Chapter 7
The Cretaceous-Tertiary Plateaus

S. Zouhri, A. Kchikach, O. Saddiqi, F.Z. El Haïmer, L. Baidder and A. Michard

7.1 General

References: The tectonic considerations hereafter are summarized after the synopsis of the Phanerozoic evolution of northern and central Africa by Guiraud et al. (2005). The role of the Trans-Saharan Seaway in the Late Cretaceous faunal exchanges has been also addressed recently by Courville (2007).

Morocco displays two sets of Cretaceous-Tertiary plateaus with unequal extension (Fig. 7.1). A first, western group includes the Oulad Abdoun Plateau, also referred to as the Plateau des Phosphates, the Ganntour Plateau and the Meskala Plateau north of the Atlas Mountains, and finally the coastal Laayoune-Bou Craa Plateau south of the Atlas. All these plateaus overlie a Variscan basement, and appear in close connection with the Atlantic Coastal Basins described in Chap. 6.

S. Zouhri
Hassan II University, Faculté des Sciences Aïn Chock, Lab. of Géosciences,
BP 5366 Maârif, Casablanca, Maroc, e-mail: s.zouhri@fsac.ac.ma

A. Kchikach
University of Marrakech, Faculté des Sciences et techniques Cadi Ayyad,
Lab. "Géoressources", BP. 549, Marrakech, Morocco, e-mail: kchikach@fstg-marrakech.ac.ma

O. Saddiqi
Université Hassan II, Faculté des Sciences Aïn Chock, Lab. of Géosciences, BP 5366 Maârif, Casablanca, Maroc, e-mail: o.saddiqi@fsac.ac.ma

F.Z. El Haïmer
Hassan II University, Faculté des Sciences Aïn Chock, Lab. of Géosciences, BP 5366 Maârif, Casablanca, Morocco, e-mail: fzelhaimer@yahoo.fr

L. Baidder
Hassan II University, Faculté des Sciences Aïn Chock, Lab. of Géosciences, BP 5366 Maârif, Casablanca, Morocco, e-mail: lbaidder@gmail.com

A. Michard
Emeritus Pr., Université de Paris-Sud (Orsay) and Ecole Normale Supérieure (Paris), 10 rue des Jeûneurs, 75002 Paris, e-mail: andremichard@orange.fr

A. Michard et al., *Continental Evolution: The Geology of Morocco*. Lecture Notes in Earth Sciences 116,

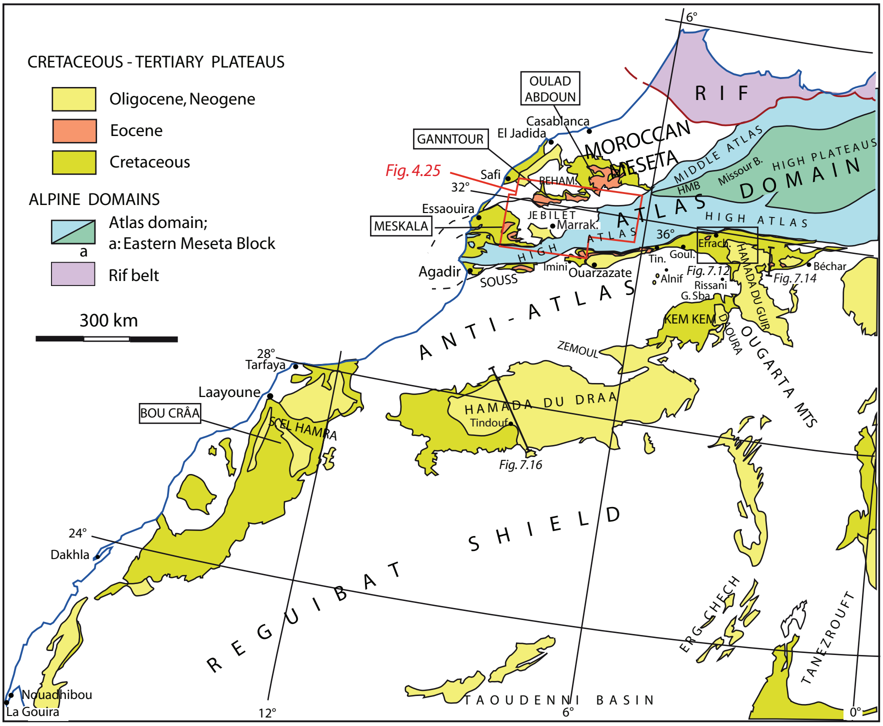

Fig. 7.1 Schematic geological map of the Cretaceous-Tertiary plateau area, after the Geological map of Morocco, 1:1, 000,000 (Geological Survey of Morocco, 1985). Errach.: Errachidia; G. Sba: Gara Sba; Goul.: Goulmima; Marrak.: Marrakech; Tin.: Tineghir

A second and eastern group corresponds to the so-called "hamadas", which extend essentially over the Sahara cratonic domain from the Guir Hamada and associated plateaus (Meski, Boudenib) to the east, to the Kem-Kem plateau, and eventually to the Draa Hamada to the southwest. The small plateaus on the northern slope of the Anti-Atlas (Imini, Goulmima) also belong to the hamada paleogeographic domain.

Both these plateau groups escaped the main effects of the Triassic rifting and those of the Alpine shortening. Their sedimentary sequence spans essentially from the late Early Cretaceous to the Neogene. Thus, neither the High Plateaus nor the Missour and High Moulouya basins of Eastern Meseta nor the Middle Atlas "Causses", whose more or less detached stratigraphic sequences include Triassic evaporites and thick Lower-Middle Jurassic limestones, are considered in this chapter. They belong to the Atlas realm, within which they simply form extended rigid blocks (see Chap. 4). Admittedly, this classification is partly conventional as the Moroccan (Western) Meseta also suffered significant Neogene faulting (e.g. North Jebilet Fault) and uplift (see Sect. 7.4).

During Cretaceous-Cenozoic times, sedimentation above the Meseta Block and the Sahara cratonic realm has been controlled by two mechanisms, i.e. faulting and active rifting episodes of the African plate linked to the Gondwana break up, and eustatic high stands related to strong warming of the global climate. By the beginning of the Early Cretaceous, a large, N-S trending Trans-Saharan Fault Zone (TSFZ) developed on the Algeria-Niger confines, in relation with the opening of the South Atlantic Ocean (Fig. 7.2A). The Saharan regions of Morocco were part of the West African Block. At that time, the marine transgression was limited to a wide gulf in the southern Algerian-Tunisian regions. In contrast, a large continental deltaic system prevailed south and west of this marine embayment, which nourished the deposition of turbidites on the North African margin (see Chap. 5).

Then, by late Barremian-early Aptian times (Figs. 7.2B, 7.3A), an active rifting episode linked to the opening of the Equatorial Atlantic Ocean reactivated large faults SE of the Hoggar massif and in the Benoue Trough. The continental fracturation, and the subsequent thermal relaxation controlled the outline of the transgression upon the Meseta, and especially above the Sahara domain during the Cenomanian-Turonian high stand. At that time, the Equatorial Atlantic Ocean and the western Tethys were connected by a Trans-Saharan Seaway situated east of the Hoggar massif (Fig. 7.3B). Shortly later, during the Late Cretaceous (late Santonian), a first compression episode linked to the onset of the Africa-Eurasia convergence was recorded within the intraplate realm itself. As a result, the Saharan seas developed a new outline during the Campanian-Maastrichtian high stand: the Hoggar massif was now bypassed along its western side, i.e. the eastern Taoudenni

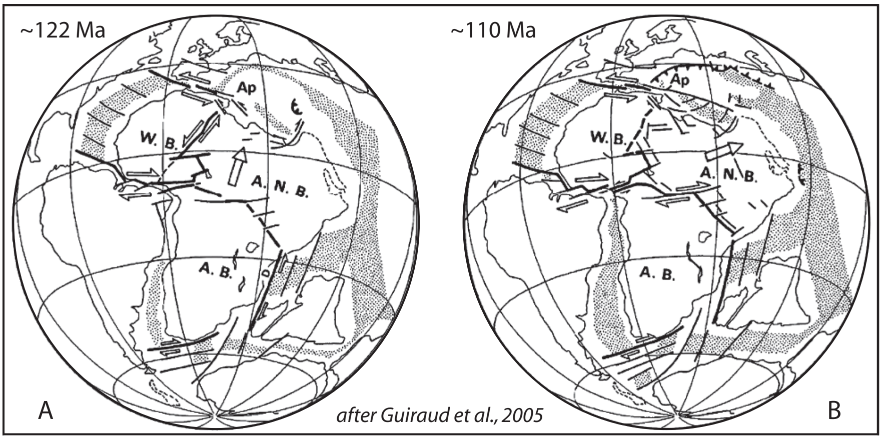

Fig. 7.2 Fracturation of the African plate during the Cretaceous Gondwana break-up, after Guiraud et al. (2005), modified. – **A**: Late Barremian (122 Ma). – **B**: Early Albian (110 Ma). Dotted: oceanic crust. AB/ANB/WB: Austral/Arabo-Nubian/Western Block. Ap: Apulia, bounded to the north by subduction planes (teeth)

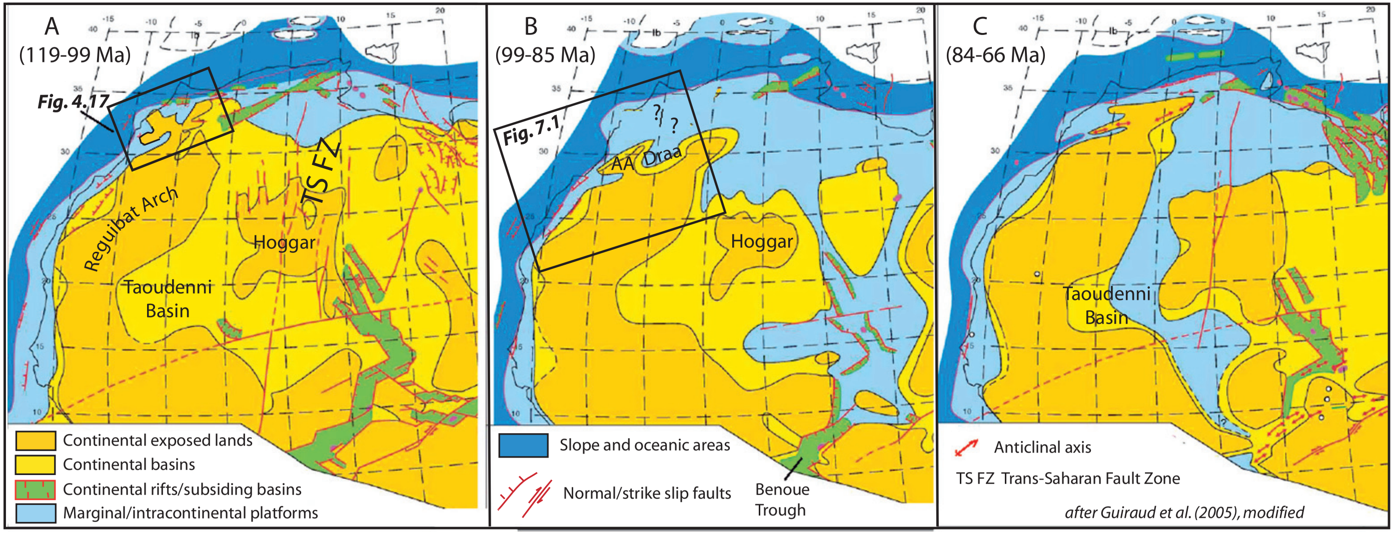

Fig. 7.3 Cretaceous paleogeography of NW Africa, after Guiraud et al. (2005), modified. – **A**: Aptian-Albian (119–99 Ma). Detail paleogeography of Morocco modified after Chap. 4, Fig. 4.17. – **B**: Cenomanian-Early Senonian (99–85 Ma), modified (the Atlas domain is regarded as entirely flooded). – **C**: Late Senonian-Mastrichtian (84–66 Ma). TSFZ: Trans-Saharan Fault Zone

Basin (Fig. 7.3C). During the latest Cretaceous, the sea progressively left the inland areas, whereas the Atlantic plateaus remained in shallow marine conditions up to the Middle Eocene (cf. Fig. 4.19).

