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Distribution and Succession of Jurassic Rocks in Gora Dongar, Pachchham "Island", Kachchh, India

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Abstract : Its prolific fossil fauna and well exposed sedimentary sequence make Kachchh, a Mesozoic pericratonic basin at the western margin of the Indian plate, one of the classic areas of Jurassic geology. The Jurassic sediments represent, for their most part, shallow, largely nearshore shelf environments characterized by a moderately rich bivalve-dominated fauna. An exception is the Eomiodon Red Sandstone Member, which is characterized by brackish biota and contains interludes of non-marine coastal plain sedimentation.

Keywords : Stratigraphy, Palaeontology, Jurassic, Pericratonic Basin, Kachchh, Gujarat.

INTRODUCTION

Kachchh, a Mesozoic pericratonic basin at the western margin of the Indian plate, has fascinated geologists and palaeontologists since the middle of the 19th Century for its abundant fossils, well exposed sedimentary sequence and mineral deposits. Gora Dongar (the southern range of hills in Pachchham "Island") Fig.1, is of particular importance, for having yielded Middle Bathonian to Lower Callovian ammonites in a sequence of siliciclastic and carbonate sediments.

Except for the general account of rocks given by Wynne (1872, p. 101) and a quite brief description of the sediments of the Gora Dongar Formation by Biswas (1980, p.21) there exists no detailed account of the Jurassic rocks of Gora Dongar. During the last decade some Bathonian ammonites were reported (Singh et al. 1983), a new bivalve genus *Agrawalimya* was described by Singh, Jaitly & Pandey (1982b) and several other new findings were published (Pandey & Singh, 1982; Pandey & Agarwal, 1984a,b; Pandey et al. 1984; Agrawal & Pandey, 1985; Pandey & Westermann, 1988). Recently, Fürsich et al. (1994) presented their work on the lithostratigraphy and depositional environments of the older part of the sequence exposed in Sadhara Dome (in the eastern part of Gora Dongar).

METHODS

In the present paper the lithostratigraphy of the younger part of the sequence, which is best exposed in the western part of the Gora Dongar hills, has been worked out. Each bed has been observed for colour, grain-size, microfacies, primary sedimentary structures, composition and diversity of macrofauna, trace fossils, and taphonomic features. The fossils, collected bed by bed, have been either identified in the field or in the laboratory. Thin-sections of the rock samples have also been studied in order to confirm the nature of the rocks. A lithostratigraphic map of the Gora Dongar area has been prepared on a 1:15,000 scale and subsequently reduced to 1:50,000 scale (Fig.2). The sedimentary sequence comprises approximately 290 m; its lithic units are described in the following with a view to facilitate their recognition in the field.

The map area is roughly 100km^2 in extent and stretches between Khavda town (23°50' 33"N: 69°43'49"E) in the west and the village of Sadhara (23°44'38"N: 69°54'40"E) in the east. Khavda is 69 km off to the north of Bhuj (23°15'16"N: 69°40'13"E), the district headquarters. The hilly range has a series of crests not exceeding 200 m. As the crest line is closer to the northern margin of the range, its slopes tend to be asymmetrical. The relief is concordant.

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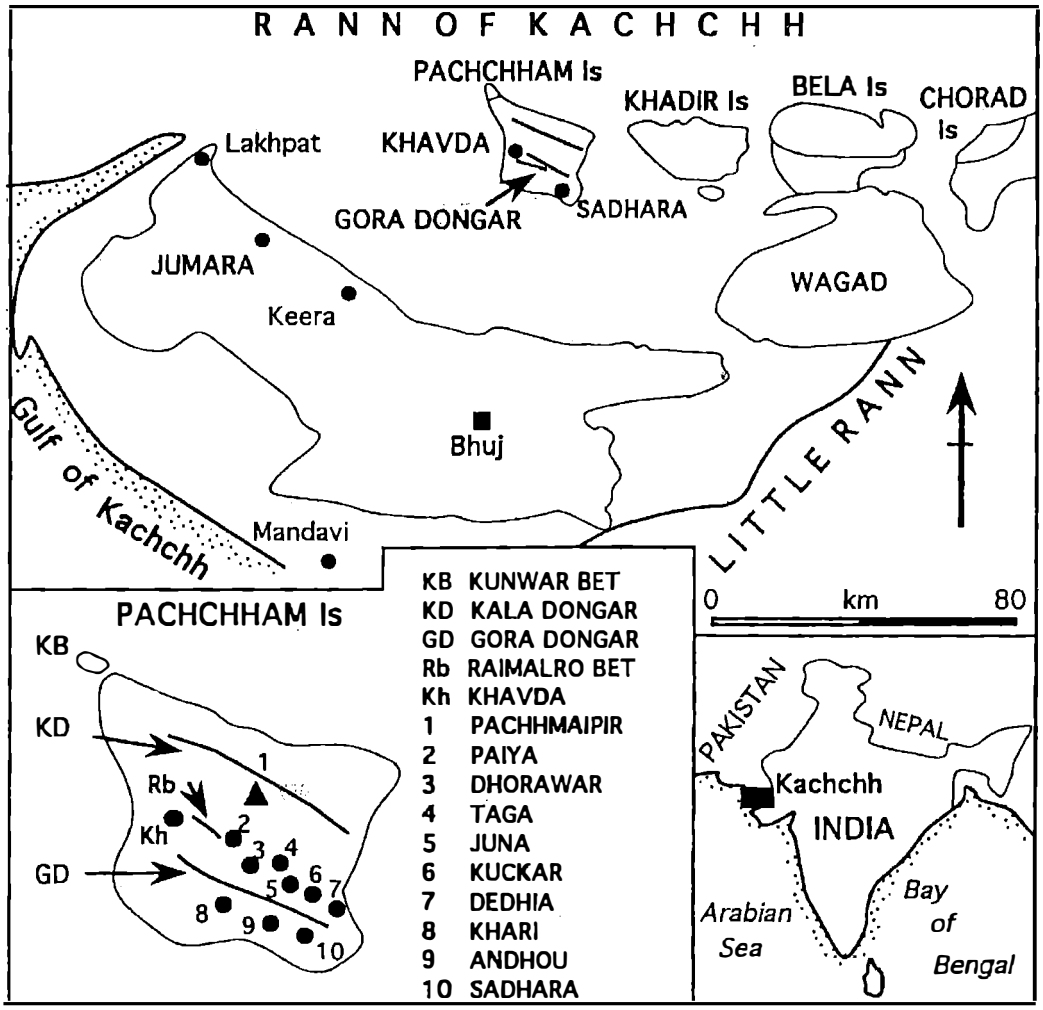

Fig. 1. Map Showing localities referred to in the text.

