Volume n° 6 - from P55 to PW06

32nd INTERNATIONAL GEOLOGICAL CONGRESS

THE CRETACEOUS-TERTIARY (K-T) BOUNDARY IN ELLES AND THE OTHER TUNISIAN OUTCROPS

Leader: D. Zaghbib-Turki

Associate Leader: N. Karoui-Yaakoub

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Florence - Italy
August 20-28, 2004

Post-Congress **P60**

The scientific content of this guide is under the total responsibility of the Authors

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AUTHORS:
D. Zaghbib-Turki, N. Karoui-Yaakoub *(Departement of Geology Faculty of Sciences - Tunis)*

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Front Cover:
The Late Maastrichtian-Danian outcrop in the Ellès I section

Leader: D. Zaghbib-Turki
Associated Leader: N. Karoui-Yaakoub

Introduction

Continuous and complete Cretaceous-Tertiary (K-T) transition interval sections are rare and scarce in the world. Until 1991, there have been no more than sixty inventoried complete sections, including the El Kef section, that has been selected as the reference section (stratotype) of this transition interval. Only half of these sections expose a well-characterized K/T boundary in the field, whereas the other sections are known by deep sea drillings (Figure 1).

Over the last decade, geological research have lead to the discovery of a few other K-T boundary interval complete sections. So, during the International Workshop on the Cretaceous- Tertiary Transition (Tunis, 1998), scientists exhibited three other complete K-T transition interval sections in Tunisia :

- Elles section, located at about 56 km from El Kef towards the southeast (Zaghbib-Turki et al., 2000 and 2001; Karoui-Yaakoub et al., 2002)
- Ain Sattara section, located at about 50 km from El Kef towards the southwest (Dupuis et al., 2001) ,
- Oued El Melah section, which is in northeastern Tunisia, and about 200 km from the El Kef reference section (Karoui-Yaakoub et al., 2002) .

In these late Tunisian sections, all the K-T boundary characteristic criteria are preserved, such as:

- the contrast in colour between the uppermost grey Maastrichtian deposits and the lowermost dark Danian deposits,
- the lithological difference between the uppermost Maastrichtian limestone and the lowermost Danian clay,

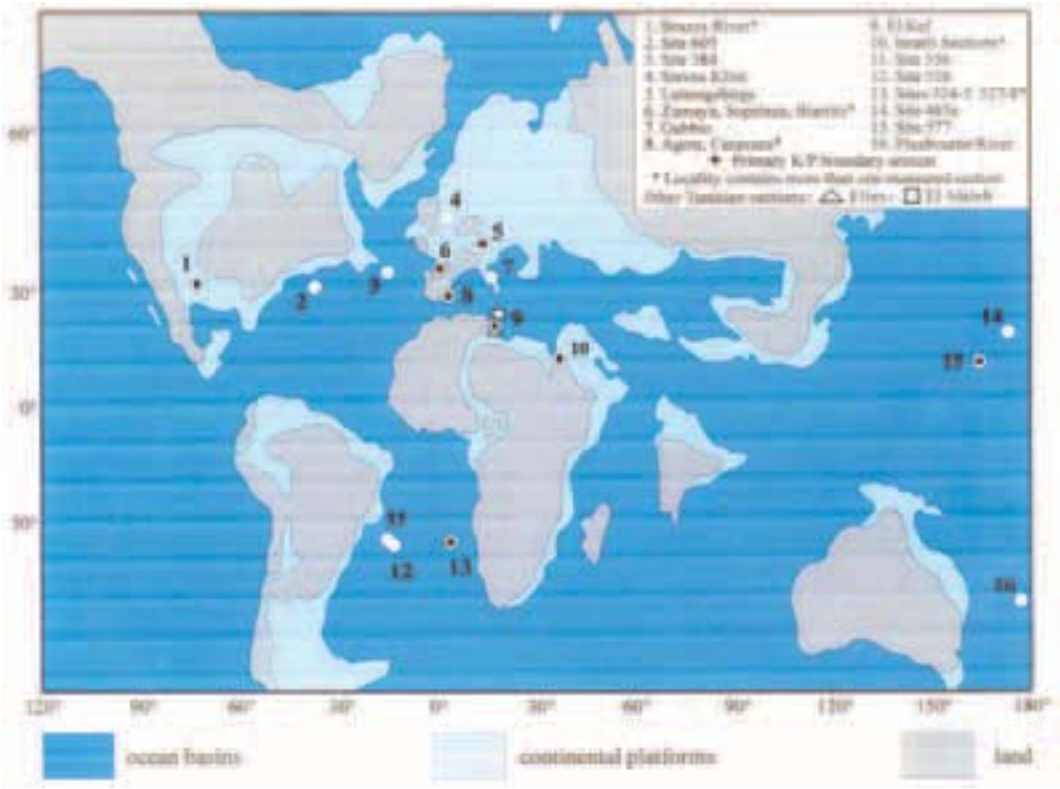


Figure 1 - Location of the main complete K-T boundary sections in the world, including Elles and El Maleh sections in their paleogeographical setting (after MacLeod and Keller, 1991)

Volume n° 6 - from P55 to PW06

- the preservation of a thin rust- coloured layer devoid of fossils,
- a high concentration of Iridium in the rust layer,
- the presence of crystals of Ni-Cr rich spinel in the rust layer,
- the insertion of the rust layer between two thin layer of gypsum,
- the contrast in fauna contents between those of Maastrichtian and Danian deposits,
- the planktonic foraminifers that are highly frequent in Maastrichtian deposits; in contrast, few species of this group occur in Danian deposits,
- especially, the planktonic foraminifers of tropical realm (Globotruncanids and Heterohelicids) that are diversified in the Maastrichtian deposits, suffer a mass extinction at and above the K-T boundary,
- the scarcity of the whole fauna in the lowermost Danian deposits,
- the lowermost Danian fauna that is composed of a few opportunist
- Maastrichtian survivor species (among these, Globotruncanids and Heterohelicids) and rare pioneers of Globigerinids.

During this workshop, we'll focus on all these criteria, and we'll observe the main changes in planktonic foraminifera associations of the K-T interval transition, and in the Lower Danian interval exposed in the El Maleh, El Kef, and Elles sections.
The main object of this workshop is to compare the K-T interval transition of the different studied stations in Tunisia and other localities known in the world that each of you have previously observed.

Summary on the geographical and the geological setting of the northern Tunisia

From the northern coast, the mountainous and hilly lands of the northern Tunisia are covered by fertile soils. The large cereal fields offer the most beautiful landscapes, that are green during the spring, becoming golden yellow at the beginning of the summer, just before the gathering of the corn in July.
The geological outcrops are mainly Cenozoic in the farthest north of Tunisia, where the Tellian Atlas is extended. This part of the Magrebide chain in the

Figure 2 - Itinerary map

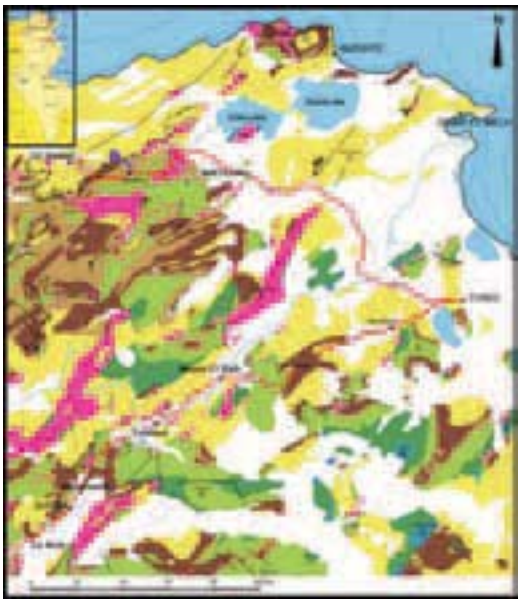


Figure 3a - Simplified geological map of northern Tunisia (after the geological map of Tunisia, scale 1/500.000 edit. O.N.M.: Geological Survey, 1985)

bordering of the Mediterranean Sea, constitutes a pile of thrust sheet units (Rouvier, 1985). The most important unit is the Numidian one, that is formed by Oligocene and Lower Miocene silicico-clastic turbidites (El Mahersi, 1992; Meulenkamp et al., 2000 c). The main thrust movement is reported to be Serravallian or Tortonian in age. After their emplacement, the different thrust sheets were folded during the Late Tortonian-Early Pleistocene interval.

In the bordering of the Medjerda valley some molassic troughs have developed, where post-orogenic Upper Miocene material has accumulated. Some basic and acid igneous rocks are present in several localities (Rouvier, 1985; Laridhi-Ouaza, 2001), and mark the Late Tortonian tectonic activity. At the front of these thrust sheets, many outcrops of Triassic material constitute the diapir or dome zone (Perthuisot, 1978; Chikhaoui et al, 1991; Perthuisot et Rouvier, 1992; Chikhaoui, 2002). Towards the south, the Central Atlas is characterized by system folds trending NE-SW (Turki, 1985). These structures are cut by faults bordering Mio-Pliocene grabens (Ben Ayed, 1986,

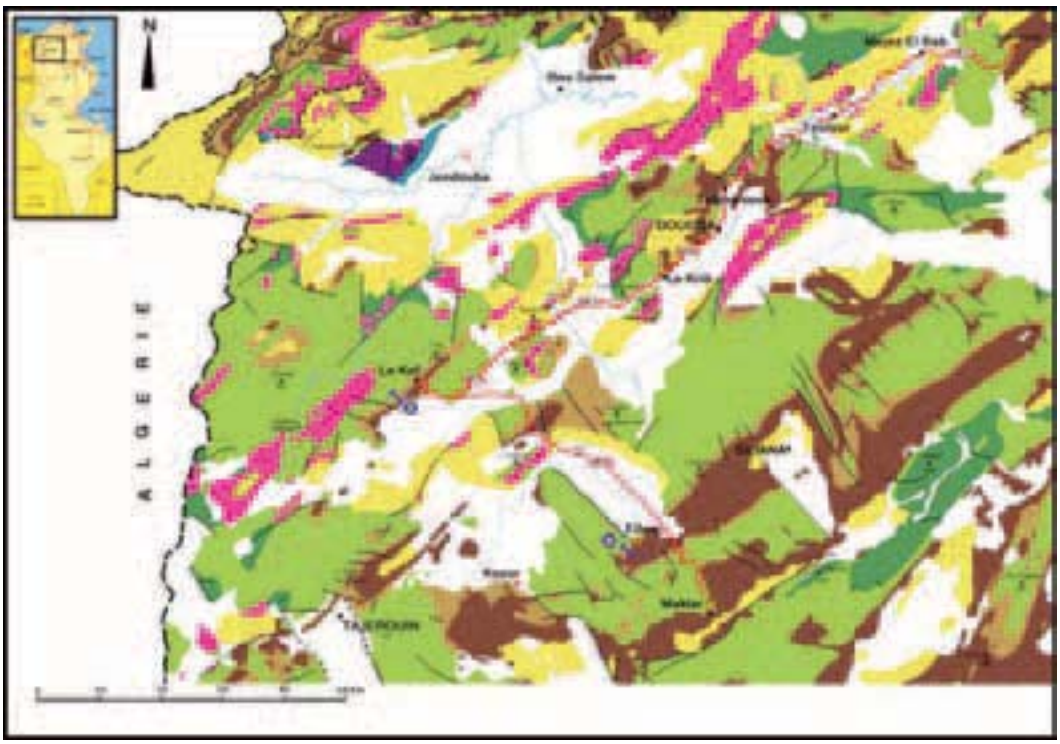


Figure 3b - Simplified geological map of central Tunisia (after geological map of Tunisia, scale 1/500.000 edit. O.N.M.: Geological Survey, 1985) [for caption see Figure 3a]

Volume n° 6 - from P55 to PW06

Chihi, 1995). According to the paleogeographical aspect, in northern Tunisia, the evaporitic, clayey, sandy, and dolomitic deposits of the Triassic material indicate a tidal flat environment. The scarce Lower Jurassic deposits are the relic of a large carbonate platform (Turki, 1985; Soussi et al., 2000; Soussi, 2000). This later was broken by syn-sedimentary normal faults (Turki, 1985), and evolved, from the Carixian stage, to a deep marine environment, rich in pelagic fauna (Ammonites, Belemnites), developed in northern Tunisia and characterizing the Tunisian Trough. By the Callovian tethyan transgression, the Tunisian Trough reaches the deepest environment (the bottom of which must be underneath the CCD boundary) characterized by jaspe or radiolarites inserted in pellite deposits as those known in Thuburnic and Mejez Elbab and Oust regions. The Cretaceous marl, chalky shales, and limestone deposits rich in pelagic fauna (Ammonites, Belemnites, and planktonic Foraminifera), show us that the deep sea was still developed atthe border of the Kasserine Island, which emerged since the Early Senonian (Burollet, 1956, Ben Ferjani et al., 1990). Especially in the Late Campanian, a tectonic instability induced the deposition of carbonate turbidites in the major part of this trough (Negra, 1995).

