# Chapter 15
# Pericratonic Basins: The Mesozoic Scenario

## 15.1 Crustal Extension in Continental Margins

The northward drifting India experienced crustal extension during the Late Triassic to Early Cretaceous period due to India moving and rotating away from Australia and Antarctica and attendant transformation along the Coromandal coast. The leading edge of the Indian continent subsided deeper into the NeoTethys Sea in the north and its western and eastern passive margins started sinking intermittently, giving rise to pericratonic basins. Embracing the whole of the Himalaya domain, the NeoTethys Ocean spread all over the subsiding part of the continental margin in western Rajasthan and Kachchh. The Indian Ocean likewise encroached on the sinking parts of the Kaveri–Palar, the Krishna–Godavari, the Mahanadi, and the Bengal–Meghalaya sectors of the passive continental margin (Fig. 15.1). The sagging of the continental crust took place along faults and lineaments of the Precambrian antiquity. This gave rise to rift-related depressions and ridges in the Late Triassic in the Jaisalmer sector, during the Middle Jurassic in Kachchh, and in the Upper Jurassic in the Coromandal Belt. There was also a seaward tilting of rift basins, leading to formation of embayments and gulfs in the Coromandal Belt and in Kachchh. During the Late Cretaceous, an arm of the sea extended deep into the land along the Narmada rift zone.

The pericratonic basins, it may be recapitulated, formed due to rifting of the continental margin and evolved in stages on the passive margins. The reactivation of subparallel faults and lineaments of considerable antiquity was responsible for their evolution. The sediments that accumulated in these basins bear strong stamp of the oceanic environments with which they were associated. The basins of Kachchh, Jaisalmer and Himalaya belong to the NeoTethys faunal province and the Bengal–Meghalaya, the Krishna–Godavari and the Kaveri–Palar basins had affinity with the Australasian domain of the Indian Ocean. There is preponderance of lamellibranchs, relative poverty of gastropods and corals, richness in



K.S. Valdiya, *The Making of India*, Society of Earth Scientists Series,
DOI 10.1007/978-3-319-25029-8_15

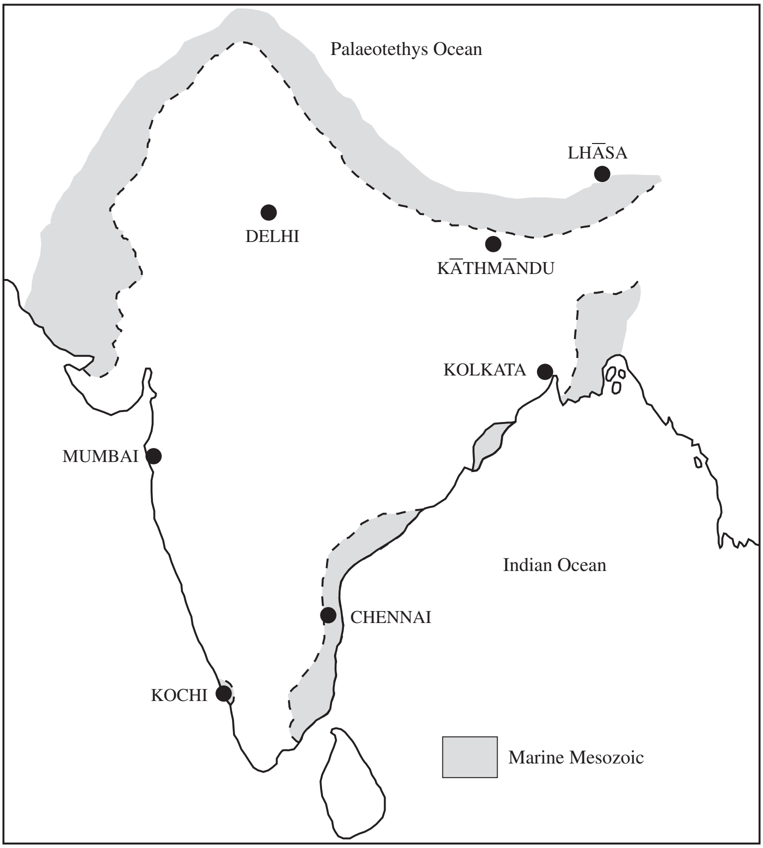


**Fig. 15.1** The NeoTethys Ocean in the north and north-west, and the Indian Ocean in the south-east and east overspread the subsiding pericratonic margin of India affected by crustal extension

the assemblage of ammonites, and notable presence of Mediterranean *Hippurites* in the Kachchh, Jaisalmer and Himalaya sectors (Krishna 1987). The Coromandal domain in the south-east is characterized by dominance of cephalopods, notable presence of gastropods and warm-water reef-building corals, and absence of *Hippurites*. Evidently, the NeoTethys Ocean and the Indian Ocean were not mutually connected in the Mesozoic.

## 15.2 North-eastern Continental Margin

### *15.2.1 Bengal Basin*

During the Mesozoic era on the passive continental margin in the northern part of Bengal and Bangladesh, there was a 100-km-wide shelf that deepened eastwards into the ocean basin (Johnson and Alam 1991). It began to subside in the Lower

Cretaceous (at 127 Ma) when the Indian plate drifted away from Antarctica. The shelf is characterized by transverse Gondwana grabens filled with Late Permian sediments of the Kuchma and Paharpur formations in the Bangladesh grabens and their equivalents in the Gondwana domain of Jharkhand and West Bengal. Unconformably overlying is a pile of volcanic rocks with intertrappean beds constituting the Rajmahal Formation of the earliest Cretaceous age. The Late Cretaceous subsurface succession comprises Sibganj, Dhananjaypur and Bolpur formations (Roybarman 1992; Khan et al. 1994, 1996; Alam 1989; Alam et al. 2003). All these formations lie under the thick pile of Indo-Gangetic sediments. The Early Cretaceous *Sibganj Formation* is an accumulation of trapwash with ferruginous red sandstone and claystone. It grades into the Dhananjaypur/Bolapur successions towards the west. Consisting of dark grey shale, the *Dhananjaypur* Formation represents the earliest marine transgression in this basin. The overlying *Bolpur Formation* comprises a fluvial facies made up of arkosic sandstone.

### *15.2.2 Meghalaya Region*

In the Jaintia and Khasi Hills in southern Meghalaya, the 150- to 200-m Cretaceous succession is exposed as thin strips of outcrops bordering the southern faulted margin of the Meghalaya massif (Figs. 15.2 and 15.3). The rocks dip gently southwards, and in Bangladesh are concealed under an alluvial expanse. Resting unconformably on partly Sylhet Volcanics and partly Precambrian gneisses, the *Jadukata Formation* along the Dauki Fault zone is a Lower Cretaceous fluvial deposits made up of conglomerate–pebbly sandstone alternation. The 150- to 180-m-thick succession of conglomerates intercalated with subarkose and volcanifeldspathic wackes is known as the *Mahadek Formation* (Fig. 15.3). The Mahadek onlaps both the Sylhet Volcanics and the Precambrian gneisses. A characteristic element of the Mahadek in many places is the localized occurrence of pyroclastic beds (Kak and Subrahmanyam 2002). Above a layer of laterite, the *Upper Mahadek* comprises marine sediments containing Companian–Maastrichtian nannofossils (Jafar 1996) and foraminifers *Globotruncana linnaena* and *Globotruncana ventricosa* (Raju and Mishra 1996; Raju et al. 2002). The homotaxial *Sibganj Formation* is characterized by pollen *Aquinopollenites indica*—assemblage of the Upper Cretaceous (Reimann 1993). Near Singrimani in the Garo Hills Gondwana, equivalent rocks are present.

### *15.2.3 Ultrabasic–Alkaline–Carbonatite Complex*

Related to a N/NE–S/SW trending shear zone and to the Sylhet Volcanics (Fig. 15.2) is a 7- to 8-km-wide dyke swarm, made up of peridotite, pyroxenite and meliltolite lamprophyre, constituting the *Jasra Complex* (Mamallan et al.

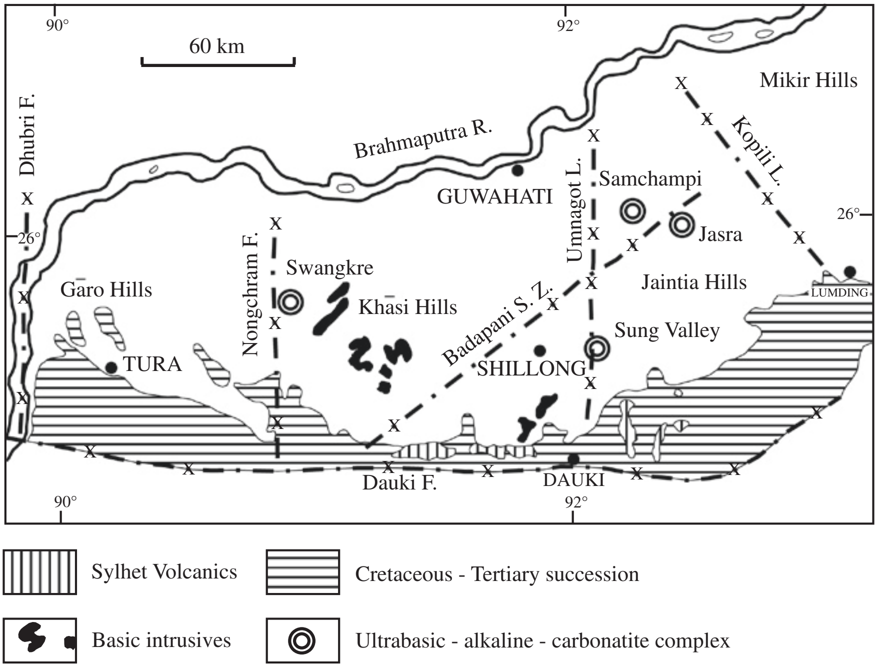


**Fig. 15.2** Tectonic framework of the Meghalaya plateau showing occurrence of ultramafic–alkaline–carbonatite complexes in the context of the Sylhet Volcanics and the Cretaceous—Tertiary sedimentary succession (after Srivastava et al. 2004a)

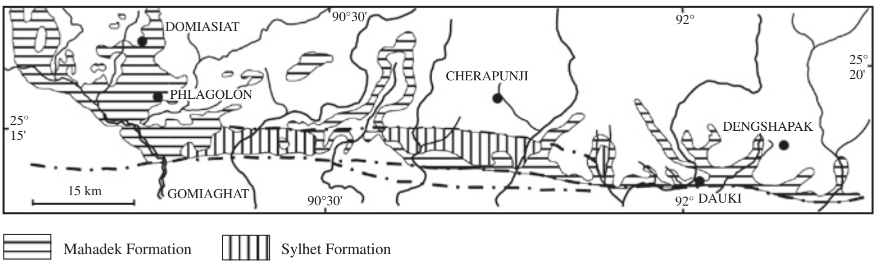


**Fig. 15.3** Extent of the exposed Mesozoic, including the Cretaceous formations in eastern continental margin (modified after Mishra and Sen 2004)

1994; Srivastava and Sinha 2004a, b). It is intruded by minor veins of ijolite, tinguite and nepheline syenite. There are two intrusive bodies of carbonatite in the Karbi Along district. Post-dating the main event of the Sylhet flood basalts by about 10 million years, there was emplacement of the carbonatite–alkaline-rock complex in the Sung Valley Jaintia Hills, Samchampi and Barbang (Mikir Hills). Geochemical and isotopic data indicate that the Sung Valley carbonatite was derived from and interacted with an isotopically heterogeneous mantle and that the carbonatites show εNd values of +0.7 to +1.8, εSr values of +4.7 to +7.0—within the range exhibited by the ocean island basalts of the Kerguelen province in the Indian Ocean, implying linkage of the two (Srivastava et al. 2005). The weighted mean $^{40}Ar$–$^{39}Ar$ age of the *Sung Valley Complex* is 107.2 ± 0.8 Ma (Ray and Pande 2001).