7.2 The Atlantic Plateaus and Their Phosphate Deposits

References: The classical stratigraphic literature on the "Plateau des Phosphates" is referenced in Michard (1976). Among the more recent titles, the most important is certainly the third volume of the *Géologie des Gîtes minéraux* marocains (2d ed., 1986), entitled *Phosphates* and essentially prepared by H.M. Salvan, A. Boujo, and M. Azmany-Farkhany. Other salient works relative to the paleogeography, petrology and exploitation of the phosphorite are those by Einsele et al. (1982), Prévôt (1990), Trappe (1992), Moutaouakil & Giresse (1993), Gharbi (1998), Kchikach et al. (2002, 2006). References concerning the Vertebrate paleontology are included in the corresponding Sect. 7.2.4. The history of the phosphorite discovery is evoked in Chap. 9.

7.2.1 Stratigraphy

The stratigraphic sequence of the Atlantic Plateaus changes from west to east and from south to north. The well-developed Triassic deposits of the Doukkala Basin are preserved locally on the western and central Jebilet Massif (cf. Fig. 4.25). They are also known in borehole from the Bahira Basin. In contrast, the sedimentary cover of the Rehamna massif begins with Upper Jurassic-Lower Cretaceous red beds including locally a thin intercalation of Lower Cretaceous (Valanginian) marine limestone (Figs. 7.4, 7.5). These red and pink beds are followed upward by shallow marine, marly limestones dated as Cenomanian-Turonian. The Turonian limestones (e.g. Settat plateau) in turn are followed upward by regressive Senonian (Coniacian-Campanian) gypsum-bearing marls. This 100–400 m thick platform sequence constitutes the substratum of the Oulad Abdoun plateau northeast and east of the Rehamna massif, and south of the Central Massif (cf. Landsat image Fig. 3.17). They also form the northeastern Laayoune – Seguiet-el-Hamra Plateau in the Southern Provinces, on top of the Smara – Zemmour Paleozoic series west of the Reguibat Arch (cf. Landsat image Fig. 1.12). In the latter case, the thin Cenomanian-Turonian marls of the inner shelf quickly change westward into the thick black shale accumulations of the Tarfaya-El Aioun (Laayoune) Basin (see Chap. 6, Fig. 6.15).

The Early Cretaceous-Senonian sequence, about 150–200 m thick, forms the base of the thinner, but much more interesting phosphorite-bearing sequence ("Série phosphatée"). The thickness and facies of the latter sequence changes laterally from the western to eastern parts of the former Atlantic gulf (cf. Fig. 4.19). The

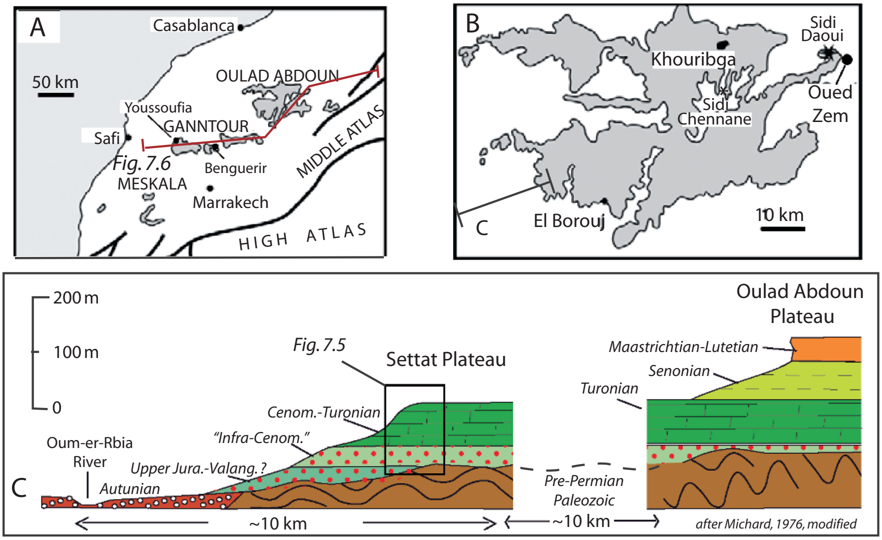

Fig. 7.4 Extension of the Phosphate Series in Western Meseta (**A**), main exploitation centers (**A, B**), and schematic cross-section of the Settat-Oulad Abdoun Plateau (**C**). – **A, B**: from Pereda Suberbiola et al. (2004), modified. – **C**: from Michard (1976), modified. Valanginian marine intercalations have been mapped both to the northwest and southeast of the Rehamna Massif (Gigout, 1954; Bolelli et al., 1959). Triassic red silts and basalts only occur in the Doukkala Basin, west of the Rehamna Massif

2D restoration of these stratigraphic variations has been obtained for the Western Meseta Atlantic embayment where the main phosphate sedimentation occurred (Fig. 7.6). The western deposits are thicker, and include black shales which progressively disappear eastward. The Maastrichtian deposits which transgress upon the lower Senonian deposits are thin and phosphate-rich in the northern Oulad Abdoun and, in contrast, become thick and marly-phosphatic southward. The

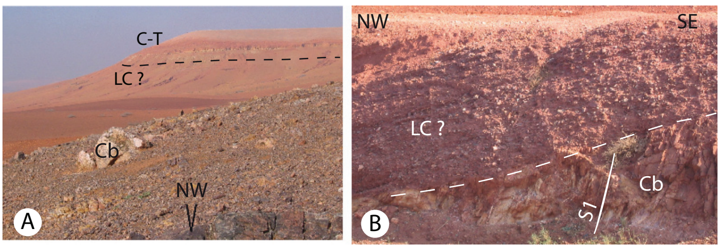

Fig. 7.5 Transgression of the Mesozoic sequence on the Variscan basement at the southwest border of the Settat Plateau, north of Mechra-ben-Abbou, Oum-er-Rbia Valley (see Fig. 7.4C, left). – **A**: Panorama. The escarpment of the Turonian plateau in the background is about 10 m high. – **B**: Detail of the basal unconformity in the 2 m-high roadcut. Cb: Folded Middle Cambrian metagreywackes (S_1: slaty cleavage); LC?: Lower Cretaceous continental/shallow marine deposits, only dated west of the Rehamna massif (Valanginian limestone intercalation); C-T: Cenomanian-Turonian marls and limestones

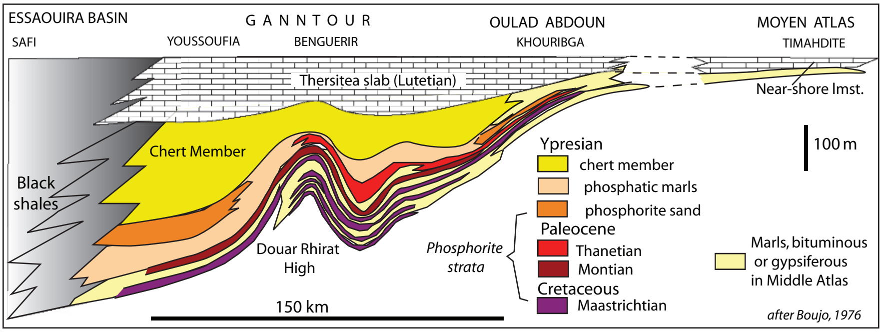

Fig. 7.6 Succession and lateral variation of the sedimentary facies of the Phosphate Series in Western Meseta, after Boujo (1976), modified. For location, see Fig. 7.4A

Montian-Thanetian beds are more uniform, consisting of unconsolidated phosphorites, but again conspicuous lateral changes occur in the Ypresian beds, where phophorite concentrations are the most important. The thick, late Ypresian cherty beds of the Ganntour Basin change north-eastward into marly phosphorite beds. The Lutetian dolomitic limestone slab ("Dalle à Thersitées") which caps the phosphate beds becomes progressively thinner eastward, being overlain by marls, gypsum and continental conglomerates (Late Eocene-Oligocene) in the Middle Atlas (Timahdite syncline; cf Chap. 4, Fig. 4.11).

The typical phosphorite sequence of the Oulad Abdoun Basin (Fig. 7.7) barely exceeds 40 m, including its Lutetian cap. The sequence begins with Maastrichtian calcareous bone-beds, followed upward by phosphatic marls (miners' "Couche III"), whereas the top of this stage consists of marly limestones and marls. The Montian (Danian) shows its usual facies of uncemented, sandy phosphorites ("Couche IIa, IIb") overlain by phosphatic limestones. The Thanetian-lowermost Ypresian consists of phosphatic limestones with nodular flints and coprolites, which gives a useful guide horizon ("Intercalaire couches I/II"). The sequence continues upward in the Ypresian with alternating beds of marly and phosphatic limestones, coarse sandy phosphorites ("Couches I, 0, A, B") with chert horizons and scarce silt or pelite layers (Gharbi, 1998).

7.2.2 Petrology and Formation of the Phosphorite Deposits

In view of both their sedimentary originality and economic importance, the sandy phosphorite deposits of the Meseta plateaus deserve some petrological comments. These very peculiar sands consist of various types of phosphate grain, coated or not (Prévôt, 1990; El Moutaouakil & Giresse, 1993). The inner part of the coated grains most often consists of phosphatic muds with laminar or concentric stromatolitic laminations, which preserve cyanobacterian nannostructures. Foraminifera, diatoms and/or radiolarians totally transformed into apatite are also

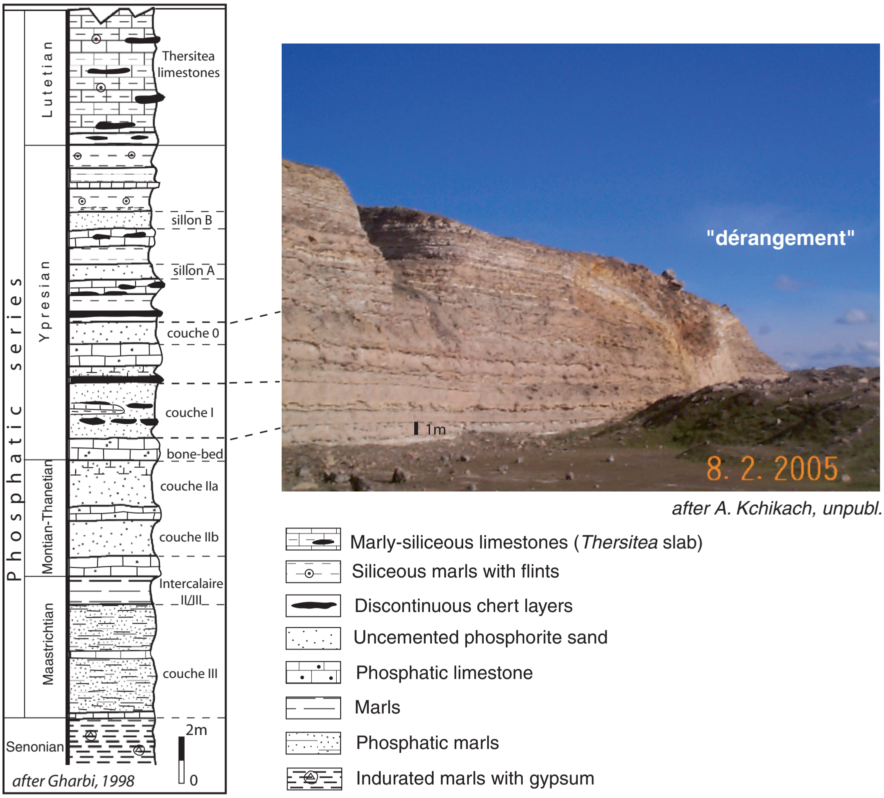

Fig. 7.7 The condensed phosphate series of the Oulad Abdoun Plateau at Sidi Daoui, after Gharbi (1998) and OCP documents. *Right*: view of the front of an exploitation showing a conspicuous "dérangement" (collapse) in the background. Photo A. Kchikach

frequent, as well as bone fragments. The coating consists of isotropic apatite. Other grains are lithoclasts of phosphatic muds with pellets, quartz grains and organic material cemented by cryptocrystalline apatite. The phosphorite sand often includes abundant coprolites transformed into apatite, as well as Vertebrate teeth and bones.