The Maastrichtian-Paleocene clayey deposits rich in planktonic Foraminifera are rarely continuous. Many sedimentary gaps of the uppermost Maastrichtian-lowermost Danian deposits may be related to the global oceanic circulation changes. Globally, during this interval, northern Tunisia is characterized by a deep sea water (see Figure 12). In the Early Eocene (Meulenkamp et al., 2000 a), an important paleogeographical reorganisation appropriates the hole of Tunisia and especially its northern part. So the previous deep sea was reduced to the Tellian Trough rich in Globigerinids and Globorotaliids during the Eocene-Oligocene interval (Meulenkamp et al., 2000 b). It bordered the Hairech-Teboursok-Ichkeul submarine ridge on which and further to the south, a shallow sea, rich in Nummulites and red Alga, was developed. During the Late Oligocene-Early Miocene epoch, this Tellian Trough accumulated silicico-clastic turbidites with argillaceous terms, rich in Globigerinids and Globorotaliids. The filling and the emersion of this Tellian Trough are simultaneously affected by the orogenic compressive phase of the Late Miocene epoch.

DAY 1

Geological information on the travel crossing

The itinerary that we'll take during our fieldtrip on the first day (Figure 2), leading to the El Maleh section, crosses the sedimentary cover in northern Tunisia following a roughly a NE-SW trend (Figure 3 a). During our travel from Tunis to the El Maleh section, we'll take the GP 7 road leading to Tabarka (160 km) close to the Tunisian-Algerian frontier. We pass near the towns of Manouba (5 km), Jedeida (20km), and Mateur (68 km), and we cross large plains with Pliocene-Miocene-Quaternary outcrops in the border of anticline or diapir structures such as that of Mornaguia-Mhamdia towards the south and Jebel Amar, and Jebel Sakkak (the most northern part of the Lansarine diapir chain) towards the north. The continental Quaternary deposits in the Mateur plain mask the Eocene imbrication structures partially towards the south. After leaving Mateur town, the anticline structure of Jebel Ichkeul appears towards the NE. It is on the border of the large and attractive lake of Ichkeul (see annex). This anticline structure is characterized by its particular shallow marine Triassic deposits, rich in bivalves, such as the *Myophoria* species, and its Jurassic deposits, rich in algae (Cyanophyta and Dasyclads) in their Lower Liassic part (Rhetian-Sinemurian), then in Ammonites and Belemnites. These Jurassic deposits give information on the evolution of their depositional environment, from a shallow marine to a basinal environment. These Triassic and Jurassic deposits are mainly modified into metamorphic rocks. Without leaving GP 7 road, we continue towards Sejnane town. Before reaching Aouana village at 3 km, the road

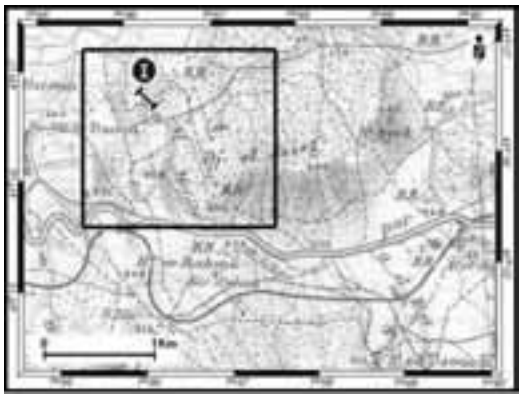


Figure 4a - El Maleh section location on the topographic Hedil map portion (n°11)

crosses Triassic rocks at the level of Jalta village, then Cretaceous and Paleocene series outcropping at the front of the Numidian thrust sheet flyschoid material (Figure3 a). When the road crosses the El Maleh River and towards the east side (to the right), quarry appears. This quarry exploits, in the Jebel El Azzag northern flank, the Campanian-Maastrichtian chalky limestone. Beyond and around this quarry, the Upper Cretaceous and Paleocene series are continuous and well exposed. Towards the north, the K-T boundary interval is complete at the El Maleh section.

El maleh section

Historical background and geological setting

Since 1999, in her Thesis, N. Karoui-Yaakoub has pointed out the Cretaceous-Tertiary transition interval deposits in the Aouana region. She has described the K-T boundary at the El Maleh section and has detailed the planktonic foraminifera contents of the Cretaceous-Tertiary transition interval deposits of this section.

The El Maleh section is located in northeastern Tunisia, at about 36 km west from Mateur town, and 3 km east from the Aouana railway station (Figure 2 and Figure 4a). It is located at the level of the geographical point X= 7G 86' ; Y= 41 G 17' 30" on the Hedil topographical and geological maps (n° 11) with 1/50.000 scale.

This section can be reached from Tunis by taking the road GP 7 that leads to Sejnene and Tabarka towns and joins the Algerian territory. About 16 km before Sejnene town, at a locality marked by the crossing of the El Maleh River, is a chalk quarry exploiting the white limestone of the Abiod Formation. There, we leave the cars. From this quarry, and about 2 km towards the north, the Cretaceous-Tertiary boundary section is reached on foot by following the wide valley of the El Maleh River (never dry), crossing the Campanian-Lower Maastrichtian series of the Abiod Formation. This series contains rare Inoceramus prints, and is rich in planktonic foraminifera (Globotrncanids, Heterohelicids). So, into this Upper Cretaceous series, known as the Abiod Formation, the valley river cuts three members. The lowest member is made up of light grey chalky mudstone with Inoceramus prints and Echinoderms. There, at 300 m from the quarry, a spring of fresh water is used for drinking by the scarce habitants. The intermediate member is composed of green marl-grey argillaceous limestone cycles. The Upper member is made up of massive chalky limestone. Continuing along the valley, we cross second cycles of green clay, that contains interbeds of argillaceous limestone and dark grey clay, then a thick and wide exposed clayey series. These argillaceous deposits, included in the El Haria Formation, are Late Maastrichtian-Paleocene in age, and contain a continuous Cretaceous-Tertiary intermediate interval. About 2 km away from the spring, and towards the east (to the right) of a very large meanders curve, in the well-exposed dark grey clayey series of the El Haria Formation, is the El Maleh section (Figure 4 a-b). In the Cretaceous-Tertiary transition interval deposits, included in the El Haria Formation, the K-T boundary horizon is marked by a thin rusty red layer (Karoui-Yaakoub et al., 2002). This rusty layer is rich in iron oxides, Iridium (Ir), and Ni-Cr spinel crystals (that are microscopic in size).

Exposure conditions of the Cretaceous-Tertiary (K-T) boundary

During spring and summer, the clayey outcrops of the El Haria formation are covered by cereal cultivation. So, these outcrops are discovered only along some steep streams. Through one of these streams, the uppermost Maastrichtian-lowermost Danian interval deposits is well exposed. Upwards, the overlain Danian clays contain a few interbeds of argillaceous limestone, clearly visible in the landscape of the El Haria Formation middle part.

According to their incoherence, these clayey deposits are often affected by rainwater and have suffered from slumps. So, for sampling and to make observation easier, it is necessary to make trenches.

Cretaceous-Tertiary (K-T) transition

In the trench, we distinguish five levels (Figure 4 b-c; Figure 5 a-c):

- level 1: subnodular compact grey marl, rich in jarosite nodules. This level is rich in keeled Globotruncanids and costulate Heterohelicids, that characterized the tropical realm of the Late Maastrichtian age. Among these planktonic foraminifera, the occurrence of the rare individuals of the *Abathomphalus mayaroensis* and *Plummerita hantkeninoides* species, indicates the latest Maastrichtian age.

- level 2: thin layer (1 cm thick) composed of a rust-coloured layer (1 to 2 mm thick), interbedded between two gypsum levels. The rust-coloured layer is rich in

