave lenticular bodies composed of cross-bedded limestone rich in lamellibranch shells (Fig. 6a), is overlain by marly levels yielding planktonic and benthic foraminifera. The transgressive systems tract (TST) of S1 consists of bioturbed bioclastic dolomitic limestone, marls with abundant lamellibranch shell fragments overlain by wackestone to packstone carbonate containing lamellibranchs, lithoclasts, benthic foraminifera, and phosphatic bioclasts. The bioturbated maximum flooding surface (MFS) overlies a level of cross-bedded oyster-bearing limestone. The highstand systems tract (HST) of S1, formed in its lower part by marls and fine dolomites, ends with a massive gypsum level.

The S2 sequence covers the entire T2 unit. Its lower limit, which overlaps the top of the highstand systems tract of the previous sequence (S1) (Fig. 6b), represents the transgressive surface. The transgressive interval of S2 is composed of marls and limestone with a packstone and wackstone textures. The latter shows ostracod and lamellibranch shells, rich in glauconite and phosphate grains. The maximum flooding surface (Fig. 6c), which caps a packstone with lamellibranches tests and abundant glauconite grains, shows mainly by the occurence of marls bearing planktonic foraminifera. The highstand systems tract of S2 is represented mainly by dolomicrosparites and gypsum showing stromatolitic laminations and desiccation cracks.

The S3 sequence corresponds to the T3 unit of the Thelja Formation that is attributed to the mid-Paleocene age. The transgressive systems tract of this sequence consists essentially of bioclastic dolomites with gypsum nodules showing burrows, mollusk shells, and phosphatic lithoclasts with local hummockey cross-stratifiction. The maximum flooding surface is represented by a very bioturbated and fossiliferous limestone horizon. The highstand systems tracts of the S3 sequence is composed of dolomicrites and dolomicrosparites with bioclast ghosts, stromalitic lamina, and massive gypsum.

The S4 sequence corresponds to the lower part of the T4 unit. Its lower limit (Fig. 6d) is considered as a transgression surface which is manifested by a sudden facies change, from massive gypsum to dolomites indicating a slight deepening of the depositional environment. The transgressive system tract of this sequence is carbonated. In its uppermost part, it shows a bioturbated surface with phosphate grains which represents

