Himalayan Forelands: palaeontological evidence for Oligocene detrital deposits in the Bugti Hills (Balochistan, Pakistan)

JEAN-LOUP WELCOMME*‡, MOULOUD BENAMMI*, JEAN-YVES CROCHET*, LAURENT MARIVAUX*, GRÉGOIRE MÉTAIS*, PIERRE-OLIVIER ANTOINE§ & IBRAHIM BALOCH||

*Institut des Sciences de l'Evolution, UMR 5554 CNRS, Université Montpellier II, CC 064, F-34095 Montpellier Cedex 5, France

§Laboratoire de Paléontologie, Muséum National d'Histoire Naturelle, 8, rue Buffon, F-75005 Paris Cedex 5, France

||Geology Department, University of Balochistan, Quetta, Pakistan

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Abstract – In the southwestern Sulaiman geological province (Balochistan, Pakistan), terrestrial detrital facies from the Bugti Hills region have yielded the richest Tertiary vertebrate faunas to be found in Asia thus far. New fossils from five successive and distinct 'bone beds' bridge the supposed Oligocene sedimentary hiatus within the Sulaiman geological province; the lowermost continental levels of the previously described Miocene Chitarwata Formation, known as the Bugti Member, are Oligocene in age in the Bugti area. Neither a mixture of heterochronic faunal elements nor endemism of any fauna is evident in this area. Additional microfaunal material from the Bugti Member constrains an Oligocene age for the lower Chitarwata Formation in Zinda Pir (northeast of the Bugti Hills). This Oligocene transition between the marine Kirthar (Eocene) and continental Siwalik (Miocene) deposits consists of a regressive fluvio-deltaic system occupying a vast floodplain. It represents an early-stage molasse in the palaeo-Indus Basin which drained western orogenic highlands resulting from the collision between the Indian and Eurasian plates.

1. Introduction

The continental collision between the Indian and Eurasian plates and the subsequent formation of orogenic highlands (Himalayan, Kandahar, Kohistan etc.) represent tectonic and depositional processes that have moulded the Cenozoic geology of Western and Central Pakistan (Fig. 1). The Himalayan Forelands display distinctive lithological and biofacies developments that characterize the northern Upper and the southern Lower Indus basins. The Lower Indus Basin is divided west-east into the Kirthar and the Sulaiman geological provinces by the Khairpur-Jacobabad High and the Quetta syntaxes. A prominent feature associated with these geological events was the Oligocene sedimentary hiatus which had long been interpreted as an erosional unconformity (e.g. Downing *et al.* 1993). Only the southernmost Kirthar geological province, less affected by tectonics, documents well-developed transgressive marine Oligocene sediments (Nari Formation), gradationally influenced by fluvial beds of the overlying Miocene Manchar Formation (Raza *et al.* 1984). The Early Miocene Gaj Formation was interpreted as the oldest geological record of the Indus delta (Kazmi, 1984). However, recent investigations in the Katawaz Basin (eastern Makran, Fig. 2) have led to the description of the Palaeogene siliciclastic Khojak Formation (Qayyum, Niem & Lawrence, 1996; Qayyum, Lawrence & Niem, 1997). This Palaeogene deltaic sequence (associated with the palaeo-Indus River) has been linked to the pre-Miocene western Himalayan orogeny. In the Sulaiman geological province, the Bugti Hills (eastern Balochistan, southern Sulaiman Range, Sulaiman Lobe; Figs 1, 2) represent an important record of Himalayan Foreland sediments, which have yielded the richest fossil land vertebrate faunas to be found in South Asia (Vickary, 1846; Blanford, 1883; Pilgrim, 1908, 1910; Forster-Cooper, 1924; Welcomme *et al.* 1997, 1999). However, the Bugti mammalian faunas have generated much controversy over the apparent mixture of heterochronic elements, especially some typical Oligocene taxa associated with characteristic Lower Miocene taxa (Pickford, 1988; Pickford & Rogers, 1987). Reviews of specimens previously collected and the results of six seasons of fieldwork by the French Palaeontological Mission, in collaboration with the Geology Department of the University of Balochistan (Quetta), have shed new light on the biostratigraphy of the Bugti area. It leads us to propose a new interpretation of the age of these deposits.

