that extends between the marine Areny Fm (upper Maastrichtian) and the Alveolina Limestone (Ypresian). The foreland basin cycle, as described here, finish earlier in the top of the Danian stage in coincidence with a regional calcimorphic paleosol (Colmenar—Tremp horizon of Eichenseer 1987) developed in the context of a generalized emersion of the carbonate platforms and lagoons (Lopez-Martinez et al. 2006). The Tremp sequence in the Serres Marginals begins with a transitional interval made of shales and marls of Danian age (López-Martínez et al. 2006) that separates the alluvial beds of the Reptile Sandstone from the Fontllonga Limestone. The age of the transitional beds in the base of the Danian allows correlating these deposits with the “upper calcareous breccia” and associated red beds that onlap the frontal limb of the Sant Corneli anticline in the locality of Sallent (Ullastre and Masriera 2006). In the wedge-top basin the Tremp sequence starts with the Talarn red beds made of overbank lutites and channels filled by conglomerates and sandstones (Cuevas 1992). Pujalte and Schmitz (2005) placed this unit in the Danian, which makes the red beds equivalent to the shallow marine Laspún Fm made of limestones, dolomites, sandstones and shales attributed to the Danian (Garrido-Megías and Ríos-Aragües 1972; Robador et al. 1990; Lopez-Martinez et al. 2006).

The upper part of the sequence is well defined in the Serres Marginals by a package of massive limestones that may reach 100 m in thickness (Fontllonga Fm or unit U3). The limestones are often recristallized and contain abundant *Microcodium*, ostracoda and charophyta representing lacustrine environments. The lateral equivalents in the Montsec area are the red beds of the Talarn Fm that grade conformably upwards into the Suterranya Limestone (Cuevas 1992) made of micritic limestones with *Microcodium,* stratigraphically similar to the Fontllonga Fm. The Suterranya Limestone continues in discontinuous lenses through the eastern part of the wedge-top basin (Tremp Syncline). Further to the northwest the thickness increases and the lacustrine facies change to shallow-marine dolomites that may be correlative with the Salarons Fm of the western Pyrenees (Robador et al. 1990; Robador 2005).

7.4 The West Iberian Continental Margin

Callapez PM, Barroso-Barcenilla F, Segura M, Soares AF, Dinis PM and **Marques JF**

The Late Cretaceous evolution of the West Iberian Continental Margin in the Estremadura and Beira Litoral Portuguese areas and its correlation with contemporaneous Atlantic and Tethyan sedimentary basins of northwestern and southern Europe and northern Africa, including many contexts of shallow carbonate platforms with highly diverse biotas, has long been a main subject for studies on Mesozoic stratigraphy and paleontology. Most researches have benefited from the existence of a diverse stratigraphic record with several highly fossiliferous units, ranging from the Cenomanian to the Maastrichtian and available in many onshore outcrops (e.g. Choffat 1885, 1900; Soares 1966, 1972, 1974, 1980; Berthou 1973, 1984a, b; Soares et al. 1982; Cunha 1992; Lauverjat 1992; Cunha and Reis 1995; Callapez 1998; Dinis 1999; Rey et al. 2006; Dinis et al. 2008; Callapez et al. 2010; Kullberg et al. 2013). To the development of such ample and significant setting also has contributed the hinge location of the western border of the Iberian Plate in front of the expanding proto-Atlantic Ocean, in the first line of the climatic and biogeographic transitions between the northern branch of the Tethyan Realm and the European Temperate Domain, especially during the major Late Cretaceous transgressions and highstands (e.g. Haq et al. 1988; Hart 1990; Hancock et al. 1993; Hardenbol et al. 1998; Haq 2014). This context was a recurrent way for oceanic events and exchanging faunas, with repercussions on the stratigraphic record and its fossil assemblages (e.g. Lloyd 1982; Néraudeau and Mathey 2000; Hay 2008; Callapez et al. 2015).

It is widely accepted that, in many aspects, the Cretaceous World was substantially different from our present day, full of geological and biotic events with remarkable developments (e.g. Skelton et al. 2003). By this way, examples such as the paleogeographic scenery of a flooded Europe and North-Africa during the Late Cretaceous, with most of their emerged areas reduced to insular landscapes (e.g. Dercourt et al. 2000), are also interesting motivations for new researches, allowing the discovery of more aspects of the prevailing climates, lands and life. For the geological history of Iberia and its western border, the Late Cretaceous was also an important interval for the tectono-sedimentary evolution of the plate, when the Mesozoic successions of the Lusitanian Basin were overlain by a thick sedimentary succession that recorded the transition to a post-rift passive setting (e.g. Wilson 1979, 1988; Wilson et al. 1989; Hiscott et al. 1990; Pinheiro et al. 1996; Alves et al. 2003, 2009; Rey et al. 2006) (Fig. 7.24).

In the next paragraphs, a concise analysis of the Upper Cretaceous post-rift infill of the West Iberian Continental Margin onshore areas is presented, together with a general overview of its main units and paleontological contents (Figs. 7.25a, 7.26, and 7.27). These outlines are also preceded by a short description of the previous Aptian-Albian series recorded from these areas, considering that the Atlantic syn-rift tectonic interval finished earlier at the West Iberian Continental Margin than in other basins of Iberia, as suggested by its intra-Aptian major unconformity, and upper Aptian to Cenomanian nearly continuous stratigraphic record. Several comparisons are also made with the nearest Spanish Iberian Basin, where many analogies stand out with

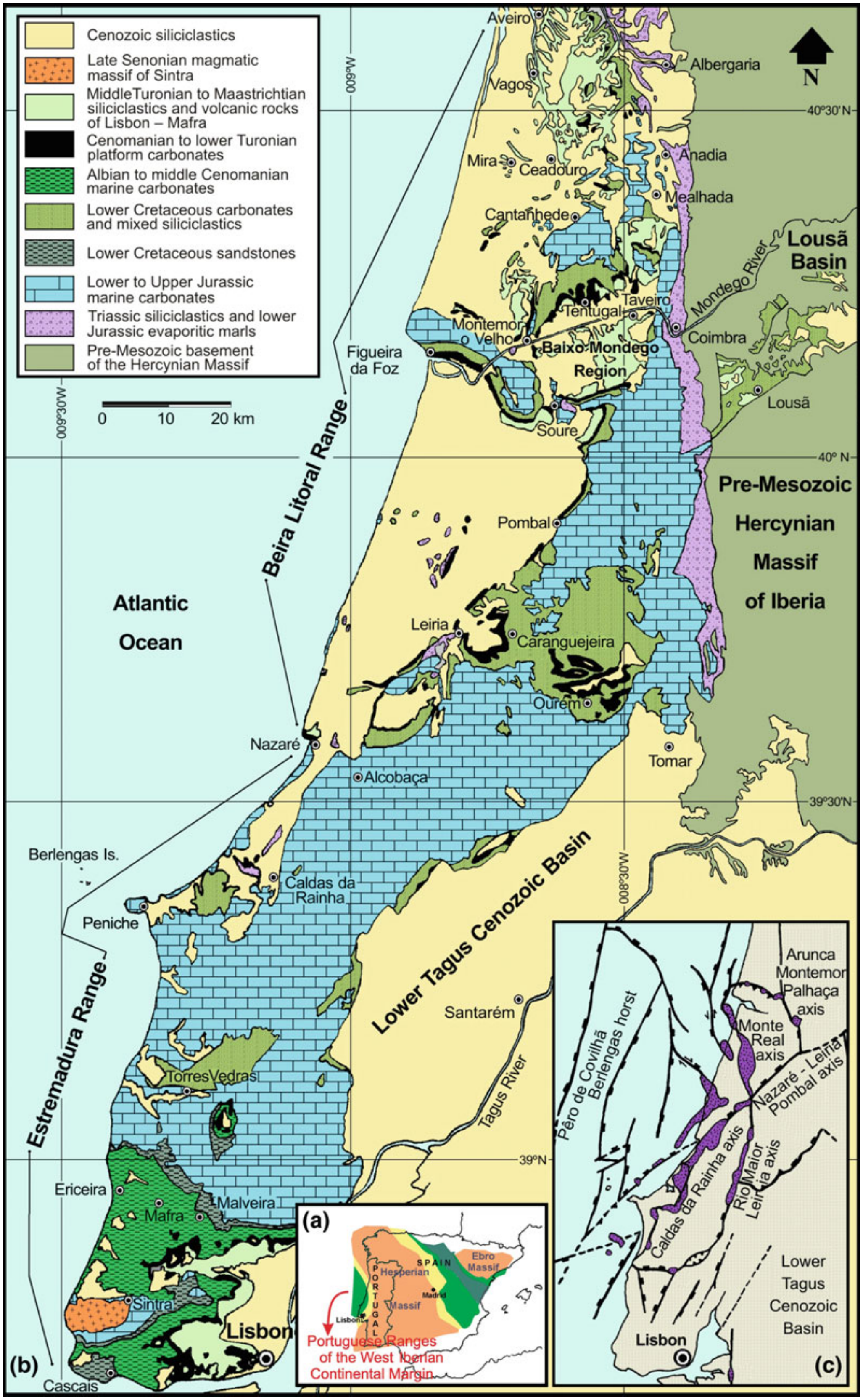

Fig. 7.24 **a** Location of the Portuguese Ranges (West Iberian Continental Margin) in the Iberian Peninsula. Distribution of the emerged land (orange), coastal areas (yellow), and marine carbonates (shallow—light green; deeper—dark green) during the Cenomanian-Turonian transition. **b** Geographical and geological setting of the Beira Litoral and Estremadura provinces of west central Portugal, corresponding to the onshore sectors of the Portuguese ranges of the West Iberian Continental Margin. **c** Simplified structural setting of the studied areas, with location of the main tectonic and diapiric axes related to the Cretaceous depositional environments and its paleogeographical evolution