STRUCTURE

The strata are arranged in a series of anticlines and synclines and display a good number of faults (Figures 3-5). The two major anticlines (A_1 and A_2) are of almost equal extension and trend WNW-ESE and E-W respectively. At the eastern end of A_2, east of 179 m, the older beds are exposed in the form of a quaquaversal unit (Q_1) to the northeast of the village of Sadhara. In addition, there are three minor anticlines: two (A_3 and A_4) in the northwestern part and one (A_5) in the southeastern extremity of the area. They trend roughly WNW-ESE, E-W, and NE-SW respectively. The axes of the first two are nearly parallel to those of A_1 and A_2 and may therefore be of the same generation. Their overall plunge/dip is westerly. The axis of A_5 appears to be the result of its superimposition over A_2 folding. Q_2, another quaquaversal unit exposed to the northwest of the village of Sadhara, is trending NW-SE. The quaquaversal attitude of the strata in Q_1 and Q_2 can be interpreted as superimposed folding at right angles to the earlier E-W trend.

In all the above mentioned anticlines the dips on the northern slope are higher than on the southern slopes.

Nine faults (F_1-F_1 to F_9-F_9) have been

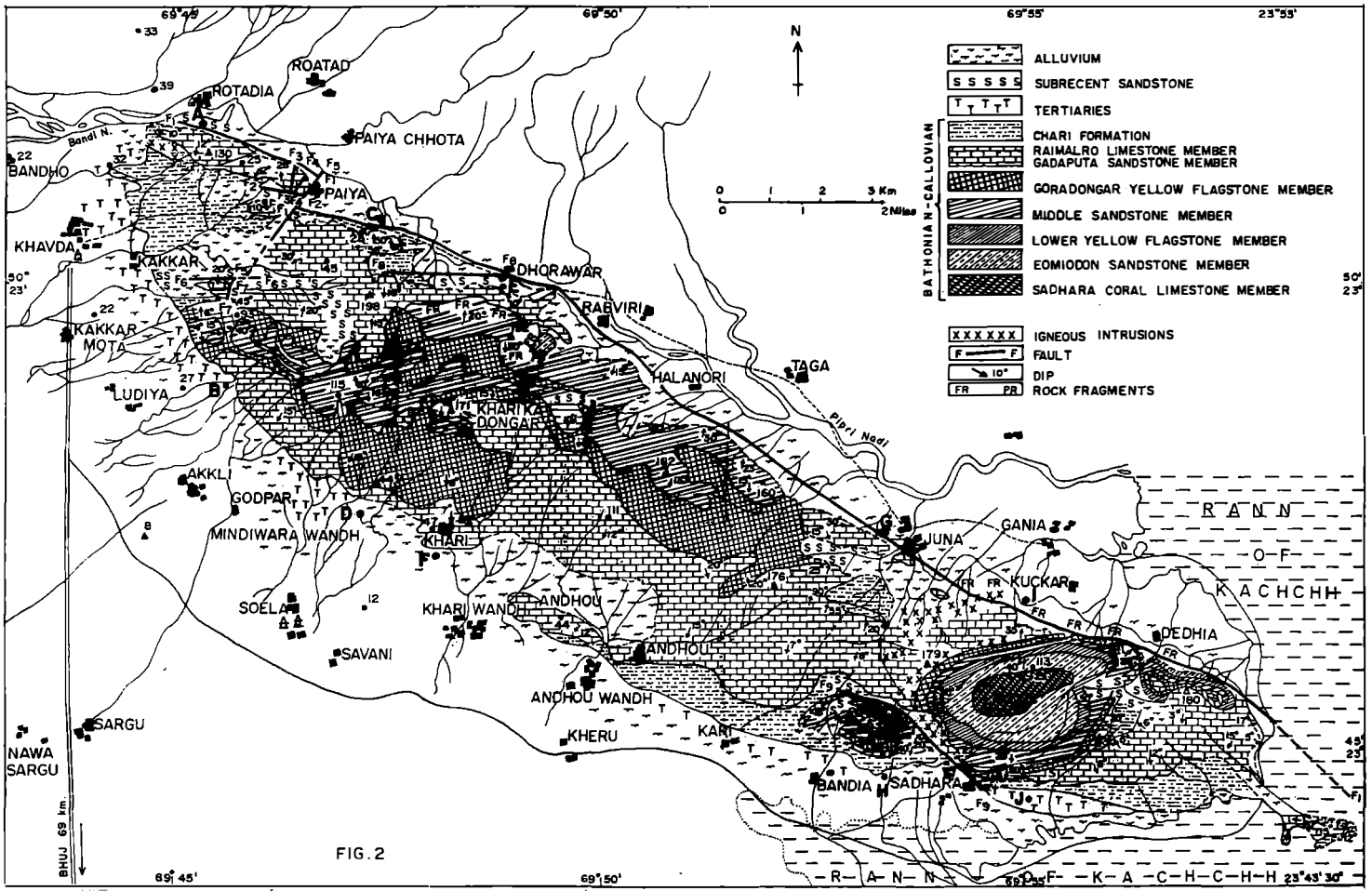

FIG. 2

Fig. 2. Lithostratigraphic map of Gora Dongar, Pachchham Island.

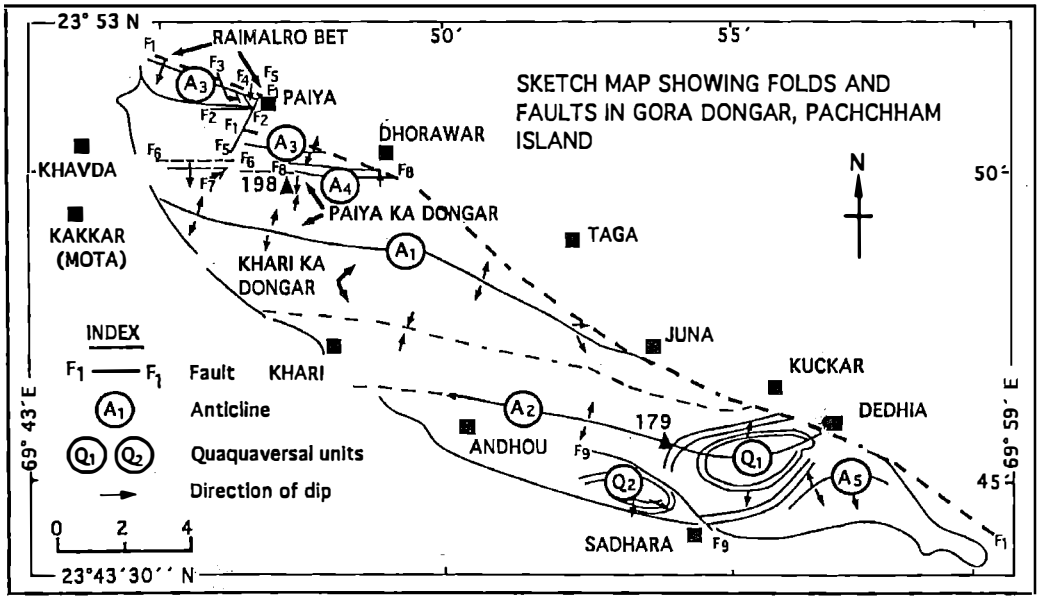

Fig. 3. Sketch map showing folds and faults in Gora Dongar, Pachchham Island.