Apatite constitutes 50–98% of the sediments, with a low CO_2 content. The origin of this extraordinary concentration of phosphate was controlled both by paleogeographic and eustatic phenomenon (El Moutaouakil & Giresse, 1993, with references therein). According to the latter authors, who particularly studied the Ganntour-Oulad Abdoun deposits, phosphorite genesis occurred in a shallow water gulf whose communication with the ocean was progressively reduced from the Maastrichtian to the Lutetian. The occurrence of dolomite, attapulgite and traces of halite indicate an obvious restriction of the communications toward the open ocean. Strong upwelling currents favoured an important biogenic fixation of phosphorus by the phyto- and zooplankton. Intertidal stromatolitic mats, especially extensive during the marine low stands, participated in this process. Mineralization of phosphorus resulted in the formation of phosphatic muds, which were fragmented and reworked as tiny chips by the tempests during high stand periods, and transported toward accumulation areas by tidal currents. As many as eight eustatic cycles have been identified based on minor transgressive-regressive sequences.

7.2.3 Mining

Morocco phosphorite deposits represent about three quarters of the phosphate reserves of the world. The largest deposits exist in the Oulad Abdoun Basin (Khouribga center), with 44% of the Moroccan reserves compared to the Ganntour Basin (Youssoufia, Bengerir, 36%), the Meskala Basin (Chichaoua, 19%), and Bou Craa (1%).

The Oulad Abdoun Basin offers the easiest conditions for open air mining (Fig. 7.8). Locally, the tabular layering suffers perturbations by roughly conical structures filled with coarse breccias, the so-called “dérangements” (Figs. 7.7, 7.8). These sterile bodies are formed by accumulations of silicified limestones, or by blocks of limestones within an argillaceous matrix. They formed through the collapse of the phosphate series above karstic caves opened by dissolution of the gypsum and/or limestones formations in the Upper Cretaceous substratum. As these collapses seriously disturb the exploitation, several exploration works by wells and boreholes attempted to localize them beneath the Quaternary cover. However, mapping by Time-Domain Electro-Magnetic method offers promising results (Fig. 7.9), and would permit (especially when combined with other methods) the definition of these structures before the mining front reaches them.

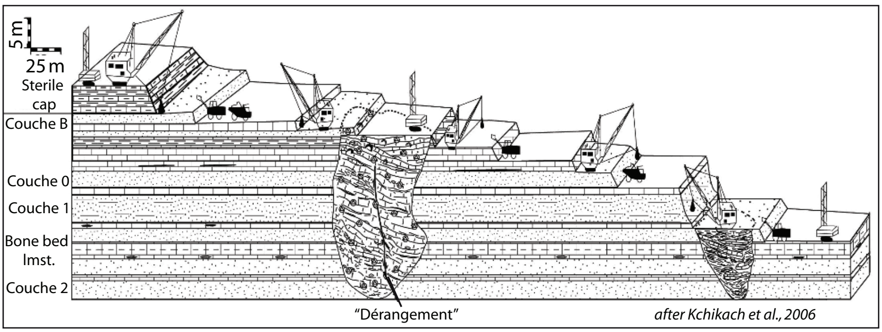

Fig. 7.8 Chain of exploitation of the Oulad Abdoun phosphorites (Sidi Chennane area), after Kchikach et al. (2006). The chain begins with the removal of the sterile cap (*left*) up to the “sillon B”, and then the phosphorite layers (“sillons”, “couches”) are mined step by step. The “dérangements” (karstic collapses) hampers the mining process

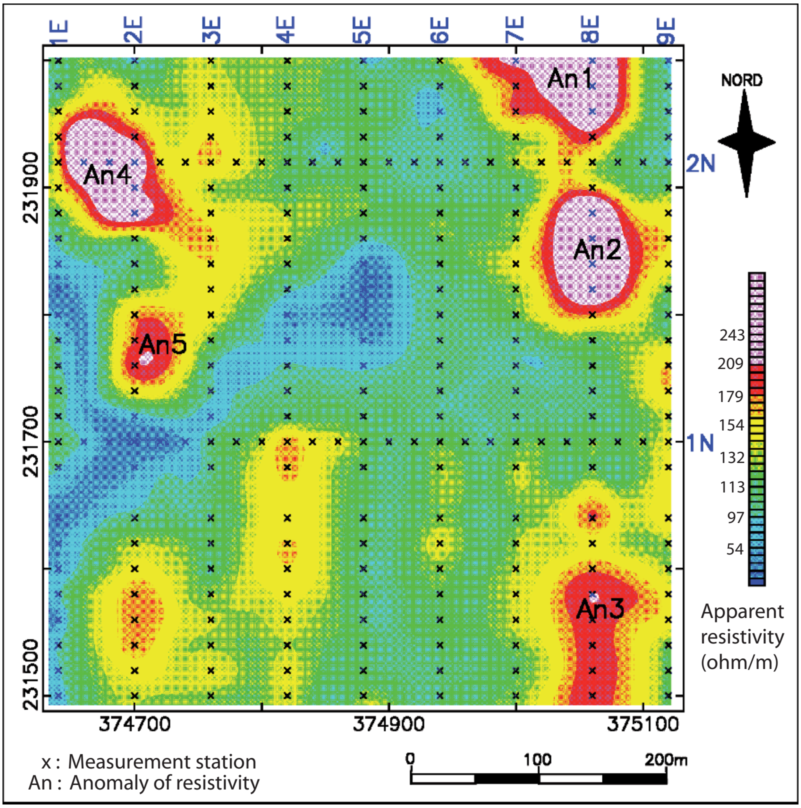

Fig. 7.9 Apparent resistivity map of an area of the Phosphate Plateau close to Sidi Chennane, based on sampling of the Time-Domain Electromagnetic Sounding method at 3 μs, after Kchikach et al. unpublished (cf. Kchikach et al., 2006). The main anomalies correspond to hidden "dérangements", as confirmed by mechanical boreholes (A1) or by further exploitation (A2)

7.2.4 The Vertebrate Fossils of the Oulad Abdoun Phosphorites

The pioneering work by Arambourg (1935, 1952) illustrated the richness of the Moroccan phosphorite deposits in Vertebrate fossils. The scientific importance of these deposits was recently confirmed with the discovery of the oldest mammals and birds on Africa. Such fossils occur within the entire phosphate series from the Maastrichtian to the base of Lutetian, and they are particularly abundant and varied in the Oulad Abdoun Basin. They constitute one of the most important references for the history of biodiversity during the end of Cretaceous-early Tertiary times, and thus deserve a summary in this chapter.

Apart from the Teleostean and Selachian groups, which are extremely abundant and diversified, the fauna includes several major taxonomic groups. The mammals from the "Plateau des Phosphates" include the most ancient herbivorous ungulate of the Proboscidean group (Fig. 7.10A; Gheerbrant et al., 1996, 1998, 2002,

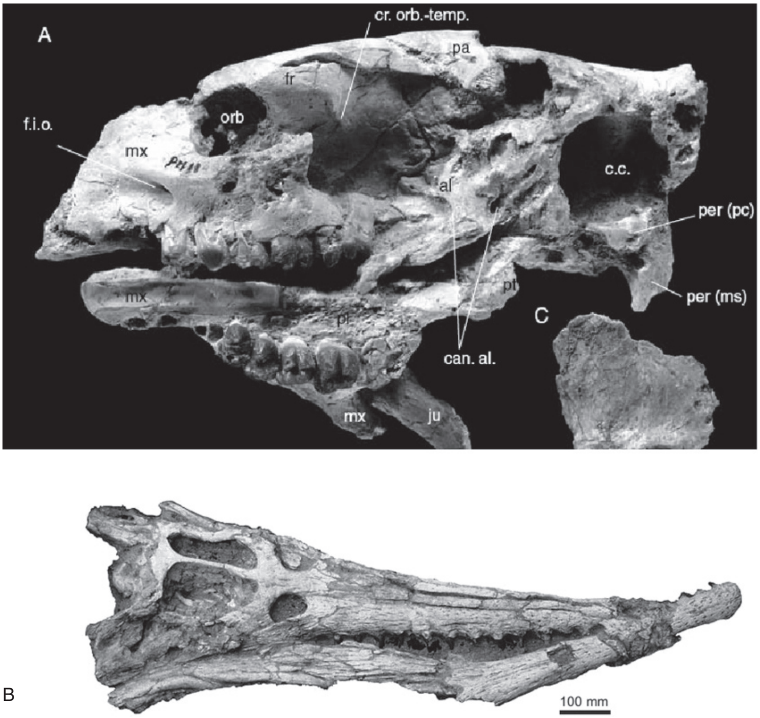

Fig. 7.10 Examples of Vertebrate fossils extracted from the Oulad Abdoun phosphorites. – **A**: Proboscidean skull, *Phosphatherium escuilliei*, after Gheerbrant et al. (1996). The body was probably carried into the sea by a river flood. The skull is almost complete, except the premaxillaries and nasal bones. The varied skull bones are clearly identified (see original publication). "C" is an isolated squamosal. This is the oldest known Proboscidean, found at the Paleocene-Eocene boundary in the Grand Daoui zone. A living reconstitution of this "elephant without trunk", weighty about 15 kg, is shown in *Maroc, mémoire de la Terre*, Edit. Muséum Nat. Hist. Nat. Paris, 1999, p. 163). – **B**: Skull and mandible of a Crocodyliform from the Oulad Abdoun Paleocene phosphorites: *Arambourgisuchus khouribgaensis*, after Jouve et al. (2005)

2003). Most of these fossils occur in the bone-bed at the bottom of the "Intercalaire Couches II/I" (Fig. 7.7) dated as lowermost Ypresian by its Selachian fossils (Gheerbrant et al., 2003). Besides the Proboscideans, two condylarths and three other taxa have been found (Gheerbrant et al., 2001, 2006). The birds are almost exclusively marine or coastal Procellariiformes, Pelecaniformes and Anseriformes, and include at least 10 species (Bourdon, 2006a, b). They are dominated by pseudoteeth birds, big, long-flight pelagic birds, up to 5 m wingspan, which thus evoke the modern albatross. The only continental bird from the Oulad Abdoun compares in size with the European white stork. Selachians (sharks and rays) are the most abundant vertebrate from the Phosphate Series, and these have been used to define a stratigraphic scale (Arambourg, 1952; Noubhani & Cappetta, 1997). Crocodyliformes are well represented by Dyrosaurids and Eusuchians in the Paleocene levels

(Hua & Jouve, 2004; Jouve, 2004, 2005; Jouve et al. 2005, 2006), whereas they are scarce in the Cretaceous levels where they are dominated by other reptilian such as the Mosasaurs. Chelonians are represented by Pleurodires and Cryptodires with several new taxa (Gaffney et al., 2006; Gaffney & Tong, 2003; Hirayama & Tong, 2003; Tong & Hirayama, 2002, 2004). Several almost complete Mosasauridae skeltons, up to 15 m long, were recently discovered from the Oulad Abdoun Maastrichtian phosphorites (Fig. 7.10B; Bardet et al., 2004; 2005a, b). Other Squamata are represented by a varanoid and a puzzling snake. Bones from a small sauropod titanosauriform (last represent of Dinosauria in Africa) is known from the Oulad Abdoun Maastrichtian beds (Pedera Suberbiola et al., 2004). The flying reptilians or Pterosauria are also represented by one of the last species of the group; it had a 5 m large wingspan.