Volume n° 6 - from P55 to PW06

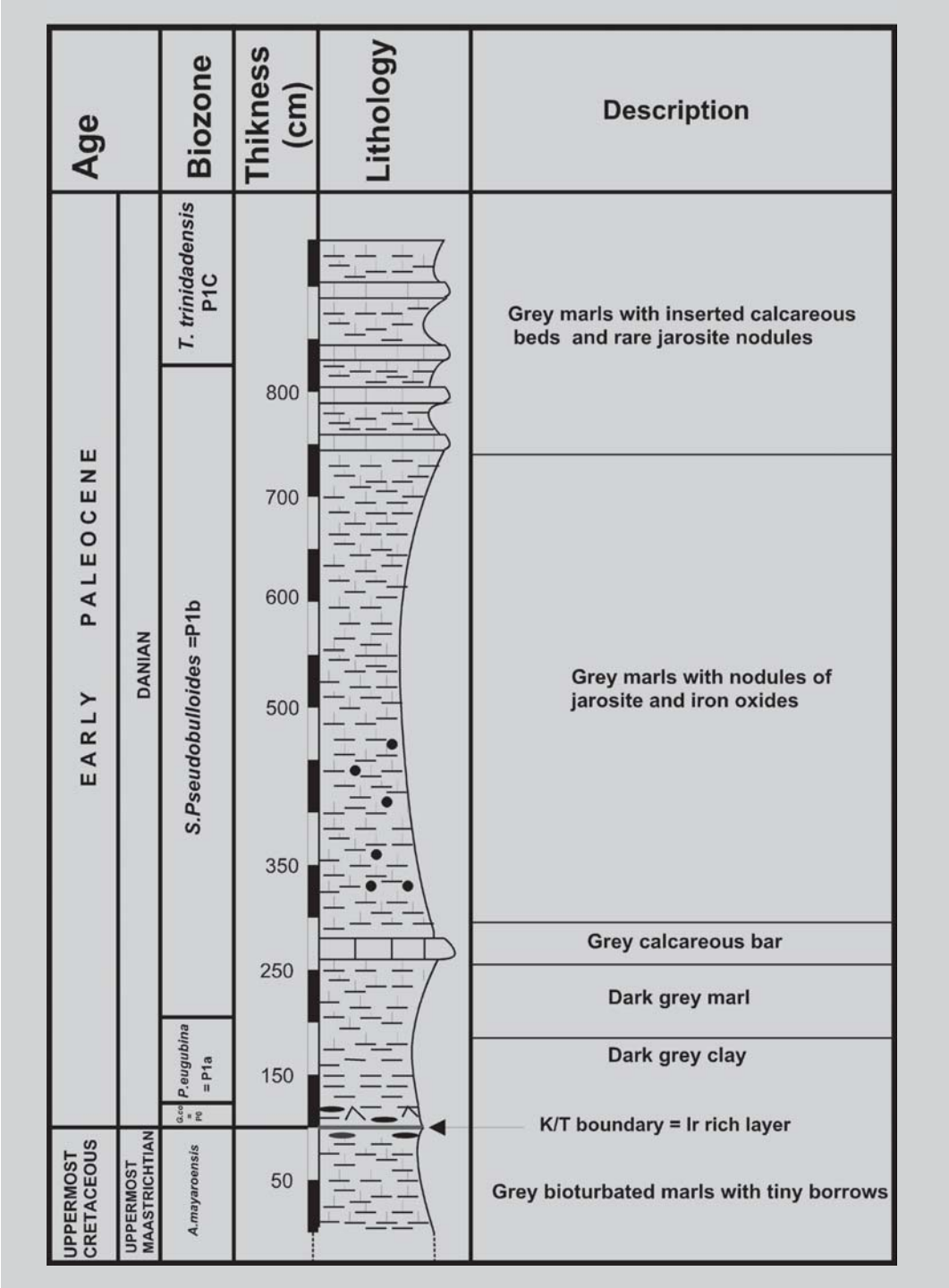


Figure 4 b - Lithological description of the K-T boundary interval in the El Maleh section

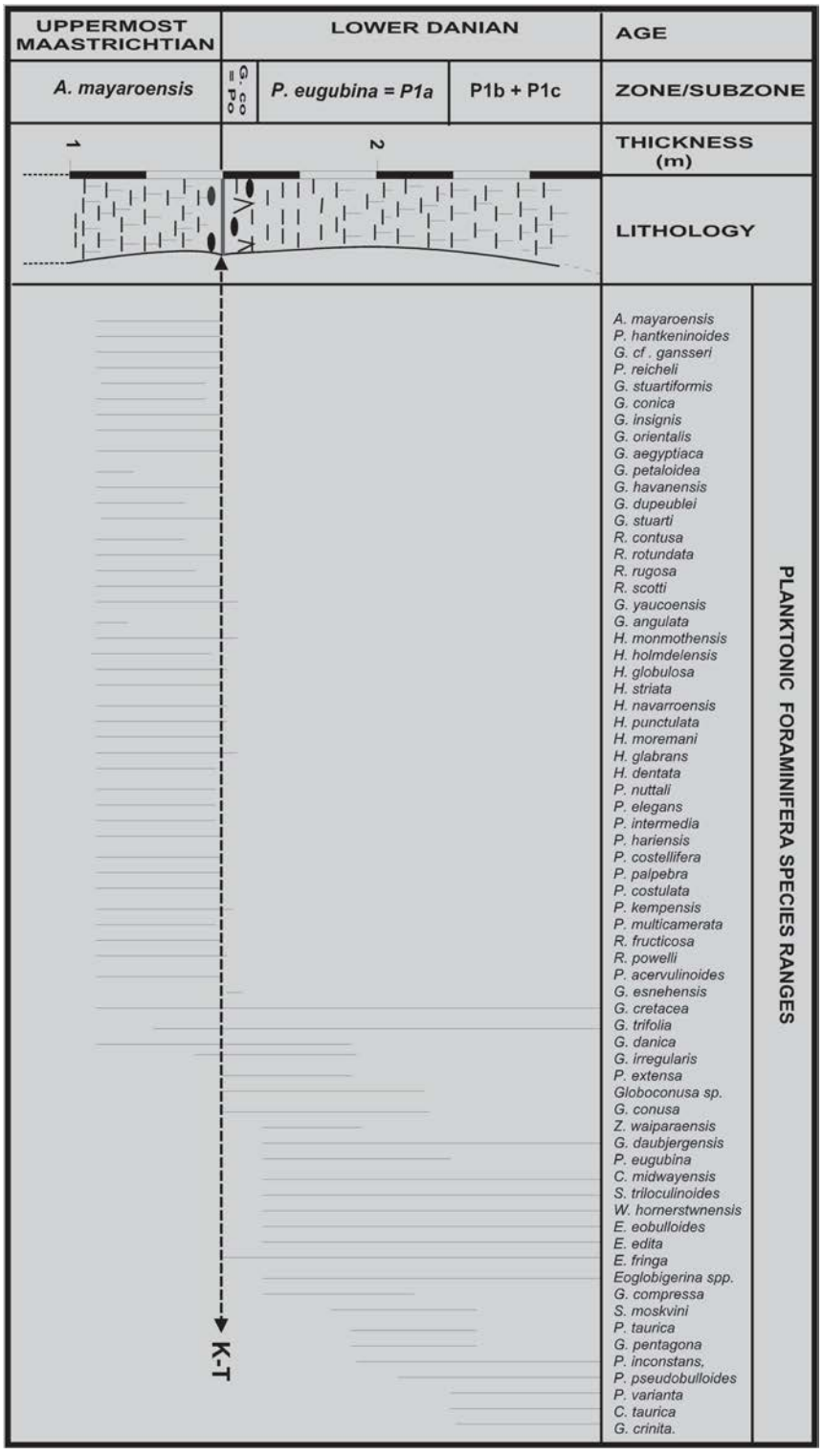


Figure 4 c Ranges of planktonic foraminerfera species in the El Maleh section of the K-T boundary interva l(Karoui –Yaakoub et al., 2002)

Figure 5 a - Panoramic view of the El Haria Formation at the level of the largest meanders curve near the El Maleh section

Figure 5 b - Landscape of the El Haria Formation in its Paleocene part at the eastern side of the meanders and the location of El Maleh section

Figure 5 c - The K-T boundary interval in El Maleh section

Iridium (4.8 +/- 0.2 ng/g*, Bobin et al., 1998; Kaoui-Yaakoub et al., 2002), and contains microscopic crystals of Ni-Cr rich spinel, and iron oxides (*the geochemical analyses are done in the laboratory of " Faibles Radioactivités de Gif"/Yvette France). This layer is totally devoid of fossils.

- level 3: 3 cm dark grey clay with rare fauna. Among those inherited from the Maastrichtian level (1), only those characterized by tiny tests are well preserved, such as those of the *Guembelitria* and *Rugoglobigerina* species. The tests of all the other keeled Globotruncanids and costulate Heterohelicids, instead, are dissolved or mineralized in iron oxide. Rare small tests of the earliest Danian species such as *Globoconusa conusa* are well-preserved. All tiny and well-preserved tests are considered as components of the autochthonous Earliest Danian association (Maastrichtian survivor species and Danian species), while the ones mineralized in iron oxide or dissolved are surely reworked.

- level 4: 10 cm plastic dark clay. There among the Cretaceous survivor species, only those of few tiny Heterohelicids (e.g. *Guembelitria cretacea*) and Globigerinelloids are present. Towards the top, some other Eoglobigerinids species appear.

- level 5: Lamellar dark clay where the calcareous foraminifera are relatively more frequent and diversified. At the base (14 cm from the level 2), among the Eoglobigerinids, *Parvularugoglobigerina eugubina* appears.

DAY 2

Geological information on the travel crossing

The itinerary that we take during our fieldtrip on the second and the third days, leading to the El Kef and Elles sections, crosses northern Tunisia from the east to the west. In Northern Tunisia the outcropping geological cover is mainly made up of Triassic, Cretaceous, Paleogene, and Neogene varied sedimentary rocks (Figure 3 b). Those of Triassic age are composed of gypsum, sandstone (psammite), dolomite and clay, rich in various neoformed crystals such as bipyramidal quartz, ankerite, aragonite, and in crystalline green rocks such as ophiolite. These sedimentary rocks, often, have a subnormal stratigraphical position. They generally occupy the

heart of diapir or dome structures, and sometimes form lamellar-shaped structures, marking out reversal or thrust faults. These outcrops are very extended and frequent in the "diapir zone" (Figure 3 b). If the Jurassic rocks in outcrop are scarce and rare, those of Cretaceous age are largely extended. They are frequently composed of marly-calcareous cycles. Those of the Lower Cretaceous may include sandstone. All these Cretaceous deposits are rich in pelagic fauna of deep-sea environments that characterize the "Tunisian Trough". The Paleocene is mainly clayey and rich in planktonic foraminifera of deep-sea environments (circalittoral to the upper bathyal domain). In northern Tunisia, the Eocene deposits are composed of two kinds of facies, the Globigerine rich facies of the deep-sea environment, and the Nummulites-rich faciès of the shallow sea environment. This Nummilites-rich facies marks a SW-NE trend shoal, bordering the Jendouba-Teboursouk-Ichkeul line.

During our journey from Tunis to El Kef we take the GP5 road to reach both the El Kef and the Elles sections. The studied sections are located in northern Tunisia, which is considered to be the most fertile region of the country. The road GP5, following the NE-SW trend, and joining Tunis to Souk Ahras in Algeria, leads to the El Kef town (175 km). It follows the ancient Roman strategic road joining Carthage to Theveste (Tebessa in Algeria), where the Roman army of Africa (the Third August's Legion) used to be stationed. It crosses the low Mejerda valley of the largest river in the whole country. This river originates in Algeria, and flows into the Mediterranean Sea near Ghar el Melh. Its Tunisian portion is 365 km long. Along its banks, it irrigates the most fertile cereal fields of the country. Near Tunis, towards the southwest, in the Mornaguia plain, the road crosses along 30 km Mio-Pliocene exposures. The Quaternary deposits form hills which reach 130 m in altitude. At 32 km from Tunis, the road cuts the Cretaceous-Eocene outcrops. Towards Mejez El Bab town (61 km), the GP5 road cuts again the Oligo-Neogene and Quaternary exposures. The Eocene and Upper Cretaceous outcrops are near the Triassic dome joining Mejez El Bab town. Testour (80 km), an Andalusian town, is built on Neogene outcrops, in the border of the Medjerda valley.

Further along, in the Teboursouk region, the road crosses the roosted syncline structure of Jebel Goraa, where the outcrops are Eocene-Cretaceous in age.

There, the ruins of an ancient Roman city are near

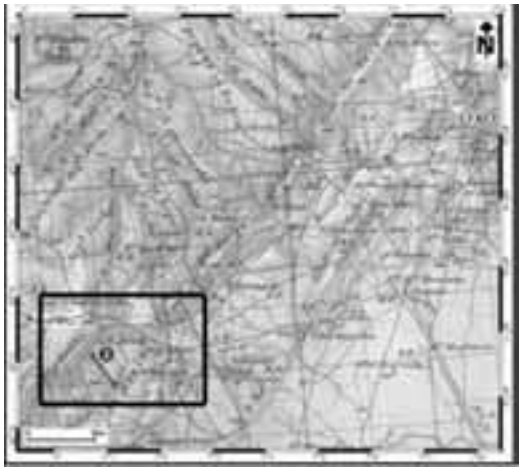


Figure 6 a: El Kef section location on a topographic Le Kef map portion (n°44)

the Ain Tounga (90 km) village, built on an Eocene outcrop with mineral springs. At the picturesque landscape of Ain Jemala village (95 km), the road cuts the Campanian-Maastrichtian chalky limestone of the Abiod Formation.