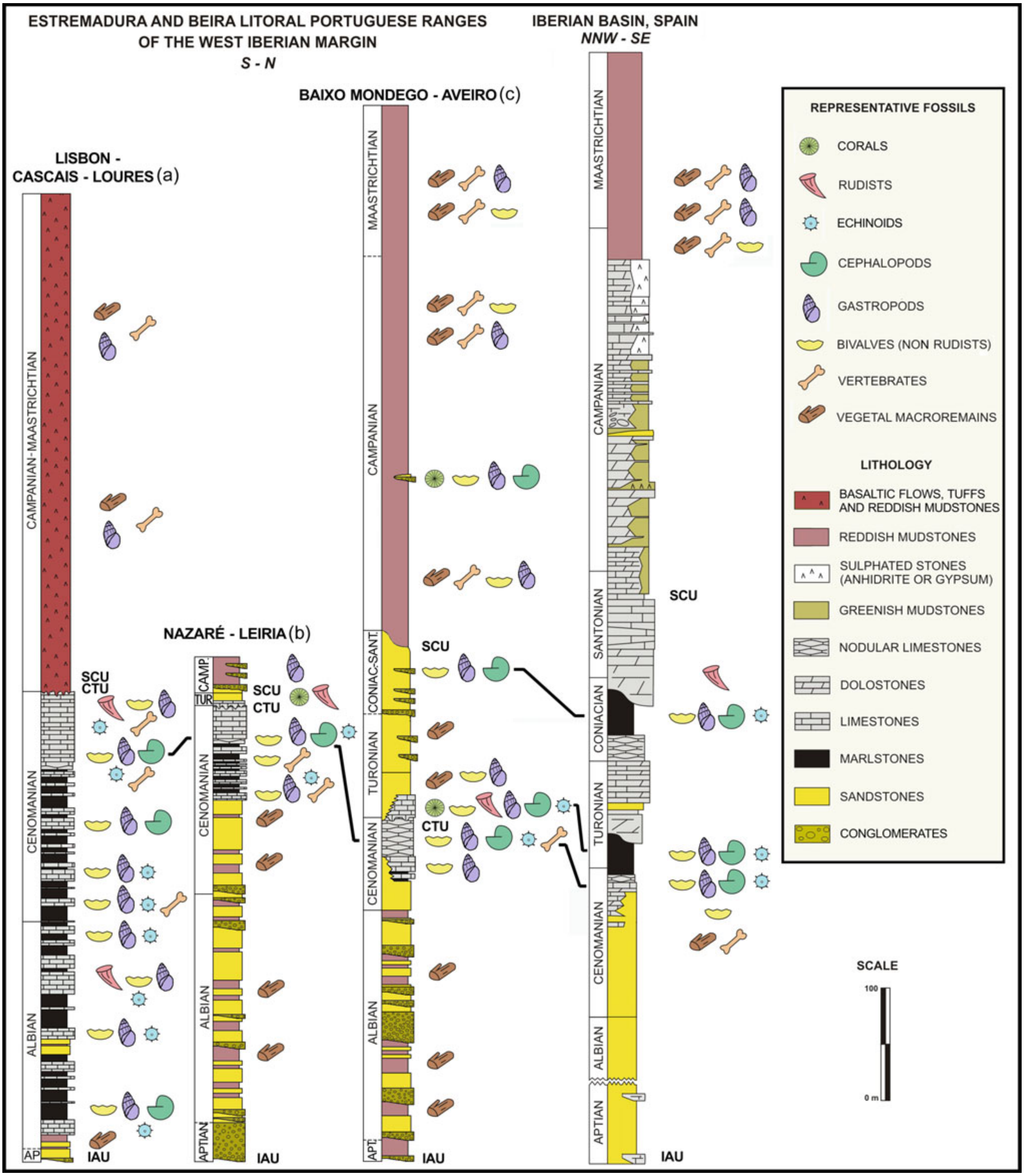

Fig. 7.25 Synthetic stratigraphic columns and most representative macrofaunal fossil groups of the Aptian-Maastrichtian sedimentary successions of West Portugal in the Estremadura and Beira Litoral ranges, including **a** the southern areas of Lisbon-Cascais-Loures with marine Aptian and lower Cenomanian, and Campanian volcanism; **b** the central areas of Nazaré-Leiria with coral and rudist reefs; and **c** the Baixo Mondego and Aveiro areas with upper Cenomanian and Lower Turonian ammonite facies, and thick successions of Campanian-Maastrichtian pelitic facies. On the right, a synthetic section corresponding to the Upper Cretaceous of the Iberian Basin in Spain has been included for comparison, including correlation based in ammonite assemblages. IAU—Intra-Aptian Unconformity; CTU—Cenomanian-Turonian Unconformity; SCU—Santonian-Campanian Unconformity

the main stratigraphic intervals and the biotic assemblages more relevant for biostratigraphic precisions and paleoenvironmental models (Fig. 7.25b).

Special emphasis goes to the middle—upper Albian, Cenomanian and Lower Turonian "West Portuguese Carbonate Platform", the largest post-rift carbonate unit of the Portuguese Estremadura and Beira Litoral ranges (e.g. Berthou 1984b; Callapez 2004, 2008a, b) (Fig. 7.28). The remaining record is mainly siliciclastic, with several coarse alluvial units related to the tectonic uplift and erosion of the basement reliefs of Iberia (e.g. Dinis 1999, 2001; Dinis et al. 2002, 2016b), a few marginal marine transgressive sequences with precise biostratigraphic markers (e.g. Lauverjat 1982; Barroso-Barcenilla et al. 2013), and a Campanian—Maastrichtian thick succession of alluvial and lagoonal "Garumnian" reddish lutites (e.g. Antunes 1979; Reis 1981; Antunes and Broin 1988) (Figs. 7.24a, b and 7.25a).

7.4.1 Summary of Researches

The first studies on the Cretaceous of Portugal go back to Sharpe (1849, 1850a, b), who described many relevant marine taxa, including the rudist and *Tylostoma* assemblages of Lisbon and Coimbra. They were followed by major contributions of Choffat (e.g. 1885, 1886, 1891, 1894, 1896, 1897a, b, c, 1898, 1900; Choffat 1901–1902). This researcher detailed an overall stratigraphic setting for the Cretaceous of Portugal, describing its main units and faunal groups, with additional contributions by Loriol (1887–88) for the echinoderms, Saporta (1894) for plant remains, Sauvage (1897–1898) for the vertebrates, and Cotter (1901) for Campanian terrestrial gastropods.

Following the stratigraphic nomenclature and intervals proposed by Choffat (*ibidem*), subsequent studies on the Cretaceous series were mostly focused on the Mesozoic and Cenozoic of the Algarve region, in the south of the country, and Estremadura and Beira Litoral, in central West Portugal (e.g. Costa 1937, 1940a, b; Teixeira 1948) (Fig. 7.24b, c). These areas have been intensively researched from the 1960's onwards, mostly by Portuguese and French workers who upgraded the previous stratigraphic setting by introducing new petrographic and micropaleontological approaches. Rey (e.g. Rey 1972, 1979, 1992, 1993, 2006, 2010) and collaborators (e.g. Rey et al. 1977, 2003, 2006, 2009) worked with Lower Cretaceous successions of Algarve and southern Estremadura, where most units are marginal marine with mixed carbonate platform and distal alluvial facies, providing a detailed stratigraphic background and sequential analysis. In the Upper Cretaceous post-rift series, mostly absent from Algarve and recorded in the onshore sectors of the Portuguese ranges of the West Iberian Continental Margin, there was also a considerable work developed in the Baixo Mondego region, by Soares et al. (e.g. Soares 1960, 1966, 1968a, b, 1972, 1980; Soares and Devriès 1967; Soares and Marques 1973; Lapa 1979; Soares et al. 1982, 1983, 1985, 1986; Barbosa et al. 1988), together with Romariz (1960), Groot and Groot (1961), Antunes and Pais (1978), Barbosa (1981), Reis (1981) and Rocha et al. (1981), among several other relevant contributions. At the same time, Ferreira (1961), Berthou et al. (e.g. Berthou 1968a, b, 1973, 1978, 1984a, b, c, d; Berthou and Philip 1973; Berthou and Termier 1973; Berthou and Lauverjat 1974, 1975, 1976, 1979; Berthou et al. 1975, 1979, 1985; Gutiérrez and Lauverjat 1978; Lauverjat 1978, 1982; Lauverjat and Pons 1978; Amédro et al. 1980; Moron 1981), and Jonet (1981), among others, extended their studies to several sectors of the onshore, with emphasis on sections of southern Estremadura.

From the 1990's onwards, the Aptian—Turonian carbonate platform units and their faunas were studied by Callapez and Soares (1991, 1993, 2001), Callapez (1992, 1998, 1999a, b, 2001, 2003a, b, 2004, 2008a, b), Reis et al. (1997), Reis (1998), Hart et al. (2005), Cabral et al. (2008), Callapez et al. (2010, 2013, 2014, 2017), Barroso-Barcenilla et al. (2011a, 2015) and Coimbra et al. (2016), among others, with the development of new biostratigraphic data, and integrated paleoecological models. The post-rift alluvial units have been also focused by Reis and Cunha (1989), Dinis and Trincão (1991, 1995), Dinis (1999, 2001) and Soares et al. (2007), and from a palynological point of view by Friis et al. (1999), Heimhofer et al. (2005), Mendes et al. (2014) and Dinis et al. (2016a, b). As stratigraphic syntheses for the Upper Cretaceous, also stand out the works of Cunha (1992), Cunha and Reis (1995), Rey et al. (2006), Dinis et al. (2008) and Segura et al. (2014).