### *15.2.4 Mineral Deposits*

In West Khasi district about 140-km SW of Shillong at Domiasiat (Fig. 15.3) and at Phlamgdiloin, rich uranium deposits are associated with sedimentary fills of a braided river characterized by plant litter and biogenic pyrite (Sengupta et al. 1991; Singh 1992; Maithani et al. 1995). Occurring in the Lower Mahadek, the Domiasiat deposit of pitchblende and coffinite is world's largest deposit of its kind.

## 15.3 South-eastern Continental Margin

The Coromandal coast embraces the Eastern Ghat terrane and the deltaic expanses of the Krishna–Godavari and the Kaveri–Palar rivers and their offshore equivalents (Sastry et al. 1973). The Mesozoic formations are exposed few and far between in the coastal stretch, but their larger parts lie concealed under younger deltaic and marine sediments of coastal and offshore shelf (Figs. 15.4, 15.5, 15.6 and 15.11; Table 15.1). The sediments here were deposited in the grabens. The East Coast, stretching from Athagarh in Odisha to beyond Ramanathapuram in Tamil Nadu, came under the sway of marine waters towards the end of the Jurassic period. Demarcated by an east–west trending boundary fault, the 700-m-thick *Athgarh Sandstone* represents an extensive alluvial fan, the distal part of which grades into the lacustrine deposits in the centre of the basin (Mishra et al. 2004) and into deltaic deposits towards the shelf. The Athagarh succession in the Mahanadi domain comprises sandstone with thin intercalations of claystone and carbonaceous shale. The shale is characterized by Early Cretaceous flora of the Upper Gondwana Rajmahal affinity (Patra 1973). Evidently, there was interfingering of land-derived sediments (with their plant contents) and the marine sediments containing invertebrate fossils, indicating a delta-front environment.

### *15.3.1 Krishna–Godavari Basin*

The coastward extension of the Gondwanic Pranhita–Godavari graben is terminated by the NE–SW trending Barpatla Ridge along the Eastern Ghat

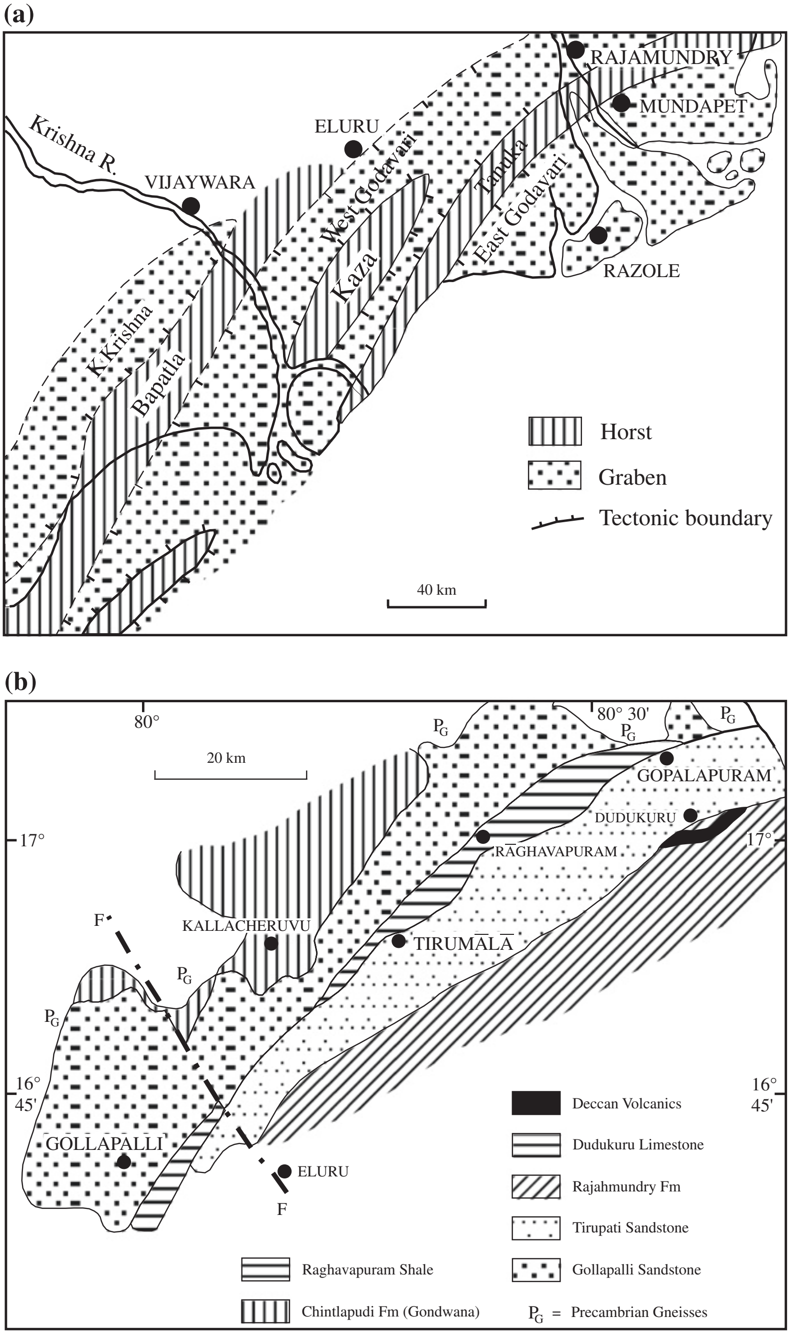


**Fig. 15.4** **a** Tectonic setting of the Krishna–Godavari domain (after Majumdar et al. 1995). **b** Exposed Mesozoic formations in the coastal stretch of Andhra Pradesh (after Prasad and Pundir 1999)

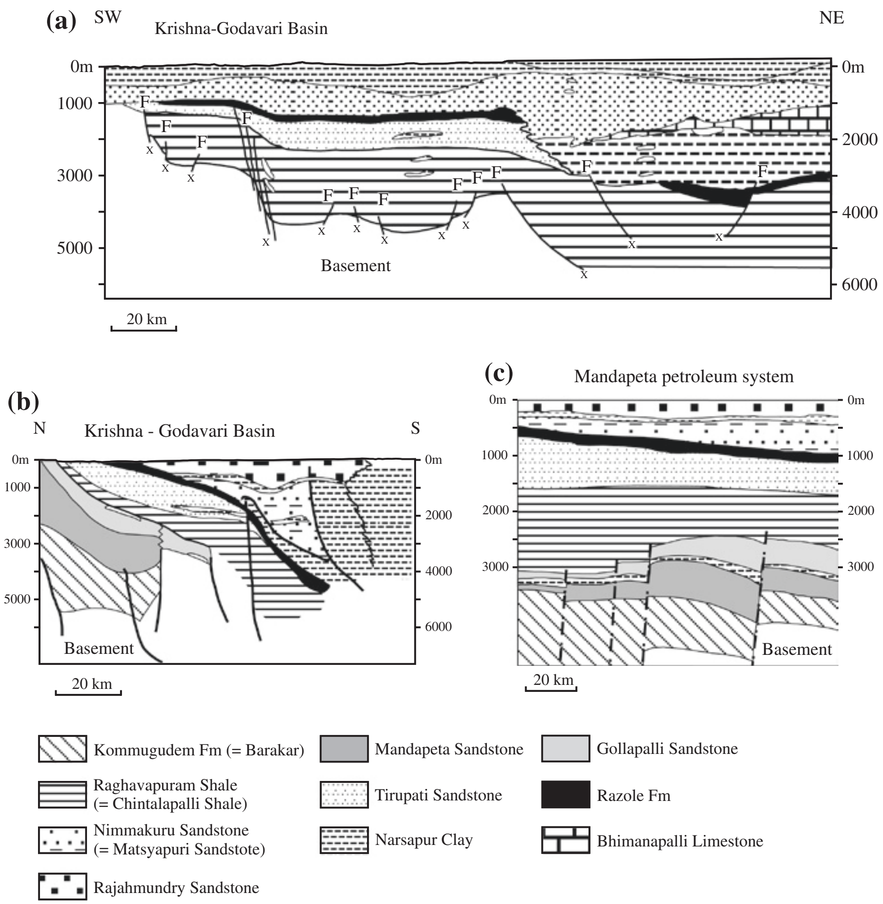


**Fig. 15.5** Structural architecture and lithostratigraphic pattern of the Krishna–Godavari Basin. Sections show the sources and the nature of the traps of the hydrocarbon deposits (modified after Majumdar et al. 1995)

characterized by ridges and grabens (Manmohan et al. 2003) that became sites of sedimentation (Figs. 15.4, 15.5 and 15.11). The tilting of later basins south-eastwards resulted in drowning of the coastal land. In the lower reaches of the Pranhita–Godavari Valley, towards the delta region, the Gondwana sediments rest on the Archaean basement. The Early Permian *Draksharama Formation* is made up of grey black shale alternating with claystone, sandstone and coal seams. Overlying is the *Mandapeta Sandstone*, comprising intercalations of shale that have yielded Triassic assemblage of palynomorphs. Unconformably overlying is the *Bapatla Sandstone*, characterized by Upper Jurassic assemblage of dinoflagellates and acritarchs (Mehrotra et al. 2002). The Cretaceous starts with the *Gollapalli/Budavada Sandstone* that rests upon the Gondwanic Mandapeta

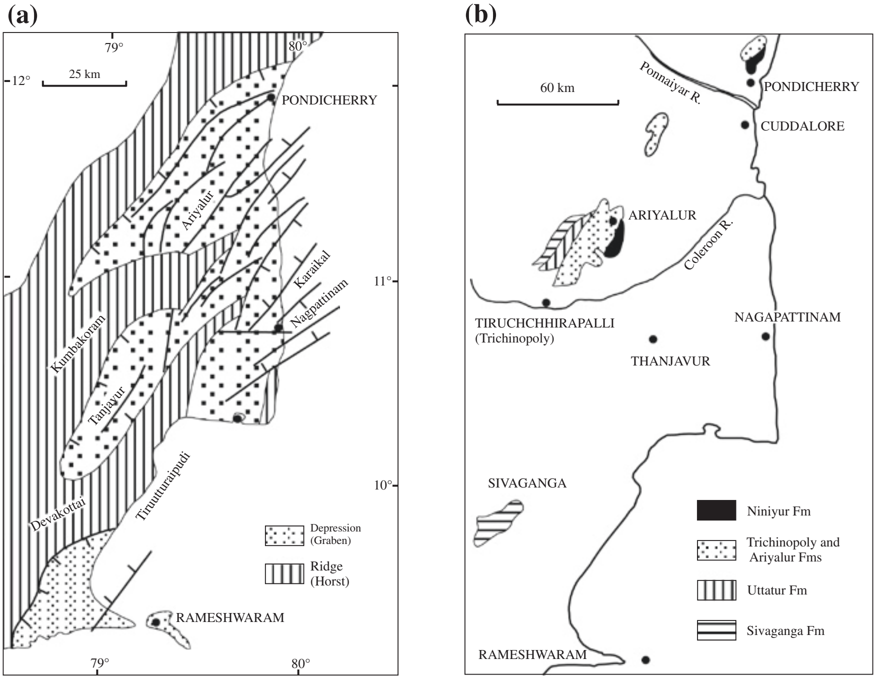


**Fig. 15.6** **a** Graben-and-horst structure developed in the Coromandal Coast, on the passive continental margin of India (modified after Sastry et al. 1977). **b** Exposed Jurassic and Cretaceous formations in the Kaveri–Palar Basin in Tamil Nadu (after Pandey and Dave 1998)