traced in the area. The northern boundary of the map area is demarcated by a major longitudinal fault (F_1-F_1). It partially cuts off the northern limbs of the anticlines A_1, A_3, A_5 and the quaquaversal unit Q_1, in the south of the village Taga, at Raimalro Bet, to the southeast of Dedhia, and south of Kuckar respectively. Also, A_1 and A_4 abut against it near Juna and Dhorawar respectively. In the northwestern part of the area there is a network of five minor faults, of which three (F_3, F_4 and F_5) are oblique whereas the fault lines F_2 and F_8 are almost parallel to the strike. All these minor faults may be splay faults caused by the release of tension associated with the major faults referred to above. Further, it is quite possible that F_7 may be either a (dislocated) component of F_5 or an offshoot of F_6, which in turn may be continuation of F_8. This, however, could not be ascertained because of a blanket of Subrecent sandstone on the beds near the conjunction of F_5, F_6 and F_7. The faults F_2 to F_8 have disturbed parts of the anticline A_3 and their effect is mainly noticed in the limestone of the Raimalro Member. Lastly, F_9 is an arcuate fault separating units Q_1 and Q_2, with a downthrow on the south.

The sedimentary strata are invaded by numerous igneous intrusions in the form of sills and dykes. The bigger ones are in the area SW and S of Raimalro Bet, intruding lower beds of the Chari Formation.

LITHOSTRATIGRAPHY

The lithology of the rock units of the Gora Dongar area varies both vertically and laterally considerably. Recent studies (Fürsich et al. under preparation) have shown that the traditional lithostratigrphic scheme (Table 1) is regionally more applicable than that proposed by Biswas (1980). The older lithostratigraphic unit names can be properly defined. The about 290 m thick sedimentary column of Gora Dongar belongs to the three formations, i.e. the Khavda, Patcham and Chari Formations. They have been grouped in eight formal/informal members. A detailed description of the older sequence of Gora Dongar (Khavda Formation), which is best exposed in the quaquaversal unit Q_1 in the eastern part of Gora Dongar, has already been published (Fürsich et al. 1994, p.99-101, Appendix). For the younger part of the sequence (Patcham Formation and lower part of the Chari Formation) best exposures are on the southern flank of the anticline A_3

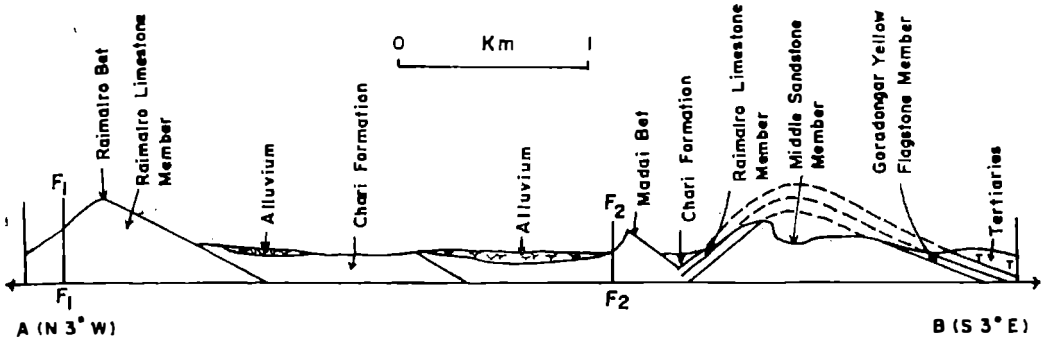

Fig. 4. Schematic Geological cross-section along Khavda-section, Gora Dongar, Pachchham Island.

(Raimalro Bet) east of Khavda. This succession (Fig. 6) is described in Appendix A. In the following each member recognized in the Gora Dongar sequence is briefly discussed (Table 2).

Khavda Formation

Sadhara Coral Limestone Member (5m+) (Fürsich et al. 1994): This member constitutes the oldest (exposed) unit in Gora Dongar and crops out in the central part of the quaquaversal unit Q_1. The lowest exposed part of the member consists of greyish to light-brown weathering, hard, well-bedded, flaggy, barren, sandy packstone to grainstone. This is overlain by thinly bedded limestones and partly bioturbated sandstones. The upper part of the member is not exposed. Sedimentary structures include oscillation ripples, and large-scale trough crossbedding.

Fossils encountered are the corals *Melikerona parva,* the bivalves *Nanogyra nana, Lopha* sp., *Protocardia keenae*, *Eomiodon indicus*, *Placunopsis* sp., *'Corbula' lyrata*, *Modiolus* sp., and the gastropod *Globularia cf. aparayensis.* Trace fossils are diverse and include *Thalassinoides, Diplocraterion parallelum, Diplocraterion habichi,*

Age		Formation
Cretaceous		Umia Fm
Jurassic	Tithonian	Katrol Fm
	Kimmeridgian	
	Oxfordian	Chari Fm
	Callovian	
	Bathonian	Patcham Fm
	Bajocian	Khavda Fm

Table 1. Traditional lithostratigraphic scheme of Kachchh; modified after Rajnath (1932).

Age	Lithostratigraphic Units		Dominant Lithology
Early Callovian	Lower Chari Formation	Lower Shale member	silty shale with iron concretions & pebble layers
Latest Late Bathonian	Patcham Formation	Raimalro Limestone Member	sandy calcarenite with chert nodules & bands
Early Bathonian - Late Bathonian	Khavda Formation	Gadaputa Sandstone Member	soft calcareous sandstone
		Goradongar Yellow Flagstone Member	calcareous sandstone, limestone, marl & oolites transition beds: sandstone
		Middle Sandstone member	medium- to coarse-grained sandstone
		Lower Yellow Flagstone member	marl, sandy micrite, calcarenite, sandstone
		Eomiodon Red Sandstone member	fine-grained sandstone
		Sadhara Coral Limestone member	sandy limestone & calcareous sandstone

Table 2. Dominant lithology of the lithostratigraphic units of Gora Dongar, Pachchham Island.