7.4.2 Main Episodes in the West Iberian Continental Margin

7.4.2.1 The Late Aptian—Albian Post-Rift Alluvial Sedimentation

The Upper Cretaceous post-rift series from the Portuguese ranges of the West Iberian Continental Margin have been extensively recorded in stratigraphic continuity with previous upper Aptian—Albian alluvial, marginal marine and carbonate platform successions. These are mostly developed in the southern areas of the onshore, between Lisbon, Cascais, Ericeira and Torres Vedras, where the Lower Cretaceous syn-rift marine record of the Lusitanian Basin is bounded upwards by a major intra-Aptian unconformity (IAU) (Figs. 7.24a, b, and 7.26a). Its stratigraphic expression is the result of important tectonic readjustments that affected the Iberian Plate, including the uplift of several sectors of the Variscan basement and the West Continental Margin (e.g. Rey et al. 2006; Dinis et al. 2016b). These

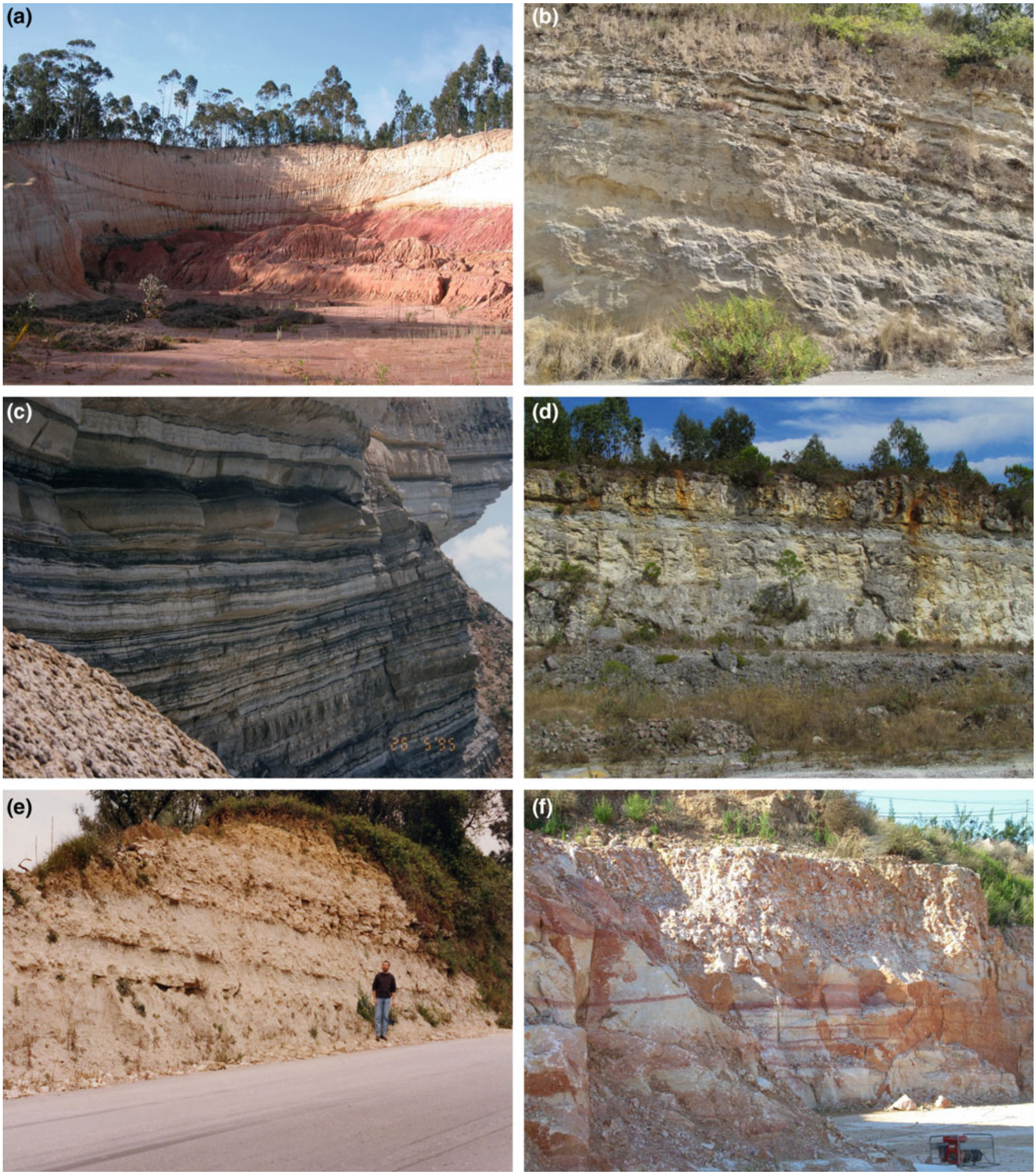

Fig. 7.26 Photographic views of representative outcrops with Cretaceous units from the Portuguese Ranges of the West Iberian Continental Margin. **a** Upper Aptian-Albian of Carritos, Figueira da Foz, showing the basal unconformity of the Figueira da Foz Fm with a large channel figure and yellowish coarse sandstones and conglomerates overlying Upper Jurassic reddish pelites. **B** Middle Cenomanian of Costa d'Arnes, Alfarelos, showing the transition of the upper member of the Figueira da Foz Fm to the first transgressive beds of the West Portuguese Carbonate Platform, locally represented by the Costa d'Arnes Fm. **C** Middle to Upper Cenomanian of Nazaré, showing the transitions of lagoonal marly facies to massive limestones with fish remains. **d** Upper Cenomanian of Salmanha, Figueira da Foz, showing the *Vascoceras* rich limestone beds of units "H", "I" and "J". **e** Basal upper Cenomanian of Olival, Ourém, showing the typical transgressive marly nodular limestones with the caphalopods *Neolobites* and *Lessoniceras*. **f** Upper Cenomanian of Negrais, Sintra, showing the rudist beds with *Caprinula* bioherms explored for ornamental stone