The town of Teboursouk (102 km) is initially built on the side of the hill and overhangs the Khaled River valley (an affluent of the Mejreda River). Then, it was extended onto the Triassic material of the nearby diapiric structure. It is adjacent to a Byzantine enclosure conquered by the Arabian dynasty. Towards the north, we note the Teboursouk plateau, made of Eocene limestone, characteristic of the El Garia formation, rich in Nummulites, well-exposed in the Ain Tounga- Khaled syncline and in the Jebel Goraa syncline and at the border of the Jebel Thibar diapir. In these Eocene rocks many quarries have been exploited since the Roman period. At km 108 , a road fork leads to the Dougga ruins (Thugga), corresponding to the most prestigious Roman archaeological site in Africa. There, we deserve a particular stop (see the annex).

Near the El Krib village, at km 139, the road crosses the Tessa River valley (the third Mejerda affluent), then a narrow gorge (Khanguet el Kedim) between Jebel Barkane (649 m) and Jebel Kebbouche (811 m). After El Krib, (124 km) the road crosses many diapirs, such as Jebel Bou Khil (738 m, on the left), with its Pb-Zn Mine, and Jebel Ben Rhazouane (on the right), also with its Pb-Zn Mine, that is still exploited.

Near El Kef, at km 143, we can see the Campanian-Maastrichtian white chalky limestone. Near Bahra village (25 km from El Kef town), the top of the

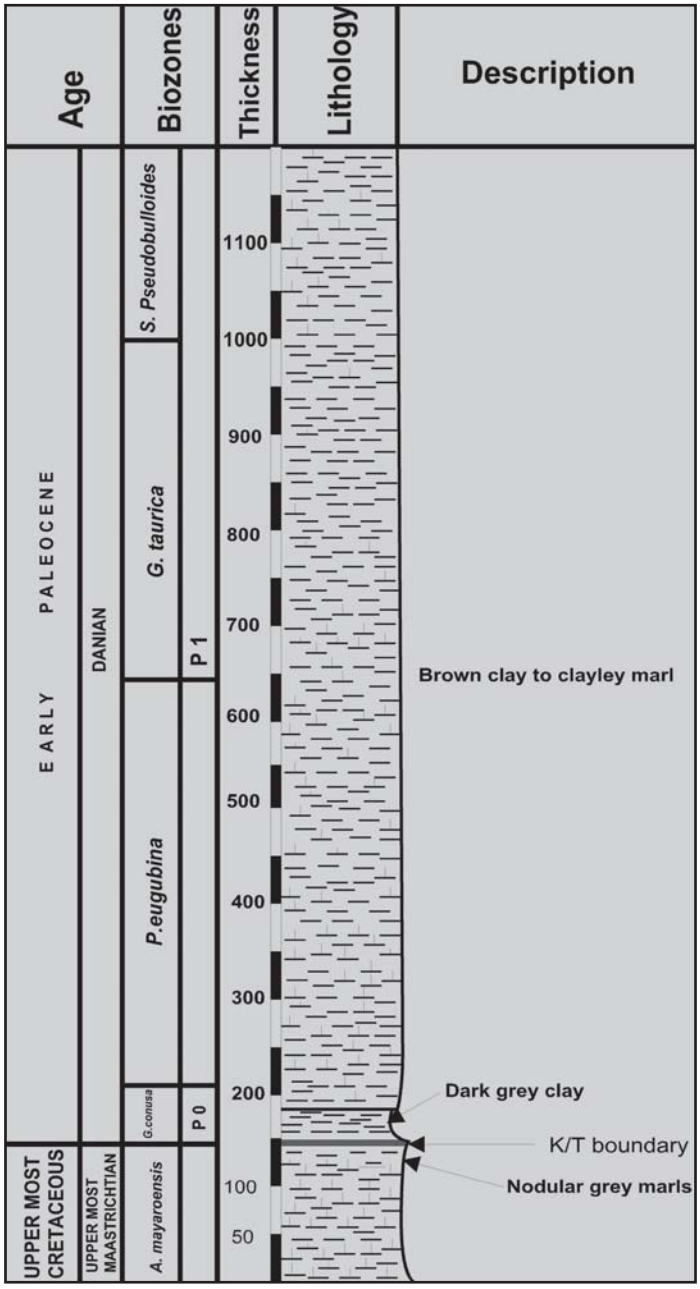


Figure 6 b - Lithological description of the El Kef section K-T boundary interval (Ben Abdelkader et al., 1995)

Paleocene series is marked by two phosphatic levels. The upper one is immediately covered by Lutetian Nummulites rich limestone. So, in this locality, we note the Ypresian gap. Along the last seven kilometers before El Kef, the rest of the Senonian series shows large exposures of marly-calcareous cycles. The El Kef region contains three main structures: the Oued Mellege anticline (where the oldest outcrop is Cretaceous in age), adjacent to Dyr El Kef Eocene syncline, and Araguib Kammra Neogene anticline. Between the Oued Mellegue anticline and the Dyr El Kef syncline, the Cretaceous-Paleocene transition is continuous. There, the El Kef section exhibits a complete K-T boundary interval.

El Kef section

Historical background and geological setting

In the El Kef region (in the north-west of Tunisia), the Upper Cretaceous, Paleocene, and Eocene series are well-exposed and continuous along the northwestern flank of the Dyr El Kef syncline (Fig 2, 3 b, 6 a).

Since 1974, Salaj has pointed out in the Hammem Mellegue valley a continuous section across the Upper Cretaceous-Lower Paleocene intermediate interval deposits. He described the Foraminifera contents of this section, and specified a global biostratigraphical scheme of the Upper Cretaceous-Paleocene interval. He also presented this section at the VI th African Symposium on Micropaleontology (Tunis, 1974), as a Hypostratotype of the Maastrichtian-Paleocene transition. This section was kept as a reference series for the Maastrichtian and the Paleocene in the Tethyan domain. At the I.U.G.S. meeting of GIPC 145 project (Sfax, 1976), it was proposed that the Geological Survey of Tunisia ensures the sampling and supervises the distribution of the geological material to be studied by the different specialists.

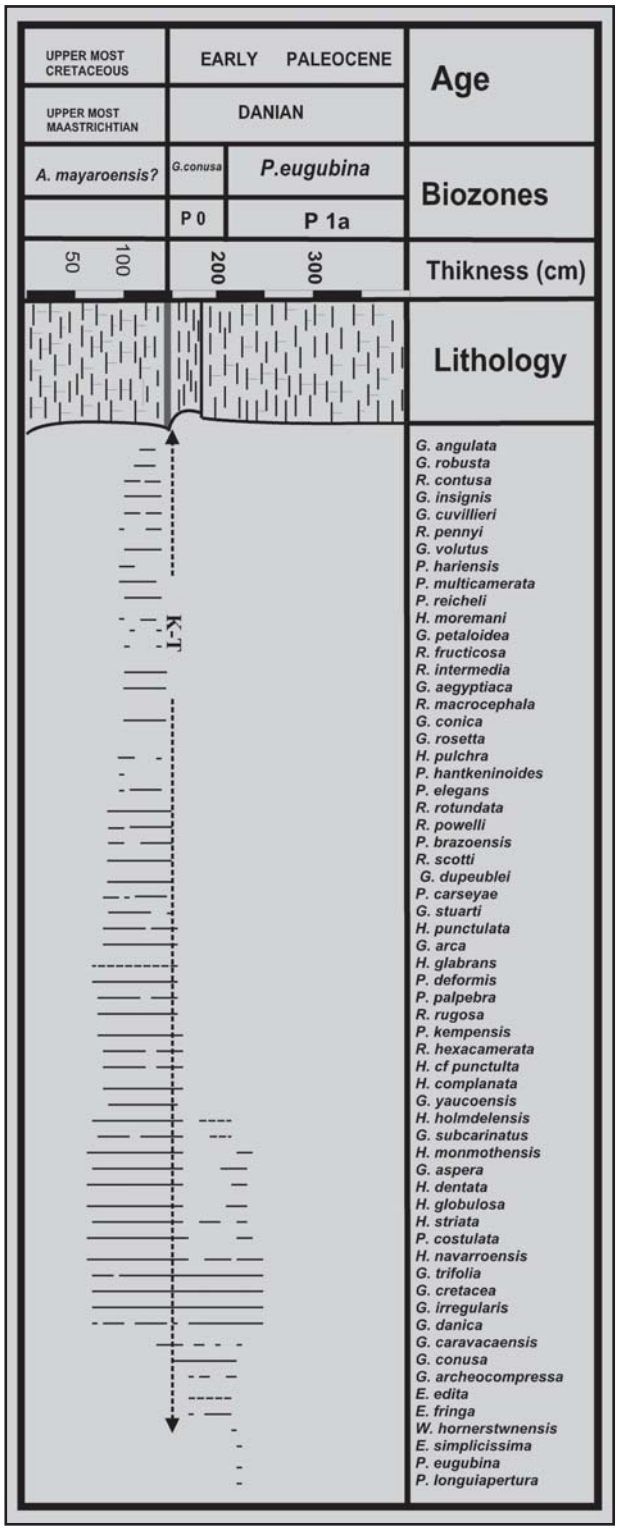


Figure 6 c - Planktonic Foraminifera species range in the K-T boundary interval at the El Kef section (Keller et al.,1995)

So, some field missions were organized during the 1978-1980 period to search precisely for the Cretaceous-Tertiary boundary in the Hammem Mellegue valley, and to specify the best section of this boundary. A precise sampling (each of 5 cm) was done along a trench, allowing an immediate biostratigraphical analysis. Once the reference section with the Cretaceous-Tertiary boundary was delimited, a core of 1 m in thickness was sampled by means of a P.V.C. tube.

From this core, whole or residue samples were sent to different specialists to be studied for their different group fauna and flora contents (planktonic Foraminifera, benthonic Foraminifera, Ostracodes, Dinoflagellates, pollens, calcareous Nannoplankton), and for their isotopic geochemistry analyses. So, many results of these studies have been published.

At the 28th International Congress of Geology (Washington, 1989), the El Kef section (=Hammam Mellegue path section) was selected as an international reference section (stratotype) for the K-T boundary interval.

In 1988, Keller published the main results of the detailed analysis on Planktonic and Benthonic Foraminifera of the El Kef section.

In 1992, an International Workshop was organized by the Commission of the International Union of Geological Sciences, with the collaboration of the "Association Tunisienne des Etudes Internationales de Géologie" (A.T.E.I.G.), and the Tunisian Geological Survey.

In 1995 and later, many results on this section of biostratigraphical and geochemical analysis were published (Ben Abdelkader et al., 1995; Rocchia et al., 1995; Keller et al., 1995; Meon H., 1998; Donze et al., 1997; Smith and Nederbragt, 1997…).