Sandstone. In the marine shelf, carbonates and clastic sediments formed a fan-shaped delta along the ridges; and turbidites covered the slopes and the graben floors. By the Campanian epoch, a large delta had emerged and was prograding rapidly (Prabakaran and Ramesh 1995). The Gollapalli/Budavada comprises micaceous ferruginous gritty sandstone and shale containing abundant plant fossils of the Upper Gondwana affinity such as *Williamsonia, Taeneopteris, Cladophlebis, Otozamites, Ptilophyllum, Pterophyllum* and *Elatocladus* of the Neocomanian age. The plant remains imply considerable contribution of terrestrial detritus and plants by rivers draining upland and coastal region. As everywhere in the pericratonic basins of India, the plant fossils along with detritus were washed down into the sea, resulting in the admixture of marine and terrestrial materials. It could also be a large prograding delta lobe over the coastal region where fluvial and marine sediments interfingered (Biswas 2003). The *Raghavapuram Shale* represents the first marine transgression. It comprises a succession of brittle shale and soft claystone, the latter characterized by a rich assemblage of ammonites, lamellibranchs, brachiopods and foraminifers. Dinoflagellete cysts, ammonites and palynofossils indicate Barremian to Early Aptian age of the Raghavapuram Shale (Prasad and

**Table 15.1** Cretaceous lithostratigraphy of the Krishna–Godavari Basin (based on Biswas 2003)

| Age | Inland | | Subsurface and offshore |
|---|---|---|---|
| | Rajahmundry–Ellore Belt | Guntur–Ongole Belt | |
| Palaeocene | Razole | | |
| - - - *Unconformity* - - - | | | |
| Upper Cretaceous | Tirupati Sandstone | Pavalur Sandstone | Chintalapalli Shale |
| - - - *Disconformity* - - - | | | |
| Lower Cretaceous | Raghavapuram Shale | Vemavaram Shale | Gajulapadu Shale/Raghavapuram Shale |
| - - - *Unconformity* - - - | | | |
| | Gollapalli Sandstone | Budavada Sandstone | Krishna Fm/Pennar Fm |
| - - - *Unconformity* - - - | | | |
| Late Jurassic | Nellore Claystone, Chintalapudi Sandstone | | Bapatla Sandstone |
| - - - *Unconformity* - - - | | | |
| Permo-Triassic | | | Mandapeta Sandstone, Kommugudem Fm, Draksharama Argillite |
| - - - *Unconformity* - - - | | | |
| Precambrian basement | | | |

Pundir 1999). The *Tirupati Sandstone* is a formation of coarse- to medium-grained white grey sandstone containing pollens of the Cenomanian angiosperms and gymnosperm plants (Kapoor et al. 1999).

The Tirupati Sandstone and its offshore equivalent to the *Chintalapudi Sandstone* are conformably overlain by the Rajahmundry Volcanics/Razole Volcanics of the Palaeocene age.

## *15.3.2 Hydrocarbon Deposits of Krishna–Godavari Basin*

Rich in organic material, the Raghavapuram Shale is the source rock of oil and gas; and the associated sandstone serves as the reservoir rock *in the offshore zone*. The deposits (Fig. 15.5) are confined to the lower part of the Raghavapuram where high-gamma and high-resistivity anomalies have been detected (Manmohan et al. 2003). The gas-bearing sandstone straddles across the unconformity on top of the high-gamma and high-resistivity horizon at the base of the formation. According to some workers, this part of the Raghavapuram Shale represents the deposit of an estuarine valley fill, deposited in lowstand tract. An incised valley carved out earlier in the underlying unit was filled back by sediments during the Cenomanian–Turonian transgression (Chitra Rao and Asthana 2000). This is the feature which

**Table 15.2** Jurassic–Cretaceous lithostratigraphy of the Kaveri–Palar Basin in Tamil Nadu (after ONGC 1993)

| Age | Onland unit | Subsurface and offshore formation |
|---|---|---|
| Palaeocene | Niniyur Group | |
| - - - - - - - - - - - - - - - - - - - - - - - - - - - - - *Unconformity* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - | | |
| Late Upper Cretaceous | Ariyalur Group | Proto Novo Shale, Komarakshi Shale, Nannilam Shale |
| - - - - - - - - - - - - - - - - - - - - - - - - - - - - - *Unconformity* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - | | |
| Middle Upper Cretaceous | Trichinopoly Group | Kadavasal Shale |
| - - - - - - - - - - - - - - - - - - - - - - - - - - - - - *Unconformity* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - | | |
| Early Upper Cretaceous | Uttatur Group | Bhuvanagiri Formation, Sattapadi Formation |
| - - - - - - - - - - - - - - - - - - - - - - - - - - - - - *Unconformity* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - | | |
| Late Lower Cretaceous | Dalmiapuram Formation | Andimadam Formation |
| - - - - - - - - - - - - - - - - - - - - - - - - - - - - - *Unconformity* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - | | |
| Upper Jurassic to Earliest Cretaceous | Sivaganga/Therani Formation | Sivaganga |
| - - - - - - - - - - - - - - - - - - - - - - - - - - - - - *Unconformity* - - - - - - - - - - - - - - - - - - - - - - - - - - - - | | |
| Archaean basement | | |

had a significant bearing in the formation of the hydrocarbon deposits. Over 325-m-deep wells (4600–5200 m) have identified more than 160 structures of hydrocarbon deposition, out of which 48 have been proved hydrocarbon-bearing. The Mandapeta gas field is related to the Permian sandstone, and the Lingala oil field to the Lower Cretaceous Raghavapuram Shale (Rao 2001, 2002). It may be mentioned that besides the Mesozoic deposits of hydrocarbon, there are Tatipaka–Pasarlapudi gas field and Mori oil field related to Lower Eocene and Miocene-connected Ravva oil field (Chandra et al. 1994; Rao 2002) (Table 15.2).

### *15.3.3 Kaveri–Palar Basin*

Like the Krishna–Godavari Basin in Andhra Pradesh, the Palar–Kaveri Basin in Tamil Nadu coast is characterized by horst-and-graben structures beneath a thick cover of Tertiary–Quaternary sediment (Figs. 15.6 and 15.11; Table 15.2). The evolution of the structural depression commenced in the Late Jurassic and continued all through the Cretaceous and the Cenozoic (Banerji 1972; Sastry et al. 1968; Sastry et al. 1977). In the Santonian interval 87.5–84 million years ago, strong faulting caused subsidence of high grounds, leading to development of steeply sloping river valleys, acceleration of terrestrial erosion, transgression of the sea, and high influx of detrital sediments into the basin (Ramkumar et al. 2005). The basin extends over offshore with an easterly tilt, as is evident from progressive eastward-thickening of the sedimentary succession. The larger basin comprises five subbasins, each representing a graben oriented in the NE–SW direction parallel to the coast (Fig. 15.6a).

Resting on the Archaean gneisses–khondalites or locally on patches of the inland Gondwana sedimentary rocks, the Mesozoic succession begins with the Pre-Albian *Sivaganga Formation* near Ariyalur and its near temporal equivalent the *Therani Formation* near Thanjavur. Characterized by calcareous concretions in feldspathic sandstone and conglomerate at the base, the *Sivaganga Formation* forms isolated hillocks in Ramanathapuram. It comprises fluvial, lacustrine and paludal sediments and is characterized by plant fossils (filicales, cycades, gingkos and conifers) of the Upper Jurassic to lowermost Cretaceous age. The plant assemblages represent terrestrial material washed down by streams into a tide-swept estuary. Or possibly there was interfingering of fluvial and marine environments of deposition. The claystone in the upper part of the Therani Formation contains ammonites and arenaceous foraminifers of Neocomanian–Aptian age (Mamgain et al. 1973; Banerjee 1982). Palynormorph assemblage together with plant *Ptilophyllum* corroborates the Early Cretaceous time span of the Therani–Sivaganga succession (Venkatachala 1977). In the northern Palar Basin, the *Satyavedu Formation* in the north, the *Avadi Formation* in the central part and the *Sriperumbadur Formation* in the south represent the Neocomanian–Aptian succession (Kumaraguru and Trivikram Rao 1994).

The overlying marine formation *Dalmiapuram* comprises coralline-algal reef limestone with black shale. Besides ammonites, there are foraminifers and ostracodes of the Aptian to Albian age (Jain 1968; Bhatia and Jain 1969; Banerji 1970; Banerji et al. 1996). The Dalmiapuram Limestone is intensively used for manufacture of cement.

The *Uttatur Group* comprises reefal limestone, greenish grey gypseous shale and black carbonaceous shale. The bioherms developed during the Middle Aptian to Cenomanian time, along an edge of the block associated with an active fault parallel to the coast, as borne out by breccias and conglomerates intimately associated with the reefs. The bioherm, that grew as high as 150 m, is composed of sponges and a variety of scleractinid corals and algal crust (Steinhoff and Bandel 2000). The Karai claystone with gypseous shales and phosphatic nodules in the Uttatur Group is very rich in planktonic and benthic foraminifers, the $\delta^{18}O$ values of which indicate near-surface sea water temperature of 29 °C and seafloor temperature of 21 °C (Dasgupta et al. 2006). The Late Cretaceous *Trichinopoly Group* is made up of Garudamangalam and Paravay formations, comprising calcareous gritty and conglomeratic sandstone with bands of sandy limestone and gypseous shale and marlite. The *Ariyalur Group* comprises cross-bedded green sandstone (locally conglomeratic) interbedded with grey and purple shale. The biohermal limestone within the succession is known as the Kallankurichchi Limestone (Sundaram et al. 2001). *Phylloceratina, Lytoceratina* and *Ammonitina* found near Pondicherry comprise most diverse Upper Maastrichtian ammonite assemblage

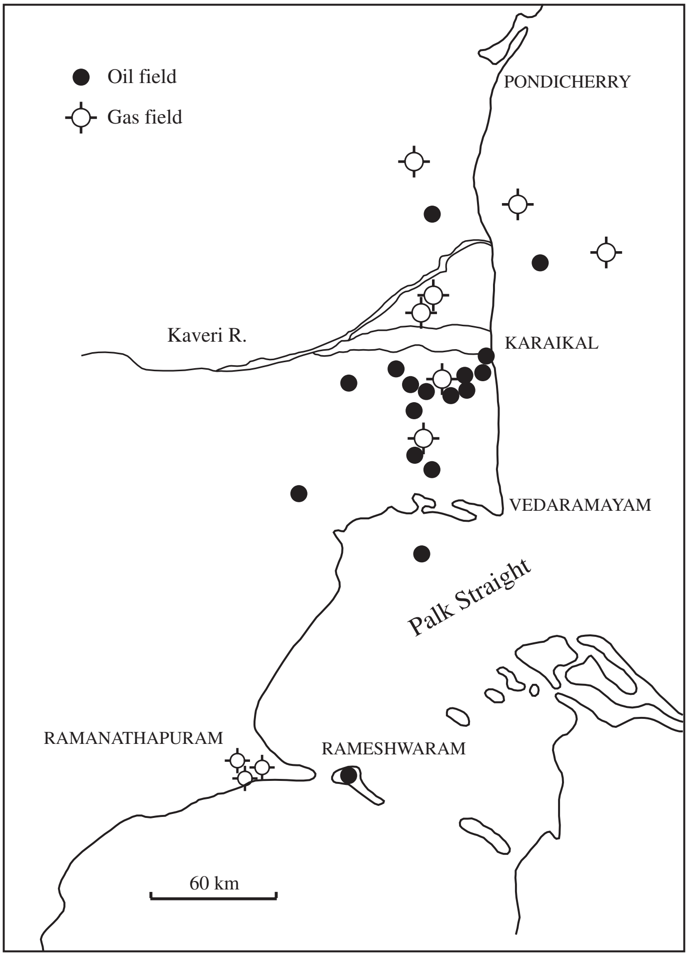


**Fig. 15.7** Location of oil and gas fields in the Kaveri–Palar Basin (after Govindan et al. 2000)

anywhere known (Kennedy and Henderson 1992). The Kallakkudi Limestone (Albian–Cenomanian) and the Kallankuruchchi Limestone (Maastrichtian) are composed of packstone and greenstone, representing carbonate shoals. These two horizons have yielded condensate with 49° API gravity and hydrocarbons (Yadagiri and Govindan 2000; Govindan et al. 2000). The Early Cretaceous shale deposits that accumulated in depressions under anoxic conditions are the sources of hydrocarbons (Fig. 15.7) in the Kaveri–Palar Basin (Raju and Mishra 1996; Raju et al. 2002). The petroleum fields of the offshore zone tap these pay horizons. The top part of the Createaceous succession of the Kaveri Basin records gradual change of climate and sea level as reflected in the change in isotope geochemistry of sediments, which received increased influx of detrital material from land (Ramkumar et al. 2004).