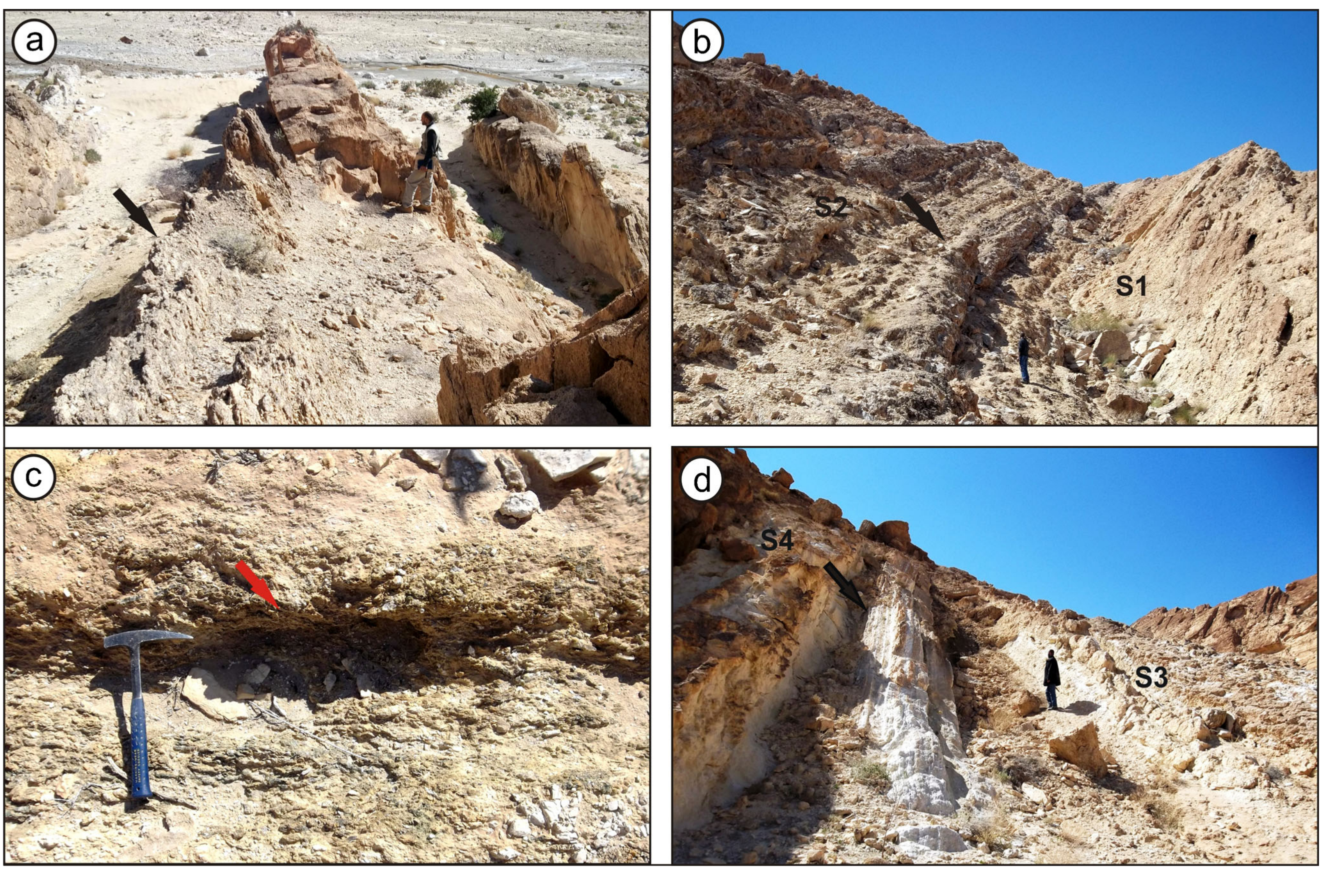

Fig. 6 Outcrops corresponding to the S1, S2, S3, and S4 genetic stratigraphic sequences at Oued Thelja section. **a** Lumachelic limestone with erosive base (*black arrow*); sequence boundary of S1. **b** Boundary between S1 and S2 sequences (*black arrow*). **c** Lumachelic indurated marl with glauconite (*red arrow*) representing the maximum flooding level within S2. **d** Boundary between S3 and S4 sequences (*black arrow*)

the maximum flooding surface. The highstand system tract of the dolomitic and marly S4 sequence ends with stromatolitic carbonates and desiccation breccias.

The S5 sequence covers the middle part of the T4 unit of Thelja Formation (mid-Paleocene). The lower limit of this sequence, rich in phosphate grains, corresponds to a lithological discontinuity (Fig. 7a).

The transgressive system tract of this sequence consists of dolomitic limestone and fine dolomites. The uppermost part of this carbonate facies, rich in phosphatic and fossiliferous grains, corresponds to a maximum flooding surface. The highstand systems tract of S5 sequence is represented by scarce bioclastic dolomites, iron oxides, and phosphatic pellets.

The S6 sequence includes the upper part of the T4 unit of Thelja Formation. The lower limit of this sequence, underlined by an erosive base, represents a clear lithological discontinuity. Two system tracts are recognized within this sequence. The transgressive systems tract of the S6 sequence consists of dolomitic limestone with abundant lithoclasts, bioclasts, and pelletoids. The maximum flooding surface, very bioturbed, is located at the base of a packstone limy facies with gasteropods, lamellibranch shells, and phosphate grains which constitutes the main facies of the highstand system tract of this sequence (Fig. 7b).

The S7 sequence, 14.5 m thick, corresponds to the C1 unit of Chouabine Formation (Fig. 4). The lower limit of this sequence is a very bioturbed lithological discontinuity materializing a transgressive surface (Fig. 7b). The transgressive interval of the S7 sequence is represented by marls interbedded with phosphatic limestones and phosphorites. The maximum flooding surface is located in the middle part of the marl, on top of a phosphatic limestone rich in foraminifera and especially glauconite. The highstand system tract of this sequence consists of alternations of marl, phosphates, and phosphatic limestone (Fig. 7c).