This reference section is located 7 km to the west of El Kef town (Fig 5a). According to the topographical and geological maps, it is on the level of the geographical point X=

Volume n° 6 - from P55 to PW06

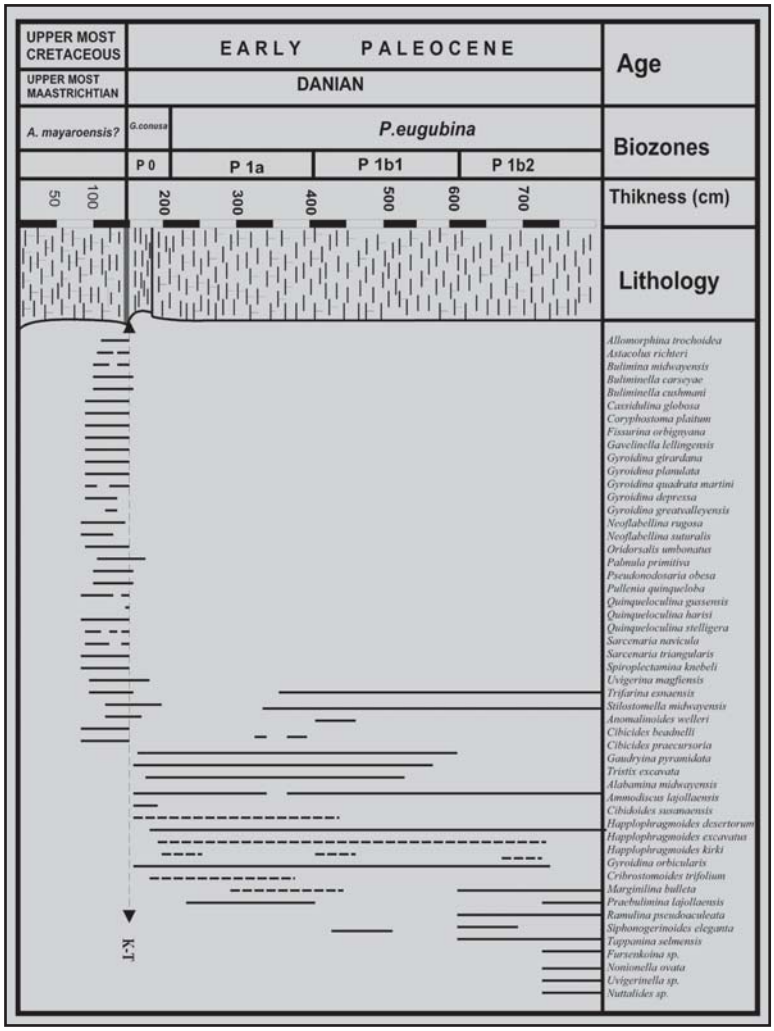


Figure 6 d - Benthonic Foraminifera species range in the K-T boundary interval at the El Kef s ection (Keller, 1988b)

7G 01'; Y= 40 G 17' of the Le Kef map n° 44, with 1/50.000 scale.

We reach this reference section by taking the exit towards Tajerouine town. A road sign shows a path leading to Hammam Mellegue, where there is a thermomineral resort. When we take the path, we can see at km 2 on the left, a topographical scarp made up of the Eocene limestone (the Metlaoui Formation). On the right we can see the

white limestone (upper calcareous member of the Abiod Formation), that is Upper Campanian-Lower Maastrichtian in age. Some faults broke and displace the limestone bars, such as at the level of the Fej El Hajar locality. On the left, a few hundred meters further on, we can observe a reservoir used to collect and keep the rainwater. Beyond this reservoir, and between the limestone bar of the Metlaoui Formation and those of the Abiod Formation, the Upper Maastrichtian-Paleocene series is well exposed, and preserves the transition interval deposits of the Cretaceous-Tertiary (K-T) boundary.

Exposure conditions of the Cretaceous-Tertiary (K-T) boundary

The uppermost Maastrichtian-lowermost Danian interval deposits are clayey. The overlain Danian clays contain a few interbeds of argillaceous limestone and these are clearly visible in the landscape of the middle part of the El Haria Formation.

According to their incoherence, this interval of uniform clayey deposits is often affected by rainwater and has suffered slumps. So, for sampling and to make observations easier, it is necessary to make trenches.

Cretaceous-Tertiary (K-T) transition section

In this trench, we can distinguish five levels (Figure 6 b-d; Figure 7 a-c):

- Level 1: a subnodular compact grey marl, rich in jarosites nodulars. It is rich in keeled Globotruncanids and costulate Heterohelicids that characterized the tropical realm of the Late Maastrichtian age. Among

Figure 7 a - Recent landscape in the El Haria Formation at the level of the El Kef section

Figure 7 b - A Trench done in the K-T boundary of El Kef section during the Workshop 1992

these planktonic foraminifera, the occurrence of the rare individuals of the *Abathomphalus mayaroensis* and *Plummerita hantkeninoides* species indicates the latest Maastrichtian age.

- Level 2: a thin layer (1 cm thick), composed of a rust-colored layer (1 to 2 mm thick), interbedded between two gypsum levels. The rust-coloured layer, rich in Iridium (3 ng/g; Robin et al., 1991 et 1992)*, contains microscopic crystals of Ni-Cr rich spinel, and iron oxides. This layer, totally devoid of fossil, indicates the K-T boundary .

- Level 3: a 8 cm dark gray clay, with rare fauna. There, we note the mass extinction of the tropical planktonic Foraminifera (keeled Globotruncanids and costulate Heterohelicids). The fauna is composed of inherited species from the Maastrichtian level: (1) tiny and well preserved tests, such as of the *Guembelitria* and *Rugoglobigerina* species, associated with small Eoglobigerinids, such as *Globoconusa conusa*, occur All the other dissolved Maastrichtian planktonic foraminifera (keeled Globotruncanids and costulate Heterohelicids), as well as those mineralized in iron oxide are surely reworked.

- Level 4: a 6 cm thick plastic dark clay. There, among the Cretaceous survivors, only few species of tiny *Globigerinelloides* (e.g. *G. aspera*, *G. voluta*), and Heterohelicids (*Guembelitria cretacea*, *G. danica*, *Heterohelix navaroensis*), are present.

- **Level 5:** Lamellar dark clay where the calcareous foraminifera are relatively more frequent and better preserved than in the levels below. Some tiny Heterohelicids reappear, with the first occurrence of

Figure 7 c - The K-T boundary in El Kef section (the knife points up the rust lauer)

Volume n° 6 - from P55 to PW06

diverse Eoglobigerinids species. Among this group, especially *Parvularugoglobi-gerina eugubina* appear at 60 cm from the K-T boundary.

ELLES SECTION

Historical Background and Geological Setting

Since 1903, Pervinquière indicated a Cretaceous-Tertiary continuous series in the Elles syncline. In 1978, Said, in her thesis, has described the Elles section and detailed the microfauna contents (planktonic and benthonic Foraminifera and Ostracoda). The author confirmed that in the Elles section, the Cretaceous-Tertiary is continuous, and

Figure 8 a - Elles section location on topographical Ebba Ksour (n° 52) and Maktar (n°52) portion maps

indicated that in the Cretaceous-Tertiary transition interval, the microfauna association changed. So, the Globotruncanids disappeared, and the Tertiary Globigerinids progressively substituted them.

At 1994, Karoui and Zaghbib-Turki pointed out, in the Elles section, the thin layer of the K-T boundary, devoid of fossil and rich in microscopic glassy spheres (Level 2 in Figure 6 b). In 1996, the authors confirm with the collaboration of Rocchia and Robin, that the rust-colored layer is rich in Iridium and in spinel Ni-Cr rich crystals. In 1998, a second International Workshop on Cretaceous-Tertiary Transition in Tunisia was organized. During this workshop with the El Kef section, two other complete K-T boundary interval sections were exhibited (the Elles section and the Ain Es Sattara section).

The main paleontological and biostratigraphical results on the Elles section, based on a precise sampling (each 2-5 cm) in the K-T boundary interval, are published by Zaghbib-Turki et al., 2000 and 2001; Karoui-Yaakoub et al., 2002; Keller et al., 2002. The authors conclude that the Elles section, a complete K-T interval occurs. This interval, similar to the El Kef section, is characterized by well-preserved and developed lowermost Danian zones and subzones.

From El Kef town, we reach the Elles section, by taking the GP 12 road, that leads to Makther town via Sers town (Figure 2, Figure 3 b). This road crosses, following its NW-SE axis, the Sers plain. The soil of this plain is used to cultivate cereals. The Sers plain constitutes a fault trough structure filled with Miocene-Pliocene-Quaternary continental deposits. This structure is on the border of folded structures. Towards the north, the Jebel Maiza anticline occurs, with wide Cretaceous outcrops joining on both sides the Henchir syncline and the Massouge syncline with Paleocene and Eocene outcrops. Joining the Lorbbeuss diapir structure, with Triassic material outcropping at the level of the northwest corner of the Sers fault trough, and towards the south there are extended Cretaceous outcrops. The Elles syncline juxtaposes the Sers fault trough at its southeastern corner. There, the Cretaceous-Tertiary interval deposits are continuous and well exposed.

The Elles section is located at about 56 km southeast of El Kef and near the hamlet of Elles. From El Kef town, we take the GP 12 road. After leaving the Sers village, located at about 35 km, we continues on the same road, crossing the wide Sers plain. At about 18 km before Makther town and to the right, a fork road leads to the Elles village. At about 3 km before reaching Elles village, and to the right at the level of a white house capola, we reach a next fork road. There, the white calcareous members and the intermediate marly-calcareous cycles of the Abiod Formation appear. The upper member of the Abiod Formation makes a topographical scarp, named Argoub El Aiacha. At the level of the El Aiacha locality, we leave the cars. Upwards to the south (on the left), the El Haria Formation outcrop appears. From there, and 2 km towards the south, the Cretaceous-Tertiary boundary section is reached on foot by crossing the wide exposure of Campanian-Lower Maastrichtian of the Upper member of the Abiod Formation. This formation is white chalky limestone, rich in

Inoceramus prints and Cancellophycus ichnofossils, with rare *Stegaster* and rich in planktonic foaraminifera (Globotruncanids, Heterohelicids). When we reach the valley of the Ain El Karma River, we move forward in the El Haria Formation that is clayey and Lower Maastrichtian p.p.-Paleocene in age. So, the El Haria Formation exposure is extended between two bars of chalky limestone, the Upper Cretaceous bar of Argoub El Aiacha and the Lower Eocene bar of Jebel Madhkour.

The K-T boundary interval of the Elles I section is located at about 300 m towards the south, from the Ain El Karma river valley (Figure 6 a). According to the topographical and geological maps, it is on the level of the geographical point X= 7G 49'; Y= 39 G 94' of the Makthar map n° 53, within 1/50.000 scale. In the same region, another section (Elles II), located at 100m toward the south from Elles I, is well described by Keller et al. (2002).

Exposure conditions of the Cretaceous-Tertiary (K-T) boundary

The uppermost Maastrichtian-lowermost Danian interval deposits is clayey, widely-extended and well exposed. There, many steep streams are drawn. The overlain Danian clays contain few argillaceous limestone interbeds, clearly visible in the landscape of the El Haria Formation middle part. According to their incoherence, this interval of uniform clayey deposits is often affected by rainwater. So, at the level of the streams the argillaceous material slumps. For sampling and making observations easier, it is necessary to make trenches.

Cretaceous-Tertiary (K-T) transition section

In this trench, we can distinguish five levels (Figure 8 b-d; Figure 9 a-c; Figure 10 a-b):

- Level 1: subnodular compact grey marl, rich in jarosite nodules. It is rich in keeled Globotruncanids and costulate Heter-ohelicids, that characterized the tropical realm of the Late Maastrichtian age.