This extraordinary faunal succession documents the Vertebrate evolution along a 25 My interval, involving two major climatic-biological crisis, the famous K-T crisis and the less known, but very important Paleocene-Eocene crisis. The excellent bone preservation in the phosphate-rich matrix accounts for the great value of these fossils for scientists and amateur collectors, and also for local diggers.

7.3 The Saharan and Sub-Saharan Plateaus

References: The Saharan plateaus are described by Fabre (2005), based on personal observations and previous classical works. The stratigraphy of the Errachidia-Boudenib hamadas has been studied by Ferrandini et al. (1985), Herbig (1988), and Ettachfini & Andreu (2004). The geomorphological evolution and associated paleo-alterations (carbonation, silicification) of these plateaus are described by Elyoussi et al. (1990), Ben Brahim (1994), Thiry and Ben Brahim (1997). Recent observations on the small plateaus of the Anti-Atlas northern slope (Imini, Goulmima) are reported in Rhalmi (2000) and Gutzmer et al. (2006). Paleontological references concerning the Vertebrate fossils are given in Sect. 7.3.4, and the current works on apatite fission tracks are mentioned in Sect. 7.4.

7.3.1 The Imini and Goulmima Plateaus

A narrow, but elongated zone of Cretaceous (-Tertiary) plateaus occur on the northern fringe of the central and eastern Anti-Atlas, from the Imini manganese district to Goulmima (Fig. 7.1). These Sub-Saharan plateaus correspond to the southern limb of the Ouarzazate and Errachidia-Boudenib basins, respectively, the northern limb of which is included in the folded South Sub-Atlas Zone (see Chap. 4, Figs. 4.36, 4.40, 4.41). These plateaus are more or less tilted and mildly folded in relation with the nearby Atlas fold belt.

From the stratigraphic point of view, the western part of this narrow domain is characterized by the absence or great reduction of the Lower Cretaceous deposits,

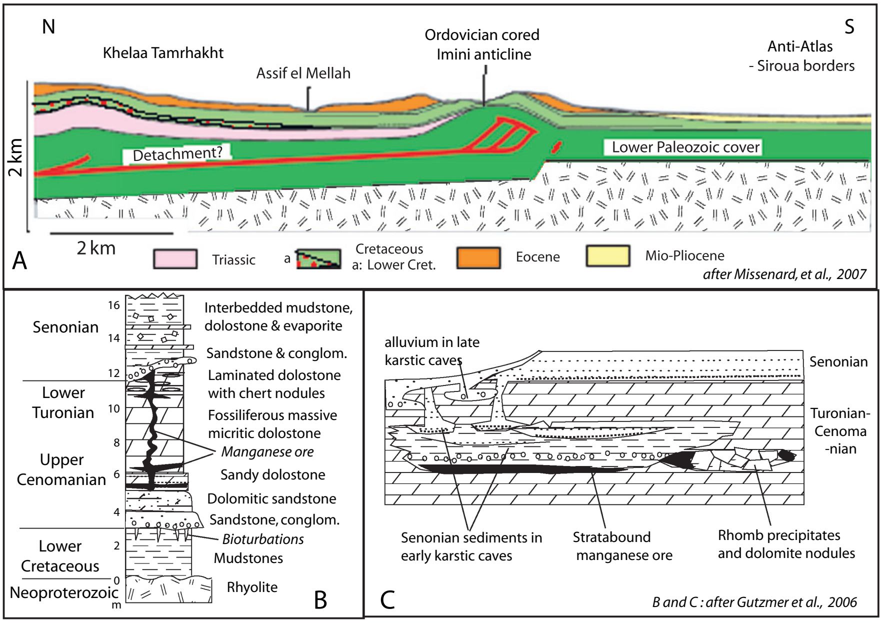

Fig. 7.11 The weakly deformed Cretaceous-Tertiary plateau of the Imini district west of Ouarzazate. – **A**: General cross-section, after Missenard et al. (2007). – **B**: Stratigraphic column, after Gutzmer et al. (2006), modified. – **C**: Localization of the stratabound manganese ore in a Late Cretaceous paleokarst, after Gutzmer et al. (2006), modified

and the direct (or almost direct) onlap of the Cenomanian-Turonian carbonates onto the Paleozoic or Neoproterozoic formations (Fig. 7.11A, B). The latter carbonate formations display clear evidence of deposition close to the shoreline of the Atlas Cretaceous gulf (cf. Chap. 4, Fig. 4.17). This particular paleogeographic location has favoured the rich manganese mineralization of the Cenomanian-Turonian dolomitic carbonates of the Imini district. The Anti-Atlas basement volcanics were the source for Mn, Pb and Ba. The stratabound ores occur in dolostone breccias and ferruginous clays which, according to Gutzmer et al. (2006), represent the earliest phase of internal sedimentation in a karstic cave system (Fig. 7.11C). The karst developed during a long period of weathering, prior to the deposition of the "Senonian" terrestrial red beds which filled the caves. The stratigraphic record ends with unconformable continental silts and conglomerates of Mio-Pliocene age. They were deposited during the mild deformation that formed the Imini anticline, 25 km south of the South Atlas Fault itself.

The J. Saghro Cretaceous-Eocene series crop out in the Tineghir area, at the eastern tip of the Ouarzazate basin. Further east, the Cretaceous plateau widens toward Goulmima and Errachidia, where it merges with the "Hamada de Meski" (Sect. 7.3.2). Lower Cretaceous continental sediments display a greater thickness than at Imini (about 200 m), and the Cenomanian-Turonian fossils record open marine sedimentation (Sect. 7.3.4). By contrast, Eocene deposits are lacking in the

Goulmima region. They occur close to Errachidia under continental facies which constitue the oldest Cenozoic deposits of the hamadas. The Goulmima Hamada is affected by a conspicuous ENE anticline (Tadighoust anticline) located above a Triassic normal fault (Saint-Bézar et al., 1998) and related to the detachment of the Mesozoic series (see Chap. 4, Fig. 4.35D). This compares with the structure of the Imini anticline (Fig. 7.11A).

7.3.2 The Hamada System in the Errachidia Region

The northern tip of the Hamada System is exposed close to Errachidia, immediately south of the South Atlas Fault (Fig. 7.12). From bottom to top, three main superimposed plateaus or "hamadas" are observed:

– the Hamada of Meski-Aoufous (Lower Hamada) is a table of Upper Cenomanian-Lower Turonian limestones above Lower Cretaceous continental redbeds that unconformably overlie the Paleozoic series of the eastern Anti-Atlas;

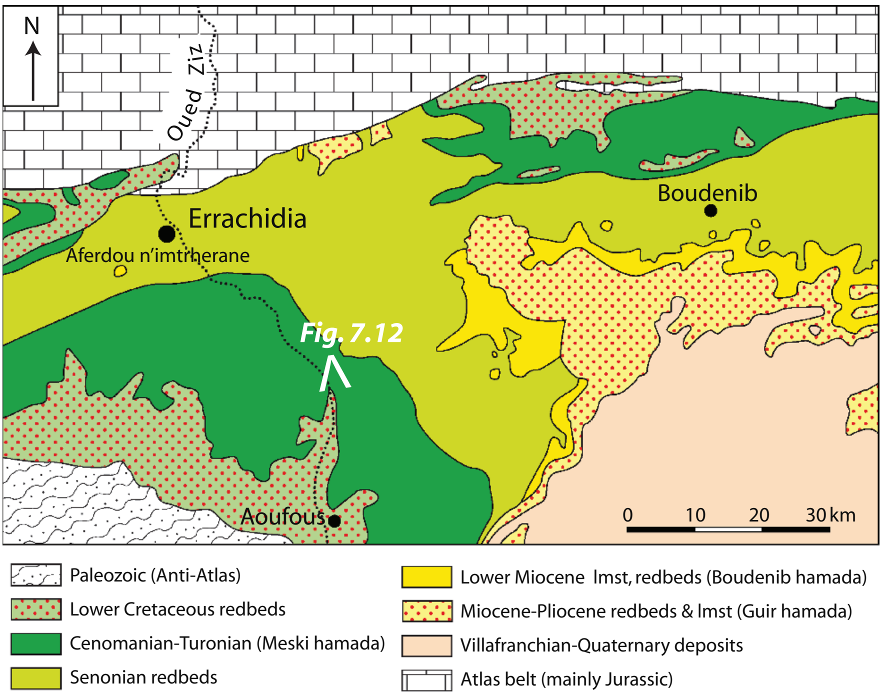

Fig. 7.12 Geological setting of the hammadas east of the Anti-Atlas (see Fig. 7.1 for location), after the Geological map of Morocco, 1:1, 000,000 (1985). Asterisk: Location of Fig. 7.13. North of Errachidia and Boudenib, the Cretaceous-Tertiary formations are clearly folded, and belong to the frontal zone of the Atlas belt (see Chap. 4, Fig. 4.35)

– the Hamada of Boudenib (Hamada à *Clavator*, Middle Hamada), whose escarpment is made of Upper Cretaceous (Senonian p.p.) redbeds topped by Lower Miocene lacustrine limestones;
– the Guir Hamada or Upper Hamada, which displays an escarpment of reddish continental siltstones (Upper Miocene?) topped by lacustrine limestones and conglomerates of probable Pliocene age.

It must be noted that limited plateaus of Eocene continental deposits are described west of Bechar, and referred to as the "Hamada à *Ceratodes*" (Fig. 7.1). The undated hill 10 km SW of Errachidia (Aferdou n'Imtrherane) is currently assigned to the Lower Miocene (Fig. 7.12), but could alternatively be an equivalent of the Eocene Hamada. If correct, the Eocene transgression of the Ouarzazate Basin would have been limited to the east between Tineghir and Errachidia, i.e. near Goulmima.

The gentle slope of the Hamada of Meski escarpement (Fig. 7.13) corresponds to reddish siltstones and sandstones with gypsum and rare limestone intercalations. These continental deposits represent the Early Cretaceous ("Infra-Cenomanian"), referred to as "Continental intercalaire" in the Kem Kem and more southern Saharan areas. The overlying table includes four members corresponding to progressive environmental changes (Ferrandini et al., 1985). The lowest, Cenomanian coastal member (Ostreidae wackstones with benthic foraminifers) displays an eastward increasing brackish tendency. The second member includes reef limestones with rudists, stromatoporidae and dasycladaceae typical of a proximal platform environment. The third member consists of *Exogyra* and *Nerinea* bioclastic limestones topped by a hard ground which marks the end of Cenomanian. The last member consists of siliceous, weakly dolomitic micrites and ostreidae limestones dated from the Turonian and corresponding to open marine conditions.