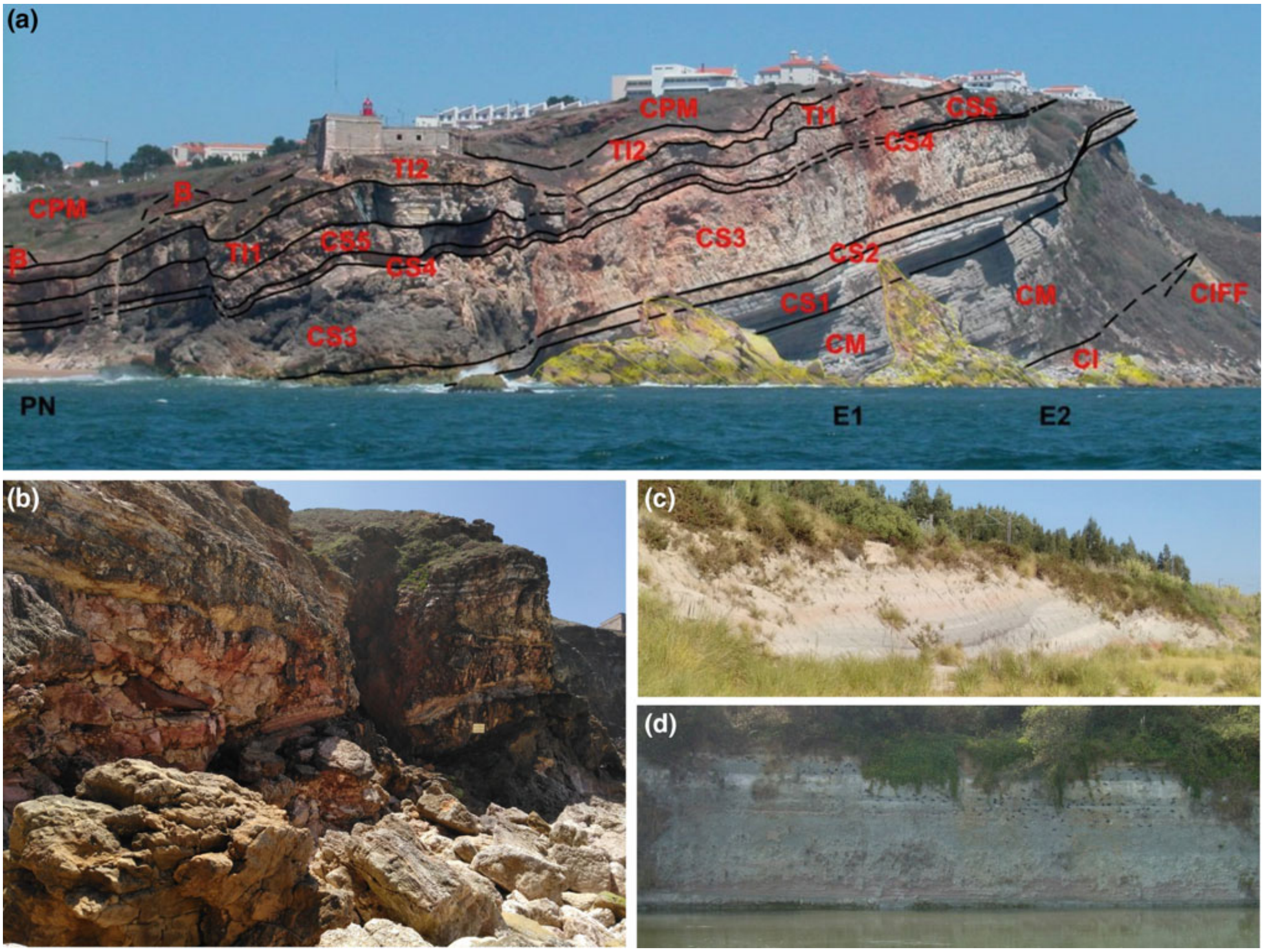

Fig. 7.27 Photographic views of representative outcrops with Cretaceous units from the Portuguese Ranges of the West Iberian Continental Margin. **a** Westside seascape of the Nazaré promontory with representation of the Upper Cretaceous main units (CIFF—Lower Cenomanian sandstones; CIFF—lower Cenomanian carbonates; CM—middle Cenomanian lagoonal carbonates (Unit “B”); CS1—upper Cenomanian nodular limestones with ammonites (Unit “C”); CS2—upper Cenomanian limestones (units “D” and “E”); CS3—upper Cenomanian calcarenites with *Caprinula* remains (units “F”, “G” and “H”); CS4—Marls with thalassinoid burrows (Unit “I”); CS2—uppermost Cenomanian limestones with *Durania* (Unit “J”); TI1—Endokarst and lower Turonian micaceous limestones with debris of *Radiolites* (Unit “L”); TI2—Coarse alluvial limestones with abraded rudist debris. β—Basaltic intrusions; CPM—Campanian-Maastrichtian conglomerates and reddish clays with terrestrial gastropods. **b** Detail of the Cenomanian-Turonian transition in the northern beach of Nazaré. **c** upper Campanian of Vagos, Aveiro, showing greenish and reddish lagoonal pelites of the Viso Fm, which yield diverse vertebrate remains typical of the “Garum” facies. **d** Maastrichtian of Aveiro, showing the “Garum” greenish lagoonal pelites of the Aveiro Fm, which have yielded *Rosasia* turtles and fish debris

major paleogeographical changes marked the beginning of the post-rift tectono-sedimentary history of the West Iberian Continental Margin, with the widespread deposition of alluvial conglomerates and coarse sandstones (Dinis 2001). These siliciclastic lithosomes that overly the Jurassic and marginal marine Lower Cretaceous sedimentary infill of the Lusitanian Basin are always present as the basal succession of the upper Aptian—Maastrichtian passive series described in the next paragraphs (Fig. 7.25).

The above mentioned IAU breakup unconformity is interpreted as the stratigraphic response to the last extensional episode that affected the West Iberian Continental Margin, after isostatic and thermal readjustments at the periphery of the Atlantic rift axis, and that also resulted in tectonic uplifting on the Iberian Plate and its marginal blocks (e.g. Hiscott et al. 1990; Dinis 1999). Due to that major event, this post-rift margin gradually evolved to a passive context where thermal subsidence and sea-level changes became the most effective controls on the depositional processes.

The facies architecture of the upper Aptian—Cenomanian siliciclastic series that overlie the IAU, suggests that the main alluvial drainage was directed to southwest, as a result of the erosion of uplifted reliefs with Variscan rocks located in central Iberia, and marginal to the basinal ranges (Rey 1972, 1979; Cunha and Reis 1995; Dinis 1999, 2001). The main concerned units are the Rodízio Fm in southern Estremadura (Rey 1992, 1993), the Figueira da Foz Fm in central and northern Estremadura (Dinis 1999, 2001), and the Lomba do Alveite Fm in the continental Lousã Basin (Reis and Cunha 1989; Cunha 1992). All these units record a long stratigraphic interval of continental sedimentation, ranging from the upper Aptian to the Albian, in the first example, but reaching the middle and upper Cenomanian for the remaining units (e.g. Dinis and Trincão 1991, 1995). Diverse fossil palynomorphs and macroplant remains have been used as biostratigraphic markers for these units, including findings of new angiosperms (e.g. Groot and Groot 1962; Moron 1981; Friis et al. 1999; Heimhofer et al. 2005; Mendes et al. 2014). Their upper boundary has been drawn by micro and macrofossil elements that were sampled from the first marginal marine beds of the transgressive carbonate platform sequences located above the siliciclastic successions (e.g. Soares 1966, 1972; Rey 1972, 2006, 2010; Berthou 1973, 1984a, b, c; Lauverjat 1982).

The Figueira da Foz Fm comprises two basal members related to proximal and distal positions in the paleogeographic setting, both equivalents to the basal member of the Rodízio Fm from southern Estremadura. The Calvaria Member comprises conglomerates and coarse sandstones originated from alluvial braided systems that gradually change westwards, to sandstones and lutites with interbedded carbonates of the Famalicão Member (Dinis 1999, 2001). This succession is followed by a new increment on clastic sedimentation, with progradation of braided alluvial systems with sandy-conglomeratic facies (Salgueira Member). This unit laterally changes westwards to alluvial sandstones related to moderate sinuosity flows (Gondemaria Member), and to prodelta mudstones and sandstones (Faneca Member) (Dinis 1999, 2001). They have been considered as equivalent to the upper member of the Rodízio Fm.

Facies architecture on the upper part of the Figueira da Foz Fm clearly shows a gradual evolution to a marginal marine context, more effective after the middle Albian, with replacement of the previous alluvial paleoenvironments by transitional systems, with deltaic, estuarine and mixed carbonate-siliciclastic inner platform settings (e.g. Rey 2006, 2010; Rey et al. 2006). This transition is recorded by the Caldelas and Cachucho members, showing a succession of braided deltaic sandstones with interbedded carbonates lying on the top (Dinis 1999, 2001).

The sequence organization of the Rodízio Fm and Figueira da Foz Fm suggests the individualization of three 3rd order cycles during the late Aptian and early to middle Albian, where the eustatic control was probably enhanced by extensional events occurred on the Galiza banks, northwestern Spain (Dinis et al. 2002; Rey et al. 2003, 2006, 2009; Rey 2006, 2010).

7.4.2.2 The Albian—Middle Cenomanian Carbonate Platform System

From the middle Albian onwards, a carbonate platform gradually replaced the fluvio-deltaic units above mentioned (e.g. Rey et al. 2006) (Fig. 7.25a). The first transgressive beds with mixed carbonate—siliciclastic facies and shallow marine fossil assemblages are diachronic, reaching the early late Cenomanian, when all the onshore sectors of the Portuguese ranges of the West Iberian Continental Margin were finally occupied by the so-called West Portuguese Carbonate Platform (e.g. Soares 1974; Lauverjat 1982; Berthou 1984a, b, c; Callapez 1998, 2008a). During the middle and late Albian, and the early Cenomanian, the marginal marine carbonate sedimentation was confined to some sectors of southern Estremadura, mostly located around Lisbon, Cascais and Ericeira, where at least eight 3rd order transgressive—regressive depositional sequences have been identified, with biostratigraphic markers, mostly foraminifera, providing accurate temporal precision (e.g. Rey 1972, 1979, 2006, 2010; Berthou 1973, 1984b, c; Rey et al. 1977, 2006).

The middle Albian to middle Cenomanian carbonate succession was defined as representative of the “Bellasian”, a local stage proposed by Choffat (1885, 1886, 1900) and commonly used by subsequent authors. It is organized in a set of four units with mixed and carbonate facies and Tethyan faunal assemblages, including rudist buildups and oyster biostromes typical of inner to middle shelf environments (e.g. Rey 1972, 1979; Rey and Cugny 1977). The basal “Bellasian” units with *Knemiceras uhligi* and *Polyconites subverneuili* have a middle to late Albian age based in their orbitolinid content (Rey et al. 1977; Berthou and Schroeder 1979; Rey 1979), and their depositional architecture and diachronic boundaries suggest a lateral transition from an open middle shelf to a more restricted rimmed inner shelf, with small rudist fringes and a rich and diverse benthic fauna, suggesting a markedly transgressive context (Rey and Cugny 1977). The following units with *Ilymatogyra pseudafricana* and *Harpagodes incertus*, respectively record the lower and middle Cenomanian. In a lithostratigraphic sense, the first two units where redefined as the Galé Fm (Rey 1992), and the following as the Bica Fm (Dinis et al. 2008).

The *Ilymatogyra pseudafricana* unit is very distinctive due to the abundance of biostromes with this species, *Ceratostreon flabellatum* and other oyster-like bivalves. These rather restricted inner shelf sequences are more developed in southern Estremadura (Choffat 1900; Berthou 1973, 1984b, c), but also occur in the lower part of the Nazaré section (Fig. 7.27a). They are characterized by fossil assemblages of moderate diversity, with infaunal bivalves, echinoids, turtles