The S8 sequence represents the lower part of the C2 unit of the Chouabine Formation (Ypresian age). The basal discontinuity of this sequence is indicated by an irregular surface that indicates the beginning of a marine transgression (Fig. 7c).

Fig. 7 Outcrops corresponding to the S5, S6, S7, S8, S10, and S11 genetic stratigraphic sequences at Oued Thelja section. **a** Boundary between S4 and S5 sequences (*red arrow*) and the maximum flooding surface of S5 sequence (*black arrow*). **b** Conglomerate erosive base representing boundary between S6 and S7 sequences (*red arrow*) and the maximum flooding surface of S7 sequence (*black arrow*). **c** Boundary between S7 and S8 sequences corresponding to a transgressive surface (*red arrow*). **d** Erosive base corresponding to the transgressive surface of S10 sequence and the boundary between S9 and S10 sequences (*red arrow*), boundary between S10 and S11 sequences (*black arrow*), and the maximum flooding surfaces of these sequences (*yellow arrow*)

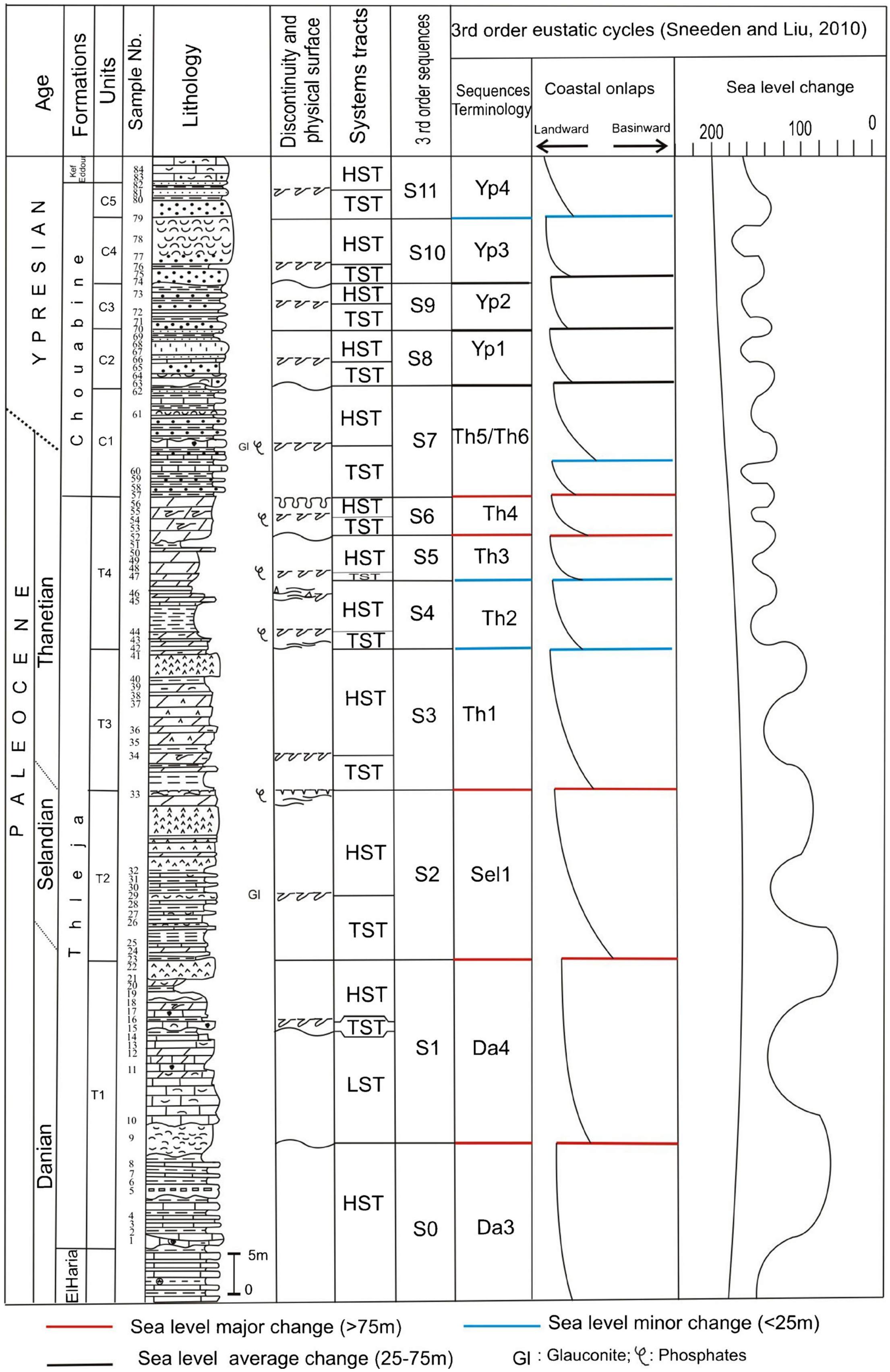

Fig. 8 Correlation of Paleocene sequences of Thelja section (Gafsa basin) with Sneeden and Liu (2010) global cycles