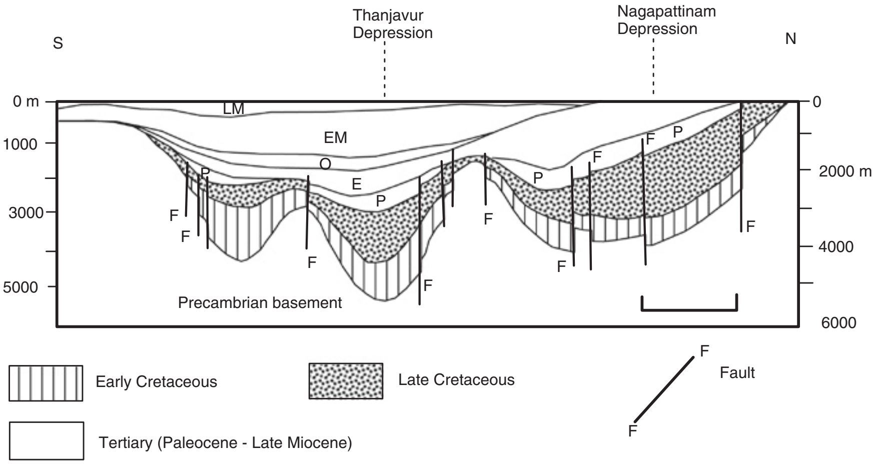


**Fig. 15.8** Cross section shows subsurface structure and lithostratigraphy of the Kaveri–Palar Basin (Sastry et al. 1997)

The names Uttaltur, Trichonopoly and Ariyalur were given by H.F. Blanford in 1862. The subsurface Cretaceous succession exhibiting considerable lateral facies variation in the onland part of the basin (Fig. 15.8) extends eastwards over the continental slope. The offshore extension of the Uttattur Group is represented by the *Andimadam Conglomerate* and the *Sattapadi Shale* ranging in age from Pre-Albian to Cenomanian. The Sattapadi Shale is overlain by the *Bhuvanagiri Formation* made up of predominant sandstone with minor shale. The Bhavanagiri contains Cenomanian to Conacian species of *Rotalipora* and *Marginotruncana*. The offshore facies of the Ariyalur Group are described as the *Palk Bay Formation* of calcareous sandstones, the *Kudavasal Shale*, the *Nannilam Shale*, the *Porto Novo Shale* and the *Komarakshi Shale* containing Campanian to Maastrichtian species of foraminifers including *Rosita*, *Globotruncana* and *Abathomphalus* (Raju and Mishra 1996). The faunas indicate the depositional environment varying from outer shelf to bathyal zone.

## 15.4 North-western Continental Margin

### *15.4.1 Kachchh Basin*

The north-western part of the Indian continental margin experienced lithospheric stretching and rifting in the Late Triassic (Biswas 1982, 1987, 2003, 2005). The resulting depression (rift valleys) is oriented east–west (Figs. 15.9 and 15.11; Table 15.3). The depositional sites were of the nature of embayment between the uplifted Tharad–Nagarparkar Ridge in the north, the raised-up Saurashtra High

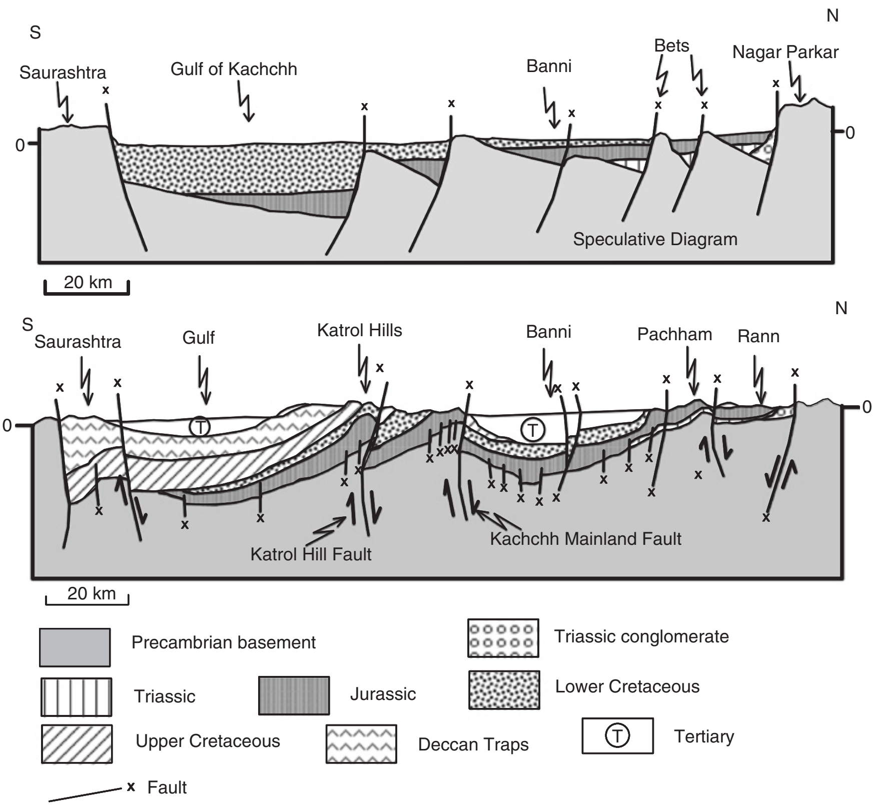


**Fig. 15.9** Rifting of the north-western continental margin gave rise to the Kachchh Basin, comprising a series of ridge- and half-graben-oriented east–west (after Biswas 2005)

**Table 15.3** Mesozoic lithostratigraphy of the Kachchh and Jaisalmer basins in north-western continental margin of India

| Age | Kachchh Basin | Jaisalmer Basin |
|---|---|---|
| Late Cretaceous | Deccan traps | Parh Formation |
| - - - - - - - *Unconformity* - - - - - - - | | |
| Early Cretaceous | Bhuj | Goru<br>- - - - -*Unconformity*- - - - -<br>Habur |
| - - - - - - - *Unconformity* - - - - - - - | | |
| Upper Jurassic | Katrol | Pariwar<br>Bhadesar/Baisakhi |
| | Chari | |
| Middle Jurassic | Patcham | Jaisalmer |
| Lower Jurassic | | Lathi |
| Upper Triassic | | Shumarwali |
| - - - - - - - *Unconformity* - - - - - - - | | |
| Precambrian/Proterozoic basement, Permian Karampura | | |

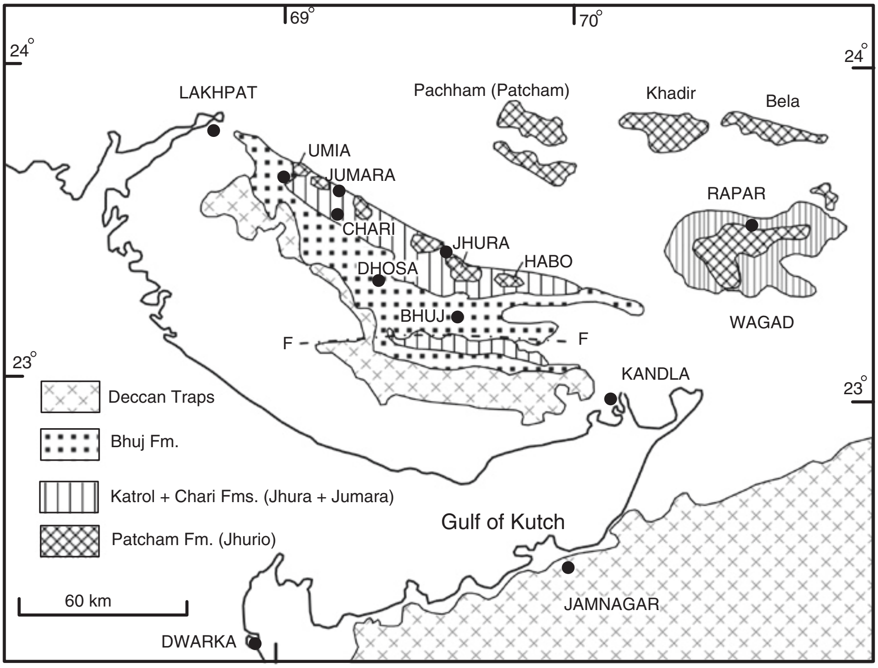


**Fig. 15.10** Sketch map showing the Jurassic–Cretaceous formations in the Kachchh Basin (after Biswas 1992)

in the south and the Radhanpur–Barmer High in the east. A NNE–SSW trending high divides the basin into two parts—the western part exhibiting progressive thickening and facies variation of sediments, and the eastern part having shallow-water sediments (Biswas and Deshpande 1983). The sediments, laid down on the Archaean and Proterozoic basements, provide a coherent record of stratigraphy of the Mesozoic (Agrawal 1957, 1977, 1981; Krishna 1987). The lithostratigraphic nomenclature was proposed by W. Waagen in 1873.

The sedimentation in the Kachchh Basin (Figs. 15.9, 15.10 and 15.11; Table 15.3) started in the Middle Jurassic time. The *Patcham Formation* (also described as Jhurio) comprises Bajocian–Early Callovian carbonate–shale association. The bioclastic limestone of the upper part contains rich assemblage of corals, molluscs, brachiopods, ammonites and bryozoans and foraminifers. In the lower part, the shale is interbedded with thick limesone with golden oolites. The overlying *Chari Formation* (Jumara) comprises laminated shales with intercalation of siltstone, marl and bioclastic limestone of deltaic environment. The limestone is oolitic; the characteristically golden coloured oolitic limestone is known as the *Dhosa Oolite*. The sedimentary rocks making the Jhumra, Juma and Habo domes in western Kachchh contain ostracode assemblages indicating their Bathonian to Callovian (Middle and Upper Jurassic) ages, and also pointing to the similar assemblages in Laurasian as well as Indo-East African provinces along