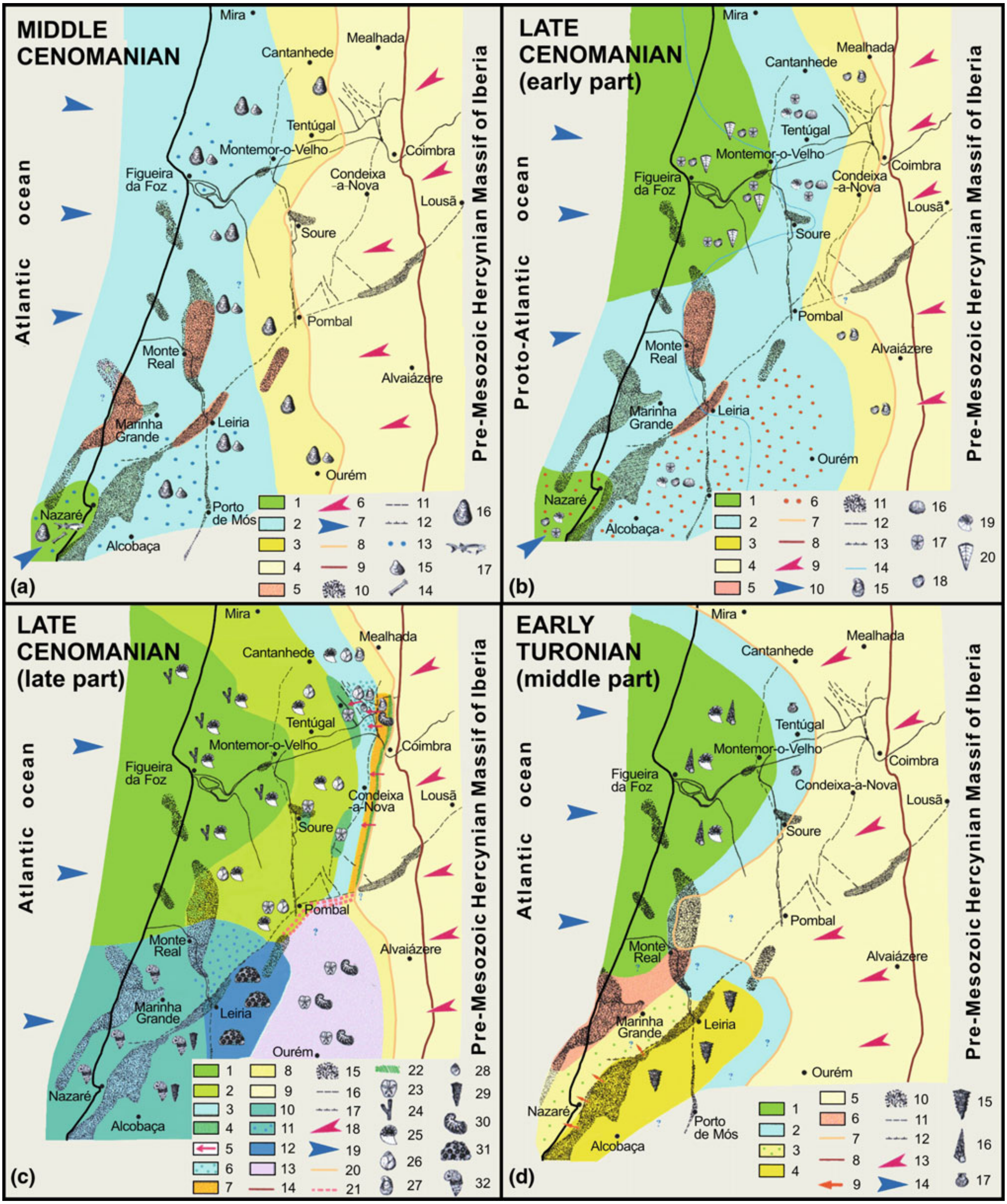
MIDDLE CENOMANIAN
Atlantic ocean
Pre-Mesozoic Hercynian Massif of Iberia
Mira
Mealhada
Cantanhede
Tentúgal
Montemor-o-Velho
Coimbra
Figueira da Foz
Condeixa -a-Nova
Lousã
Soure
Pombal
Monte Real
Alvaiázere
Marinha Grande
Leiria
Ourém
Nazaré
Porto de Mós
Alcobaça
(a)
LATE CENOMANIAN (early part)
Proto-Atlantic ocean
(b)
LATE CENOMANIAN (late part)
(c)
EARLY TURONIAN (middle part)
Condeixa-a-Nova
(d)

Fig. 7.28 Aspects of the paleogeographic evolution of the West Portuguese Carbonate Platform in the Beira Litoral and northern Estremadura ranges of the West Iberian Continental Margin, in Portugal, during the Cenomanian and Turonian stages. **a** middle Cenomanian (1: Shallow subtidal lagoon with laminated muds. 2: Inner shelf with mixed sedimentation and low faunal diversity. 3: Tidal flats with coarse sands. 4: Alluvial plain with braided drainage. 5: Emerged areas and shoals. 6: Clastic influx. 7: Direction of marine incursion. 8: Shoreline. 9: Iberian Massif western border. 10: Diapiric axes. 11: Main faults. 12: Nazaré-Leiria-Pombal axis. 13: Ostracod rich facies. 14: *Anisocardia* communities. 15: Turtles and crocodiles. 16: *Gyrostrea* communities. 17: Fish species). **b** early part of the late Cenomanian (1: Middle to outer shelf with highly diverse faunas of *Pycnodonte*, ammonites and echinoids. 2: Middle shelf with diverse faunas, including ammonites and nautiloids. 3: Inner shelf with mixed sedimentation. 4: Braided alluvial plain with micaceous sands. 5: Shoals. 6: Alveolinid's rich carbonate muds. 7: Shoreline; 8: Iberian Massif western border. 9: Clastic influx. 10: Direction of marine incursion.11: Diapiric axes. 12: Main faults. 13: Nazaré-Leiria-Pombal axis. 14: Boundary of *Praealveolina* carbonate rich muds. 15: Exogyrinidae oyster's communities. 16: *Heterodiadema* and related epifaunal echinoids. 17: *Hemiaster* infaunal echinoids. 18: *Pycnodonte* communities. 19: *Neolobites vibrayeanus*. 20: *Pinna* communities). **c** late part of the late Cenomanian (1: Middle to outer shelf with *Vascoceras* ammonites and ahermatypic branching corals. 2: Middle shelf with *Vascoceras* ammonites and diverse benthic faunas with *Tylostoma*, oysters and pectinids. 3: Inner shelf with mixed carbonate and micaceous sedimentation. 4: Upper subtidal oxygenated substrates with *Hemiaster* echinoids and *Thalassinoides* burrows. 5: Tidal channels. 6: Fault controlled barrier areas. 7: Restricted marine coastal lagoons. 8: Tidal flat with mixed micaceous sedimentation. 9: Braided alluvial plain with micaceous sands. 10: Calcarenitic shoals with patch-reefs of *Caprinula* rudists. 11: Fore-reef slope. 12: Reef complex with massive and branched corals, including Microsolenidae. 13: Inner-reef lagoons with oysters and echinoids. 14: Iberian Massif western border. 15: Diapiric axes. 16: Main faults. 17: Nazaré-Leiria-Pombal axis. 18: Clastic influx. 19: Direction of marine incursion. 20: Shoreline. 21: Barrier shoals. 22: Areas with adapted seashore vegetation. 23: *Hemiaster* infaunal echinoids. 24: Deep water communities with ahermatypic branching corals. 25: *Vascoceras* ammonites. 26: *Tylostoma* gastropods. 27: *Rhynchostreon* oysters. 28: *Ampullina* gastropods. 29: *Radiolites* rudists. 30: *Ceratostreon* oysters. 31: Reef communities with hermatypic corals. 32: Reef communities with *Caprinula* rudists). **d** middle part of the early Turonian (1: Open middle shelf with reoriented *Turritella* concentrations. 2: Inner shelf with prograding micaceous sands. 3: Middle shelf with mixed sedimentation and rudist debris. 4: Middle shelf shoals with biostromes of *Radiolites* rudists. 5: Braided alluvial plain with micaceous sands. 6: Emerged areas and shoals. 7: Shoreline. 8: Iberian Massif western border. 9: Coarse bioclastic influx 10: Diapiric axes. 11: Main faults. 12: Nazaré-Leiria-Pombal axis. 13: Clastic influx. 14: Direction of marine incursion. 15: *Radiolites* biostromes. 16: *Turritella* communities. 17: *Syncyclonema* communities)

and fishes, thus suggesting a slightly more open environment of lagoon or littoral plain, located in a more distal paleogeographic context (Callapez 1998; Callapez et al. 2014).

At the middle Cenomanian, the transgressive onlap was much more evidenced (Fig. 7.26b), and the marginal marine carbonate facies were expanded to the central and northern ranges of the continental margin, located in Estremadura and Beira Litoral (Fig. 7.28a). In these onshore areas, the interval recorded by the unit with *Harpagodes incertus* suggests the existence of large spaces of inner shelf environments occupied by shallow domains of littoral plains and restricted lagoons with oysters (mostly *Gyrostrea ouremensis*) and scarcely diverse benthic faunas (Fig. 7.26c).

A similar succession was recorded in the Spanish Iberian Basin, where the widespread sandstones of the Utrillas Fm, with sporadic vegetal and vertebrate remains, were progressively replaced by carbonate deposits of shallow platform containing abundant marine molluscs (e.g. Segura et al. 2010, 2016; Torices et al. 2012; Barroso-Barcenilla et al. 2016) (Fig. 7.25b). See Sect. 7.2 for details.

7.4.2.3 The Early Late Cenomanian Transgressive Event

The 3rd order depositional sequence UZA-2.4 (Haq et al. 1988) has an expressive record in the West Portuguese Carbonate Platform (WPCP), where its maximum flooding surface corresponds to the generalization of fully marine carbonate facies rich of stenohaline invertebrates, including many cephalopods and echinoids (Fig. 7.25a). By this time, the platform reached its maximum extent on the onshore, fully occupying the present-day Estremadura and Beira Litoral ranges (Fig. 7.28b). Nodular limestones and marly limestones with the nautiloid *Angulithes mermeti* and an ammonoid assemblage dominated by *Neolobites vibrayeanus*, together with *Calycoceras naviculare* and rare *C. guerangeri*, are present elsewhere (Berthou 1984c, d; Berthou et al. 1985; Callapez 1998, 2004; Callapez and Soares 2001) and allow a precise correlation with the standard zone of *Calycoceras guerangeri* (Kennedy 1984) (Fig. 7.26e). This succession is of major importance for interregional correlations, namely with other European and North-African basins, where the widespread of *Angulithes* and *Neolobites* seems to be a major biotic event on the Tethyan Realm, occurred at the beginning of the late Cenomanian. Of special interest is the record in the Iberian Basin (Castilian Ramp in Sect. 7.2), where similar cephalopod assemblages are also well represented, and the outstanding diversity of the benthic fauna, mostly bivalves, gastropods and echinoids has similarity with the Portuguese platform and North-Africa (e.g. Barroso-Barcenilla et al. 2011a; Segura et al. 2014) (Fig. 7.25b).