In this paper we compare several selected sections measured in the Bugti Hills, located both to the north and south of the unvegetated Zin anticline (Fig. 2); we then further compare these to Sulaiman Range sections (Zinda Pir Dome: southern Sulaiman Range, about 100 km to the northeast of the Bugti area;

‡ Author for correspondence: welcomme@isem.univ-montp2.fr

Figure 1. General outline of the Indian subcontinent in South Asia (a) showing the location of Pakistan. Map of Pakistan (b) showing the location of the study area in eastern Balochistan (southern region of the Sulaiman Lobe, Bugti Hills; Fig. 2b).

Fig. 2). We briefly describe the lithofacies with a special emphasis on fossiliferous localities, and interpret their depositional environment in a biostratigraphic context.

2. Stratigraphic and faunal settings

In the Kirthar and Sulaiman provinces, the Middle to Upper Eocene deposits consist mainly of interbedded carbonates and shales of the marine Kirthar Formation (Blanford, 1879; Williams, 1959; Shah, 1977; Gingerich *et al.* 1997). From the base to the top, this formation comprises the Habib Rahi Limestone Member, the Domanda Shale Member, the Pir Koh Limestone Member and the Drazinda Shale Member. In the Sulaiman Range, the Kirthar Formation is disconformably overlain by the Chitarwata Formation (Hemphill & Kidwai, 1973), for which an Early Miocene age is generally assumed (Raza & Meyer, 1984; Flynn, Jacobs & Cheema, 1986; Friedman *et al.* 1992; Downing *et al.* 1993). Nevertheless, a Late Oligocene to Early Miocene age was originally considered on the basis of the palyno-assemblage from the Toi Nala section (Hemphill & Kidwai, 1973).

The Bugti area displays equivalents of the Kirthar and Chitarwata formations. In addition, the uppermost member of the Kirthar Formation (Drazinda Shale) is conformably and transitionally overlain by the lowermost level of the Oligocene marine Nari Formation. This level is predominantly composed of the white to grey massive crystalline limestone of the Nal Member (= Lower Nari), which yields the typically Oligocene neritic foraminifer *Nummulites bouillei*. From east to west (Fig. 3), the lowermost level of the Chitarwata Formation consists of a ferruginous crust, comparable to the Zinda Pir 'well-indurated ferruginous siltstone' defined by Downing *et al.* (1993). In the Bugti area, this basal crust yields *Nummulites clypeus* (= *N. intermedius-fichteli*), also typical in the Oligocene Lower Nari Formation (Nal Member, Kirthar province) (e.g. Shah, 1977), associated with molluscs (*Pecten substriatus*, oysters), selachians, sirenians and remains of rhinocerotoids (*Cadurcotherium indicum* and large-sized *Paraceratherium bugtiense* in the Paali section), further indicating an Early Oligocene age. This basal ferruginous crust is the expression of a widespread differential erosional palaeosurface (Fig. 3). From east to west, it overlies the massive limestone of the Oligocene Nal Member in the Dasht-i-Goran and Kadjuri Chauki sections (V, VI), the top of the Eocene Drazinda Shale Member in the Hargaï section (V), the limestones of the Pir Koh Member in the Pazbogi section (IV), marls of the Domanda Shale Member in the Paali section (III), and directly overlies limestones of the Habib Rahi Member in the Kumbi and Lundo sections (I, II). This palaeosurface, expressed as differential erosional unconformities, corresponds to an intra-Early Oligocene orogenic phase.

In all sections, the Chitarwata Formation (about 70 m thick) is increasingly influenced by clastic sediments, from littoral (base) to estuarine–deltaic (middle) and fluvial systems (top). Thirty metres above the ferruginous crust, the sequence evolves into a regressive fluvio-deltaic environment. The lowermost part is composed of alternating cycles of fine-grained sands and sandstones. This sequence contains lenses of sandstone, rare coal beds and numerous palaeosol horizons with root traces. In Paali C2, sands have yielded a rich and diversified vertebrate fauna, including fishes, reptiles, micro- and macromammals (Welcomme *et al.* 1999) (Figs 3, 4). Among them, rodents (sciurids, cricetids: Marivaux, Vianey-Liaud & Welcomme, 1999), rhinocerotoids (*Paraceratherium bugtiense*, cf. *Diceratherium* sp.), lophiomerycid and tragulid ruminants are very similar to those of Oligocene Eurasian faunas (Europe for cricetids and sciurids; Kazakhstan, Caucasus, Mongolia and China for large mammals (e.g. Russell & Zhai, 1987)).