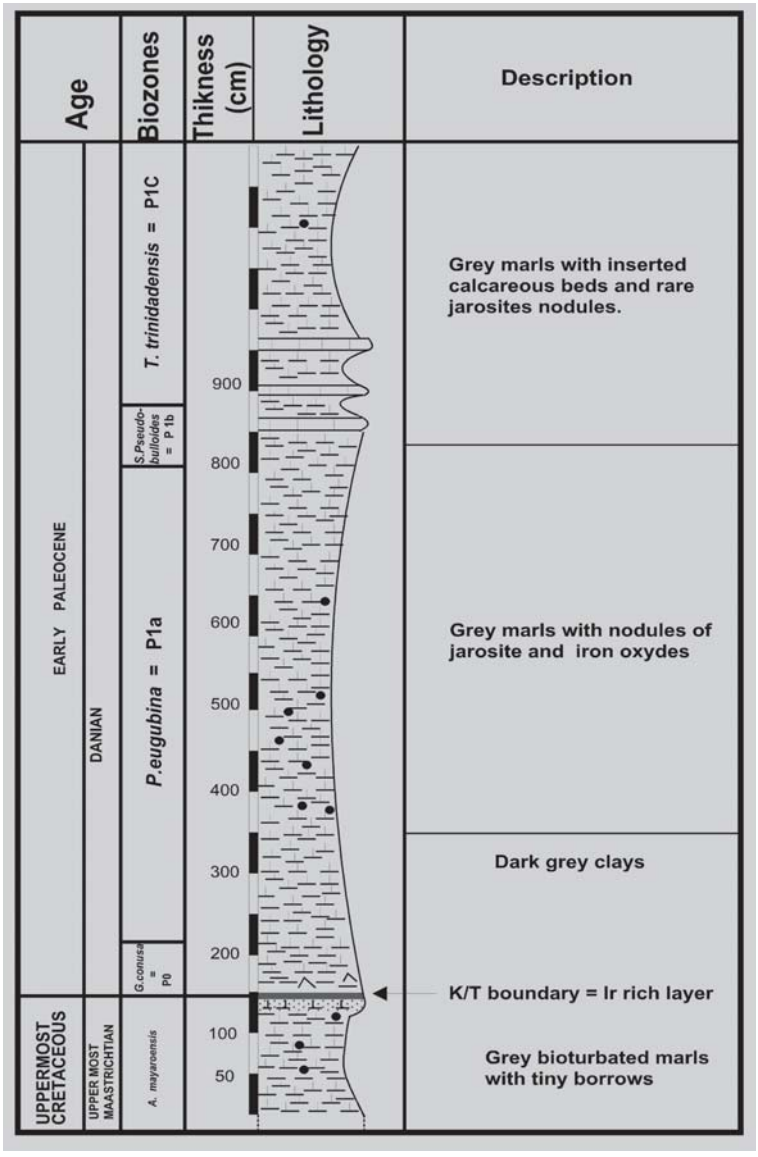


Figure 8 b - Lithological description of the Elles I section K-T boundary interval

Figure 9 a - Panoramic view of the Maastrichtian-Eocene interval in the Elles syncline (the arrow indicates the El Haria Formation)

Among these planktonic foraminifera, the occurrence of the rare individuals of *Abathomphalus mayaroensis* and *Plum-merita hantkeninoides* species indicates the latest Maastrichtian age.

- Level 2: a thin layer (1 cm thick) composed of a

Figure 9 b - Landscape in the El Haria Formation of Elles (the arrow indicates Elles I section)

rust-colored layer (1 to 2 mm thick), interbedded between two gypsum levels. The rust-colored layer is rich in Iridium (4.7 +/-0.2 ng/g; Robin et al, 1998; Zaghbib-Turki et al., 2000 et 2001; Karoui-Yaakoub et al., 2002)* and contains microscopic crystals of Ni-Cr rich spinel and iron oxides. This layer, totally devoid of fossil, indicates the K-T boundary.

- Level 3: a 8 cm dark grey clay with rare fauna. Among those inherited from the Maastrichtian level (1), only those characterized by tiny tests are well preserved, such as those of the Guembelitria and Rugoglobigerina species. All the other keeled Globotruncanids and costulate Heterohelicids are badly preserved and mineralized in iron oxide. Rare small tests of *Globoconusa conusa* and other small Eoglobigerinids are also well preserved. Tiny and well-preserved tests are considered as components of the autochthonous Earliest Danian association(Maast richtian survivor species and Danian species), while the ones dissolved and mineralized in iron oxide are surely reworked.

- Level 4: a 6 cm plastic dark clay. There, among the Cretaceous survivors, only few species of tiny Globigerinelloides (e.g. G. aspera, G. voluta). Heterohelicids (*Guembelitria cretacea*, *G. danica*, *Heterohelix navaroensis*), are present. They are associated with Eoglobigerinids.

- Level 5: Lamellar dark clay, where the calcareous foraminifera are relatively more frequent and better preserved than in the lower levels. Some tiny Heterohelicids reappear, with the first occurrence of diverse Eoglobigerinids species. Among the small species of this group, especially *Parvularugoglobigerina eugubina* appears at 65 cm below the K-T boundary.

Biostratigraphical data

Numerous biostratigraphical charts have been proposed, and discussions have concerned the Cretaceous-Tertiary transition interval. The main biostratigraphical charts proposed are summarized in the following table (Figure 11).

During our field trip, in all the studied sections, the distribution of planktonic Foraminifera leads to the distinguishing of the following biozones and subzones:

Figure 9 c - The K-T boundary interval in the Elles I section

Figure 10 a - El Haria Formation outcrop at the level of Elles II section (The arrow indicates the K-T boundary)

***Abathomphalus mayaroensis* zone:**
In Level 1 of the studied sections, the indicator species is present until the top. It is associated with Globutruncanids (e.g. *Rugoglobigerina reicheli*, *R. rugosa*, *Globotruncanella petaloidea*, *Plummerita hantkeninoides*, and *Globotruncana aegyptiaca*) and in Heterohelicids (e.g. *Pseudotextularia elegans*, *Racemiguembelina fructicosa*, *Guembelitria cretacea*, *Planoglobulina hariensis*, and Heterohelix spp.).

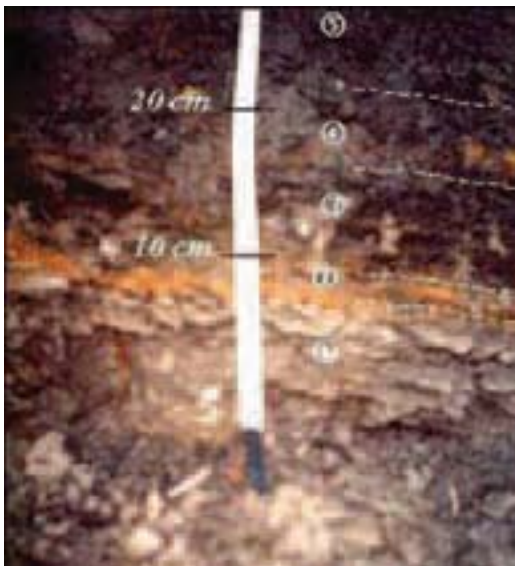
The K-T boundary
In level 2, the thin rust layer marks the K-T boundary. It is rich in Iridium (3 to 4.8ng/g)*, and in spinel crystals. The foraminifera, like the other types of fossil, are absent in this rust layer.

***Globoconusa conusa* zone (= *P0*)**
The deposits of the *Globoconusa conusa* biozone are varied in thickness (10 cm at El Maleh; 50 to 60 cm at El Kef; 66 cm at Elles). So, this zone is less thick in the El Maleh section than elsewhere. It usually stretches into both levels 3 and 4, and continues in the lower parts of level 5 lower parts.

- In level 3, the dark clay contains a rare fauna. There we note a mass extinction of the Cretaceous foraminifers. The survivor species are characterized by tiny and well-preserved tests. The other Danian species, such as *Globoconusa conusa* which appears at the base of this level, also have tiny and well-preserved tests. In addition, this level contains several Maastrichtian tests dissolved and mineralized in iron oxide that are reworked from level 1. So, tiny and well-preserved the Earliest Danian foraminifer tests are considered as the components of the autochthonous association (Maastrichtian survivor species and Danian pioneer species), while dissolved tests as well as tests mineralized in iron oxide are surely reworked.
- In level 4, among the Cretaceous survivors, *Guembelitria* (*G. cretacea and G. trifolia*) are the most frequent species. They are associated with Eoglobigerinids, which are more frequent than in the level below.
- In level 5, at the base, where the clays are enriched with carbonates, the foraminifers are still more frequent and diversified.

***Parvularugoglobigerina eugubina* subzone (= *P1a*)**
The first appearance (F.A.) of this total range (T.R.) subzone species occurs in the level 5.
Based on the > 63 µm size fraction, in the El Melah section, this F.A. is at 12 cm above the rust layer; but in the El Kef and Elles sections, it is at 50 to 66 cm. At El Maleh, the *P1a* subzone spans 140 cm. At El Kef, the *P1a* subzone is 4.5 m thick (Keller, 1995), and at Elles I, it is still thicker (5.6 m) (Zaghbib-Turki et al., 2000 a; Zaghbib-Turki et al., 2001; Karoui-Yaakoub et al., 2002; Keller et al., 2002).

Figure 10 b - The K-T boundary in the Elles II section



Volume n° 6 - from P55 to PW06

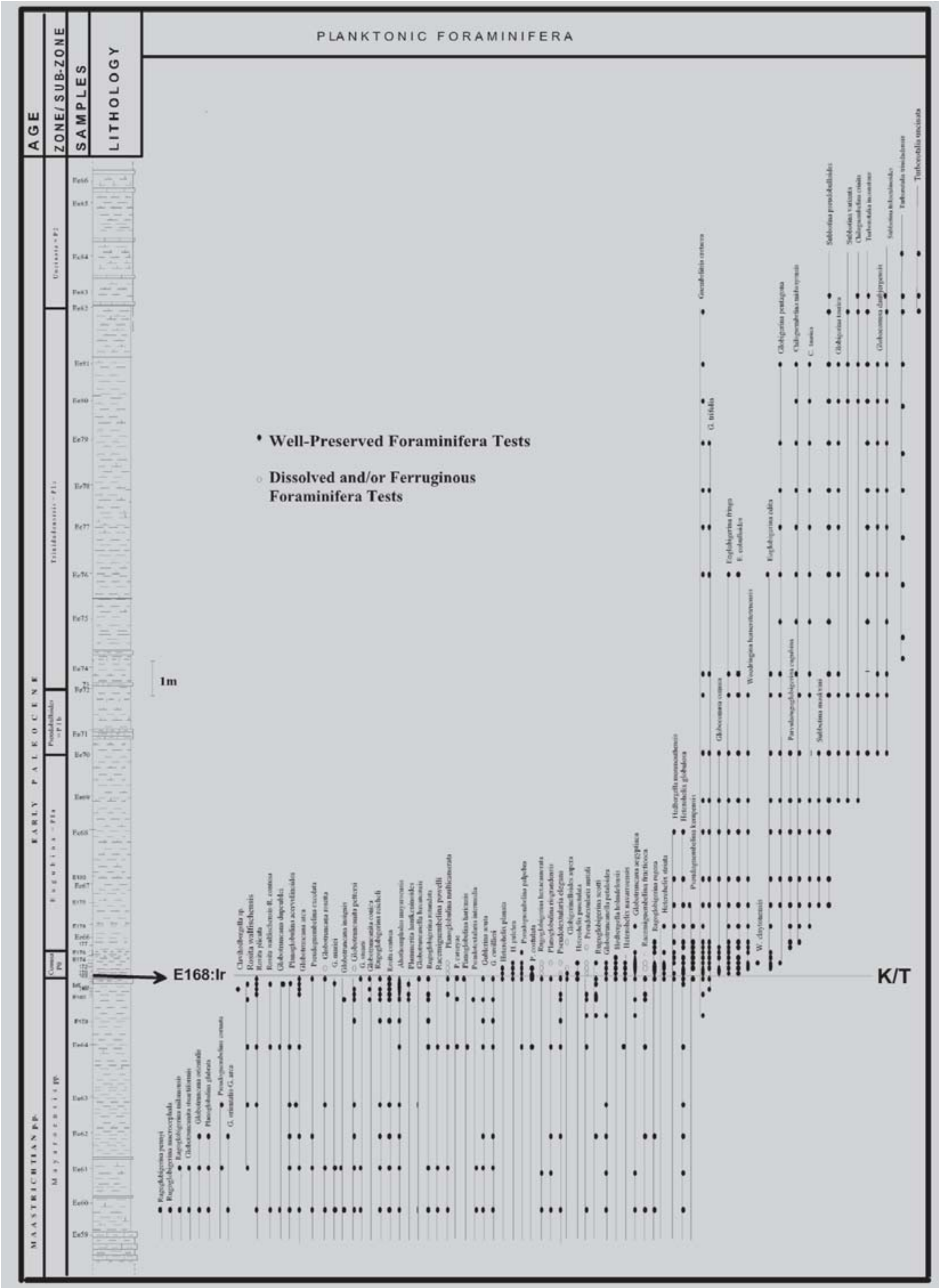


Figure 8 c - Planktonic Foraminifera species range in the K-T boundary interval of Elles I section (Zaghbib Turki et al. 2000, 2001)