The late Cenomanian benthic faunas of the WPCP have been extensively studied (e.g. Choffat 1886, 1898, 1901; Loriol 1887–1888; Moura 1958; Soares 1966, 1968a, b, 1972; Soares and Devriès 1967; Berthou 1973; Berthou and Termier 1973; Soares and Marques 1973; Callapez and Soares 1991, 1993; Callapez 1992, 1998). The highly diverse assemblages known from the basal Cenomanian parasequences with *Angulithes* and *Neolobites* are rich in the bivalves *Neithea dutrugei*, *N. hispanica*, *Exogyra (Costagyra) olisiponensis*, *Ceratostreon flabellatum* and *Rhynchostreon suborbiculatum*, the gastropods *Aporrhais costae*, *Harpagodes incertus*, *Cimolithium tenouklense*, *Tylostoma ovatum*, *T. torrubiae* and *Plesioplocus olisiponensis*, and the echinoids *Diplopodia variolare*, *Anorthopygus michelini*, *Heterodiadema ouremense*, *H. lybicum*, *Hemiaster lusitanicus* and *H. scutiger*. They occur side to side with abundant benthic foraminifera, including large alveolinids (Berthou 1973, 1984a; Lauverjat 1982; Hart et al. 2005).

7.4.2.4 The Middle Late Cenomanian Rimmed Carbonate Platform

The sedimentary succession correlative to the middle part of the upper Cenomanian stands out by a noteworthy diversity of shelf facies in the carbonate platform, suggesting the individualization of new paleogeographical domains in the West Portuguese Carbonate Platform (WPCP) after the beginning of deposition of the 3rd order sequence UZA-2.5 (Haq et al. 1988; Barroso-Barcenilla et al. 2011a; Segura et al. 2014) (Figs. 7.25a, and 7.28c). There is evidence of significant structural control on sedimentation during this interval, with the reactivation of several N–S and NE–SW tectonic axes, with diapiric activity known since the Jurassic. They include the structures of (1) Arunca—Montemor—Palhaça, (2) Rio Maior—Leiria, (3) Marrazes—Monte Real—Carriço, (4) Caldas da Rainha—Valado de Frades, (5) Nazaré—Leiria—Pombal, and (6) Pero da Covilhã—Berlengas (Berthou 1973, 1984b; Berthou and Lauverjat 1979; Callapez 1998), whose diastrophic activity resulted in flexures and slightly uplifted areas that contributed to divide the platform into several open or rimmed, and outer to inner shelf areas, with distinct facies and fossil assemblages (Fig. 7.24c).

As first noted by Choffat (1896, 1897a, b, c, 1900), the areas of the Portuguese Estremadura located between Lisbon and the Nazaré—Leiria—Pombal axis are characterized by the widespread of "rudist facies" with thick sequences of massive calcarenite limestones rich on *Caprinula* buildups, together with scleractinian coral reefs in the region of Leiria. These domains of rimmed platform strongly contrast with those found on the northern ranges of the carbonate platform, mostly recorded in the Baixo Mondego region, where "ammonite facies" of nodular limestones and marly limestones are always dominant, and rudists are absent.

From a paleobiogeographical basis, this fact means that the southern ranges of the WPCP evolved as a complex system of rimmed, middle and inner shelf domains, with back-reef lagoons and littoral plain areas with scarce alluvial input (Berthou 1973, 1978, 1984b; Berthou and Lauverjat 1979; Lauverjat 1982; Callapez 1998, 2008a, b). Due to the shallow water column, the sedimentary and biotic responses were always lying on the dependence of sea-level oscillations, and local tectonics related with the main active axes above mentioned. On the contrary, the northern areas of the platform evolved as a non-rimmed shelf, where the low marginal reliefs allowed the development of littoral and braided alluvial plain environments with mixed carbonate-siliciclastic, micaceous sedimentation (Soares 1966, 1980; Lauverjat 1982; Callapez 1992, 1998, 2008a, b).

It is just in this northern area, near the locality of Figueira da Foz, in the seaside end of the Baixo Mondego region, where the upper Cenomanian and Lower Turonian successions reach their largest stratigraphic development, and yield several ammonite assemblages dominated by Tethyan Vascoceratidae, allowing detailed biostratigraphic precisions with the Iberian Basin in Spain and with other European, North-African and American platform contexts (Barroso-Barcenilla et al. 2011a). After Choffat (1897a, b, 1900) and subsequent authors (Berthou and Lauverjat 1974, 1975; Berthou et al. 1975, 1979, 1985; Soares 1980; Lauverjat 1982; Callapez 1998, 2001, Callapez 2003a, b; Callapez and Soares 2001; Barroso-Barcenilla et al. 2011a), the local ammonite rich stratigraphic units comprise a basal upper Cenomanian sequence with *Neolobites* (units "C" and "D") followed by a middle upper Cenomanian succession of limestones with *Vascoceras gamai* and *Euomphaloceras septemseriatum* (units "E", "F" and "G"), correlative to the *Metoicoceras geslinianum* standard biozone (Kennedy 1984) (Fig. 7.26d).

This succession of carbonate units can be followed also into the southern areas of the carbonate platform with "rudist facies", where the beginning of reef colonization is correlative of the Unit "F". In these large areas of middle to inner shelf confined by barrier structures, extensive calcarenitic shoals were developed with massive biostromes of *Caprinula*, *Sauvagesia* and *Radiolites* (Callapez 2008a, b), as part of a succession equivalent of units "F" and "G" (Figs. 7.26f and 7.27a). More locally, between Leiria, Caranguejeira and Ourém, the same units corresponded to a reef complex with microsolenid corals, and large back reef lagoon with marls rich in bivalves and echinoids, mostly dominated by assemblages with *Ceratostreon flabellatum* and *Hemiaster scutiger* (Choffat 1900; Crosaz 1976; Crosaz-Galletti 1979; Callapez 1998).

7.4.2.5 The Cenomanian—Turonian Transition

The biotic changes occurred at the transition between these two "mid" Cretaceous stages have been strongly emphasised since the 1970s (e.g. Bengtson 1977; Berthou et al. 1979), as they took place during an important interval of eustatic sea-level rise marked by a major ocean anoxic event (OAE-2), and were widely recorded in marine successions of northwest and southern Europe, North- and West-Africa, Middle East, Brazil, Mexico and the Western Interior of the

United States (e.g. Kennedy 1984; Haq et al. 1988; Hart 1990, 2000; Kennedy and Cobban 1991; Hancock et al. 1993; Hardenbol et al. 1998; Haq 2014). Both the Portuguese and Spanish carbonate platforms are not exceptions to this scenery, yielding many paleontological elements corresponding to warm marine communities of the Tethyan Realm, together with a biostratigraphic background where several ammonite rich sequences correlative of the uppermost Cenomanian and lower Turonian can be recognised, despite the relative scarcity of planktonic foraminifera.

As pointed out by Lauverjat (1982), Berthou (1984a, b, c, d) and Berthou et al. (1985), the uppermost Cenomanian beds of the West Portuguese Carbonate Platform (WPCP) record a Tethyan ammonite assemblage with *Pseudaspidoceras pseudonodosoides*, *Spathites* (*Jeanrogericeras*) *subconciliatus* and globose vascoceratids, including *Vascoceras kossmati* and *V. douvillei* (Fig. 7.25a). This association, where *Fagesia superstes* and, more locally, *Rubroceras alatum* and *R. burroense* are also present (Callapez 1998, 2004; Callapez and Soares 2001; Barroso-Barcenilla et al. 2011a; Callapez et al. 2017), is correlative of the *Neocardioceras juddii* standard biozone (e.g. Kennedy 1984) on the basis of the common occurrence of this species and *P. pseudonodosoides* in New Mexico, USA (Cobban et al. 1989).

In the northern sector of the carbonate platform, this uppermost Cenomanian succession correlative of the mid part of the UZA-2.5 is recorded by the units “H”, “I” and “J” of Choffat (1900), with highest thickness of 10 m near Salmanha (Figueira da Foz) (Fig. 7.26d). The Unit “H” is a set of massive limestone beds with scattered ahermatypic branched corals, hemiasterids and moulds of *Tylostoma* gastropods. It is overlain by marly strata with abundant *T. ovatum* and *Hemiaster scutiger* (Unit “I”), followed by a 4.5 m thick limestone bed (Unit “J”) with a karstic paleosurface developed at its top and related with the existence at the Cenomanian—Turonian boundary of a regional unconformity (CTU) (Fig. 7.25a). In the southern areas of the WPCP, between Leiria, Nazaré and Lisbon, the same units are correlative of rimmed platform bioclastic facies and biostromes with *Durania arnaudi*, *Chondrodonta joannae* and *Radiolites lusitanicus* (e.g. Lauverjat 1982; Berthou 1984b; Callapez 1998, 2008a, b). As in the Baixo Mondego region, the top unconformity of this succession (CTU) is related with subaerial exposure of the carbonate beds, especially in Nazaré where the endokarst is well-exposed (e.g. Corrochano et al. 1998) (Fig. 7.27b).