The overlying levels contain no more marine or deltaic animals such as selachians, sirenians or oysters. Lithofacies and faunal compositions suggest a fluvial depositional environment, with three successive fossiliferous ferruginous crustal strata (F = 1, J1 = 2, J2 = 3; Figs 3, 4). In each of these three layers, the fauna is identical, with more advanced Oligocene mammals such as rhinocerotoids (medium-sized *P. bugtiense*, *Aprotodon smithwoodwardi*, *C. indicum*), schizotheres, anthracotheres (e.g. *Anthracotherium bugtiense*), entelodont (*Paraentelodon* sp.), *Lophiomeryx* sp. and *Palaeohypsodontus* sp. All of these genera have representatives in the Oligocene sequences of Central and

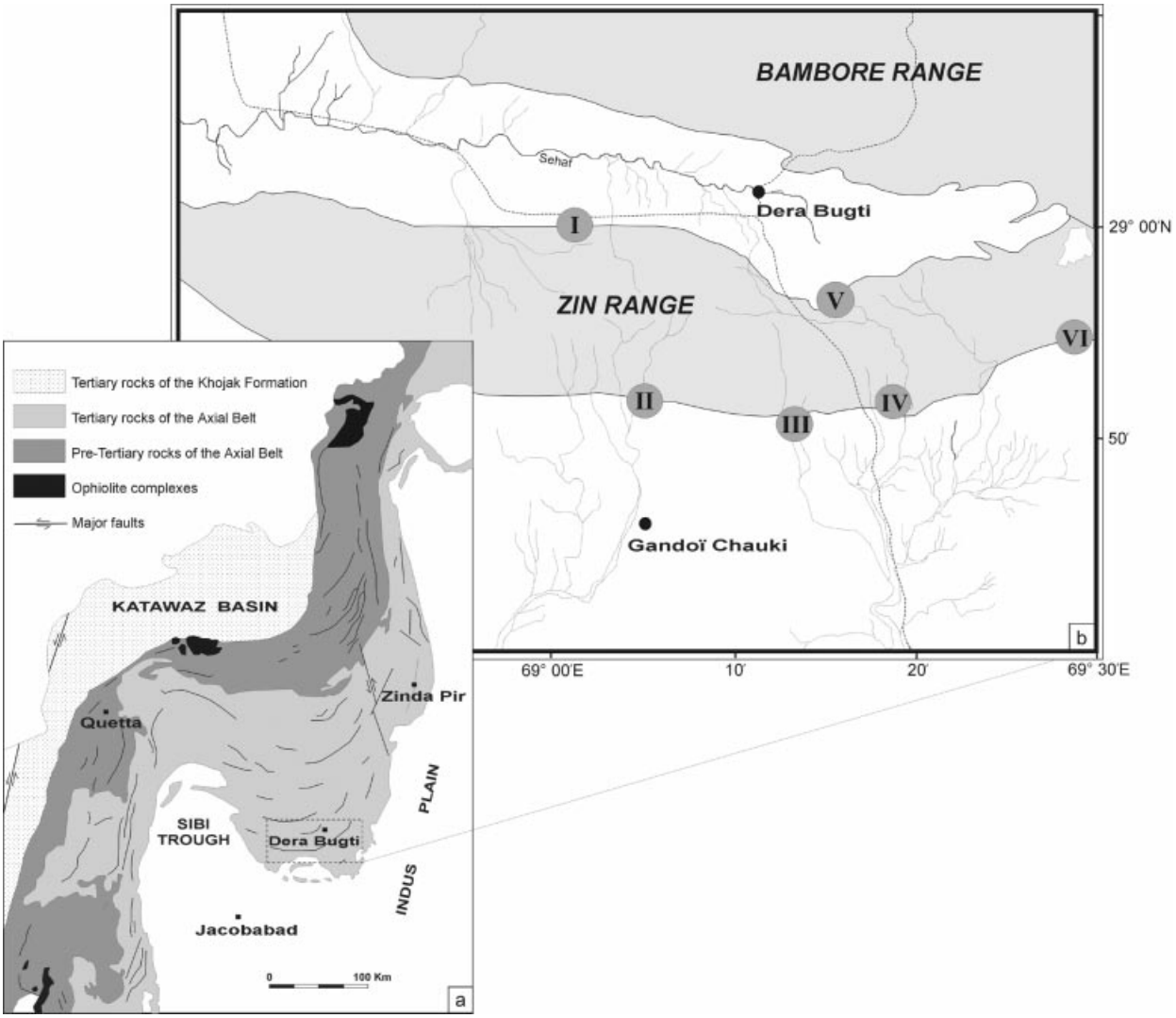

Figure 2. (a) Simplified geological map of northeastern Balochistan (modified from Johnson *et al.* 1999) showing location of the Bugti Hills in the southern part of the Sulaiman Lobe. On the simplified map of the Bugti area (b), points labelled I-VI on both sides of the Zin anticline correspond to selected stratigraphic sections measured and detailed in Figure 3.