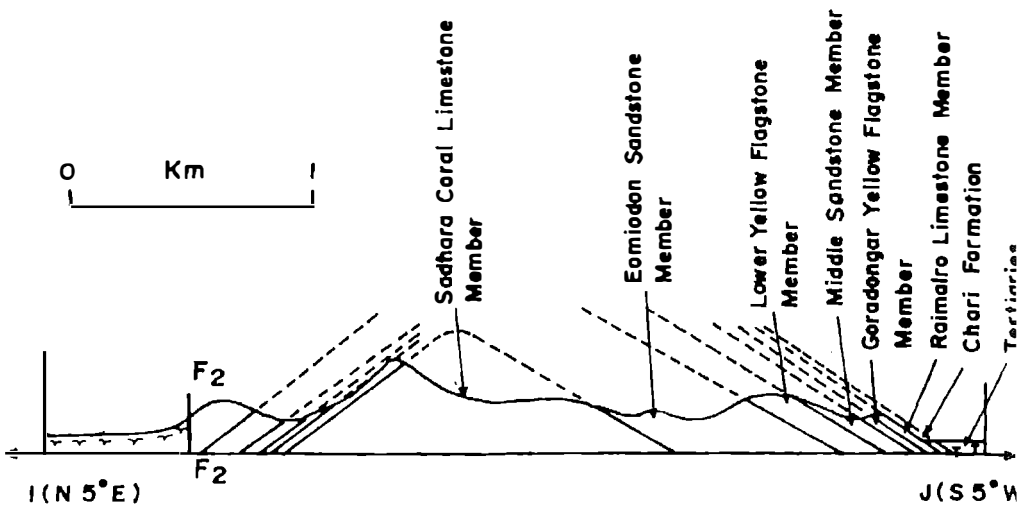

Fig. 5. Schematic geological cross-section along Sadhara-section, Gora Dongar, Pachchham Island.

Rhizocorallium jenense, Cylindrichnus concentricus, Planolites and *Skolithos.*

Eomiodon Red Sandstone Member(35m) (Fürsich et al. 1994): Good exposures of the beds of this member are found in a nallah cutting about 3 km northwest of Khari and as an inlier in Q_1 and Q_2. It is composed of reddish to variegated, soft or hard, laminated or bioturbated, poorly to well sorted, partly silty, fine-to coarse-grained sandstones with a 40 cm thick shell bed and a 2.2 m thick unit of light-grey,argillaceous-silty fine sand with caliche nodules in the uppermost 20 cm.

Sedimentary structures are horizontal lamination, large-scale trough crossbedding and ripple marks.

Fossils are of low diversity and include the bivalves *Eomiodon*, *Protocardia* (P) *keenae*, other protocardiids, *"Corbula" Iyrata, Agrawalimya pseudosulcata*, and *Isognomon* (M) *patchamensis.* The trace fossils *Skolithos* and *Diplocraterion parallelum* occur, as do pieces of wood.

Lower Yellow Flagstone Member (33 m) (Fürsich et al. 1994): The member is best exposed in the quaquaversal unit Q_1. It is also well exposed in the quaquaversal unit Q_2. The lower part of the member, which is partly poorly exposed, consists of yellowish-brown, fine-sandy marl with numerous 5-10 cm thick intercalations of harder, slabby-weatheri sandy micrite, graded medium grain calcarenites, fine-grained, partly bioturbat sandstone, or shell beds. The upper part of t member consists of 5 to 15 cm thick beds soft, fine-grained, calcareous, shelly san stones; the lower beds are highly bioturbate while the upper beds are laminated.

Sedimentary structures : Small-scale ripple

Fossils: The diversity is high; the fauna dominated by the bivalves *Mytilus (Mytilu jurensis, Lycettia, Modiolus imbricat Modiolus glendayi, Bakevellia walto Isognomon* (M) *patchamensis, Gervill (Virgellia) sobralensis, 'Corbula' lyra Protocardia* cf. *grandidieri, Nanogyra nan Placunopsis radiata, Pronoella* sp., *Thrac depressa*, a pholadomyoid, and a neritops gastropod. Near monospecific pavements *Eomiodon indicus* occur.

Middle Sandstone Member (93 m) (Fürsi et al. 1994): Outcrops of this member ha been encountered on both northern and sou ern flanks of Gora Dongar. The best outcr is along the western slope of the quaquaver unit Q_1 where the section has been measur In other outcrops such as those south of t village of Dhorawar and Taga the fossilifer part of the member has yielded abundant, w preserved *'Corbula' Iyrata* together w

Protocardia, *Pseudotrapezium*, *Eomiodon* and *Nicaniella*. The member is also exposed 3 km northeast of the village Godpar and 2 km north of the village Khari. It consists of partly