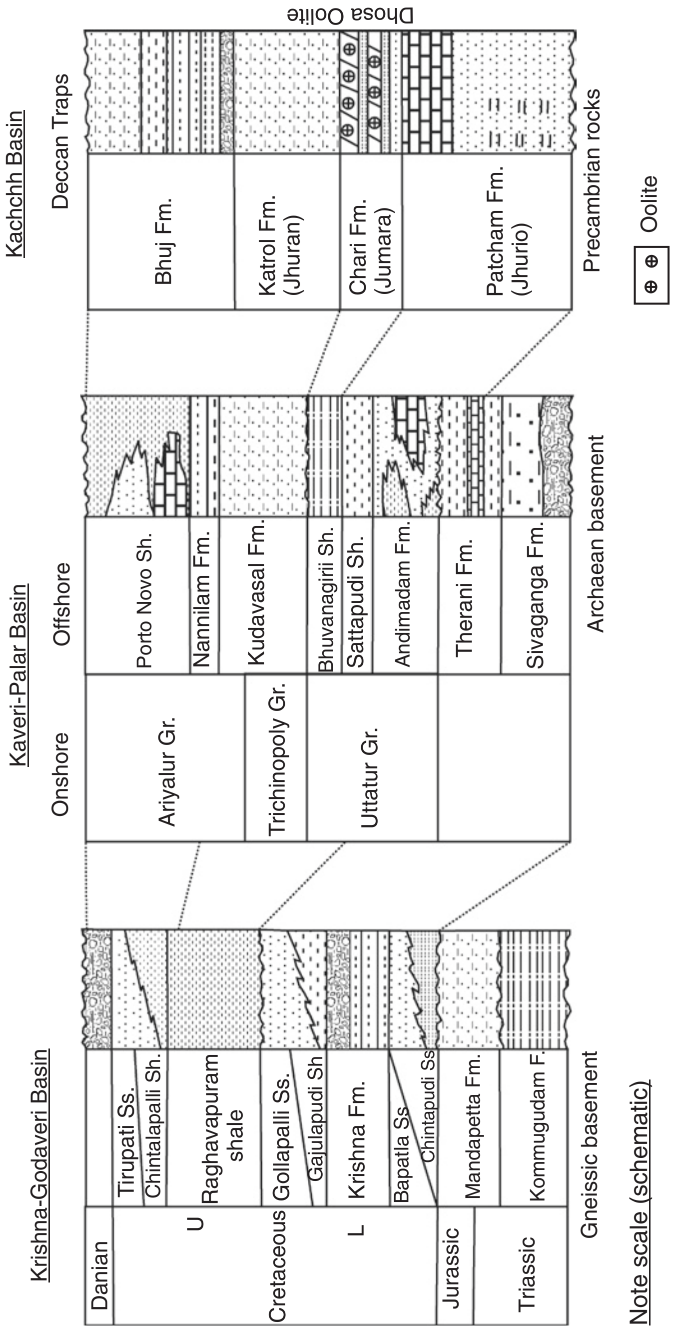


**Fig. 15.11** Lithological logs of the Mesozoic formations of the Kachchh and the Jaisalmer basins

the Tethys. Across a paraconformity, the thick coursing upwards succession of cross-bedded sandstone and shale characterized by ferruginous concretions of the *Katrol Formation* (Jhuran) belong to the Upper Jurassic to very Early Cretaceous (Kimmeridgian to Neocomanian) period. It consists of yellow brown cross-bedded feldspathic sandstone with cyclic interbeds of yellow-laminated sandstone, grey carbonaceous shale and locally kaolinitic white shale and dark brown to purple bioturbate siltstone. Even as littoral zone expanded and the delta complex grew into the open sea to the west, the fluvial processes had become active (Krishna et al. 1998).

The Jurassic succession is overlain probably with break by the Cretaceous rocks, 1000–1200 m in thickness (Table 15.3) and ranges in age from Berriasian–Valanginian to Late Turonian–Coniacian (Krishna 1991). Fission-track dating of glauconite from the uppermost horizon (Bhuj Formation) placing it between 112 and 89 Ma (Biswas 2005) confirms the early Upper Cretaceous age of the youngest horizon of the Mesozoic of Kachchh. The *Bhuj Formation* (Table 15.3), made up of Ghuneri, Ukra and Upper Unit, comprises grey silty shale with limonitic parting and locally carbonaceous shale. As elsewhere, there is a rich assemblage of *Ptilophyllum* flora, understandably derived from the land through rivers and streams. The bioturbated sandstone characterized by iron oxide enrichment and leaf impressions contains Middle Albian nannofossils. The *Ghuneri Member* is made up of rhythmic alternation of red and yellow sandstone and shale and with bands of ironstone or ferruginous sandstone and lensoid bodies of coal formed in a deltaic environment. The *Ukra Member* consists of glauconitic sandstone, shale and oolitic limestone and marl that contain abundant ammonites and pelecypods as well as fossil wood. Occurring in the westernmost part of the basin, this horizon represents a short transgressive episode in the delta-front during sea-level high-stand in the Aptian time. Plant fossils *Ptylophyllum, Otozamites, Cladophlebis* and *Williamsonia* recall upper Gondwana flora. It is overlain by Upper Member comprising cross-bedded coarse-grained sandstone with ferruginous bands, limestone and white kaolinitic clays. The hummocky cross-bedding indicates interference of storm waves with ebb-tide currents along a prograding shoreline (Bose et al. 1986). Such features such as wavy lamination, ripple drift lamination and flaser bedding indicate that the sediments of the terminal horizon of the Kachchh Cretaceous were deposited in tidal channels and tide-affected shelf embracing tidal flats and lagoons (Krishna et al. 1983).

In the Wagad–Rapar–Adesar area in north-eastern Kachchh, the feldspathic, locally ferruginous and conglomeratic sandstone with minor shale contain both marine fossils and plant remains of the Lower Cretaceous age. These sediments represent nearshore deposits in a tidal environment where the distributary channels had NW–SE direction (Bandyopadhyay 2004).

It may be stressed that the Jurassic rocks of Kachchh have acquired global importance for their exceptionally rich ammonite assemblages, particularly of the Callovian–Tithonian (Upper Jurassic) time span (Krishna 1987, 1991; Krishna and Cariou 1986; Krishna et al. 1998). The ammonite assemblage, including *Gregoryceras fouguei, Euaspidosa*, *Perisphinctes* and *Epimayaites*, implies

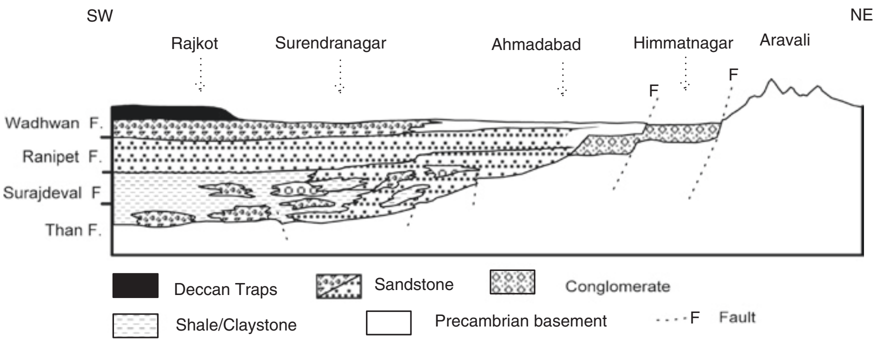


**Fig. 15.12** Pattern and environment of deposition of the sediments of the Dhrangadhra succession in north-eastern Saurashtra (after Casshyap and Aslam 1992)

connection of the Kachchh fauna with that of Indo-African faunal province. The horizon of the Dhosa Oolite, an important stratigraphic marker, is characterized by a faunal assemblage that contains elements of both the Indo-African (Mayaitinae) and the Tethyan (Perisphinctinae) faunal provinces.

In north-eastern Saurashtra, there is a 500- to 600-m-thick succession of cross-bedded feldspathic and ferruginous sandstones with intercalations of shale containing leaf impressions of the Gondwana affinity and local layers of conglomerate above the Early Proterozoic basement. The succession is known as the *Dhrangadhra Formation* (named by F. Fedden in 1884). This succession (Fig. 15.12) is time transgressive of the *Wadhwan Beds* in the Surendranagar district. The two formations are regarded as the inland facies of the marine Cretaceous. The upward-coarsening lower part was formed by the distributaries of a delta in the proximity of the shoreline, while the upper part is made up of deposits of subtidal to tidal and beach zones (Casshyap and Aslam 1992; Aslam 1992). At the top is a horizon of fossiliferous limestone interbedded with pebbly sandstone and mudstone deposited in embayments and estuaries. The calcareous upper part interbedded with lava flows of the Wadhwan contains, besides the plant *Cladophlebis*, remains of a fish of the Upper Tithonian to Albian age (Borkar 1973).

The Sadara Sill in the Pachchham area in Kachchh having composition transitional between basalt and basanite, and characterized by Sr, B, Pb and LREE enrichment and Nb, Cr, Y, Cs, Lu depletion, shows magnetic pole in the pre-Deccan Volcanism period in the 85- to 91-Ma interval (Ray et al. 2006). It must have been emplaced along faults resulting from the rifting of the crust in Kachchh.

### 15.4.2 *Jaisalmer Basin*

The Jaisalmer Basin is one of the four basins developed in the Rajasthan continental margin—the Bikaner–Nagaur Basin, the Barmer Basin, the Sancher Basin and

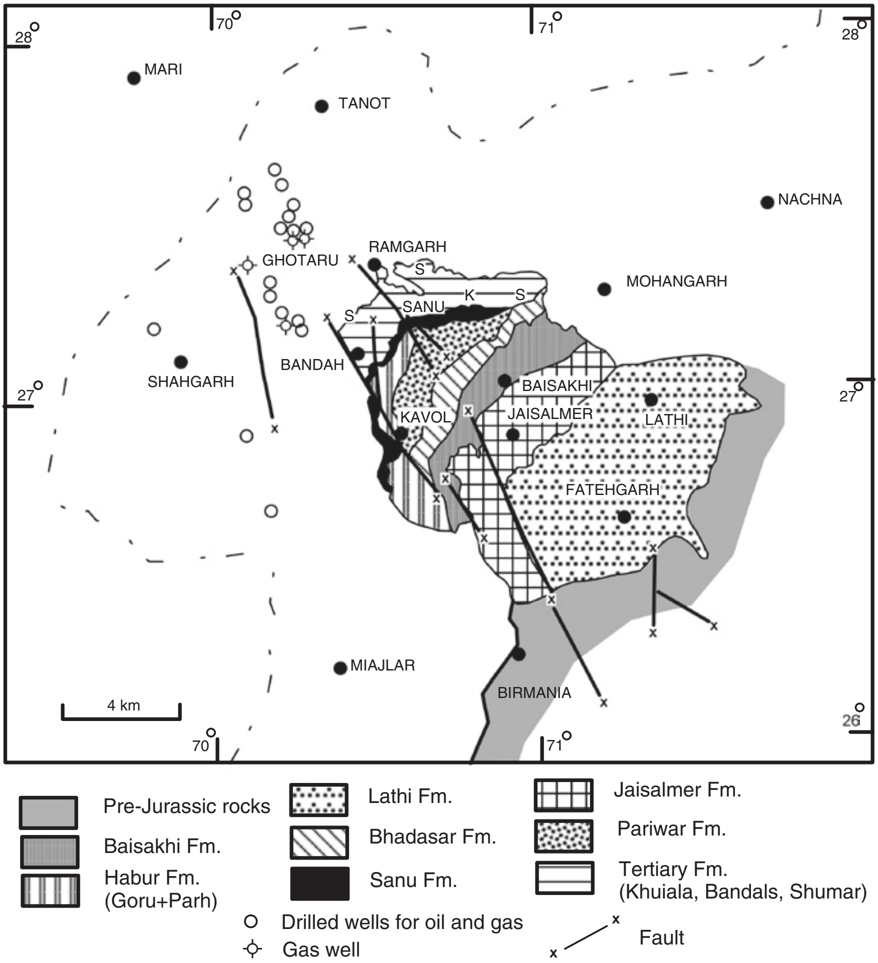


**Fig. 15.13** Sketch map showing the Mesozoic formations of the Jaisalmer Basin and adjoining areas in western Rajasthan. Important structural lines delineate the tectonic boundaries (based on Singh 1996 and Sinha-Roy 1984)

the Jaisalmer Basin, the last one being pericratonic (Datta 1983). The Bikaner–Nagaur Basin is a Precambrian–Palaeozoic Basin, and the Barmer and Sancher basins evolved in the Middle Jurassic. In the Jaisalmer Basin (Fig. 15.13; Table 15.3), sedimentation commenced in the Permian time and continued throughout the Mesozoic and the Cenozoic. It may be pointed out that while the Barmer Basin in the south received its sediments dominated by heavy mineral hornblende from this Mewar–Marwar Ridge, the Jaisalmer Basin was fed by rivers draining the Jaipur–Ajabgarh–Alwar region of the central Aravali Range, as testified by staurolite, kyanite and garnet (Siddique 1963). The 1200-m-thick Jaisalmer succession on the continental shelf is characterized by several cycles of carbonate sedimentation.