Eastern Asia: Kazakhstan (Gromova, 1959; Lucas & Emry, 1996), Mongolia (Dashzeveg, 1991; Meng & McKenna, 1998) and China (Wang, 1992).

A faunal turnover is observed in the following fossiliferous levels (M = 3bis and Q = 4), 25 to 40 m above J2 = 3, respectively (Figs 3, 4); hyracodonts, amynodonts, entelodonts, lophiomerycids are absent. In contrast, proboscideans (*Prodeinotherium* sp., *Gomphotherium* sp.), more advanced rhinocerotids (*Plesiaceratherium naricum*, '*Diceratherium*' *abeli*, *Chilotherium blandfordi, Bugtirhinus praecursor*), ruminants (*Dorcatherium* sp., *Eotragus* sp.) and a listriodont suid (*Bunolistriodon affinis*) occur, thus documenting an Early Miocene age (Welcomme *et al.* 1997, 1999; Antoine & Welcomme, 2000). This event corresponds to major faunal exchanges between Africa and Eurasia, known as the 'Proboscidean Datum Event' (Madden & Van Couvering, 1976; Tassy, 1990). The sedimentary composition changes from sandstones to oxidized microconglomerates, enriched with allochtonous eroded quartz pebbles, feldspars and micas. It corresponds to the typical south-flowing fluvial system of Miocene Siwalik sedimentation. Thirty metres above in the Dera Bugti section (Fig. 3), the levels 6 and 6bis have yielded a diversified fauna with typically late Early Miocene macromammals, such as the artiodactyls *Sivameryx palaeindicus* and *Progiraffa exigua*, and rodents *Prokanisamys benjavuni*, *Spanocricetodon khani* and *Megacricetodon daamsi* (Welcomme *et al.* 1997).

Higher in the section (W; Figs 3, 4), a new locality recently yielded a Middle Miocene fauna (Welcomme *et al.* 1999) comparable to the Chinji fauna in the Lower Siwaliks (Badgley, Downs & Flynn, 1998).