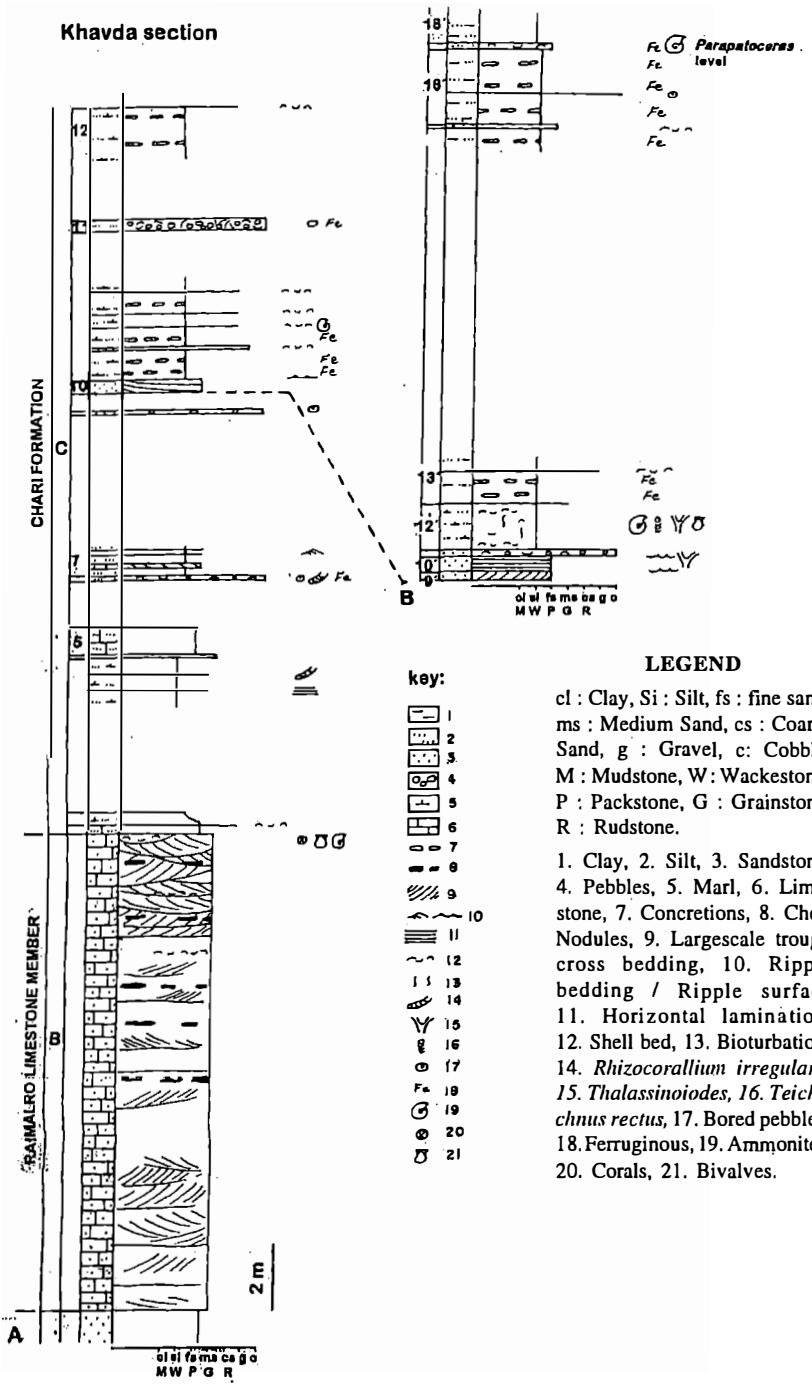

Fig. 6. Sedimentological log of the Jurassic of the Khavda area. The section has been measured in two parts, the lower one (**A**) exposed in the Raimalro Bet and the southern foothills east of Khavda, the upper one (**B**) south of the Khavda-Taga road. The two sections are separated by a major fault. Bed numbers refer to the Lithology of the Khavda section given in the Appendix.

crossbedded, party bioturbated, brown to white weathering, medium-to coarse-grained, poorly sorted, micro-conglomeratic sandstones.

Sedimentary structures: Large-scale trough-crossbedding, small-scale ripple bedding, horizontal lamination.

Fossils are concentrated in a 0.5 m thick shell bed and include the bivalves *Palaeonucula cuneiformis, Modiolus* (M.) *imbricatus, Modiolus glendayi, Bakevellila waltoni, Protocardia* (P.) cf. *grandidieri, 'Corbula' Iyrata, Nicaniella extensa, Eomiodon baroni, Pseudotrapezium bathonica, Agrawalimya pseudosulcata,* the trace fossils *Skolithos* and *Planolites,* and wood and plant remains.

Goradongar Yellow Flagstone Member (44m) (Biswas 1980): The member is well exposed northwest of the village Khari, about 3.5 km southeast of Khavda and along the western slope of the quaquaversal unit Q_1. The member starts with transitional beds of well-bedded, flaggy, micro-conglomeratic fine-grained, calcareous sandstones with 2-3 cm thick shell beds in a micritic sandstone matrix, and fine-to-medium grained, in places ferruginous sandstone. Except for the lower part, the member is composed of yellow, thin-bedded, fossiliferous, partly bioturbated, partly laminated, fine-sandy calcareous sandstones, limestones and marl. The base is formed by a 0.1 m thick conglomerate with pebbles of quartz and sandstone. Higher in the sequence near-monospecific shell beds and a level with reworked, encrusted and bored concretions occur.

In the Khavda-section this member consists of yellow fossiliferous silty to fine-sandy marl and micritic limestone with several beds of Golden Oolite (containing Fe-ooids, iron-coated grains, and reworked clasts and bioturbated calcarenite exhibiting low-angle planar and trough-crossbedding. Interbedded with the Golden oolite and limestones are trough-crossbedded calcarenites and a 25 cm bed of fine-grained, well sorted calcareous sandstone with oscillation ripples at the top and traces of *Thalassinoids*. Two ammonite levels have been recorded from this member. The lower level is a shelly, fine-sandy marly micrite, while the upper level is rubbly, bioturbated fossiliferous micrite, both ocurring near the top of the member.

The name Kharidongari was proposed for this member by Pandey, Singh and Agrawal (1984) because it was first observed southwest of "Khari ka dongar" in Gora Dongar, Pachchham "Island". Additional field work showed that the member shows variation in microfacies all along Gora Dongar. The name "Goradongar Flagstone member" proposed earlier by Biswas (1980) is therefore more appropriate and hence retained. Petrographically the lower part consists of grainstones, floatstones, and packstones while in the upper part partly sandy wackestones and packstones dominate.

Sedimentary structures include large-scale low angle crossbedding, small-scale ripple bedding and oscillation ripples.

Fossils are abundant and represented by the bivalves *Palaeonucula cuneiformis, Palaeonucula stoliczkai, Grammatodon jurianus, Modiolus glendayi, Camptonectes sp., Chlamys curvivarians, Plagiostoma complanata, Nanogyra nana, Placunopsis radiata, Catinula sandalina, Nicaniella extensa, Trigonia* (T.) *nitida, Vaugonia* (O.) sp., *Inoperna sowerbyana, Protocardia (Tendagurium) bannesianum, Protocardia* (P.) *Patchmensis, 'Corbula' Iyrata, Pholadomya* (B.) *Iyrata, Pholadomya* (P.) *inornata, Homomya hortulana, Agrawalimya pseudosulcata, Unicardium aequalis, Neocrassina* (N.) *pandeyi, Isocyprina Ieckhamptonensis, Pteria polyodon, Ceratomyopsis striata, Ceratomya* cf. *concentrica, Corbulomima,* and *oysters.* The gastropods include *'Trochus actaea', Globularia* cf. *eparcyensis, Pictavia* sp., *Quadrinervus* cf. *amoenus, Neritoma* (*Neridomus*) sp., *Pseudomelania* (Oonia) cf. *conica* and *Nododelphinula* sp. Further elements are the coral *Axosmilia kachensis, serpulids,* and the trace fossils *Rhizocorallium irregulare, Teichichnus rectus, Thalassinoides*, and striated burrows. Cephalopods are represented by nautiloids and the ammonites *Paracenoceras* cf. *kumagunense, Calliphylloceras disputabile, Clydoniceras pachchhamense, Clydoniceras*

triangulare, Clydoniceras sp. *indet., Micromphalites (Clydomphalites)* cf. *clydomcromphalus, Micromphalites (Clydomphalites)* sp. *indet., Procerites* cf. *schloenbachi, Gracilisphinctes arkelli* and *Bullatimorphites* n. sp. A.