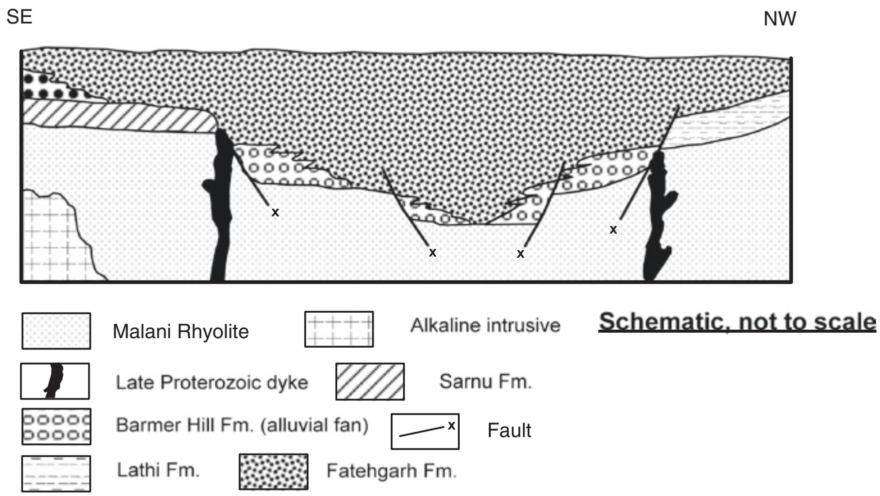


**Fig. 15.14** Structure and lithostratigraphy of the Barmer Basin illustrates the pattern and sequence of the Mesozoic sedimentation in Rajasthan (after Sisodia and Singh 2000)

The Barmer Basin (Fig. 15.14) is a narrow N–S-oriented fault-lined depression. In the Barmer Basin, the Lower Cretaceous *Sarnu Formation* is exposed along the western-faulted margin. The horizon consists of dominant fine-grained to pebbly feldspathic sandstone with plant fossils (the Sarnu is unconformably overlain by Palaeocene Fatehgarh Formation). The intertidal to neritic shelf deposit at the base gives way upwards to a fining-upward succession of sandstone, locally ferruginous and phosphatic and containing fossil wood. Its upper part is made up of tidal-flat mud (Sisodia and Singh 2000).

In the Jaisalmer Basin (Fig. 15.13 and Table 15.3) overlying the Permian Karampura Formation, the *Shumarwali Formation* of the Triassic time comprises a sequence of fluvial to deltaic and shallow epineritic clastic sediments. The Early Jurassic *Lathi Formation* represents the continuation of the Triassic sedimentation nearly the same environment on an intertidal to neritic shelf. The sediments of the overlying *Jaisalmer Formation* were laid down on the extensive stable shelf, in which several cycles of carbonate depositions took place. The situation then changed, and sandstone–shale alternation of the *Baisakhi* and *Bhadasar formations* was laid down in the Upper Jurassic time. The Cretaceous period commences with the deposition of yellow brown siltstone–sandstone alternation, calcareous feldspathic sandstone and claystone (with a fossil of tree trunk) making up the *Pariwar Formation*. Palynomorph assemblage and arenaceous foraminifers indicate Neocomanian age of the deltaic sediments of the Pariwar Formation (Das Gupta 1975; Dave and Chatterjee 1996; Mehrotra et al. 2002). The overlying *Habur Formation* comprises alternation of cross-bedded calcareous sandstones and coquinoidal limestone, foraminiferal limestone and shale. This nearshore sequence is characterized by the Lower Aptian to Middle Albian ammonites and foraminifers (Krishna 1987). The succeeding *Goru*

*Formation* consists of greenish grey locally pyritous shale, and calcareous siltstone with marl. The glauconite grains give Rb–Sr age of 103.3 ± 3.0 Ma (Vijan et al. 2000) confirming the Albian age. The thick succession of argillaceous limestone and marl exposed in the Parh Hill in Sindh (Pakistan) and its subsurface easterly extension in western Rajasthan is known as the *Parh Formation*. The Parh contains Coniacian fossils (Mukherjee et al. 1995). At the top of the Cretaceous formation, the horizon described as "Siliceous Earth" contains volcanic ash made up of glass shards, agglutinates and hollow spheroids at Matti-ka-god and Ni-rich vesicular glass, sanidine spherules, magnesioferrite crystals with soot at Bariyara, implying an event that possibly could be related to the K–T boundary (Sisodia et al. 2005).

## 15.5 Northern Continental Margin

Even as a large part of the subcontinent including Saurashtra, Kachchh, Marwar, Meghalaya–Bengal and Coromandal coast came under the sway of sea water, the leading edge of the northward-moving India (which had been the site of sedimentation all through the Proterozoic and Palaeozoic) started to subside during the Cretaceous. The sea continued to deepen progressively along the northern periphery. In the deep sea were deposited siliceous and calcareous oozes and pelagic clays, giving rise to chert beds and limestones and shales. Phosphatic nodules and glauconite, occurring locally, indicate deep and cold water that was deficient in oxygen. Simultaneous with the subsidence of the northern edge of India, an oceanic trench started forming along the edge of the Tibetan landmass, and by the end of the Cretaceous the trench had become more than 2000 m deep.

The sinking of the seafloor was followed by its fissuring. Through the fissures came out lavas on a grand scale all along the tract. A chain of volcanic sea mounts and islands developed in front of the sinking continental margin of India. The arc-shape chain of volcanic island stretched from Kohistan in the west to Shigatse in the east. By then, the northward-moving Indian plate had come close to the Tibetan landmass of the Asian plate. In between lay the arcuate chain of volcanic islands and a trench filled with sediments.

This aspect is dealt with in Chaps. 16 and 17.

## 15.6 An Arm of Sea Inside Central India

Related to the regional Narmada graben, there were a number of linear depressions of the nature of half-graben in central India (Tripathi and Lahiri 2000). These were sites of fluvial sedimentation. Reactivation of faults caused down-faulting in the zone of the Narmada graben, inviting sea water from the west. In the Narmada Valley, the Upper Cretaceous is thus represented by the fluvial horizon succeeded by a marine formation.

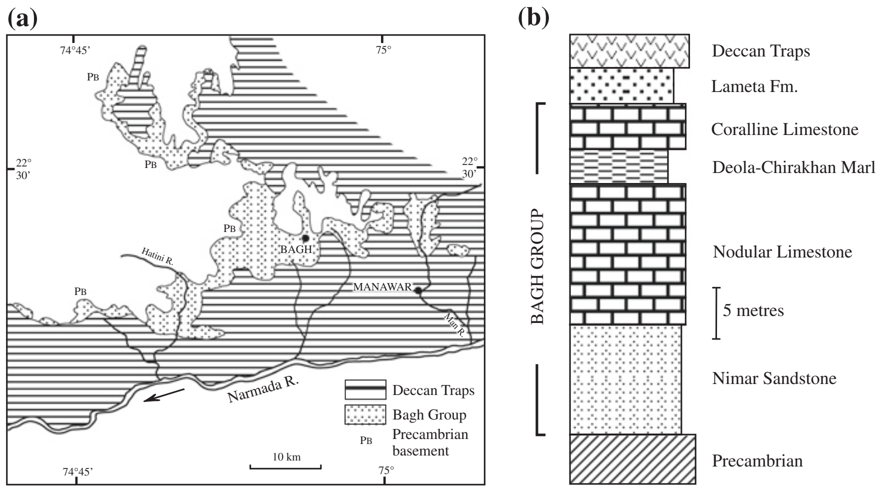


**Fig. 15.15** **a** *Sketch map* showing the spread of the Bagh Beds, a Cretaceous formation in the Narmada Valley (after Tripathi and Lahiri 2000). **b** Lithology of the Bagh Beds as seen in the man river section near Deola (after Taylor and Badve 1995)

Outliers of conglomerate and gritty calcareous sandstones measuring a few tens to a few hundred metres in thickness were first described as the *Nimar Sandstone* by P.N. Bose in 1884 in the area of the famous Bagh Caves in the Narmada Valley. In and around Chakrud, polymictic conglomerate, strongly graded pebbly sandstone that is characterized by hummocky cross-bedding, and ripple-marked mudstone with limestone, bear testimony to the influence of alternating fair weather and storm conditions in the site of the Nimar sedimentation (Bose and Das 1986). Possibly tides were also active (Ahmad and Akhtar 1990; Akhtar and Ahmad 1991). The upward-fining sequence of the Nimar was laid down in freshwater, as carbon- and oxygen-isotopic composition of limestone indicates (Bhattacharya et al. 1997a, b). The Nimar Sandstone is succeeded by the *Karondia Limestone* representing a platform deposit formed on the ramp of the shelf dotted with islands in the subtidal zone (Akhtar and Khan 1997). The upper part of the sequence has yielded Cretaceous benthic foraminifers (Rajashekhar 1991) and nannoplankton species *Marthastenites furcatus* of the Turonian age (Jafar 1982).

The marine incursion in the Late Cretaceous is represented by small isolated outcrops of the *Bagh Beds* in the Dhar district, Madhya Pradesh (Fig. 15.15). W.T. Blanford gave the name in 1869. The group extends eastwards as far as Barwaha. The Bagh Beds unit comprises three formations (Fig. 15.15). The *Nodular Limestone* in the lower part is a clastic carbonate characterized by ripple marks formed in shallow-water environment (Singh and Srivastava 1981; Akhtar and Khan 1997), containing rich assemblages of pelecypods and gastropods (Chiplonkar et al. 1977; Chiplonkar 1959, 1987) and benthic foraminifers (Rajashekhar 1991). In the upper part near Kukshi, the Late Turonian marker ammonite *Prionocyclus germari* occurs in the Hathni Valley (Kennedy et al. 2003). Essentially, a bryozoan carbonate horizon, the *Coralline Limestone* is characterized by the dominant bryozoan *Chiplonkarina dimorphora* of "Lower Cenomanian–Turonian age" (Taylor and Badve 1995).

The Bagh Beds give way upwards to feldspathic arenite and carbonates—recognized as the Lameta Formation of lacustrine origin. The Lameta has been discussed in detail in Chap. 14.

## 15.7 Mesozoic Panorama of Marine Life

### *15.7.1 Prolific and Diverse Life*

As a consequence of Hercynian tectonic upheaval towards the end of the Permian, the sea withdrew from a large part of the continental margin the resultant reduction of environmental niches caused decline in the population of marine invertebrates and extinction of many. The Late Permian was a time of large-scale extinction of marine life all over the world (Kummel 1961). But the return of the sea in the Jurassic and Cretaceous periods over much larger areas of the Indian continental margin, as already elaborated, enlarged the areal extent of the habitats of the marine communities. Availability of diverse niches promoted vigorous growth and proliferation of life in the Mesozoic. By the Middle Triassic, the marine fauna became extremely prolific and diverse, particularly in the Himalayan domain belonging to the Tethyan faunal province. And this trend continued till the end of Cretaceous.

### *15.7.2 Age of Ammonites*

One among the cephalopods, the ammonites dominated marine fauna of the Triassic time. Not only were they abundant and widespread but also very diverse in spite of three extinctions they suffered before their final disappearance at the end of the Cretaceous. Each time, the surviving stock evolved to more diverse and more abundant forms, far grander in scale than that of the previous period (Kummel 1961). The size of ammonites ranged from 2.7 m to a few millimetres, and the shape varied from flat, globular, loosely coiled to tightly coiled shell. *Turrilites* was an uncoiled ammonite, and *Acanthoceras* developed spines on their shell for self-defence. The Early Triassic ammonites were unoriented forms with rather simple ceratitic sutures. The Middle Triassic forms were highly ornamented with ribs or nodes or both giving rise to ammonite sutures. They persisted towards the end of the Triassic, giving way to those who had more complex pattern of development—the lytoceratids and phylloceratids peopling the Himalayan domain.

The nautiloids evolved slowly and became highly specialized in ornamentation and pattern of suture during the Late Triassic. Only one group of nautiloids survived extinction, and it produced great number of species belonging to *Nautilus* in the Jurassic. In the Jurassic and Cretaceous, the belemnoids became abundantly widespread.