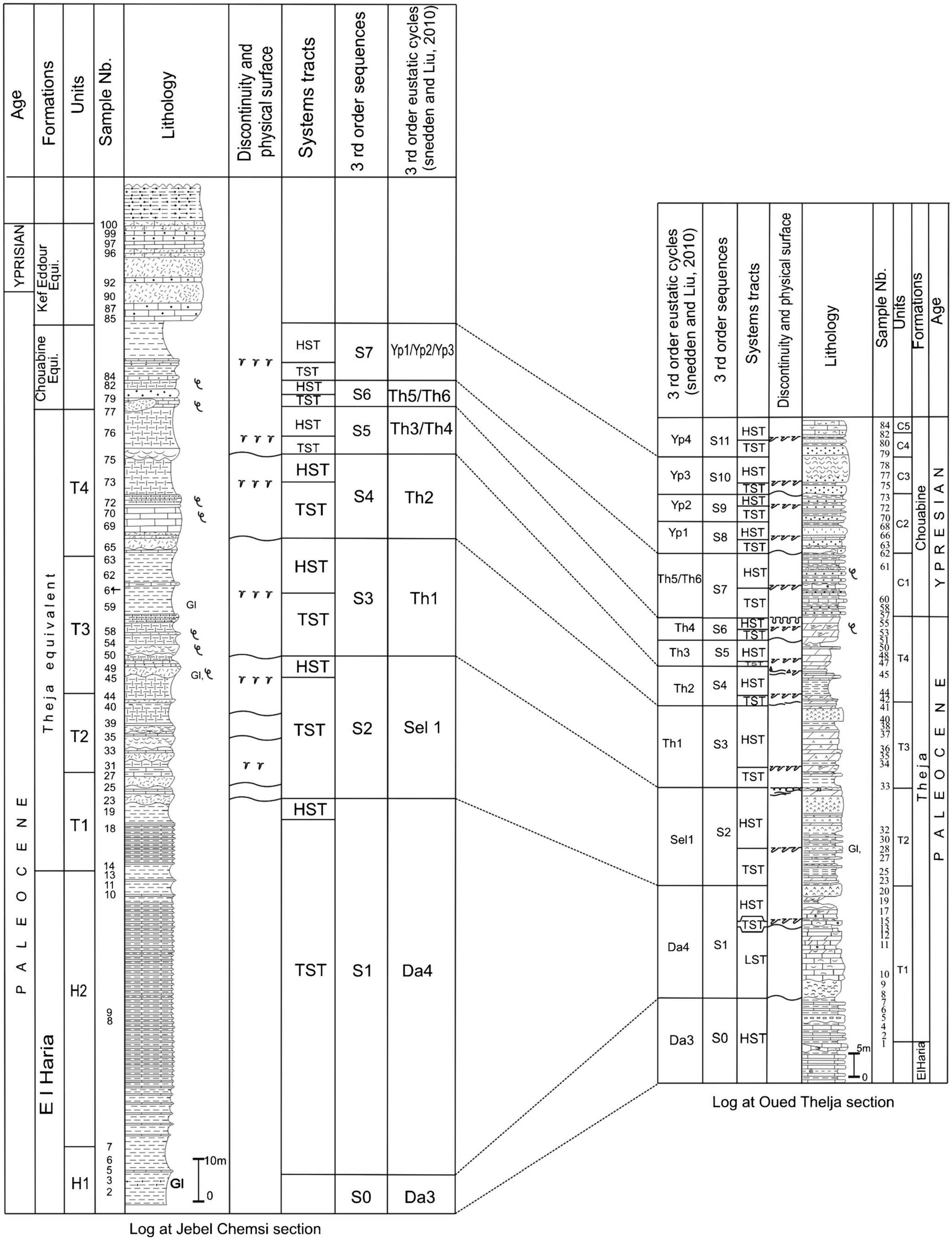

Fig. 9 Correlation between sequences detected at Jebel Chemsi section and Oued Thelja section

The transgressive interval of S8 sequence consists mainly of phospharenites with a carbonated matrix. The maximum flooding surface is represented by a bioturbed horizon. The highstand systems tract of this sequence consists, in its lower part, of marl and phosphatic layers alternations. Its upper part is formed by a siliceous limestone bed.

The S9 sequence, 8 m thick, corresponds to the upper part of the C2 unit and to the entire C3 unit of the Chouabine Formation. The transgressive systems tract of this sequence, limited at its base by an erosive surface (transgression surface), is represented by marl and phosphate alternations. It is bounded to the top by a maximum flooding surface which corresponds to a very bioturbated horizon capping the phosphatic series. The highstand systems tract of S9 sequence consists of marls and phosphate alternations (Fig. 7d).

The S10 sequence, 10 m thick, coincides with the C4 unit of the Chouabine Formation. Its lower limit corresponds to a transgression surface is irregular, bioturbated and rich in interclasts. The transgressive system tract and the highstand system tract of this sequence are represented mainly by phosphatic deposits.

The maximum flooding surface corresponds to a very bioturbated limit indicating a sedimentary condensation (Fig. 7d).

The S11 sequence, 7 m thick, is superimposed by the C5 phosphatic unit of the Chouabine Formation which constitutes a transgressive interval. This interval consists mainly by phosphatic deposits. The transgressive surface coincides with an abrupt phosphatic deposit appearance covering the lumchellic limestone. Higher, the base of the calcareous Kef Eddour Formation corresponds to a highstand system tract that consists of phosphatic limestone rich in lamellibranch. The maximum flooding surface corresponds to a very bioturbated surface; burrows filled with phosphate grains show a low sedimentation rate.