The lower part of the Hamada of Boudenib escarpement consists of argillaceous sandy redbeds with gypsum and salt. These poorly dated formations conformably overlie the Turonian limestones, and thus probably correspond to Senonian sediments deposited in a confined environment. The Aquitanian succession of the

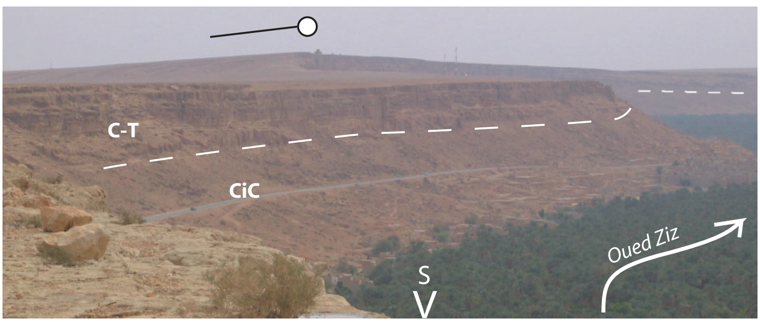

Fig. 7.13 View of the Meski Hamada escarpment from Ait Chaker (south of the Meski "Blue Spring"; location in Fig. 7.12) looking southward on the Oued Ziz Valley. CiC: Lower Cretaceous continental redbeds. C-T: Cenomanian-Turonian marine limestones. Note the widely open fold related to the Atlas Orogeny

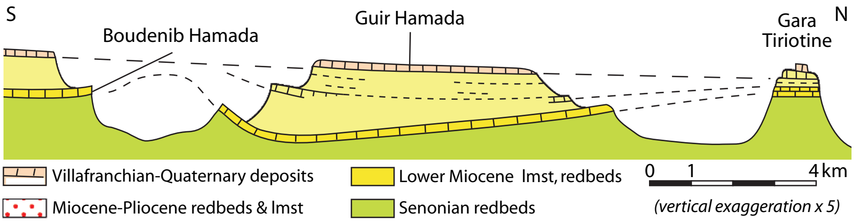

Fig. 7.14 Cross-section of the eastern border of the Guir Hamada, half-way between Boudenib and Bechar: an example of mild Mio-Pliocene deformation south of the South Atlas Fault. After Lavocat (1954), modified

plateau (formerly classified as Upper Oligocene) starts with *Melanatria* calcareous sandstones, and continues upward with lacustrine limestones with abundant gastropods of the genus *Clavator*, associated with sands and conglomerates. Although these Lower Miocene deposits overlie conformably the Upper Cretaceous redbeds, an important hiatus occurs in between, as indicated by the local occurrence of the Eocene "*Ceratodes* Hamada". An unconformity is observed west of Bechar.

Sediments of the Guir Hamada form the uppermost cuesta of the Hamada System. The escarpment consists of continental siltstones and sandstones with limestone intercalations. The plateau corresponds to lacustrine/palustrine silicified limestones (Fig. 7.14). The sequence is poorly dated and was assigned to the "Mio-Pliocene". On top of the Hamada, continental sedimentation continues into the Villafranchian, whose silty-conglomeratic deposits are cemented by thick diagenetic calcretes. Diagenetic silicifications are widespread throughout the Boudenib and Guir Hamada formations (Fig. 7.15). Their development was likely related to wet climatic stages (Thiry & Ben Brahim, 1997; see also Chap. 8).

Slightly different dipping planes and local unconformities between the plateaus and underlying redbeds (Fig. 7.14) suggest syntectonic sedimentation at the southern rim of the uprising Atlas belt. Open folding of the Meski Hamada next to Aoufous (Fig. 7.13) is probably related to far-field stress induced by the Atlas orogenic episode. Further south along the western border of the Guir Hamada, the Mio-Pliocene sediments overlie directly the Lower Cretaceous redbeds (e.g. east of Rissani), and then the Tafilalt Paleozoic series (see Geological map of Morocco, scale 1/200,000, sheet Tafilalt-Taouz). The Miocene-Pliocene deposits also disappear, and then the Plio-Quaternary formations of the uppermost Hamada overlie the south-eastern Tafilalt Massif directly. Still further to the SW in the Kem Kem area, the Cretaceous and Miocene-Pliocene formations again develop, suggesting a regional deformation of the Anti-Atlas basement and Mesozoic cover during the Neogene phase of the Atlas Orogeny.

7.3.3 *The Draa Hamada*

The Draa Hamada is the largest of the "Grandes Hamadas" System, which also includes the Guir Hamada and the smaller Daoura Hamada (Fig. 7.1). The Draa

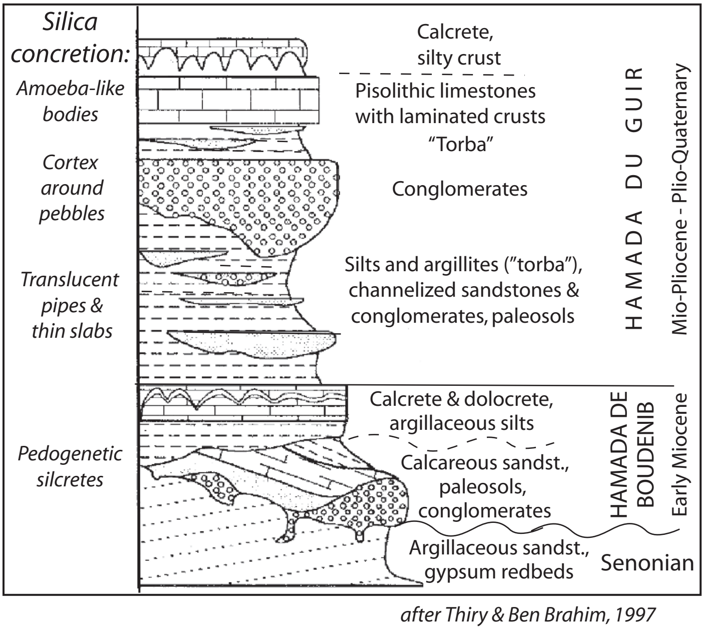

Fig. 7.15 Schematic sedimentary column of the continental hamadas in the Boudenib area, showing the associated calcrete and silcrete formations, after Thiry & Ben Brahim (1997), modified

Hamada extends onto the Tindouf basin between the southernmost Anti-Atlas aureoles (Carboniferous series of the J. Ouarkziz massif) and the Reguibat Precambrian arch. Most of this Saharan plateau consists of Cenozoic continental deposits, loosely assigned to the Miocene-Pliocene and passing upward to Quaternary formations (see Chap. 8). However, Cretaceous sediments also occur in the western part of the basin, including a thin wedge of Cenomanian-Turonian shallow marine limestones (Fig. 7.16). The overlying sandstones and conglomerates with silicified wood have been formerly considered as Paleogene, but they are currently assigned to the "Mio-Pliocene". The synformal geometry of the Draa Hamada testifies for large wavelength deformation of the northwest Saharan lithosphere during the Late

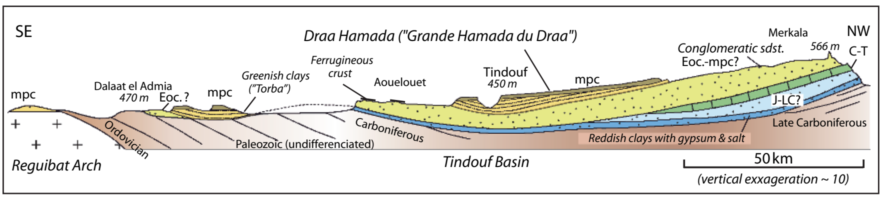

Fig. 7.16 Schematic cross-section of the Great Draa Hamada, after Gevin (unpubl. Report, 1974), in Fabre (2005), modified. Vertical scale strongly exaggerated. See Fig. 7.1 for location

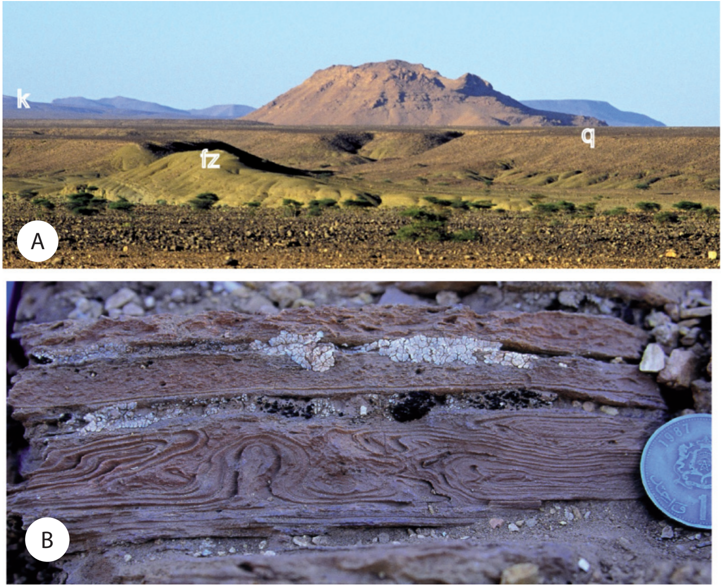

Fig. 7.17 Mio-Pliocene deposits in the Eastern Anti-Atlas. – **A**: The northern Tourt, one of the two Miocene-Pliocene hills 15 km SE of Alnif, as seen from the south (k: Cambrian; fz: Fezzouata Fm.; q: Quaternary terrace). – **B**: Seismites in the silty lacustrine/palustrine limestones of the higher beds of the hill (Upper Miocene-Pliocene). Diameter of the coin: 3 cm. Photos L. Baidder

Cretaceous (cf. Anti-Atlas swell and Draa/Tindouf embayment, Fig. 7.3B), reactivated during the Neogene.

North of the Kem Kem plateau, the twin pink hills named "Tourt" close to Alnif (Fig. 7.17A) give evidence of the large extension of the Miocene-Pliocene deposits between the Draa and Guir Hamadas, respectively. They overlie unconformably the Lower Ordovician Fezzouata formation, and consist of coarse sandy carbonates at the bottom, homologous to the Lower Miocene Boudenib limestones, topped by micritic, lacustrine/palustrine silty limestones homologous to those of the Guir Hamada. In the latter deposits, slump balls and convolute bedding have recorded a significant, synsedimentary seismic activity (Fig. 7.17B). This can be regarded either as a far field effect of the Atlas Orogeny, or more probably as echoing the coeval volcanic activity responsible for the emplacement of nephelinites and basanites in the neighbouring J. Saghro (cf. Chap. 4).

7.3.4 The Vertebrate Fossils of the Kem Kem and Goulmima Plateaus

In common with the Vertebrate fossils of the Phosphate Plateau, those of the Sub-Saharan Plateaus from the Errachidia-Tafilalt region deserve special mention. The rich fossil faunas from the Kem Kem and Goulmima plateaus occur in continental and marine beds, respectively. Together, they document the crucial period of the Gondwana break-up (see above, Fig. 7.2).