### *15.7.3 Reef Builders and Associated Invertebrates*

The pelecypods became very widespread and diverse in the Mesozoic era. The important forms include *Monotis, Exogyra, Gryphaea, Mytilus, Hippurites, Trigonia, Inoceraus, Pecten* and *Ostrea.* One group of pelecypods—the rudistids—became attached to the bottom and built reefs in shallow warm waters. Likewise, corals built conspicuous reefs. The reef-building corals belonged to the order *Sclerictinia*, which first appeared in the Middle Jurassic and became dominant by the Late Jurassic and in the Cretaceous. Echinoderms became very abundant and diverse in the later part of the Mesozoic. Rare in the Triassic, the bryozoans increased in number appreciably during the Jurassic and Cretaceous times. There was explosive growth of planktonic foraminifers during this period. First appearing in the Triassic, the phytoplankton Coccolithophores (made up of calcareous microscopic plates) proliferated greatly and eventually formed the famous chalk beds of the Cretaceous. The siliceous diatoms and the dinoflagellates evolved and increased in number and varieties in cooler waters during the Cretaceous.

### *15.7.4 Marine Vertebrates*

In the Early Permian seas lived small reptiles having slender long body, small neck, teeth-bearing jaws and paddle-like short legs. The *Mesosaurus* was the oldest aquatic reptile. By the Late Cretaceous, they had grown in size—as much as 25–9 m in length. The *Pleisiosurus* was 3.5–6 m long. And *Ichthyosaurus* measured 3 m in length having a streamlined body, flipper-like forelimbs and powerful tail for propulsion.

Among fish, the lung fish crossopterigians were important. By the Late Cretaceous, the advanced group of fish teleosts became dominant. Shark-like fish *Otodus, Pycnodus* and *Ptychodus* were common in the Trichinopoly Formation.

Labyrinthodonts, represented by *Archegosaurus*, possessed crocodile-like long snout, and their eyes were surrounded by rings of long plates, and the body was covered with overlapping scales. *Archegosaurus* occurs in the Triassic of Kashmir of the Tethyan domain. It was a contemporary of *Gondwanasaurus* which lived in the Panchet Basin near Pachmarhi in Madhya Pradesh.

## References

Agrawal, S. K. (1957). Kutch Mesozoic. A study of the Jurassic of Kutch with special reference to Jhura dome. *Journal of the Palaeontological Society of India, 2*, 119–130.

Agrawal, R. K. (1977). Structure and tectonics of Indo-Gangetic plain. In V. L. S. Bhimasankaram (Ed.), *Geophysical Case Histories* (pp. 27–48). Hyderabad: Association of Exploration Geophysicists.

Agrawal, S. K. (1981). Kachchh Mesozoic: Some problems and recent contributions. *Recent Researches in Geology, 4*, 482–492.

Ahmad, A. H. M. & Akhtar, K. (1990). Clastic environments and facies of the Lower Cretaceous Narmada basin, India. *Journal Sedimentary Petroleum*.

Akhtar, K., & Ahmad, A. H. M. (1991). Single cycle cratonic quartzarenites produced by tropical weathering: The Nimar Sandstone (Lower Cretaceous) Narmada Basin, India. *Sedimentary Geology, 71*, 23–32.

Akhtar, K., & Khan, D. A. (1997). A tidal island model for carbonate sedimentation: Karondia limestone of Cretaceous Narmada basin, India. *Journal-Geological Society of India, 50*, 481–489.

Alam, M. (1989). Geology and depositional history of Cenozoic sediments of the Bengal Basin of Bangladesh. *Palaeogeography, Palaeoclimatology, Palaeoecology, 69*, 125–139.

Alam, M., Alam, M. M., Curray, J. R., Chowdhury, M. L. R., & Gani, M. R. (2003). An overview of sedimentary geology of the Bengal basin in relation to the regional framework abd basin-fill history. *Sedimentary Geology, 155*, 179–208.

Aslam, M. (1992). Delta plain coal deposits from the Thar formation of the early Cretaceous Saurashtra basin Gujarat, Western India. *Sedimentary Geology, 81*, 181–193.

Bandyopadhyay, A. (2004). Sedimentation, tectonics and palaeoenvironment in eastern Kachchh, Gujarat. *Journal-Geological Society of India, 63*, 171–182.

Banerji, R. K. (1970). On the stratigraphy and microplaeontology of Dalmiapuram formation (Lower Cretaceous)—a new rock-stratigraphic unit of South India. *Journal of the Palaeontological Society of India, 15*, 32–41.

Banerjee, R. K. (1982). Sivaganga formation, its sedimentology, micropalaeontology and sedimentation history. *Journal-Geological Society of India, 23*, 450–457.

Banerji, R. K. (1972). Stratigraphy and micropalaeontology of the Cauvery basin, part I, exposed area. *Journal of the Palaeontological Society of India, 17*, 7–30.

Banerji, R. K., Ramaswamy, S., Malini, C. S., & Singh, D. (1996). Uttatur group redefined. *Memoirs-Geological Society of India, 37*, 213–299.

Bhatia, S. B., & Jain, S. P. (1969). Dalmiapuram formation: A new Lower Cretaceous horizon in South India. *Bulletin Indian Geologists' Association, 2*, 105–109.

Bhattacharya, S. K., Jani, R. A., Tripathi, S. C., & Lahiri, T. C. (1997a). Carbon and oxygen isotopic composition of Intertrappean limestones from Central and Western India and their depositional environment. *Journal-Geological Society of India, 50*, 289–296.

Bhattacharya, A., Nandi, A., & Dutta, A. (1997b). Triassic mega- and micro-plant fossils from the Kamthi formation of Talchir coalfield, Orissa, with chronological significance. *Special Publication of Geological Survey of India, 54*, 123–126.

Biswas, S. K. (1982). Rift basins in western margin of India and their hydrocarbon prospect, with special reference to Kutch. *Bulletin of American Association Petroleum Geological, 66*, 1497–1513.

Biswas, S. K. (1987). Regional tectonic framework, structure and evolution of the western marginal basins of India. *Tectonophysics, 135*, 307–327.

Biswas, S. K. (1992). Tertiary stratigraphy of Kutch. *Journal of the Palaeontological Society of India, 37*, 1–29.

Biswas, S. K. (2003). Regional tectonic framework of the Pranhita–Godavari basin, India. *Journal of Asian Earth Sciences, 21*, 543–551.

Biswas, S. K. (2005). A review of structure and tectonics of Kutch basin, Western India, with special reference to earthquakes. *Current Science, 88*, 1592–1600.

Biswas, S. K., & Deshpande, S. V. (1983). Geology and hydrocarbon prospects of Kutch, Saurashtra and Narmada basin. In L. L. Bhandari, et al. (Eds.), *Petroliferous Basins of India* (pp. 111–126). Dehradun: KDM Institute of Petroleum Exploration.

Borkar, V. D. (1973). New fossil fishes from the intertrappean beds of Surendranagar District, Gujarat State. *Current Science, 42*, 12.

Bose, P. K., & Das, N. G. (1986). A transgressive storm- and fair-weather wave dominated shelf sequence: Cretaceous Nimar formation Chakrud, Madhya Pradesh, India. *Sedimentary Geology, 46*, 147–167.

Bose, P. K., Shome, S., Bardhan, S., & Ghosh, G. (1986). Facies mosaic in the Ghuneri member (Jurassic) of the Bhuj formation Kutch, Western India. *Sedimentary Geology, 46*, 293–309.

Casshyap, S. M., & Aslam, M. (1992). Deltaic and shoreline sedimentations in Saurashtra basin, Western India: An example of infilling in an early Cretaceous failed rift. *Journal of Sedimentary Petrology, 62*, 972–991.

Chandra, K., Srivastava, D. C., Sharma, R. & Pal, M. (1994). Hydrocarbon prospects and status of exploration in Gondwana basins of India. *Proceedings of the International Gondwana Symposium* (pp. 1177–1197). New Delhi: Oxford-IBH.

Chiplonkar, G. W. (1959). Bryozoa from the Bagh Beds. *Proceedings of the Indian Academy Science* (*Earth and Planet Science*), *10B*, 98–109.

Chiplonkar, G. W. (1987). Three decades of invertebrate palaeontology and biostratigraphy of marine Cretaceous rocks of India. *Special Publication of Geological Survey of India, 2*(1), 305–339.

Chiplonkar, G. W., Ghare, M. A., & Badwe, R. M. (1977). Bagh Beds—their fauna, age and affinities: A retrospect and prospect. *Biovigyanum, 3*, 33–60.

Chitra Rao, A. M., & Asthana, M. (2000). Cretaceous valley fill sandstone of Nandigama area, Krishna–Godavari basin, A.P. *Journal-Geological Society of India, 56*, 27–38.

Das Gupta, S. K. (1975). A revision of the Mesozoic-tertiary stratigraphy of the Jaisalmer basin, Rajasthan. *Indian Journal of Earth Science, 2*, 77–94.

Dasgupta, K., Saraswati, P. K., Kramar, U., Ravindran, C. N., Stuben, D., & Berner, Z. (2006). *Oxygen Isotopic Composition of Albanian–Turonian foraminifera from Cauvery basin, India: Evidence of warm sea surface temperature*. Soc: Journal Geological. 66.

Datta, A. K. (1983). Geological evolution and hydrocarbon prospects of Rajasthan basin. *Petroleum Asia Journal* (pp. 93–100). Dehradun: ONGC.

Dave, A., & Chatterjee, K. (1996). Integrated foraminiferal and ammonoid biostratigraphy of Jurassic sediments in Jaisalmer basin, Rajasthan. *Journal-Geological Society of India, 47*, 477–490.

Govindan, A., Ananthanarayanan, S., & Vijayalakshmi, K. G. (2000). Cretaceous petroleum system in Cauvery basin, India. *Memoirs-Geological Society of India, 46*, 365–382.

Jafar, S. A. (1982). Nannoplankton evidence of Turonian transgression along Narmada valley, India and Turonian–Coniacian boundary problem. *Journal of the Palaeontological Society of India, 27*, 17–30.

Jafar, S. A. (1996). The evolution of marine Cretaceous basins of India: Calibration with nannofossil zones. *Journal-Geological Society of India, 37*, 121–134.

Jain, S. P. (1968). Ostracodes from the pre-Cretaceous grey shales of Dalmiapuram, South India. *Bulletin Industrial Geologists' Association, 2*, 70–71.

Johnson, S. Y., & Alam, A. M. N. (1991). Sedimentation and tectonics of the Sylhet through, Bangladesh. *Geological Society of America Bulletin, 103*, 1513–1527.

Kak, S. N., & Subrahmanyam, A. V. (2002). Depositional environment and age of Mahadek formation of Wahblei river section, West Khasi Hills, Meghalaya. *Journal-Geological Society of India, 60*, 151–162.

Kapoor, P. N., Prasad, B., Swamy, S. N., & Shukla, S. D. (1999). Palynostratigraphy and hydrocarbon source potential of Cretaceous sediments in Krishna subregion India. *Geoscience Journal, 20*, 21–24.

Kennedy, W. J., & Henderson, R. A. (1992). Non-heteromorph ammonites from the upper Maastrichtian of Pondicherry South India. *Palaeontology, 35*, 381–442.

Kennedy, W. J., Phansalkar, V. G., & Walaszczyk, T. (2003). *Prionocyclus germari* (Reuss 1845), a late Turonian marker fossil from the Bagh Beds of Central India. *Cretaceous Research, 24*, 433–438.

Khan, A. A., Sattar, G. S. & Rahman, T. (1994). Tectogenesis of the Gondwana rifted basins of Bangladesh in the so-called Garo–Rajmahal Gap and their pre-drift regional tectonic correlation. *Proceedings of the 9th International Gondwana Symposium* (pp. 647–655). New Delhi: Oxford-IBH.

Khan, A. A., Sattar, G. S. & Rahman, T. (1996). Technogenesis of the Gondwana rifted basins of Bangladesh in the so-called Garo–Rajmahal gap and their pre-drift regional tectonic correlation. *Ninth International Gondwana Symposium* (Vol. 2, pp. 647–656). Hyderabad: Geological Survey of India.

Krishna, J. (1987). An overview of the Mesozoic stratigraphy of Kachchh and Jaisalmer basins. *Journal of the Palaeontological Society of India, 32*, 136–152.

Krishna, J. (1991). Discovery of Lower Berriasian (Lower Cretaceous) ammonoid genus Argentiniceras from Kachchh (India) and its relevance to Jurassic-Cretaceous boundary. *Newsletter Stratigraphy, 23*, 141–150.