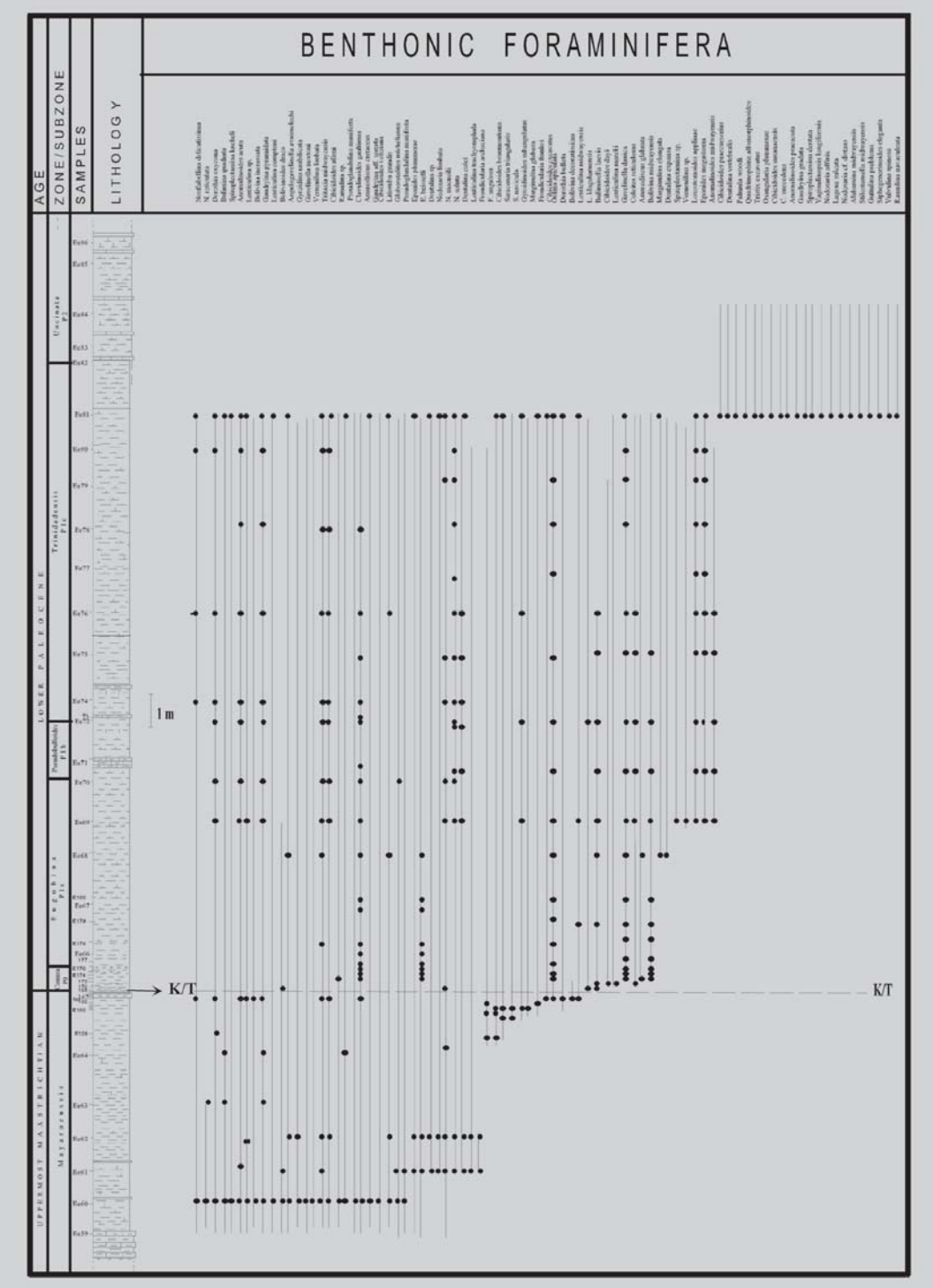


Figure 8 d - Benthonic Foraminifera species range in the K-T boundary interval of the Elles I section (Zaghbib-Turki et al. 2000 , 2001)

Volume n° 6 - from P55 to PW06

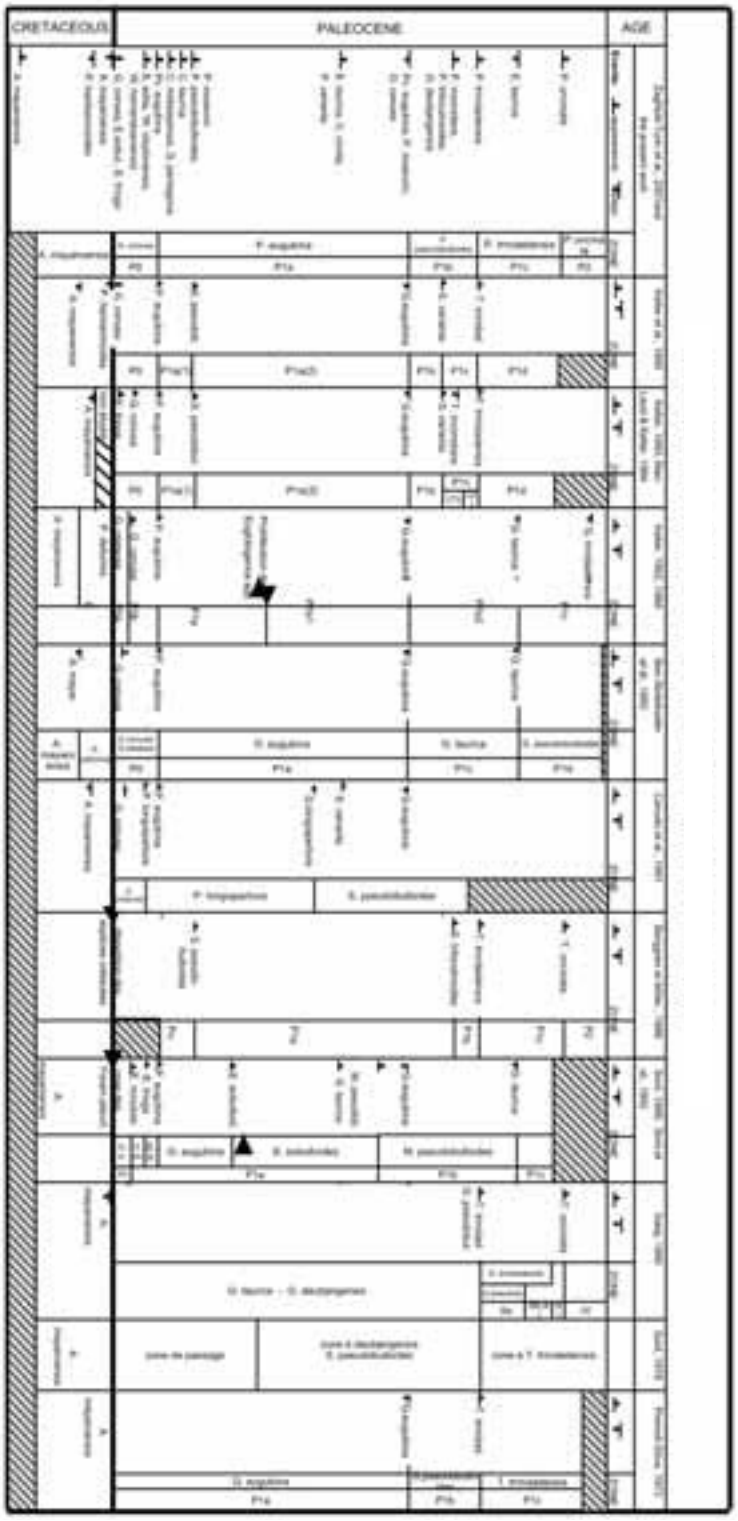


Figure 7 - Different proposal biostratigraphical charts of the Cretaceous-Tertiary transition interval

***Parasubbotina pseudobulloides/P. varianta* subzone (= *P1b*)**

This subzone spans from the last appearance (L.A.) of *Parvularugoglobigerina eugubina* that may be simultaneous with the first appearance of *Parasubbotina varianta*, and the first appearance of *Praemurica trinidadensis.* Along the interval deposits of this subzone, *Parasubbotina pseudobulloides* is the most abundant species. The other planktonic foraminifers are frequent and still more diversified.

Paleogeographical setting

The richness in the planktonic foraminifers species of the El Maleh section, compared to those of the El Kef and Elles sections (Karoui et al., 2002; Keller et al. 2002), informs us that the marine paleoenvironment was not homogenous during the Maastrichtian-Danian transition in the northern Tunisia. It was deeper at the El Maleh section than in the El Kef and Elles sections. At the level of the El Maleh section the slope/bathyal domain of Tunisian Trough was located and was included in the southern Tethyan Sea . At the level of the other sections, the Tunisian Trough became shallower at the border of the continental shelf, before reaching the emerged land known as Kasserine Island (Figure 12).

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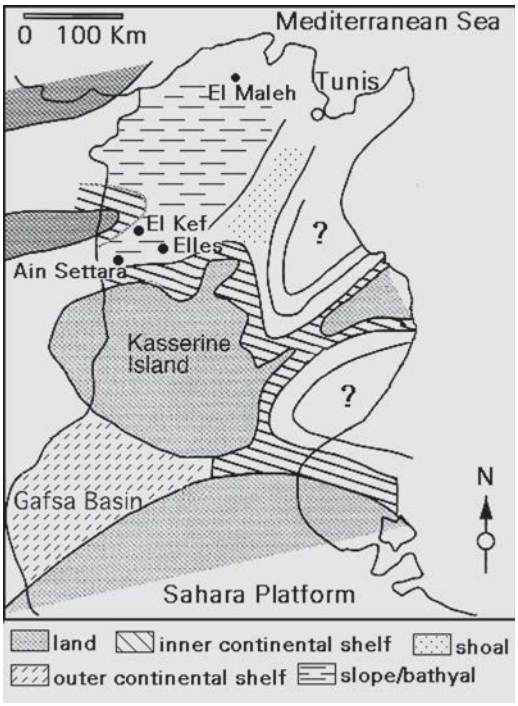

Figure 12 - Paleogeography of Tunisia during the Late Maastrichtian and Early Tertiary with paleolocations of the K-T sections

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Annex

Historical and Tourist Additional Information

Ichkeul park

According to its particular ecosystem, Ichkeul Park is an interest ecological site. It is inventoried on the international lists of Biosphere Reserves (UNESCO), Cultural and Natural Heritage in the World (UNESCO) and of RAMSAR Convention (on the coastal wet zones).