Gadaputa Sandstone Member (28 m) (Biswas 1990): The member is widely exposed in detached outcrops and in different nala cuttings in the area. It attains its maximum thickness along the southern flank of the quaquaversal unit Q_1. In the Sadhara section the member begins with a 0.4-0.5 m thick coarse-grained, locally conglomeratic strongly ferruginous sandstone with large-scale trough cross-bedding and megaripples on the upper surface. This is followed by soft to hard, silty fine-to coarse-grained, thin-bedded, partly bioturbated and ferruginous sandstones with some calcareous layers. At many places, e.g. along the northern flank of the quaquaversal unit Q_1 this member has been intruded by a sill and consequently the beds are slightly baked, at other places the sequence is disturbed by dykes.

Petrographically the member is composed of calcareous quartz arenite. The detrital quartz sand (90%), chert fragments, feldspar (5%) and mucovite flakes and fine-to medium-grained, subangular to subrounded and possess moderate sphericity.

Biswas (1980: 21) described this member to consist of about 10 m thick, pale-brown to pink, massive, current-bedded, medium-to-coarse-grained quartz-arenites becoming calcareous upward at "Gadaputa Hills", east of Khavda at the south-west end of Pachchham "Island", not far from the Khavda section.

Sedimentary structures include wave and current-ripples, megaripples, and large-scale trough-crossbedding.

The only fossil recorded is the bivalve *Modiolus glendayi.*

Patcham Formation

Raimalro Limestone Member (15 m) (Biswas 1980): It is the most prominent member in the Gora Dongar sequence, because of its yellowish colour, hard and compact nature, its occurrence at the summits of most of the peaks and vast expanse on the southern slopes of the hill range. The thickness of the member increases westward from 2-3 m in the Sadhara section to 15 m in the Khavda section. It is a thick-bedded, sandy, bioclastic calcarenite, with medium-to-large-scale low angle trough-crossbedding, some thin intraformational pebble layers, chert bands and chert nodules, and some lenticular conglomerate layers consisting of reworked calcarenite pebbles. The carbonate content increases towards the top. The upper third of the unit contains several lenticular shell beds composed of large, thick-shelled bivalves.

Fossils are concentrated in nests and lenses and include the bivalves *Modiolus glendayi, Gervillella, Camptonectus laminatus*, C. *auritus, Plagiostoma* cf. *jumarense, Plagiostoma* cf. *amniferum, Ctenostreon, Meleagrinella, Vaugonia, Lopha, Neocrassina,* the corals *Stylina kachensis,* and *Lochmaeosmilia trapeziformis,* several species of gastropods and the ammonite *Macrocephalites madagascariensis.*

Sedimentary structures are medium-to large-scale low angle trough-crossbedding and ripple marks.

Chari Formation

Lower shale member (25.5 m+) (Fürsich et al. 1994): Higher up in the succession, the member is well exposed along the southern side of the Raimalro Bet in the extreme north-western part of the area. Moreover, isolated outcrops are seen all along the southern foot hills of Gora Dongar. The member is composed of heavily bioturbated (in parts) silty to fine-grained sandstone, fine-sandy calcarenite, packstones (biomicrites) with intercalations of shell beds, thin pebble layers, scattered claret ironstone concretions, and occassional marl layers. The member starts with silt topped by a layer of shell debris, laterally grading into crossbedded sandy grainstone with streaks of golden oolites. Shell beds consist mostly of ostreid bivalves. In the upper part of this unit two shell beds are almost monospecific one dominated by *Nicaniella*, the other by rhynchonellid brachiopods. These two monospecific shell beds sandwich a biomicrite unit with reworked pebbles (2-3 cm in diameters)

and a bed of purple, polymictic conglomerate of reworked white and red concretions in a matrix of shelly ferruginous siltstone.

Sedimentary structures include large-scale low-angle trough-crossbedding, horizontal lamination, and oscillation ripples.

Fossils are the bivalves *Nuculoma wynnei, Palaeonucula cuneiformis, Pseudolimea duplicata, Meleagrinella, Plagiostoma, Dentalium, Nanogyra, Praesaccella, Camptonectes, Ctenostreon proboscideum, Pleuromya uniformis, Actinostreon,* the ammonites *Macrocephalites formosus,* M. *chariensis*, M. *inflatus, Dolikephalites* aff. *flexuosus*, D. aff. *subcompressus, Kamptokephalites,* K. *dimerus*, K *lamellosus*, K. *magnumbilicatus Indocephalites transitorious,* I. *Kheraensis*, I. *diadematus, Parapatoceras tuberculatum,* belemnite guards, rhynchonellid brachiopods, ossicles of *Pentacrinites* and "*Isocrinus*" and the trace fossils *Rhizocorallilum irregulare*, *Thalassinoides* and *Teichichnus*.

BIOSTRATIGRAPHY

Although ammonites are rare in the sedimentary sequence of Gora Dongar, they occur in some well defined levels. The lower 200 m of the sequence is devoid of any ammonites, but predominently yield bivalves. Other groups such as corals, gastropods, trace fossils and plant remains are rare and of no stratigraphic value. Five levels of a characteristic bivalve assemblage dominated by *Eomiodon*, *Protocardia* and '*Corbula*' *Iyrata* have been recognized within this part of the succession. The lower four levels occur within the Eomiodon Red Sandstone member, while the fifth is found in the middle of the Middle Sandstone member (both belonging to the Khavda Formation). The latter crops out best at south of the village of Dhorawar (Wynne, 1872, p. 101; Agrawal and Pandey, 1985). These beds have been dated as ? Lower to Middle Bathonian (Agrawal and Pandey, 1985), based on the fact that they are sandwiched between the beds with the earliest ammonite find on Kala Dongar indicative of Late Bajocian age (Singh *et al.* 1982a) and those containing Middle Bathonian ammonites (see below).

The earliest ammonite level of Gora Dongar occurs in shelly, fine-sandy micrites, about 200 m above the base of the Gora Dongar sequence within the Goradongar yellow Flagstone Member (Khavda Formation). The level yielded *Clydoniceras triangulare, Bullatimorphites* n. sp. A and *Procerites (Gracilisphinctes)* sp. (Pandey and Agrawal, 1984a: Pandey and Westermann, 1988; Fürsich *et al.* 1994). The second ammonite level, a rubbly, bioturbated fossiliferous micrite about 1.2 to 1.5 m above the first level, occurs also within the Goradongar Yellow Flagstone Member. This level is represented by index species such as *Clydoniceras pachchhamense*, *Micromphalites* (Clydomphalites) cf. *clydomicromphalus*, *Micromphalites* (*Clydomphalites*) sp. *indet.*, *Procerites* cf. *scholoenbachi* and *Procerites* (*Gracilisphinctes)* arkelli (Pandey and Callomon, 1995). These two levels have been considered as a single faunal horizon (Table 3) and correlated with type horizon of *P. arkelli* of Madagascar of Middle Bathonian, which partially probably represents Progracilis Zone of Europe (Pandey & Callomon, 1995).