Krishna, J., & Cariou, E. (1986). The Callovian of Western India: New data on the biostratigraphy of the ammonites and correlation with Western Europe. *Newsletter Stratigraphy, 17*, 1–8.

Krishna, J., Pathak, D. B., & Pandey, B. (1998). Development of Oxfordian (Early Upper Jurassic) in the most proximately exposed part of the Kachchh Basin at Wagad outside the Kachchh mainland. *Journal-Geological Society of India, 52*, 513–522.

Krishna, J., Singh, I. B., Howard, J. D., & Jafar, S. A. (1983). Implications of new data on Mesozoic rocks of Kachchh Western India. *Nature, 205*, 790–792.

Kummel, B. (1961). *History of the Earth: An introduction to historical geology* (p. 610). Delhi: Eurasia Publishing House.

Kumaraguru, P. & Trivikram Rao, A. (1994). A reappraisal of the geology and tectonics of the Palar basin sediments, Tamilnadu. *Proceedings of the 9th International Gondwana Symposium* (pp. 821–831), New Delhi: Oxford-IBH.

Maithani, P. B., Taneja, P. C., & Singh, R. (1995). A sandstone-type uranium deposit at Phlangdiloin, West Khasi Hills, Meghalaya. *Journal Atomic Minerals Science, 3*, 45–60.

Majumdar, S. K., Basu, B., Shivashankar, J., Arunachalam, A. & Rangaraju, M. K. (1995). Palakollu–Pasarlapudi petroleum system, Krishna–Godavari basin, India. In *Proceedings of the Petrotech-5: Technology Trends in Petroleum Industry* (pp. 495–508). New Delhi: B.R. Publishing Corporation.

Mamallan, R., Kumar, D., & Bajpai, R. K. (1994). Jasra ultramafic–mafic–alkaline complex: A new find in the Shillong Plateau NE India. *Current Science, 66*, 64–65.

Mamgain, V. D., Sastry, M. V. A., & Subbaraman, J. V. (1973). Report of ammonites from Gondwana plant beds at Terani, Tiruchirapalli. *Journal-Geological Society of India, 14*, 198–210.

Manmohan, M., Rao, M. R. R., Kamaraju, A. V. V. S., & Yalamarty, S. S. (2003). Origin and occurrence of Lower Cretaceous high-gamma-high-resistivity Raghavapuram Shale—a key stratigraphic sequence for hydrocarbon exploration in Krishna–Godavari basin, A.P. *Journal-Geological Society of India, 62*, 271–289.

Mehrotra, N. C., Venkatachala, B. S., Swamy, S. N., & Kapoor, P. N. (2002). *Palynology in Hydrocarbon Exploration* (p. 159). Bangalore: Geological Society of India.

Mishra, U. K., & Sen, S. (2004). Dinosaur remains from Dirang, West Khasi Hills district, Meghalaya. *Journal of the Geological Society of India, 63*, 9–14.

Mishra, B., Pandya, K. L., & Maejima, W. (2004). Alluvial fan-lacustrine sedimentation and its tectonic implications in the Cretaceous Athgarh Gondwana basin Orissa, India. *Gondwana Research, 7*, 375–385.

Mukherjee, M. K., Bhandari, S. K. & Purkayastha, D. (1995). Hydrocarbon prospects and evidence of presence of Proterozoic basin in Lunar–Miajlar area, Rajasthan. *Proceedings of the International Petroleum Conference* (pp. 133–164). New Delhi: B.R. Publishing Corporation.

ONGC. (1993). *Lithostratigraphy of Indian Petroliferous Basins*. Dehradun: KDM Institute of Petroleum Exploration. 11.

Pandey, J., & Dave, A. (1998). *Stratigraphy of Indian Petroliferous Basins* (p. 248). Dona Paula: National Institute of Oceanography.

Patra, B. P. (1973). Notes on some Upper Gondwana plants from Athgarh sandstone, District Cuttack Orissa. *Palaeobotanist, 20*, 325–333.

Prabakaran, S. & Ramesh, P. (1995). Basin evolution, stratigraphy and depositional systems in Krishna–Godavari basin, India. In *Proceedings of the Petrotech-5: Technology Trends in Petroleum Industry* (pp. 229–249). New Delhi: B.R. Publishing Corporation.

Prasad, B., & Pundir, B. S. (1999). Biostratigraphy of the exposed Gondwana and Cretaceous rock of Krishna–Godavari basin, India. *Journal of the Palaeontological Society of India, 44*, 91–117.

Rajashekhar, C. (1991). Foraminifera from the Nodular limestone, Bagh Beds, Madhya Pradesh, India. *Journal-Geological Society of India, 38*, 151–168.

Raju, D. S. N. & Mishra, P. K. (1996). Cretaceous stratigraphy of India: A review. In: A. Sahni (Ed.), *Cretaceous Stratigraphy and Palaeoenvironments* (L. Rama Rao volume) (Vol. 37, pp. 1–34). Bangalore: Geological Society of India.

Raju, D. S. N., Ramesh, P., Mohan, S. G. K. & Uppal, S. (2002). Sequence and bio-chronostratigraphic subdividions of the Cretaceous and Cenozoic of India—with notes on Pre-Cretaceous events: An overview. *First Association of Petroleum Geologists Conference, Mussoorie* (pp. 119–129).

Ramkumar, M., Stuben, D., Berner, Z., & Schneider, J. (2004). Geochemical and isotopic anomalies preceding K/T boundary in the Cauvery basin, South India: Implications and Cretaceous events. *Current Science, 87*, 1738–1746.

Ramkumar, M., Subramanian, V., & Stuben, D. (2005). Deltaic sedimentation during Cretaceous period in the northern Cauvery basin, South India: Facies architecture, depositional history and sequence stratigraphy. *Journal-Geological Society of India, 66*, 81–94.

Rao, G. N. (2001). Sedimentation, stratigraphy, and petroleum potential of Krishna–Godavari basins, East Coast of India. *American Association of Petroleum Geologists Bulletin, 85*, 1623–1643.

Rao, G. N. (2002). Petroleum Geology: Krishna–Godavari basin. *Journal-Geological Society of India, 60*, 705–706.

Ray, J. S. & Pande, K. (2001). $^{40}$AR–$^{39}$Ar age of carbonatite–alkaline magmatism in Sung Valley, Meghalaya, India. *Proceedings of the Indian Academic Science* (*Earth and Planetary Science*), *110*, 185–190.

Ray, A., Patil, S. K., Paul, D. K., Biswas, S. K., Das, B., & Pant, N. C. (2006). Petrology, geochemistry and magnetic properties of Sadara Sill: Evidence of rift related magmatism from Kutch basin, Northwestern India. *Journal of Asian Earth Sciences, 27*, 907–921.

Reimann, K.-U. (1993). *Geology of Bangladesh*. Berlin: Gebrüder Borntraeger. 160 p.

Roybarman, A. (1992). Geological history and hydrocarbon exploration in Bengal basin, India. *Journal Geological, 64*, 235–238.

Sastry, M. V. A., Mamgain, V. D., & Rao, B. R. J. (1968). Biostratigraphic zonation of upper Cretaceous formation of Trichinopoly District, South India. *Memoirs Geological Society of India, 2*, 10–17.

Sastry, V. V., Raju, A. T. R., Sinha, R. N., Venkatachala, B. S., & Banerjee, R. K. (1977). Biostratigraphy and evolution of the Cauvery basin, India. *Journal-Geological Society of India, 18*, 355–377.

Sastry, V. V., Sinha, R. N., Singh, G., & Murti, K. (1973). Stratigraphy and tectonics of sedimentary basins of east coast of Peninsular India. *American Association of Petroleum Geology, 74*, 655–678.

Sengupta, B., Bahuguna, R., Kumar, S., Singh, R., & Kaul, R. (1991). Sandstone-type uranium deposit at Domiasiat West Khasi Hills District, Meghalaya, Northeastern Indian. *Current Science, 61*, 46–47.

Siddique, H. N. (1963). The Jodhpur-Malani divide separating the Barmer and Jaisalmer basins. *Journal-Geological Society of India, 4*, 97–108.

Singh, R. (1992). Evolution of exploration concepts for sandstone-type uranium deposits in Meghalaya, India. *Journal Atomic Minerals Science, 5*, 1–11.

Singh, M. P. (1996). Mesozoic–Tertiary biostratigraphy and biogeochronological dalum planes in Jaisalmer Basin, Rajasthan, In: J. Pandey, R. J. Azmi, A. Bhandari, & A. Dave (Eds.) *Contrib. XV Indian Colloquium on Micropalaeontology and Stratigraphy*. Dehradun: KDMIPE, WIHG Publication.

Sinha-Roy, S. (1984). Precambrian crustal interaction in Rajasthan, NW India. *Indian Journal of Earth Sciences,* CISM Volume, 84–91.

Singh, S. K., & Srivastava, H. K. (1981). Lithostratigraphy of Bagh Beds and its correlation with Lameta Beds. *Journal of the Palaeontological Society of India, 26*, 77–85.

Sisodia, M. S., & Singh, U. K. (2000). Depositional environment and hydrocarbon prospects of the Barmer basin Rajasthan. *NAFTA, 9*, 309–326.

Sisodia, M. S., Singh, U. K., Lashkari, G., Shukla, P. N., Shukla, A. D., & Bhandari, N. (2005). Mineralogy and trace element chemistry of the siliceous earth of Barmer basin, Rajasthan: Evidence for a volcanic origin. *Journal Earth System Science, 114*, 111–124.

Srivastava, R. K., Mohan, A., & Filho, C. F. F. (2005). Hot-fluid driven metasomatism of Samalpatti carbonatites South India, evidence for mineral chemistry, trace elements and stable istotope composition. *Gondwana Research, 8*, 77–85.

Srivastava, R. K., & Sinha, A. K. (2004a). Geochemistry of early Cretaceous alkaline ultramafic–mafic complex from Jasra Karbi Aglong District Shillong Plateau, Northern India. *Gondwana Research, 7*, 549–561.

Srivastava, R. K., & Sinha, A. K. (2004b). Early Cretaceous Sung valley ultramafic-alkaline-carbonatite complex, Shillong Plateau, Northeastern India: Petrological and genetic significance. *Contribution Mineralogy and Petrology, 80*, 241–263.

Steinhoff, D., & Bandel, K. (2000). Palaeoenvironmental significance of early to middle Cretaceous bioherm sequences from the Thiruchirapalli District, Tamilnadu, Southeastern India. *Memoirs-Geological Society of India, 46*, 257–271.

Sundaram, R., Handerson, R. A., Ayyaasami, K., & Stilwell, J. D. (2001). A lithostratigraphic revision and palaeoenvironmental assessment of the Cretaceous system exposed in the onshore Cauvery basin, Southern India. *Cretaceous Research, 22*, 743–762.

Taylor, P. D., & Badve, R. M. (1995). A new chelostone bryozoan from the Cretaceous of India and Europe: A cyclostome homeomorph. *Palaeontology, 38*, 627–657.

Tripathi, S. C., & Lahiri, T. C. (2000). Marine oscillation event stratification: An example from Late Cretaceous Bagh carbonate sequence of Narmada valley, India. *Memoirs Geological Society of India, 46*, 15–24.

Venkatachala, B. S. (1977). Fossil floral assemblage in the east coast Gondwana—critical review. *Journal-Geological Society of India, 18*, 378–379.

Vijan, A. R., Rathore, S. S., Vig, K. C., Bansal, M., Singh, M. P., & Prabhu, B. N. (2000). K–Ar and Rb–Sr ages of Cretaceous glauconites from Jaisalmer basin, Rajasthan. *Journal-Geological Society of India, 56*, 15–25.

Yadagiri, K., & Govindan, A. (2000). Cretaceous carbonate platforms in Cauvery basin: Sedimentology, depositional setting and subsurface signatures. *Memoirs-Geological Society of India, 46*, 323–344.