These stratigraphic data related to the CTU and the lack of any basal Lower Turonian record, suggest that the Portuguese ranges of the West Iberian Continental Margin were affected by compression and uplift at the end of the Cenomanian and the beginning of the early Turonian, with reactivation of several tectonic and diapiric axes of the WPCP, including the Nazaré—Leiria—Pombal and Caldas da Rainha structures (Callapez 1998, 2008a, b). For the rudist rich domains of Estremadura, this uplift resulted on the final emersion of the carbonate platform, while in the northern sector of Baixo Mondego there was a return to fully marine conditions during the middle part of the early Turonian (Fig. 7.28d).

In the type area of Salmanha (Figueira da Foz), the karstified Cenomanian limestones of the CTU are overlain by a parasequence with yellowish micritic limestones and marls of restricted tidal flat with rare Turonian inoceramids (*Mytiloides subhercynicus*, *M. mytiloides*) (Unit “K”), followed by 5 m of plated limestones with oriented concentrations of *Turritella* cf. *uchauxensis* and other small benthic invertebrates (Callapez 1999a, b), finishing with a *Thalassinoides* bed (Unit “L”) (Fig. 7.25a). This Lower Turonian succession is contemporaneous of the UZA-2.5 highstand and yields a rich ammonite assemblage with vascoceratids (Berthou 1984d; Berthou et al. 1985), correlative of the Tethyan biozone of *Thomasites rollandi* (Chancellor et al. 1994). Besides the index species, *Kamerunoceras douvillei*, *Vascoceras durandi*, *V. kossmati*, *Fagesia superstes*, *F. tevesthensis*, *Neoptychites cephalotus*, *Choffaticeras* (*Leoniceras*) *barjonai* and the same inoceramids of the previous unit also occur. This association is quite identical to those of other Iberian and North-African, namely Algerian and Tunisian basins (Barroso-Barcenilla et al. 2011a), where the carbonate platform areas were much more extensive at this interval.

7.4.2.6 The Early Turonian Retreat of the Carbonate Platform

After the tectonic uplift of the rudist domains of the Portuguese Estremadura, the latest infill episodes of the West Portuguese Carbonate Platform (WPCP) were centred in the northern onshore of the Portuguese ranges of the West Iberian Continental Margin, being mostly recorded in several areas of the Baixo Mondego region. Besides the ammonite rich UZA-2.5 highstand limestones of Figueira da Foz mentioned above (Unit “L”), the Lower Turonian sedimentary succession of Baixo Mondego records a lateral change of these carbonate inner shelf facies to a large micaceous tidal flat developed eastward, near Tentúgal and Coimbra (Figs. 7.27a and 7.28d), also communicated with alluvial plain domains with fine-grained micaceous siliciclastics, extensive to the continental Lousã Basin. This 15-20 m thick marginal marine to fluvial succession consists of finely laminated beds of yellowish, very fine to fine-grained sandstones, gradually replaced upwards by coarser micaceous sandstones (Furadouro Fm, Barbosa 1981; Barbosa et al. 1988 = “Grés Fino a Muito Fino Micáceo”, Soares 1966); partly equivalent to the Choisa Fm of the Lousã Basin (Reis and Cunha 1989; Cunha in Soares et al. 2007). Facies architecture suggests a paleogeographic setting dominated by large braided alluvial systems, and sourced by moderate reliefs located in the nearby wester border of the Iberian Massif. More to the south, near the uplifted border of the Nazaré—Leiria—Pombal axis, the middle lower Turonian carbonate platform of Baixo Mondego was also bounded by a large extension of rudist biostromes with *Radiolites peroni*, a conical shaped species well-adapted to restricted and moderately agitated shallow water conditions (Callapez 2008a, b).

The stratigraphic transition to the upper part of the Lower Turonian is markedly regressive. Near Figueira da Foz, it is recorded by at least 10 m of whitish to pink biocalcarenitic limestones with cross-bedded structures (units "M" and "N" of Choffat 1900), rich in branched scleractinian corals, the rudists *Radiolites peroni* and *Apricardia laevigata*, the nerineids *Polyptyxis* spp., the gastropod *Actaeonella caucasica grossouvrei* and many other faunal elements typical of patch-reef and para-reefal high-energy carbonate shoals (Callapez 1999a). This limestone succession is increasingly micaceous upwards and ends up with 3–4 m of coarse sandstones, showing that the final retreat of the WPCP was followed by accentuated progradation of the nearby tidal-flat and alluvial micaceous systems (e.g. Soares 1966, 1980; Callapez 2008a, b).

7.4.2.7 The Late Turonian—Santonian Alluvial Infill Episodes

The onshore stratigraphic record of this long interval shows substantial development in the northern Portuguese ranges of the West Iberian Continental Margin and in the nearest continental Lousã Basin, but it is absent from all Estremadura areas located southward the parallel of Nazaré. It contains thick successions of alluvial siliciclastics dominated by coarse sandstones and conglomerates interbedded with lutites, showing many similarities with the upper Aptian, Albian and Cenomanian alluvial members of the Figueira da Foz Fm above mentioned (Fig. 7.25a). They reveal a markedly regressive context that persisted long after the retreat of the West Portuguese Carbonate Platform (WPCP), suggesting that the Portuguese margin was increasingly uplifted at that time, as result of compressive movements already initiated during the Cenomanian—Turonian transition, when the Estremadura ranges with rudist facies of the WPCP located southward the Nazaré—Leiria—Pombal axis were raised and emerged. This stratigraphic setting strongly contrasts with that of the Iberian Basin in Spain, where the carbonate platform systems were widely developed until the early late Santonian and include rich Coniacian fossiliferous shelf facies (e.g. Segura et al. 2014; see Sect. 7.2 for details) (Fig. 7.25b).

The Upper Turonian, Coniacian and Santonian coarse alluvial successions are much thicker westward Coimbra, across the Mondego river valley (Baixo Mondego region), in several areas of northern Beira Litoral, between Figueira da Foz, Mira, Vagos, Cantanhede and Aveiro, and in the continental infill of the Lousã Basin. The lithostratigraphic setting comprises the Oiã Fm (Barbosa 1981; Barbosa et al. 1988 = "Grés Grosseiro Superior" Fm, Soares 1966 = "Grés de Rebolia-Alencarce" Fm, Soares and Reis 1984; Soares et al. 2007 = Picadouro Fm of Lousã Basin, Reis and Cunha 1989; Cunha *in* Soares et al. 2007), followed by the Verba Fm (Barbosa 1981) and the "Picoto-Seadouro Sandstone" (Choffat 1900; Barbosa 1981) in the areas located between Cantanhede and Vagos. Both the Oiã Fm and the Verba Fm are siliciclastic successions related with the progradation of braided alluvial systems with sinuous channels, where the main facies are whitish and yellowish, cross-bedded coarse quartzarenites and subarcosarenites, interbedded with conglomerates and lutites defining finning-upwards sequences.

The paleontological content of these units is usually scarce, but can yield plant macroremains and palynomorphs consentaneous with a Turonian to Coniacian age (Gutiérrez and Lauverjat 1978; Lauverjat 1982). The only known exception goes to the Picoto—Seadouro Fm (Barbosa 1981), a local marginal marine unit interbedded with the alluvial lithosomes, just known from the type locality of Picoto—Seadouro, near Covões (Cantanhede), where Choffat (1898, 1900) found a molluscan assemblage with the ammonite *Hemitissotia ceadouroensis*, the gastropod *Glauconia* sp. and abundant eurytopic bivalves. After Barroso-Barcenilla et al. (2013), this cephalopod species (=*H. celtiberica*) and *H. turzoi* occur in successive levels on the upper Coniacian series of the Iberian Basin, related to the maximum flooding surface of the 3rd order sequence UZA-3.2 (sensu Haq et al. 1988; Segura et al. 2014) (Fig. 7.25).

There is no known record of any alluvial or marginal marine unit lying in stratigraphic continuity above the upper Coniacian Picoto—Seadouro Fm. Near the type locality, this unit is cut by a thick succession of Campanian reddish pelitic beds, posing the question if there is any undoubtedly Santonian record in the onshore of the West Iberian Continental Margin. It is likely that to this stage would correspond alluvial siliciclastics consentaneous with the Verba Fm coarse facies of northwest Beira Litoral, but the lack of exposures does not allow to confirm if the Picoto—Seadouro Fm with the *Hemitissotia* assemblage is merely the proximal end of a carbonate platform, which interbedded with alluvial sandstones during a highstand interval.

7.4.2.8 The Campanian—Maastrichtian Reddish "Garumn"

The Uppermost Cretaceous onshore sedimentary record of the Portuguese ranges of the West Iberian Continental Margin is characterized by the widespread accumulation of alluvial, deltaic and marginal marine successions of reddish and greenish pelites interbedded with sandstones (Fig. 7.25 a), suggesting a long depositional interval during the Campanian—Maastrichtian. Facies are mostly organized as finning-upwards sequences with channel infill structures, laminated fine-grained flood-plain deposits, and bioturbated carbonate paleosols with a variety of plant remains, ichnofossils, aquatic molluscs and vertebrates, including large chelonians (Fig. 7.27c). Their overall features are comparable to the Campanian to Lower Paleogene "Garumn" facies of southwestern Europe, including those of other basins of Iberia.