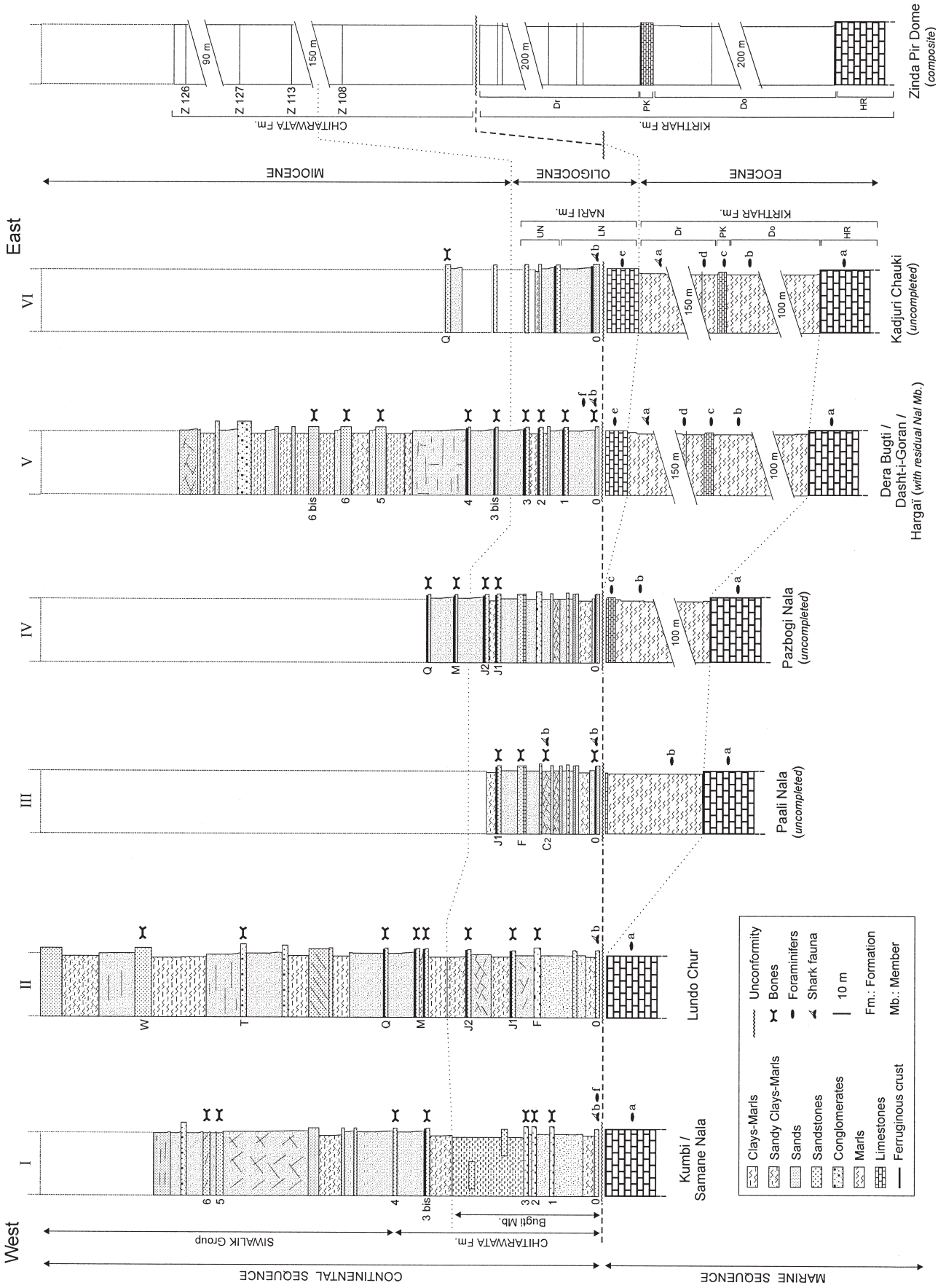

Figure 3. For legend see facing page.

3. Age of the lower Chitarwata Formation in the Sulaiman geological province: biochronological, palaeobiogeographic and magnetostratigraphic implications

Several geological sections have been established (Welcomme *et al.* 1997, 1999) in the Bugti Hills. A careful comparison of the Dera Bugti area deposits and faunas can be made with the Chitarwata Formation from the Sulaiman geological province (Hemphill & Kidwai, 1973; Downing *et al.* 1993).

3.a. The Bugti Member

In the Bugti area, Raza & Meyer (1984) have proposed the term 'Bugti Member' for the lower fossiliferous sequence of the assumed Early Miocene Chitarwata Formation. The locality Y-GSP 417 (Pazbogi nala, South Gandoï syncline), initially described from the Bugti Member, yielded a rodent fauna mostly representing a new sub-family of endemic Pakistani rodents, the baluchimyines (Flynn, Jacobs & Cheema, 1986). Later, this rodent assemblage from Y-GSP 417 was associated with the assumed Early Miocene megafauna, apparently occurring in the same level, about ten kilometres to the west (Lundo: Raza & Meyer, 1984). The authors interpreted these taxa as endemic rodents which had evolved on the Indian Subcontinent during a long phase of geographic isolation (from Eocene to Early Miocene times).

We have recently discovered an extremely rich rodent fauna in Paali (C2). This new locality is located only a few kilometres away from Y-GSP 417 in the South Gandoï syncline of the Bugti area. The Paali locality is part of the Bugti Member, about ten metres under level F (Fig. 3), where typically Oligocene macromammals have been reported (see Section 2). The former includes some baluchimyine species described by Flynn, Jacobs & Cheema (1986) from Y-GSP 417 and several species of primitive cricetids (*Atavocricetodon*, *Pseudocricetodon*, Early Oligocene European-like). These cricetids strongly differ from the Early Miocene forms described in Z 113, Z 126 (Zinda Pir Dome: Lindsay, 1996), DB6 (Fig. 4, Bugti Hills: Welcomme *et al.* 1997) and Lower Siwalik faunas (e.g. Lindsay, 1994). These new fossil cricetids, associated with baluchimyines, further assign an Early Oligocene age to the lowermost levels of the Chitarwata Formation in the Bugti area (Marivaux, Vianey-Liaud & Welcomme, 1999; Welcomme *et al.* 1999). In addition, a baluchimyine rodent has been described in the Late Eocene Krabi Basin of Thailand (Marivaux *et al.* 2000). Although it is more primitive, it is distinctly similar to the species of the Bugti Hills; the Early Oligocene age of Bugti baluchimyines is corroborated. The presence of several sciurids (*Oligopetes* sp.), zapodids and anomalurids in the Paali locality (L. Marivaux, unpub. Ph.D. thesis, Univ. Montpellier, 2000) finally allows us to reject the endemism of any rodent fauna in the Bugti Hills.