The Paleocene-Eocene sedimentary series of Jebel Chemsi section is represented by eight sequences (S0, S1, S2, S3, S4, S5, S6, and S7) of type 2 (Fig. 9). Each sequence is represented by a transgressive system tract and a highstand system tract. The incomplete S0 sequence corresponds to the lower part of the El Haria Formation, and the S1 sequence extends over its upper part. This sequence expands also over the lower half of the basal unit of the Thelja Formation lateral equivalent. The transgressive systems tract of S1, beginning with a glauconitic marly level, is composed of marls with calcareous intercalations yielding planktonic and benthic foraminifera. The highstand system tract consists of marl and fine limestone alternations, ending with azoic marls.

The S2, S3, S4, and S5 sequences, which are part of the Thelja Formation lateral equivalent, begin with planoconvex lenticular bodies which consist of cross-bedded bioclastic limestones with, in their upper part, calcareous clay or phosphatic indurated marl. These carbonate facies correspond to transgressive system tracts capped by highly bioturbated horizons indicating a maximum flood level. The highstand system tracts of these sequences are composed mainly of azoic to subazoic marls and clays.

The S6 and S7 sequences are represented by the lateral equivalent of the carbonate and marly Chouabine Formation. Transgressive systems tracts of these sequences consist of fine limestones which are locally bioclastic and phosphatic. The maximum flooding surfaces are detected within the bioturbated uppermost parts of the phosphatic facies. Highstand system tracts of S6 and S7 sequences are represented by indurated marl with scarce bioclasts.

Global scale correlations

Stratigraphic and sedimentological analyses of the Paleocene-lower Eocene transition series of the Oued Thelja section allowed the definition of eleven genetic stratigraphic sequences. Comparison of these sequences with the global chart of Sneeden and Liu (2010) shows tight correspondences across third-order cycles.