The remaining ammonite levels belong to the *macrocephalites* Range-Zone (Table 3) and correspond to the *Macrocephalus* Beds of Spath (1933, p.740). On the basis of the stratigraphic distribution of *Macrocephalites* in Gora Dongar three levels within the *Macrocephalites* Range-Zone can be recognized. The oldest occurs in the Raimalro Limestone Member (Patchman Formation) and is characterized by *Macrocephalites madagascariensis*. It corresponds to the triangularis association of Jai Krishna & Westermann (1987) and to the Triangularis Zone or "Lower Macrocephalus Beds Zone" of Spath (1927, p. 51). It has been correlated with the Patcham Limestone of Jumara dome (Mainland) and assigned to latest Late Bathonian (Callomon 1993; Fürsich *et al.* (1994, p. 101).

The two younger levels occur within the Lower Shale member of the Chari Formation and are best exposed in the Khavda section. The lower one is represented by *Macro-*

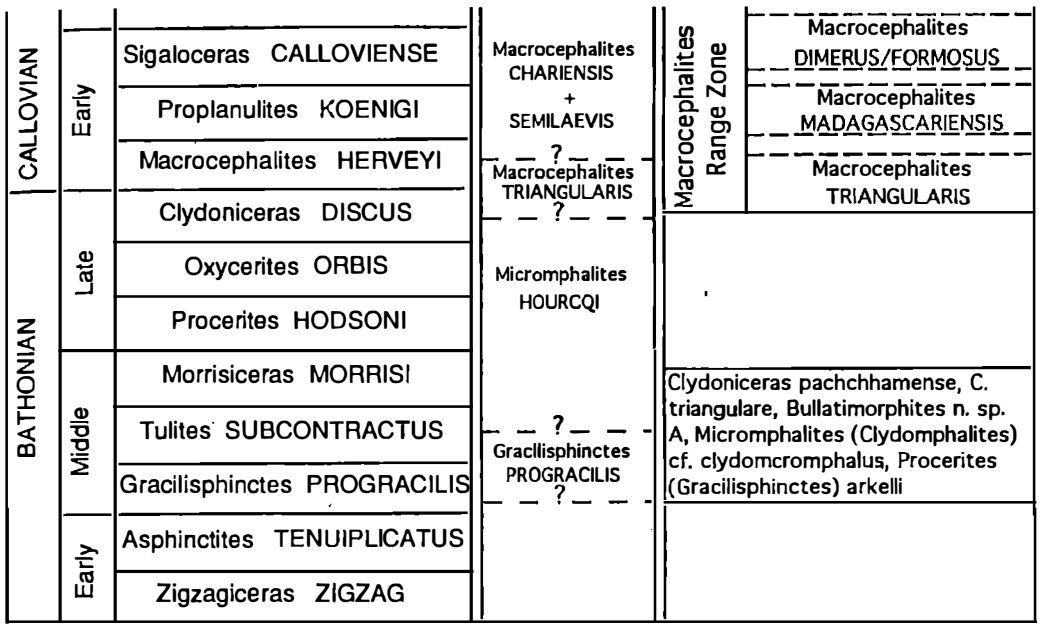

Table 3. The Standard NW-European chronostratigraphy of Bathonian-Early Callovian as reference time-scale for dating the faunal horizons of the Ethiopian fanal province.

cephalites formosus, M. *chariensis*, M. *inflatus*, M. *madagascariensis*, M. *triangularis*, *Dolikephalites* aff. *flexuosus*, D. aff. *subcompressus*, *Indocephalites kheraensis*, I. *transitorius*, I. cf. *diadematus* and I. *chrysoolithicus*, while the upper is characterized by *Macrocephalites formosus*, M. *chariensis*, *Dolikephalites* spp., *Kamptokephalites dimerus*, K. *lamellosus*, K. *magnumbilicatus*, I. *diadematus* and *Parapatoceras tuberculatum*. They correspond to the madagascariensis and dimerus/formosus association of Jai krishna & Westermann (1987) or the Dimerus Zone, or "Middle Macrocephalus Beds zone" and Tumidus Zone, or "Upper Macrocephalus Beds zone" respectively (Spath 1927, p.51). They indicate an Early Callovian age (Agrawal & Pandey 1985).

The two Bathonian ammonite levels (=single faunal horizon) are considerably below the oldest *Macrocephalites*-bearing bed. At present it can not be ruled out that other European zones occur between the Progracilis Zone and the Macrocephalus Zone. In Gora Dongar the interval is represented by sandy facies of the Gadaputa Sandstone member (Biswas 1980). Time-correlation within the Ethiopian faunal province seems possible, because the ammonite guide/index species of the Middle Bathonian and the Lower Callovian in Kachchh and Madagascar (Collignon, 1985) are very similar (Table 3). Species common to both areas are *Gracilisphinctes arkelli* (Middle Bathonian), *Macrocephalites madagascariensis*, M. (M.) *formosus*, and M. *Semilaevis* (Lower Callovian) (Singh et al. 1983; Jai Krishna & Westermann 1985). Westermann & Callomon (1988) compared the *Procerites* described by Collignon (1964) with *P. quercinus* (Terquem & Jourdy) and suggested correlation with the Upper Bathonian Hudsoni Zone of Europe.

DEPOSITIONAL HISTORY OF THE JURASSIC OF GORA DONGAR

The find of the ammonite *Leptosphinctes* in lower parts of the sedimentary succession in Kala Dongar, the northern hill range of Patcham

'Island', demonstrates that the sea transgressed onto the area at least by Late Bajocian times (Singh et al. 1982a). These older sediments, represented largely by sandstones, do not crop out in Gora Dongar. The lower part of the succession on Gora Dongar is best exposed at the Sadhara Dome (Fürsich et al. 1994). It starts with the Sadhara Coral limestone member, an impure carbonate, whose funal and trace fossil content points to a nearshore shallow subtidal environment. The Eomiodon Red Sandstone member higher up in the succession represents a sand bar system followed by restricted bay (as evidenced by brackish water biota) and finally coastal plain environments with caliche. The overlying Lower Yellow Flagstone member testifies a return to fully marine, shallow subtidal conditions, subject to storm influence.

The Middle Sandstone member is another bar complex, as in the base of the Goradongar Yellow Flagstone Member. The upper half of the latter member is represented by silty marls and limestones indcative of shallow subtidal conditions. Near Khavda beds of Fe-coated grains (Golden Oolite) are intercalated between the more marly facies of the Gora Dongar Yellow Flagstone Member. The 'Golden Oolite' has probably been derieved from a shallower, nearshore place of origin. The Gadaputa Sandstone Member represents submarine dune/interdune deposits.