In the light of our new data (micro- and macromammals), the Bugti Member is here considered as Oligocene (Lower and Upper Nari Formation), therefore, an Oligocene age is assigned for the lower Chitarwata Formation. This age has been previously suggested (e.g. Blanford, 1883 ; Friedman *et al.* 1992) and recently argued by Welcomme & Ginsburg (1997). In addition, fossils from twelve successive and distinct 'bone beds' demonstrate that there is actually no mixture of heterochronic elements, except in early 1900s collections (Welcomme *et al.* 1999). Thus, there is no evidence for an abrupt Miocene turnover between the Chitarwata and Lower Siwalik faunas, as is usually suggested (e.g. Flynn, Jacobs & Cheema, 1986). In this context, the hypothesis of faunal isolation of the Indian Subcontinent from Late Eocene until Early Miocene times (Flynn, Jacobs & Cheema, 1986) can now be refuted, and the so-called 'Bugti Hills endemism' must definitely be rejected.

3.b. The lower Chitarwata Formation in the Zinda Pir Dome anticline

3.b.1. Biochronological implication

The erroneous Early Miocene dating for the base of the Bugti Chitarwata Formation (Bugti Member) was subsequently extended to the Zinda Pir Dome of the Sulaiman geological province in the last decade (Downing *et al.* 1993; Flynn & Cheema, 1994). In this area, about 100 km to the northeast of the Bugti Hills (Fig. 2), Flynn & Cheema (1994) reported the discovery of a rodent locality (Z 108) which yielded rodent taxa similar to their previously described Y-GPS 417 locality

Figure 3. Selected stratigraphic sections measured in the Bugti Hills (I-VI) and compared to the Zinda Pir Dome section (composite section adapted from Gingerich *et al.* (1997) for the Kirthar Formation (Rakhi Nala) and Downing *et al.* (1993) for the Chitarwata Formation (Dalana Nala, DGA&B)). The Bugti Hills sections reveal westward differential Eocene/Oligocene erosional unconformities. Fossiliferous levels recorded to the north of the Zin anticline (from Kumbi/Samane, Dera Bugti/Hargaï/Dasht-i-Goran sections) are labelled by numbers. Fossiliferous levels recorded to the south of the Zin anticline (from Lundo, Paali, Pazbogi and Kadjuri Chauki sections) are labelled by alphabetical letters. Fossiliferous correspondences between both sides have been established on the basis of direct faunal comparisons (1 = F; 2 = J1; 3 = J2; 3bis = M; 4 = Q; 5/6/6bis = T). Nari Formation: LN = Lower Nari (Nal Member); UN = Upper Nari. The lowermost levels of the Chitarwata Formation in the Bugti area are actually Oligocene in age and are equivalent to the Nari Formation. Kirthar Formation: HR = Habib Rahi Limestone Member; Do = Domanda Shale Member; PK = Pir Koh Limestone Member; Dr = Drazinda Shale Member. Foraminifer faunas: a to d = typical Eocene forms (Middle to Upper Eocene); e and f = typical Lower Oligocene forms. Shark faunas: faunal turnover between a and b.