Correlations identified that are summarized as follows (Fig. 8):

- The S1 sequence matches the middle and upper part of the T1 unit of Thelja Formation and is the equivalent of the Da4 cycle.
- The S2 sequence, which covers the entire T2 unit of Thelja Formation, is the equivalent of the Sel1 cycle.
- The S3 sequence corresponds to the T3 unit of Thelja Formation and is correlated with the Th1 cycle.
- The S4 sequence coincides with the lower part of the T4 unit of Thelja Formation and is correlated with the Th2 cycle.
- The S5 sequence, represented by the middle part of T4 unit of Thelja Formation, matches the Th3 cycle.
- The S6 sequence, represented by the upper part of T4 unit of Thelja Formation, is attached here to the Th4 cycle.
- The Th5 and Th6 cycles, around the Tahnetian-Ypresian transition, correspond in our study area to the S7 sequence; the latter matching the C1 unit of Chouabine Formation.
- The S8 sequence, which corresponds to the lower part of the C2 unit of Chouabine Formation, corresponds to the Yp1 cycle.
- The S9 sequence that extends to the upper part of C2 unit and the whole of the C3 unit of Chouabine Formation is correlated with the Yp2 cycle.
- The S10 sequence, represented by the C4 unit of Chouabine Formation, corresponds to the Yp3 cycle.
- The S11 sequence, covering the C5 unit of Chouabine Formation and the lower part of Kef Eddour Formation, corresponds to the Yp4 cycle.

The sedimentary series around the Paleocene-Eocene interval of Jebel Chemsi section is represented by eight stratigraphic sequences (S0, S1, S2, S3, S4, S5, S6, and S7) of type 2. The correlation of these sequences with those detected at Oued Thelja does not show a tight correspondence (Fig. 9). The third-order cycles Da3, Da4, Sel1, Th1, and Th2 correspond respectively to S0, S1, S2, S3, and S4 sequences at Jebel Chemsi. Other cycles of Paleocene-Eocene transition are represented at this section by amalgamated sequences. Indeed, the location of Jebel Chemsi corresponds, during the Paleocene-Eocene transition, to a sheltered marine environment where minor relative sea-level changes have not been recorded.

Conclusions

At Oued Thelja, the vertical variation of facies and sedimentary characters of the Palaeocene-Ypresian interval, represented by Thelja, Chouabine, and Kef Eddour Formations, indicates diverse depositional environments.

Each of the sedimentary sequences of Thelja Formation shows that the depositional environment evolved from a coastal to a sebkha environment. Phosphate deposits of Chouabine Formation characterize a marine environment that oscillates between circalittoral and shallow subtidal. The succession of Kef Eddour Formation indicates a shallow marine environment characterizing an occasionally agitated inner platform. At Jebel Chemsi, the slightly phosphatic marls, correlated with the phosphorite of Chouabine Formation of the Oued Thelja characterize a sheltered lagoon environment. At Jebel Chemsi, the carbonate deposits of the Kef Eddour Formation reflect a shallow subtidal environment with low to moderate energy. Occasionally, the occurence of abundant quartz grains indicates a very proximal sedimentation relative to exposed lands. The floating lithoclast facies is the result of a debris flow deposits.

In the Oued Thelja section, the stratigraphic and sedimentological analysis of the Paleocene-Eocene transition allowed to define eleven genetic stratigraphic sequences. The Thelja Formation consists of six sequences, while Chouabine Formation contains five third-order sequences. The correlation of those sequences with the third-order cycles of the global chart of Sneeden and Liu (2010) shows a tight fitness.

The third-order global cycles are represented in part in Jebel Chemsi by amalgamated genetic stratigraphic sequences that characterize sheltered marine environments unfavorable to the recording of minor relative sea-level changes. Later, we consider to record the relative sea-level changes of the Paleocene-Eocene transition in the Sraa El Ourtene zone (Kef area in the North-Ouest of Tunisia) and in the Meknassy-Mazzouna basin (CentralTunisia). We will try to establish correlations with well-studied sections outside Tunisia (Middle East, for example).

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