The Raimalro Limestone Member varies strongly in thickness. 15 m thick in the khavda section it decreases to a mere 2-3 m at Sadhara. As the upper boundary appears to be synchronous, the decrease in thickness eastward is most likely due to a lateral facies change into sandstones of the Gadaputa Sandstone Member. The presence of large-scale trough cross-beds, megaripples, scours and intraformational pebble layers indicate a shallow water, high energy environment for most of the time.

The boundary to the overlying Chari Formation is always sharp and characterized by a change from carbonates to generally fine-grained siliciclastics. The dominant facies is bioturbated argillaceous silt with layers of claret-coloured ferruginous concretions (this is also the characteristic facies to the Chari Formation on Kachchh mainland), which was deposited below storm wave base. Intercalations of crossbedded or laminated grainstone or sandstone beds near the base of the formation suggests occassional storm influence. Repeated intercalations of thin layers of conglomerate most likely represent phases of non-sedimentation and erosion of the sea floor, as most pebbles consists of reworked concretions. Thus the Bathonian to Lower Callovian sediments at Gora Dongar record several phases of shallowing and deepening of the depositional environment, most of which are represented as asymmetric sedimentary hemicycles (Fürsich et al. 1994). A more detailed analysis of the driving forces of the cyclic sedimentation pattern, be they tectonic, climatic, or eustatic, must be postponed, however, unitl a comprehensive facies pattern within a biostratigraphic framework is available for the whole basin.

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Appendix : LITHOLOG OF THE KHAVDA SECTION

Khavda Formation, Gadaputa Sandstone Member

A sandstone, fine to medium-grained, calcareous, some crossbedded, seen to 1m

Patcham Formation, Raimalro Limestone Member (15 m)

B limestones, sandy, calcarenitic, thick-bedded, with medium-to large-scale low angle trough cross bedding, weathering light-brown or buff; with some thin intraformational pebble layers, chert bands and chert nodules; carbonate content varying; base more sandy than top. Upper third of unit with several lenticular shell beds composed of large, thick-shelled bivalves; fauna: *Neocrassina, Meleagrinella, Ctenostreon, Stylina kachensis, Lochmaeo smilia trapeziformis,* several species of gastropods, *Macrocephalites* sp.-top forming prominent plateau on scarps, sharp boundary **15m**

Chari Formation

C shales, silty, with scattered red ironstone concre tions and intercalations thin pebble layers **32,5m+**

1 packstone silty, topped by layer of shell debris rich in cidaroid spines; laterally grading into crossbedded sandy grainstone with streaks of golden oolite 0.25m

2 sand, fine-grained, marly-silty, seen for not exposed, most likely fine-sandy marly silt 0.4m 3.5m

3 silt, marly with 3-5 cm thick interbeds of silty grainstone, laminated and biotur bated by *Rhizocorallium irregulare* 1.5m

4 grainstone, bioclastic, silty 0.07m
5 packstone, silty 1m
not exposed, most likely fine-sandy silt 1.5m
6 shell bed, pebbly, red with matrix of fine sandy ferruginous siltstone, top bioturbated by *Rhizocorallium irregulare* 0.2m
7 silt with interbeds of 5-15 cm thick crossbedded calcareous fine-grained sandstone 0.8m
not exposed, most likely fine-sandy silt 4.2m
8 pebble layer, pebbles consisting of oolitic packstone 0.2m
not exposed 0.6m
9 sandstone, calcareous, fine-grained, large-scale low-angle trough-crossbedded, top surface with oscillation ripples, hard, weathering in large slabs, light-brown, characteristically blue-heatred when freshly broken, prominent marker, forming slight ridges or local topographic highs that allow it to be followed across considerable distances of otherwise flat-lying and featureless terrain 0.4m
10 silt, soft, recessive
a. silt, fine-sandy 0.85m
b. gravel-stone, shelly, ferruginous, purple, marker 0.15m
c. silt, fine-sandy, marly, gypsiferous, with white silty micrite and claret silty ironstone concretions and some 2-5 cm thick intercalations of shelly silty packstone layers; fauna: *Macrocephalites madagascariensis* (M) and (m), *Praesaccella, Pseudolimea duplicata, Nuculoma wynnei, Palaeonucula kaoraensis* 2m
not exposed, most likely fine-sandy marly silt 1.5m
11 conglomerate, purple, polymictic, pebbles consisting of white and red concretions; matrix:shelly ferruginous siltstone 0.4m
not exposed, most likely fine-sandy marly silt 2m
12 silt, fine-sandy, marly, highly bioturbated, with claret silty ironstone concretions 1.5m
13 shell bed, full of Actinostreon gregarea; additional faunal elements: belemnites, rhynchonellids 0.05m

section continues around 0.5km SW of the road; bed (9') measured south of major fault corresponds to bed (9)

9' sandstone, fine-grained, calcareous, large-scale trough-crossbedded, top surface with large oscillation ripples 0.3m
10' sandstone, fine-grained, laminated; surfaces with oscillation ripples, *Thalassinoides* (0) 0.5m
11' pebble layer, shelly, ferruginous, with quartz gravel 0.15 m
12' siltstone, rubbly, marly, fine-sandy, highly bioturbated, turning soft after 30cm, trace fossils, *Teichichnus (a) Thalassinoides (c); fauna: Macrocephalites formosus, Indocephalites, Plagiostoma, Pseudolimea, Nanogyra* 1.5m
13' silt, argillaceous, fine-sandy with intercalations of claret ironstone concretions and thin shell beds, poorly exposed 1.5m
not exposed 9.5m

transfer to a more prominent stream-cutting 300 further W, the principal Chari fossil locality in the area

14' silt, argillaceous, fine-sandy, gypsiferous, with levels of claret ironstone concretions 0.7m
15' shell bed with *Ctenostreon proboscideum and Actinostreon* 0.1m
16' silt, argillaceous, fine-sandy with levels of claret ironstone concretions; 1 m above base: 10 cm fine-grained sandstone with reworked claret ironstone concretions 2.4m
17' siltstone, fine-sandy, full of comminuted shell debris, claret to purple, strongly ferruginous, richly fossiliferous, in two courses (Paratoceras Bed); fauna: *Macrocephalites chariensis (c) M. formosus, (c) M. (Dolikephalites) sp., M (Kampto-kephalites) sp. (c), Indocephalites sp. (r), Para toceras tuberculatum, Trigonia, Palaeonucula, Ctenostreon* 0.2m
18' silt, argillaceous, highly gypsiferous, seen for 1.5m