The Kem Kem fossiliferous beds are exposed along the escarpment of the Cenomanian-Turonian plateau south of the Tafilalt Paleozoic region (Fig. 7.18). The escarpment consists mainly of red sandstones (200 m thick "Continental intercalaire"), overlain by coloured gypsum marls, which finally pass up into Cenomanian marly limestones. The particular interest of the Vertebrate fossils of the "Continental intercalaire" in this region dates from the years 1940–1950 when R. Lavocat collected a rich fauna of "fishes", turtles, crocodiles, dinosaurs and pterosaurs (e.g. Lavocat, 1951, 1954). Indeed, the Kem Kem Dinosaurian and Pterosaurian assemblage is one of the richest of Africa. In 1995, an international team discovered the skull of one of the greatest carnivorous dinosaurs, *Carcharodontosaurus saharicus*, a Theropod which was probably as tall as the famous *Tyrannosaurus* (about 15 m long; Buffetaut, 1989a; Russel, 1996; Sereno et al., 1996; Amiot et al., 2004). Theropods are also represented by four other families in the Kem Kem beds: (i) the Spinosaurids, probably fish-eating animals, with *Spinosaurus aegyptiacus* (Buffetaut 1989a, 1989b, 1992; Dal Sasso et al., 2005) and *Spinosaurus maroccanus* (Russel, 1996); (ii) the Abelisaurids (Russel, 1996; Mahler, 2005); (iii) the Noasaurids, with *Deltadromeus agilis* (Sereno et al., 1996), probably a running hunter; and (iv) the Dromaeosaurids (Amiot et al., 2004). The giant herbivorous sauropods are represented by *Rebbachisaurus garasbae* (found at Gara Sba and dedicated to the Aït Rebbach tribe; Lavocat 1951, 1954; Russel, 1996), whose dorsal vertebras measure 1 m, and which probably reached 20 m in length. Other sauropods, belonging to the Titanosaurid and Dicraeosaurid families (Russel, 1996; Sereno et al., 1996; Russel et Paesler, 2003) are also known. In contrast, the Ornithischians are only known by their foot casts yet. It is notable that remarkable dinosaur tracks and skeletons are also known

Fig. 7.18 View of the "Continental intercalaire" of the Kem Kem Plateau in the Gara Sba area (east of Oum Jerane; see Fig. 7.1 for location). The age of these rich fossiliferous horizons is debatable, Albian (?) or Cenomanian (Sereno et al., 1996). The whitish blocks are Turonian limestones from the overlying plateau (not shown). Photo S. Zouhri

from the Atlas synclines, being dated at ca. 160 Ma. This is the case of the tall sauropod *Atlasaurus imelakei* from the Bathonian-Callovian (Guettioua Fm) of the Tilougguit syncline of the central High Atlas south of Beni Mellal (Monbaron et al., 1999).

In addition to the dinosaurs, the pterosaurs were particularly diversified in the Tafilalt region. Three Pterodactyloid families have been recognized (Kellner et Mader, 1996, 1997; Mader & Kellner, 1997, 1999; Wellnhofer & Buffetaut, 1999). All ecological niches were occupied. Many species of "fish" populated the rivers, among them fresh water sharks, a giant coelacanth, dipneusts and bone fishes actinopterygians, whose remains are remarkably preserved, sometimes including the muscle fibres (Russel, 1996; Cavin & Dutheil, 1999; Dutheil, 1999; Cavin et al., 2001). According to the latter authors, the Cenomanian-Lower Turonian ichtyofauna of the Tafilalt and neighbouring areas includes 680 taxa from both fresh water and marine environments. At least five species of crocodile occupied the river shorelines, including a giant (Buffetaut, 1976, 1989a, 1994; Sereno et al., 1996). Four fresh water turtle families have been described (de Broin, 1988; Tong & Buffetaut, 1996; Gmira, 1995; de Lapparent de Broin, 2000; Gaffney et al., 2002). Snakes and varanus are also present in the area (Rage & Escuillé, 2003). Besides of the Vertebrates, insects and angiosperms complete this uncommon, 110–95 My old terrestrial environment.

The Goulmima plateau enables paleontologists to document a slightly younger period in a marine environment. The Vertebrate fossils are preserved within calcareous nodules included in the Lower Turonian marly limestones, also dated by their ammonites. The environment corresponds to an open marine platform, probably rich in plankton. Numerous new fish species have been described (one of them named *Goulmimichthys*), together with more cosmopolitan species. The reptilian fauna (Bardet et al., 2003a, b) includes mosasaurs and plesiosaurs, which were typical predators of the Cretaceous seas. Among the plesiosaurs, both the Elasmosaurids (characterized by their long neck) and the Polycotylids (shaped as good swimmers; Fig. 7.19) have been described. The mosasaurs from Goulmima belong to the earliest forms of this group, whose spectacular radiation occurred around 90 Ma, and which populated the most varied marine niches up to the K-T crisis.

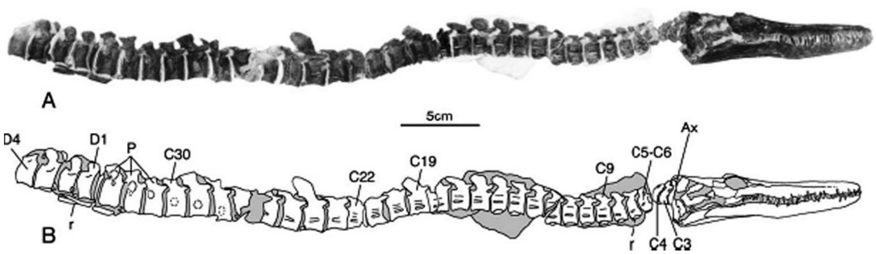

Fig. 7.19 *Thililua longicollis*, a small, but nicely preserved plesiosaur skelton (**A**) from the Turonian beds of Goulmima. – **B**: Interpretation: Ax: axis; **C**: cervical vertebra; **D**: dorsal; P: pectoral; r: rib. After Bardet et al. (2003a)

7.4 Vertical Movements in the Plateau Domains

From the tectonic point of view, two questions arise concerning the Cretaceous-Tertiary plateaus, (i) why does the Triassic-Jurassic sequence is lacking (no deposition or erosion?), and (ii) how much the plateaus were affected by the Atlas deformation during the Late Eocene-Neogene?

7.4.1 Atlantic Plateaus

The lack of Triassic-Jurassic deposits at the bottom of the Phosphate Plateau and Ganntour has been taken for years as evidence for a subaerial exposure of the Western Meseta basement during this time interval. This was the concept of "Terre des Almohades" of Choubert & Faure-Muret (1960–62) or "Dorsale du Massif hercynien central" of du Dresnay (1972, in Michard, 1976), currently referred to as the West Moroccan Arch (WMA; see Chap. 4, Figs. 4.4, 4.7). In the classical view, this land was emergent up to the late Early Cretaceous, except locally (Fig. 4.17). However, new studies based on low-temperature thermochronology of basement rocks (mostly granites) make compulsory to revisit this concept (Ghorbal et al., 2007; Saddiqi et al., 2008).

In fact, the WMA suffered contrasted vertical movements during the Triassic-Jurassic interval. The results obtained by Saddiqi et al. (2008) on the Jebilet and Rehamna granites are summarized hereafter (Fig. 7.20). These Variscan granites, whose emplacement occurred at about 330 Ma and 300–290 Ma, respectively (see Chap. 3, Fig. 3.23), yielded apatite fission-track (AFT) ages around 192 Ma and 152 Ma, respectively. Their low-temperature T-t paths have been modelled using, in addition to the age dataset, the fission-track length measured in the same samples, and taking into account the available geological constraints. The Jebilet T-t path presented here (Fig. 7.20C) clearly indicates that the studied granite suffered a weak heating ($T < 75\,^{\circ}C$) after its Permian exhumation (around 260 Ma). In other words, the Jebilet basement subsided by about 1500 m during the Triassic-Early Jurassic (admitting a slightly improved geotherm in relation with the context of rifting and magmatic activity). The Rehamna granite, which emplaced later and at greater depth, was not completely exhumed at 260 Ma, and then reached a slightly higher temperature (ca. 90 °C) at 180 Ma.

Both the Jebilet and Rehamna massifs reached again the surface around 120–95 Ma, i.e. before the widespread Cretaceous onlap. Thus, the major role of the Late Jurassic-Early Cretaceous uplift is clearly illustrated here, as in the Zaer Massif (Ghorbal et al., 2007). This uplift event was responsible for the active denudation of the Variscan basement (see Fig. 7.5B above) of the former Western Meseta platform domain, which changed to a complex of emerged islands and peninsula (Fig. 4.17).

The last parts of the modelled T-t paths show the slight burial heating related to the Cretaceous Eocene sedimentation and the more rapid exhumation during

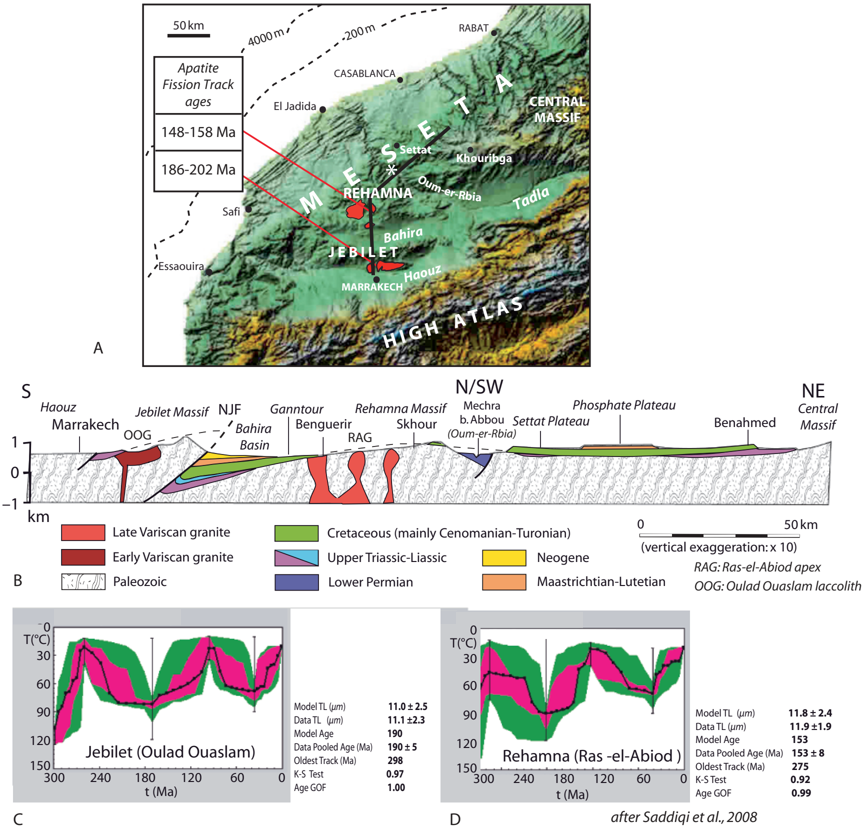

Fig. 7.20 Vertical movements in the south-western Moroccan Meseta (Rehamna and Jebilet Massifs), based on stratigraphy and apatite fission-track (AFT) data, after Saddiqi et al. (2008). **A**: Location of the studied massifs and corresponding AFT ages from their Variscan granites. Bold black line: location of cross-section **(B)**. – **B**: Cross-section showing the different types of granites and the geologic constraints used in the modelling experiments (Permian erosion, Triassic-Liassic onlap, Cretaceous unconformity, post-Lutetian uplift). – **C**, **D**: Examples of modelling experiments (AFTsolve program) for the Jebilet **(C)** and Rehamna **(D)** granites. The importance of the pink areas respective to the green ones in the T-t diagrams shows the excellent fit of the modelled T-t paths with the AFT data, as also shown by the quantitative indications on the right. TL: track lengths

the Late Eocene-Neogene interval. This final exhumation is coeval with the Atlas shortening and, indeed, the Jebilet massif can be regarded as part of the Atlas system, being bounded to the north by an important reverse fault. However, it must be kept in mind that the uplift of all the deformed regions south of the Maghrebide collisional belt (Meseta, Atlas and Anti-Atlas domains) does not only rely on crustal shortening, but was greatly enhanced by the development of a hot mantle anomaly underneath (e.g. Missenard et al., 2006; Chap. 1, Sect. 1.5; Chap. 4, Sect. 4.5, 4.6).

7.4.2 Saharan Plateaus

The behaviour of the future Hamada domain (i.e. the central and eastern Anti-Atlas and Ougarta Belts, and the Tindouf, Reggane and Bechar Basins) during the Triassic-Early Jurassic was recently questioned. In the eastern Anti-Atlas, Robert-Charrue (2006) argued that the Triassic extension would have been able to reactivate, again as normal faults, the N-dipping Cambrian paleofaults inverted during the Variscan compression. Actually, the Triassic-Liassic extension allowed gabbroic magmas of the CAMP (cf. Chap. 1) to emplace as huge dykes into the crust (e.g. Chap. 2, Fig. 2.2), and to form a number of sills in the already folded Paleozoic series (Hollard, 1973). However, the Triassic-Early Jurassic facies of the Atlas southern border strongly suggest the proximity of emerged lands southward (see Chap. 4, Figs. 4.7, 4.8). Accordingly, we may assume that the Anti-Atlas formed at that time the emergent shoulder of the High Atlas rift.