These siliciclastic systems rest unconformably on the previous Cretaceous units of the northern range of the Portuguese onshore, including the Baixo Mondego, Mira and Aveiro regions of Beira Litoral, suggesting a fully reorganization of the sedimentary systems with substantial fluvial incision and reorientation of drainage patterns to NNW (e.g. Cunha 1992; Cunha and Reis 1995; Rey et al. 2006; Dinis et al. 2008), as a consequence of diastrophic episodes that deformed the continental margin, with uplift and erosion of the preceding sedimentary setting. The age of this basal unconformity (SCU) (Fig. 7.25a) is difficult to determine without precise biostratigraphic markers. However, the occurrence of a lower to middle Campanian fossil assemblage with the ammonite *Hoplitoplacenticeras marroti* (Choffat 1900), more than 120 m above pelitic strata sampled from a geological drilling near the locality of Mira, suggests that this erosive and slight angular unconformity could be positioned in the lowermost Campanian, or even in the upper Santonian. The presence of a well-developed silcrete in the eastern sectors of the basinal area (e.g. Reis and Cunha 1989; Cunha 1992; Cunha and Reis 1995) also reinforces de possibility of a large interval of subaerial exposure, non-sedimentation and weathering in these areas, previous to the beginning of deposition of the "Garumn" series.

After Rey et al. (2006), this late Santonian to early Campanian tectono-sedimentary event can be explained by a significant intensification of the N-S Alpine compression that affects the Iberian Plate. This interval is also consentaneous with the transition of the oceanic accretion to a compressive phase in the Bay of Biscay (e.g. Sibuet et al. 2004), and to the cycle of magmatic activity that affected the west and southwest of Portugal after the 80 Ma (e.g. Ferreira and Macedo 1979; Ribeiro et al. 1979; Macintyre and Berger 1982), with implantation of the Sintra, Sines and Monchique subvolcanic massifs, and the active volcanism in the Lisbon, Malveira and Mafra regions (e.g. Zbyszewski and Jesus 1954; Aires-Barros 1979) (Fig. 7.25a).

As main lithostratigraphic units, stand out the Taveiro Fm (Soares et al. 2007) and the Viso Fm (Barbosa et al. 1988 = Vagos Fm, Barbosa 1981), where the main paleontological elements presently known suggest that they are mostly correlative to the upper Campanian and Maastrichtian (e.g. Antunes and Pais 1978; Antunes 1979; Antunes and Broin 1988). The Taveiro Fm records more proximal alluvial meandering systems with dominant reddish pelitic facies (Cunha and Reis 1995), mostly exposed in the southern areas of the Baixo Mondego region, between Alfarelos and Taveiro (near Coimbra), where Antunes and Pais (1978) described an interesting vertebrate fauna with fish, turtle and dinosaur remains. These facies are also equivalent to the Buçaqueiro Fm of the continental Lousã Basin (Cunha in Soares et al. 2007), a proximal 70 m thick siliciclastic unit of whitish and yellowish, quartzarenitic to arcosarenitic coarse sandstones.

The Viso Fm records the deltaic and lagoonal, marginal marine sedimentary systems of this extensive Upper Cretaceous series. This unit is mostly centred in the Beira Litoral areas of Mira, Vagos and Aveiro (Fig. 7.27d), where the overall thickness of the reddish and greenish pelites can be larger than 500 m. The typical Viso facies are very productive for vertebrates, bivalves and other fossil remains. Besides the large chelonian *Rosasia soutoi*, these materials have yielded more than 12 fish taxa, including *Scaphanorhynchus raphiodon*, *Mysledaphus bipartitus*, *Atractosteus* sp., *Amia* sp., *Coelodus* sp., *Enchodus* sp., cf. *Diplomystus* sp., *Paralbula casei* and *Platocodon* cf. *nanus*, mosasaurs, archosaurs Crocodylia indet., *Megalosaurus pannoniensis* and Theropoda indet., and numerous fragments of small amphibians, birds, and mammals. These rich assemblages are completed by many freshwater and brackish invertebrates and microfossils, including the molluscs *Corbicula marioni*, *Corbula* sp., *Glauconia* sp. and *Anadromus* sp., ostracods and crustaceans (Antunes and Broin 1988).

With a more local expression and an early—middle Campanian age, the less than 10 m thick Mira Fm ("Conglomerado de Mira" of several authors) records a marginal marine, transgressive succession interbedded with the "Garumn" reddish pelites of the Viso Fm. Besides the above mentioned ammonite *Hoplitoplacenticeras marroti*, it includes a rich invertebrate fauna in the basal conglomeratic beds, mostly with corals and molluscs, together with concentrations of foraminifera (*Larrazetia*) (e.g. Choffat 1900; Costa 1937; Gutiérrez and Lauverjat 1978; Lauverjat 1982).

The Campanian continental successions also outcrop near Nazaré, where clast-supported calcitic conglomerates with materials eroded from Cenomanian rudist limestones are interbedded with reddish clays (Sítio da Nazaré Fm = "Conglomerados e argilas do Sítio da Nazaré"; Antunes 1979) This facies architecture suggests a paleoenvironment located near active alluvial fans, and possibly related with the uplift of the Nazaré—Leiria—Pombal and Caldas da Rainha structures. These beds also yield an interesting terrestrial gastropod fauna with *Anadromus ribeiroi*, *Punctum basalticum* and *Anastomopsis elongatus*, allowing correlations with the Campanian of Provence, in southern France, and the "Volcanic Complex of Lisbon" (Antunes 1979).

This last volcano-sedimentary unit dominates many landscapes around the regions of Lisbon, Cascais and Malveira, where a thick succession of at least six basaltic flows interbedded with tuffs rich in pyroclastic ashes and lapilli, overlies upper Cenomanian rudist limestones of the West Portuguese Carbonate Platform (Zbyszewski and Jesus 1954; Aires-Barros 1979). With a very variable thickness that can reach nearly 400 m (Moniz and Ribeiro 2011), these sequences seem to record a long interval of active volcanism occurred between 100 and 70 Ma ago, according to geochronologic precisions based on Rb/Sr and K/Ar (e.g. Miranda et al. 2009). They also show a fossil content with a rich fauna of terrestrial gastropods with *Anadromus ribeiroi*, *Punctum basalticum*, "*Pupa*" *tournoueri*, "*Bulimus*" *carnaxidensis* and "*B*." *olisiponensis*, together with plant remains of *Cinnamomum broteri* related with the *Debeya* flora of Beira Litoral, and freshwater vertebrates, including remains of frogs, tritons and crocodiles (Antunes 1979).

7.5 A Synthesis Essay

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In this section we refer to the main aspects of the geodynamic evolution of Iberia during the Late Cretaceous, and the related tectono-sedimentary episodes that occurred in the sedimentary basins, including the various domains of the North, South and West Iberian Continental Margins. During the Late Cretaceous, the evolution of Iberia determined a series of changes in the superregional stresses and, consequently, tectonic movements in the different tectono-sedimentary domains of the plate interior. Tectonic activity was however of different intensity in each domain, depending on its location relative to the stress field and previous tectonic structuration. The areas with thinned lithosphere such as the deeper areas of the continental margins (Prebetic, Subbetic in the south, and the Basque Cantabrian Basin in the north of the plate) showed more sensitivity to changes in the plate stresses. Contrarily to stress intensity and tectonic activity, which notably vary spatially, the timing of the tectonic pulses in the various basins and domains was nearly isochronous.

The section is intended as a summary in which the evolution of the different basins is integrated in the framework of the main phases of Iberia evolution. With this approach in mind, referencing of previous works has been reduced to the maximum. Instead, the previous sections of this chapter are profusely referenced. Figure 7.29 summarizes this essay of synthesis.

7.5.1 Post-rift Inception and Thermal Relaxation (Late Albian to Middle Cenomanian)

All the three continental margins experienced the rift to post-rift transition by the "mid" Cretaceous. The period was characterized by a progressive decrease of tectonic activity in all the regions. Despite the dominance of the thermal relaxation in the lithosphere, preexisting tectonic lineaments continued being active and determined local subsidence changes in all basins, particularly during the late Albian. Also, halokinetic tectonics promoted by the Keuper evaporites (Late Triassic) played an important role in some areas of the Prebetic, the Basque Cantabrian Basin, and very particularly, of the South Pyrenean Basin.

In the West Iberian Continental Margin, associated to the opening of the North Atlantic, this rift-to-drift transition took place earlier than in the rest of domains, probably as soon as in the Aptian (Sect. 7.4), when a major tectonic change occurred causing the uplift of the western and eastern borders of the basin, along with an important widening of the area of sedimentation.

In the South Iberian Continental Margin, more specifically in the Prebetic Platform and the South Iberian Ramp, the end of the rifting episode is marked by a regional unconformity of earliest late Abian age (in the places of minimum hiatus). This transition is marked everywhere in the continental margin by a drastic tectono-sedimentary reorganization. Subsidence became generalized and relatively homogeneous, and extensive clastic sedimentation, mostly continental sands (Utrillas Fm), occurred, covering not only syn-rift deposits but also older units including Variscan rocks towards the plate interior.

In the North Iberian Continental Margin, the cessation of rift tectonics was complex, occurring later than in the other two margins and rather anisochronously, with extensional tectonics prevailing until the early Cenomanian in the areas of strong syn-rift extension such as the Basque Cantabrian Basin and the present-day North Pyrenean Zone. However, the basins peripheral to the rift system main axis evolved earlier to post-rift conditions. The syn-rift to post-rift transition produced major paleogeographical reorganization with development of large depositional domains, including the South Pyrenean Basin, the Basque Basin, the Navarre-Cantabrian Basin and the Castilian Ramp. Extensive terrigeneous sedimentation covered these areas unconformably, overlaying older rocks, ranging from the Lower Cretaceous to the pre-Mesozoic Variscan basement (see Sect. 7.2).

In the South Pyrenean Basin such post-rift geometry and subsidence were locally complicated by halokinesis of the Keuper facies. This was the case of the small (7.5 km wide) but highly-subsiding (> 1600 m of upper Albian—lower