At 75 km from Tunis toward the north, Ichkeul Park is characterised by its superb landscape. It is composed of a mountain overhanging a lake bordered of swamps.

Jebel Ichkeul Mountain, with its Triassic and Jurassic sedimentary cover, is 511 m high. Its vegetation is mainly composed of olive trees.

Ichkeul lake

Ichkeuk lake is 8 500 ha wide and about 2 m deep during the winter. It is highly controlod by the regional hydrological system. It is linked to the sea by the Tinja river via Bizerte Lake. During the rainy seasons, Ichkeul Lake receives simultaneously the fresh waters of six rivers (Oued Tinja, Oued Sejnane, Oued Maleh, Oued Ghézala, Oued Joumine and Oued Tine). So, during the winter the lake is characterised by a low salinity. However, during the dry seasons (at summer) this salinity increases up to 70 g/l.

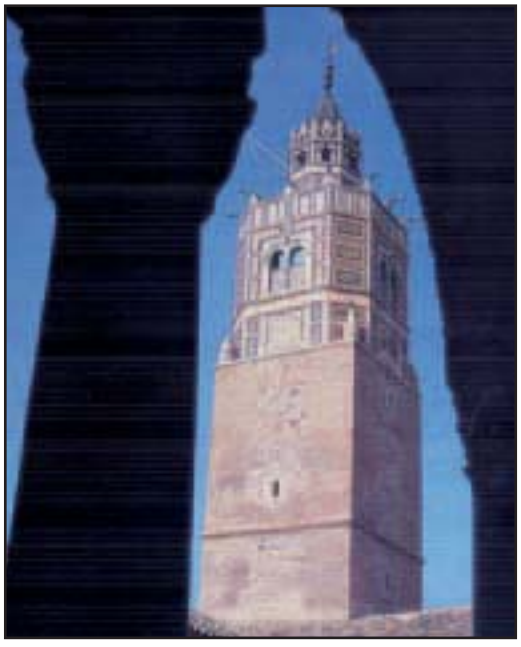
The bottom of the lake is cover of a dense vegetation of Potamogeton. This vegetation is the main food source for many thousands of migratory birds (100 000 to 200 000 birds/year of various species) coming from the occidental Arctic lands.

The swamps bordering the lake, entirely flooded at the winter, can reach an emerged space of 2737 ha. Tere, sedentary birds to put down and to build their nests use the vegetation composed of reeds irregular ring. Besides, the swamps constitute a privileged environment for buffalos.

Ichkeul ecosystem.

Testour

Testour, is an Andalousian town is built at the end of the XVth century, on the ancient Tichilla Roman site. It is characterised by its wide streets, tilled roofs and its eccentric mixed minaret with a church like base and an Arabic shaped top. There are settled the first



Minaret of the great Mosque Testour

Spanish Chechia (red caps) makers. There is also developed the typical Andalusia music named Malouf.

El Kef and its neighberhood

El Kef town is characterized by its high altitude (700-850m). It is built on the southern flank of the Dir el Kef Syncline. To the south, it overhangs bare hills, whereas to the North there are forests of pine and oak. It's not a tourist city in spite of its numerous archaeological sites (e.g. thermae, reservoirs). The oldest city was controlled by Carthage. The antique Sicca Veneria received, after the first Punic wars the mercenaries of Sicilia whom Carthagenians feared.

The gathering of thousands of soldiers (230-237 B.C.)

caused a rebellion known as the "War Mecenaries". A colony under Augustin Sicca was very prosperous during the II and the III centuries and ruined by wars against the Arabic people. During the French protectorate, the modern town was built at the foot of the southern side of the walls. The ruins of the Hugue thermae is located nearby the Hotel de la Source (a Roman spring) that was modified into achurch. Dar El Kous ruins show a Roman basilica dedicated to Saint Peter.

From the corner of the Hotel de la Source, an alley leads to the fortress of Sidi Bou Makhlouf mosque next to the synagogue (closed now). Upward we can see Ali Turki (father of Husain Ben Ali, the founder of the Husainid monarchy) mausoleum (end of XVII century). We can visit Sidi Ben Aissa Zaouia (1784) modified into a regional museum of popular arts and traditions. There some Roman columns are around the place. Farther we can see the octagonal minaret and the two white cupola of Sidi Makhlouf mosque. To reach Belvedere Park, the President Palace and the ancient Kadria Zaouia (1834) we must take the road of Tunis as far as the fork.

Dougga ruins

The archaeological site of Thugga, in the suburbs of the new Dougga village, conjures up successively Libyco Punic and Roman everyday life.

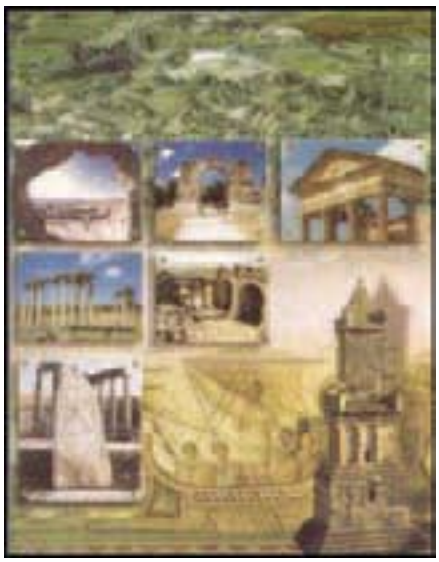
This site is particularly attractive by its diversity and panoramic location. It overhangs all the khaled wadi plain, where dominate immense fields of olive and corn.

The Libyco-Punic civilisation is marked by some reminiscences, such as the high defensive wall and the mausoleum dedicated to a Numid prince at the end of the III century B.C.

After the Carthage collapse (146 B.C), Thugga followed Massinissa kingdom that, perhaps, built his residence and a temple, which completely disappe-

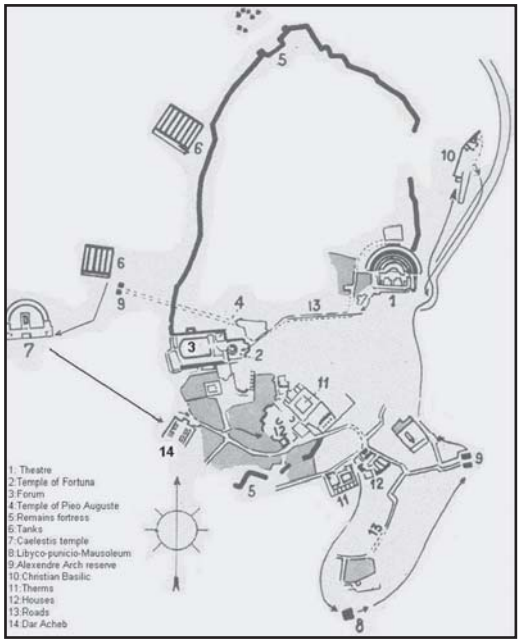
ared. The city had kept its Berber connection during two centuries, while the Roman suburb was extended and participated in the African prosperity during the II and III centuries until its annexation to the province of Africa by Caesar in 46 B.C. Thugga, rapidly became an administrative centre under the reign of Septine, then the colony at 261 A.D. and its prosperity declined progressively.

Along our visit we contemplate the immense Theatre built during 166-169 A. D. This edifice with 15 m high steps was used to receive 3500 people. An excavation house (on the left of the theatre) leads by a Roman way to a large place named Wind Rose having 8 m graven motif. Its three steps lead to Au-



Tourist interest in Dougga (Mosaic, temple, fortress….)

Volume n° 6 - from P55 to PW06



The plan of Dougga ruins

gust Temple (III century A.D.). Toward the North, the Auguste Temple made of three rooms (one of which is paved with green stone schist). Ten columns precede it. Next to it, on the Fortune Temple there is a mosque. The Mercury temple succeeds ten columns. Toward the south (at the feet of the mosque) a paved walk had crossed the market, which was destroyed while the Byzantine fortress was built). Downward, there is Licinian thermae (built in III century and modified in IV century A.D.). It is characterised by its rooms having asymmetrical repartition around the frigidarium and the caldarium and decorated with mosaic. These large rooms were used to various activities (gymnastic with different behaviour: hot, warm and cold; massage,). Beside the market place, the Capitol edifice shows the most beautiful Roman monument in North Africa. It was dedicated to Jupiter, Junon and Minerve. Its six columns are well preserved and its bas-relief represents a man carried away by an eagle. The head of the Jupiter statue, which is 6.5 m high, was found in a crypt. A few steps lead to the Forum (40 m long; 24 m wide). Alexander Severe arch (225-235) is seen westward. Minerve temple (138-46 A.D.)is not far. Some reservoirs such as those of Ain El Hammam collect the water from the spring that is 12 km far. A path connects the reservoirs of Ain El Hammam to the Temple of Junon and Caelestis (222-235). On the west corner of the Forum, a pth passes under the Capitol and in front of the rectangular framing of Dar el Achab (164-166 A.D.). The motif of the entry of thr pavement shows the circus of Thugga. Then, the temple of Tellus has two small rooms. Its sanctuary is decorated with three nooks and connected to the therms by a dark tunnel. Many houses with mosaic are named (e.g. Ommia, Tibi, Felicia). A second Theatre was needed for initiations and Myries celebration. Next to it, there are the Thermes of Cyclopes with latrines made of horseshoe shaped stone where twelve holes are drilled with gutter under the seats. The Trifolium House is next to Cyclope Thermes. Lower down, we reach the Libyco-Punic Mausoleum built in III century B.C. This monument (built for Ateban, Ieptamah and Palou: architect and master-builders) is 21 m high and have many floors with decorated corner and statues. Backward the mausoleum, by the Roman curved way joining Carthage to Theveste (Tebessa), we reach Saturne Severe Arch (205 A.D.) and Saturn Temple (195 A.D.)., from which we can admire the valley of Khaled wadi.

Dougga neighbors archaeological sites

After Dougga ruins (108 km from Tunis) we must regain the GP5 road, along what there are other ancient monuments. Then, the ruins of the Byzantine fortress is at 114 Km. At 124 Km, a few metres from the road, a triumphal arch shows the entry of the ancient Musti, founded by Caius Marius after his victory in the war against Jugutha (II century B.C.). These ruins preserve some shops and the temple of Ceres, Pluton and Appolon. There are also the remains of an olive-oil press. The XVIth century Byzantine fortress was built with the ancient monument stones.

El Krib, a village located 1 km from Musti, is prosperous viewing its fertile soil. The Byzantine ruins of Aunobari are on the side road. Borj Messauod, next to Sidi Moussa marabout, is located on the site of the antique Thacia (Marcus Cornelius Rufus mausoleum).

Back Cover:
field trip itinerary

32nd INTERNATIONAL GEOLOGICAL CONGRESS

FIELD TRIP MAP

Edited by APAT