The entire Sahara domain was deformed significantly during the Early Cretaceous, particularly during the late Barremian-early Aptian, and then during the Late Cretaceous (see above, Sect. 7.1). Detail paleomagnetic study ("fold test") of Triassic-Early Jurassic sills intruded in the folded Paleozoic series of the Reggane-Ahnet region demonstrated that folding has been actually initiated during the late Paleozoic, but was significantly rejuvenated after intrusion, likely during the Cretaceous (Smith et al., 2006). A larger-scale consequence of this intraplate deformation was the shift of the Trans-Saharan Seaway to the west of the Hoggar Massif during the Senonian (see above, Fig. 7.3.C).

The Anti-Atlas was clearly affected by the Atlas Orogeny during the Cenozoic. Varied structures have been mentioned above (e.g. Figs. 7.11, 7.13, 7.14), being related to the Atlas shortening. Some Variscan reverse faults were reactivated in the Paleozoic basement at the northern border of the Saghro Massif, as documented by apatite fission track results (Malusà et al., 2007). In contrast, at the southern border of the Eastern Anti-Atlas, Baidder (2007) described a set of post-Cretaceous, ENE-trending normal faults. As a matter of fact, the interpretation of the post-Cretaceous tectonic regime in the Sub-Saharan regions is still widely open to investigation. The regional uplift, particularly that of the Anti-Atlas, was strongly enhanced by the mantle anomaly quoted above, i.e. the Morocco Hot Line, also responsible for the high elevation of the Atlas Mountains. Nevertheless, the trend of the Anti-Atlas antiform, parallel to the South Atlas Front, and the chronology of its formation (Late Cretaceous-Neogene) strongly suggest that its uplift was also controlled by the stress-induced lithosphere buckling due to the Africa-Europe convergence (Frizon de Lamotte et al., 2008).

Acknowledgments The authors thank André Charrière (Paul-Sabatier Univ., Toulouse), Dominique Frizon de Lamotte (University of Cergy-Pontoise) and Bruce Purser (University of Paris-Sud, Orsay) for their critical readings of our manuscript.

References

Anonymous, Géologie des Gîtes minéraux marocains (2d edition) – Tome III: Phosphates. *Notes Mém. Serv. Géol. Maroc* 276 (1986) 392pp.

Amiot R., Buffetaut E., Tong H., Boudad L., Kabiri L., Isolated theropod teeth from the Cenomanian of Morocco and their palaeobiogeographical significance. *Rev. Paléobio. Genève* 9 (2004) 143–149.

Arambourg C., Note préliminaire sur les vertébrés fossiles des phosphates du Maroc *Notes Mém. Serv. Géol. Maroc* 5 (1935) 413–439.

Arambourg C., Les vertébrés fossiles des gisements de phosphates (Maroc-Algérie-Tunisie). *Notes Mém. Serv. Géol. Maroc* 92 (1952) 1–372.

Baidder L., Structuration de la bordure septentrionale du craton ouest-africain du Cambrien à l'Actuel: cas de l'Anti-Atlas oriental, Unpubl. Thesis (Doct. Etat) Univ. Hassan II Casablanaca, Fac. Sci. Aïn Chok, 2007, 218pp.

Bardet N., Pereda Suberbiola X., Jalil N.-E., A new polycotylid plesiosaur from the Late Cretaceous (Turonian) of Morocco. *C. R. Palévol*, 2 (2003a) 307–315.

Bardet N., Pereda Suberbiola X., Jalil N.-E., A new mosasauroid (Squamata) from the Late Cretaceous (Turonian) of Morocco. *C. R. Palévol*, 2 (2003b) 607–617.

Bardet N., Pereda Suberbiola X., Iarochene M., Bouyahyaoui F., Bouya B., et Amaghzaz M., (2004). *Mosasaurus beaugei* Arambourg, 1952 (Squamata, Mosasauridae) from the Late Cretaceous phosphates of Morocco. *Géobios* 37 (3) 315–324.

Bardet N., Pereda Suberbiola X., Iarochene M., Amalik M., Bouya B., *Durophagous* Mosasauridae (Squamata) from the Upper Cretaceous phosphates of Morocco, with the description of a new species of Globidens. *Netherlands J. Geosci*, 84 (2005a) 167–175.

Bardet N., Pereda Suberbiola X., Iarochene M., Bouya B., Amaghzaz M., A new species of *Halisaurus* from the Late Cretaceous phosphates of Morocco, and the phylogenetical relationships of the Halisaurinae (Squamata: Mosasauridae). *Zool. J. Linnean Soc*. 143 (2005b) 447–472.

Ben Brahim M., Le sillon de Boudenib (SE marocain). Structure morphotectonique. Hamadas tertiaires et paléoaltérations associées. Morphogenèse quaternaire et aridité actuelle, Unpubl. Thesis Doct. ès-Lettres Univ. Paris I Panthéon-Sorbonne, 1994, 280pp.

Bolleli et al., Carte géologique du Plateau des Phosphates et de la Zone synclinale du Tadla, feuilles Benahmed-El Borouj 1:200.000,. *Notes Mém. Serv. géol. Maroc* 137 (1959).

Boujo A., Contribution à l'étude géologique du gisement de phosphates Crétacé-Eocène des Gantour (Maroc occidental). *Sci. Géol. Mém. Strasbourg* 43 (1976) 227pp.

Bourdon E., L'avifaune du Paléogène des phosphates du Maroc et du Togo: diversité, systématique et apports à la connaissance de la diversification des oiseaux modernes (Neornithes), Unpubl. Thesis Muséum Nat. Hist. Nat. Paris, 2006a, 330pp.

Bourdon E., A new avifauna from the Early Tertiary of the Ouled Abdoun Basin, Morocco: contribution to higher-level phylogenetics of modern birds (Neornithes). *J. Vertebrate Pal*. 26 (2006b) 44A.

Broin F. de, Les tortues et le Gondwana. Examen des rapports entre le fractionnement du Gondwana au Crétacé et la dispersion géographique des tortues pleurodires à partir du Crétacé. *Studia Salmanticensia, Studia Palaeocheloniologica* 2 (1988) 103–142.

Buffetaut E., Remarks on the Cretaceous theropod dinosaurs *Spinosaurus* and *Baryonyx. Neues J. Geol. Pal. Monats*. 2 (1992) 88–96.

Buffetaut E., A new crocodilian from the Cretaceous of southern Morocco. *C. R. Acad. Sci*. 319 (1994) 1563–1568.

Buffetaut E., Une nouvelle définition de la famille des Dyrosauridae de Stefano, 1903 (Crocodylia, Mesosuchia) et ses conséquences: inclusion des genres *Hyposaurus* et *Sokotosuchus* dans les Dyrosauridae. *Geobios* 9 (1976) 333–336.

Buffetaut E., New remains of the enigmatic dinosaur *Spinosaurus* from the Cretaceous of Morocco and the affinities between *Spinosaurus* and *Baryonyx. Neues J. Geol. Pal. Monats*. 2 (1989a) 79–87.

Buffetaut E., New remains of *Spinosaurus* from the Cretaceous of Morocco. *Archosaurian Articulation* 1 (1989b) 65–68.

Cavin L., Dutheil D. B., A new Cenomanian ichthyofauna from South-eastern Morocco and its relationships with the other early Late Cretaceous Moroccan faunas. *Geol. Mijnb*. 78 (1999) 261–266.

Cavin L., Boudad L. Duffaud S., Kabiri L. Le Lœuff J., Rouget I., et Tong H., l'évolution paleoenvironnementale des faunes de poissons du Crétacé supérieur du Bassin du Tafilalt et des régions avoisinantes (Sud-est du Maroc): implications paléogéographiques. *C. R. Acad. Sci. Paris* 333 (2001) 677–683.

Courville Ph., Echanges et colonisations fauniques (Ammonitina) entre Tethys et Atlantique Sud au Crétacé supérieur: voies atlantiques ou sahariennes ? *Carnets de Géologie – Notebooks on Geology*, Brest, 2007/02 (CG2007_M02/02). http://paleopolis.rediris.es/cg/

Dal Sasso C., Maganuco S., Buffetaut E., Mendez M.A., New information on the skull of the enigmatic theropod Spinosaurus, with remarks on its size and affinities. *J. Vertebrate Pal*. 25 (2005) 888–896.

Dutheil D. B., An overview of the freshwater fish fauna from the Kem Kem beds (Late Cretaceous: Cenomanian) of southeastern Morocco. *In*: Arratia, G. & Schultze H.-P. (Eds.), Mesozoic Fishes 2 – *Systematics and Fossil Record*, Friedrich Pfeil, München, 1999, 553–563.

Einsele G., Wiedmann J., Turonian black shales in the Moroccan Coastal basins: first upwelling in the Atlantic Ocean, in Von Rad U., Hinz K., Sarnthein M., Seibold E. (Eds.), Geology of the Nordwest African continental margin, Springer Verl., 1982, 396–414.

Elyoussi M., Truc G., Paquet H., Millot G., Triat J.M., Un piémont détritique à encroûtements carbonatés. La Hamada du Guir au Maroc. *Méditerranée*, n° h.-sér., (1990) 34–35.

Ettachfini E.M., Andreu B., Le Cénomanien et le Turonien de la plate-forme préafricaine du Maroc. *Cretaceous Res*. 25 (2004), 277–302.

Fabre J., Géologie du Sahara occidental et central. *Tervuren Afric. Geosci. Coll*. 108, 2005, 572pp.

Ferrandini M., Philip J., Babinot J.F., Ferrandini J., Tronchetti G., La plate-forme carbonatée du Cénomano-Turonien de la région d'Erfoud-Errachidia (Sud-Est marocain): stratigraphie et paléoenvironnements. *Bull. Soc. Géol. Fr* (8) 1 (1985) 559–564.

Frizon de Lamotte D., Leturmy P., Missenard Y., Khomsi S., Ruiz G., Saddiqi O., Michard A., Charrière A., Meso-Cenozoic vertical movements in the Atlas System (Algeria, Morocco, Tunisia): origin of longitudinal asymmetry of topography and rock material – an overview, *Tectonophysics* (2008), accepted with revision.

Gaffney E.S., Tong H., *Phosphatochelys*, a New Side-Necked Turtle (Pelomedusoides: Bothremydidae) from the Paleocene of Morocco. *Bull. Am. Museum Nat. Hist*. 279 (2003) 644–659.

Gaffney E. S., Tong H., Meylan P.A., *Galianemys*, a New Side-Necked Turtle (Pelomedusoides: Bothremydidae) from the Late Cretaceous of Morocco. *American Museum Novitates*, 3379 (2002) 1–20.

Gaffney E.S., Tong H., Meylan P.A., Evolution of the side-necked turtles: the families Bothremydidae, Euraxemydidae, and Araripemydidae. *Bull. Am. Museum Nat. Hist*. 300 (2006) 1–700.

Gharbi A., Les phosphates marocains. *Chron. Rech. Min*. 531–532 (1998) 127–138.

Gheerbrant E., Sudre J., Cappetta H., A Palaeocene proboscidean from Morocco. *Nature* 383 (1996) 68–70.

Gheerbrant E., Sudre J., Cappetta H., Bignot G., *Phosphatherium escuilliei* du Thanétien du Bassin des Ouled Abdoun (Maroc), plus ancien proboscidien (Mammalia) d'Afrique. *Géobios*, 30 (1998) 247–269.

Gheerbrant E., Sudre J., Iarochène M., Moumni A., First ascertained African "condylarth" mammals (primitive ungulates: cf. Bulbulodentata & cf. Phenacodonta) from the Earliest Ypresian of the Ouled Abdoun Basin, Morocco. *J. Vertebrate Pal*., 21 (2001) 107–117.

Gheerbrant E., Sudre J., Cappetta H., Iarochene M., Amaghzaz M., Bouya. B. A new large mammal from the Ypresian of Morocco: Evidence of a surprising diversity of early proboscideans. *Acta Palaeontologica Polonica*, 47 (2002) 493–506.

Gheerbrant E., Sudre J., Cappetta H., Mourer-Chauviré C., Bourdon E., Iarochene M., Amaghzaz M., Bouya B., Les localités à mammifères des carrières de Grand Daoui, bassin des Ouled Abdoun, Maroc, Yprésien: premier état des lieux. *Bull. Soc. Géol. Fr*. 174 (2003) 279–293.

Gheerbrant E., Iarochene M. Amaghzaz M., Bouya B., Early African hyaenodontid mammals and their bearing on the origin of the Creodonta. *Geol. Mag.* 143 (2006) 475–489.

Ghorbal B., Bertotti G., Andriessen P., New insights into the tectono-morphic evolution of the Western Meseta (Morocco), NW Africa) based on low-temperature thermochronology, Meeting Europ. Union Geosci. *Geophys. Res. Abstr*. 9 (2007) 09820.

Gigout M., Carte géologique de la Meseta entre Mechra-ben-Abbou et Safi (Abda, Doukkala et massif des Rehamna), 1 :200.000. *Notes Mém. Serv. géol. Maroc* 84 (1954).

Gmira S., Etude des Chéloniens fossiles du Maroc. Anatomie-Systématique-Phylogénie. *Cahiers de Paléontologie*. Paris, CNRS Editions. 140pp.

Guiraud R., Bosworth W., Thierry J., Delplanque A., Phanerozoic geological evolution of northern and central Africa: an overview. *J. Afr. Earth Sci*. 43 (2005) 83–143.

Gutzmer J., Beukes N.J., Rhalmi M., Mukhopadhyay J., Cretaceous karstic cave-fill manganese-lead-barium deposits of Imini, Morocco. *Econom. Geol*. 101 (2006) 385–405.

Herbig H.G., The Upper Cretaceous to Tertiary Hammada west of Errachidia (SE Morocco): A continental sequence involving paleosol development. *N. Jb. Geol. Paläontol. Abh*. 176 (1988) 187–212.

Hirayama R., Tong H., *Osteopygis* (Testudines: Cheloniidae) from the Lower Tertiary of the Ouled Abdoun phosphate basin, Morocco. *Paleontology* 46 (2003) 845–856.

Hollard H., La mise en place au Lias des dolérites dans le Paléozoïque moyen des plaines du Drâa et du bassin de Tindouf (Sud de l'Anti-Atlas central, Maroc). *C. R. Acad. Sci. Paris* 277 (1973) 553–556.

Hua S., Jouve S., A Primitive Marine Gavialoid from the Paleocene of Morocco. *J. Vertebrate Pal*. 24 (2004) 341–350.

Jouve S., Etude des Crocodyliformes fini Crétacé-Paléogène du Bassin des Oulad Abdoun (Maroc) et comparaison avec les faunes africaines contemporaines: systématique, phylogénie et paléobiogéographie. Unpubl. Thesis Muséum Nat. Hist. Nat. Paris, (2004), 651pp.

Jouve S., A new description of the skull of *Dyrosaurus phosphaticus* (Thomas, 1893) (Mesoeucrocodylia: Dyrosauridae) from the Lower Eocene of North Africa *Can. J. Earth Sci*. 42 (2005) 323–337

Jouve S., Iarochène M., Bouya B., Amaghzaz M., A new dyrosaurid crocodyliform from the Paleocene of Morocco and a phylogenetic analysis of Dyrosauridae. *Acta Palaeontologica Polonica*, 50 (2005) 581–594.

Jouve S., Bouya B., Amaghzaz M., A new species of *Dyrosaurus* (Crocodylomorpha, Dyrosauridae) from the early Eocene of Morocco: phylogenetic implications. *Zool. J. Linnean Soc*. 148 (2006) 603–656.

Kchikach A., Jaffal M., Aïfa T. Bahi L., Cartographie de corps stériles sous couverture quaternaire par méthode de résistivités électriques dans le gisement phosphaté de Sidi Chennane, Maroc. *C. R. Geosci* 334 (2002) 379–386.

Kchikach A., Andrieux P., Jaffal M., Amrhar M, Mchichi M., Bouya B., Amaghzaz M., Veyrieras T., Iqizou K., Les sondages électromagnétiques temporels comme outil de reconnaissance du gisement phosphaté de Sidi Chennane (Maroc): apport à la résolution d'un problème d'exploitation. *C. R. Geoscience* 338 (2006) 289–296.

Kellner A.W.A., Mader B.J., First report of Pterosauria (Pterodactyloidea, Azhdarchidae) from Cretaceous rocks of Morocco. *J. Vertebrate Pal*. 16 (1996) 45A.

Kellner A.W.A., Mader B.J., Archosaur teeth from the Cretaceous rocks of Morocco. *J. Vertebrate Pal*. 17 (1997) 62A.

Lapparent de Broin, F. de, African chelonians from the Jurassic to the present: phases of development and preliminary catalogue of the fossil record. *Palaeont. Afr*. 36 (2000) 43–82.

Lavocat R., Découverte de restes d'un grand dinosaurien sauropode dans le Crétacé du sud marocain. *C. R. Acad. Sci. Paris* 232 (1951) 169–170.

Lavocat R., Sur les dinosauriens du Continental Intercalaire des Kem-Kem de la Daoura, *19th Int. Geol. Congr*. 15 (1954) 65–68.

Mader B.J., Kellner A.W.A., First occurence of Anhangueridae (Pterosauria, Pterodactyloidea) in Africa. A new anhanguerid pterosaur from the Cretaceous of Morocco. *J. Vertebrate Pal*. 17 (1997) 525–527.

Mader B.J., Kellner A.W.A., A new anhanguerid pterosaur from the Cretaceous of Morocco. *Bol. Museu Nac*. 45 (1999) 1–11.

Mahler L. Record of Abelisauridae (Dinosauria: Theropoda) from the Cenomanian of Morocco. *J. Vertebrate Pal*. 25 (2005) 236–239.

Malusà M., Polino R., Cerrina Feroni A., Ferrero A., Ottria G., Baidder L., Musumeci G., Post-Variscan tectonics in eastern Anti-Atlas (Morocco). *Terra Nova* 19 (2007) 481–489.

Michard A., Eléments de géologie marocaine. *Notes Mém. Serv. Géol. Maroc* 252, 1976, 408pp.

Missenard Y., Taki Z., Frizon de Lamotte D., Benammi M., Hafid M., Leturmy P., Sebrier M., Tectonic styles in the Marrakesh High Atlas (Morocco): the role of heritage and mechanical stratigraphy. *J Afr. Earth Sci*, 48 (2007) 247–266.

Monbaron M., Russell D.A., Taquet P., *Atlasaurus imelakei* n.g., n.sp., a brachiosaurid-like sauropod from the Middle Jurassic of Morocco. *C. R. Acad. Sci. Paris* 329 (1999) 519–526.

Moutaouakil D., Giresse P., Pétrologie et environnement sédimentaires des phosphates méso-cénozoïques du bassin des Oulad Abdoun (Maroc). *Bull. Soc. Géol. Fr*. 164 (1993) 473–491.

Noubhani A., Cappetta, H., Les Orectolobiformes, Carcharhiniformes et Myliobatiformes (Elasmobranchii, Neoselachii) des bassins à phosphate du Maroc (Maastrichtien–Lutétien basal). Systématique, biostratigraphie, évolution et dynamique des faunes. *Palaeo Ichthyologica* 8 (1997) 1–327.

Pereda Suberbiola X., Bardet N., Iarochène M., Bouya M., Amaghazaz M., The first record of sauropod dinosaur from the Late Cretaceous phosphates of Morocco. *J. Afr. Earth Sci* 40 (2004) 81–88.

Prévôt L., Geochemistry, petrography, and genesis of Cretaceous-Eocene phosphorites. The Ganntour Deposit (Morocco): a type example. *Mém. Soc. Géol. Fr*. 158 (1990) 232pp.

Rhalmi M., Le Cénomano-Turonien au sud du Haut Atlas central (Bassins de Ouarzazate et de Errachidia-Boudenib-Erfoud). Sédimentologie, stratigraphie et diagenèse. Unpubl. Thesis Univ. Marrakech, 2000, 220pp.

Robert-Charrue C. 2006. Géologie structurale de l'Anti-Atlas oriental, Maroc. Thèse Univ. Neuchâtel, 180pp.

Russell D.A., Isolated dinosaur bones from the Middle Cretaceous of the Tafilalt, Morocco. *Bull. Muséum Nat. Hist. Nat*. (4) 18 (1996) 349–402.

Russell D.A., Paesler M.A., Environments of Mid-Cretaceous Saharan dinosaurs. *Cretaceous Res*. 24 (2003) 569–588.

Saddiqi O., El Haimer F.Z., Michard A., Barbarand J., Ruiz G., Mansour E.M., Leturmy P., Frizon de Lamotte D., Apatite Fission-Track discrepancies in granites from a tabular domain (Western Meseta, Morocco). Role of the age and depth of emplacement; consequences for the history of vertical movements. *Tectonophysics*, 2008, submitted.

Saint-Bezar B., Frizon de Lamotte D., Morel J.L., Mercier E., Kinematics of large scale tip line folds from the High Atlas thrust belt, Morocco. *J. Struct. Geol*. 20 (1998) 999–1011.

Sereno P.C., Dutheuil D.B., Iarochène M., Larsson H.C.E., Lyon G.H., Magwene P.M., Sidor C.A., Varricchio D.J., Wilson J.A., Predatory dinosaurs from the Sahara and Late Cretaceous faunal differentiation. *Science* 272 (1996) 986–991.

Smith B., Derder M.E.M., Henry B., Bayou B., Yelles A.K., Djellit H., Amenna M., Garces M., Beamud E., Callot J.P., Eschard R., Chambers A., Aifa T., Ait Ouali R., Gandriche H., Relative importance of the Hercynian and post-Jurassic tectonic phases in the Saharan platform: a paleomagnetic study of Jurassic sills in the Reggane Basin (Algeria). *Geophys. J. Int*. 167 (2006) 380–396.

Thiry M., Ben Brahim M., Silicifications de nappe dans les formations carbonates tertiaires du piedmont atlasique (Hamada du Guir, Maroc). *Geodinamica Acta* 10 (1997) 12–29.

Tong H., Buffetaut E., A new genus and species of pleurodiran turtle from the Cretaceous of southern Morocco. *N. Jb. Geol. Paläontol. Abh* 199 (1996) 133–150.

Tong H., Hirayama R., 'A New Species of *Tasbacka* (Testudines: Cryptodira: Cheloniidae) from the Paleocene of the Ouled Abdoun Phosphate Basin, Morocco.' *Neues Jahrb. Geol. Paläontol. Mh*., 5 (2002) 277–294.

Tong H., Hirayama R., First Cretaceous dermochelyid turtle from Africa. *Revue Paléobiol*. Vol. spécial 9 (2004) 55–59

Trappe J., Microfacies zonation and spatial evolution of a carbonate ramp: marginal Moroccan phosphate sea during the Paleogene. *Geol. Rundsch*. 81 (1992) 105–126.

Wellnhofer P., Buffetaut E., Pterosaur remains from the Cretaceous of Morocco. *Pal. Zeitsch*. 73 (1999) 133–142.