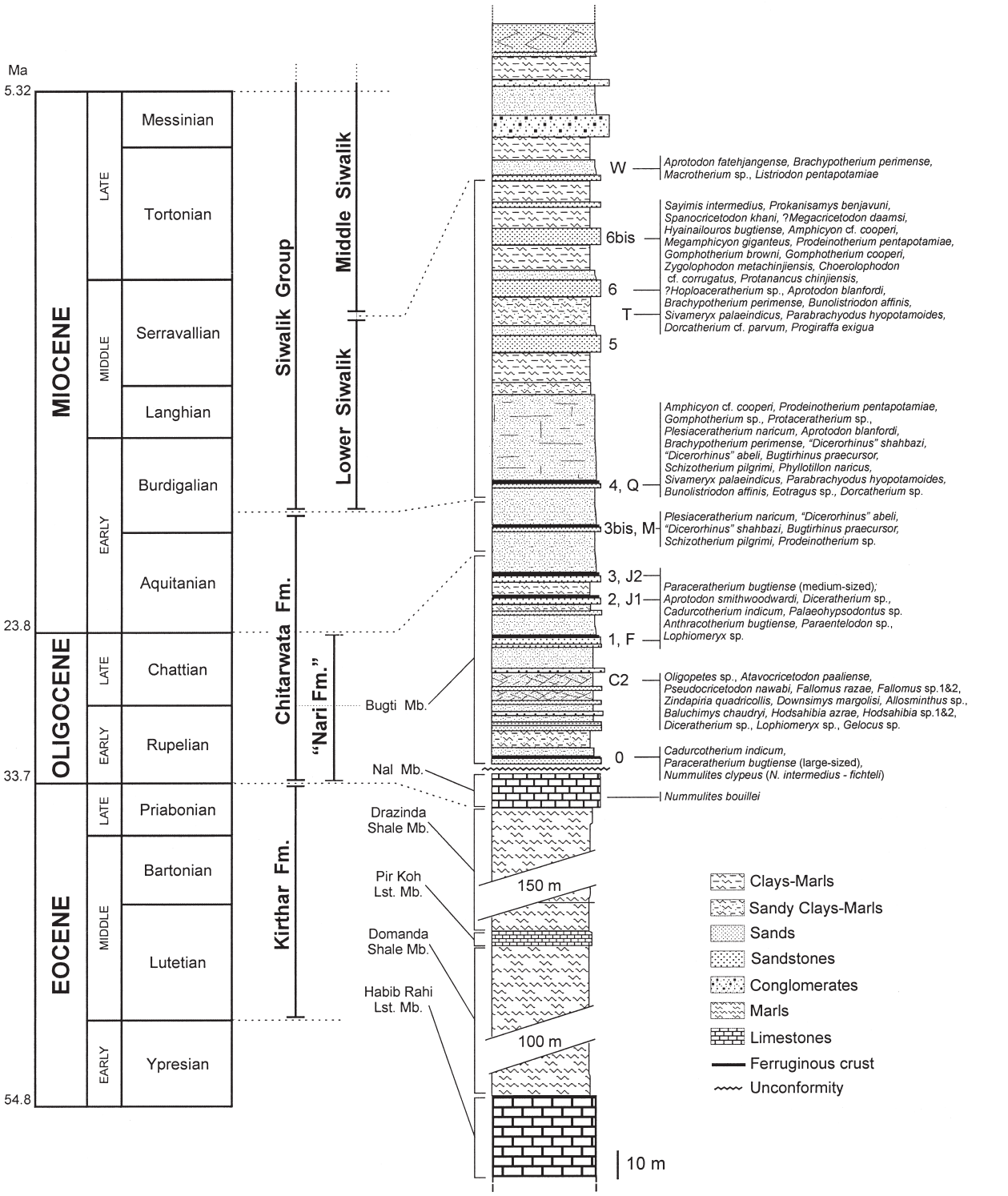

Figure 4. Synthetic biostratigraphic section of the Bugti area (Middle Eocene–Middle Miocene) in comparison with the chronostratigraphic scale (Cande & Kent, 1995). As mentioned in Figure 3 caption, fossiliferous correspondences between both sides of the Zin anticline have been established on the basis of direct faunal comparisons (1 = F; 2 = J1; 3 = J2; 3bis = M; 4 = Q; 5/6/6bis = T). The selected taxa (index taxa) for the basal Oligocene to Middle Miocene levels are labelled to the right of each fossiliferous level (after Welcomme *et al.* 1997; Welcomme & Ginsburg, 1997; Welcomme *et al.* 1999; Marivaux, Vianey-Liaud & Welcomme, 1999; Antoine & Welcomme, 2000; L. Marivaux, unpub. Ph.D. thesis, Univ. Montpellier, 2000).

Table 1. Rodent genera represented in the Zinda Pir Dome locality (Z 108) and the Bugti localities (Y-GSP 417 and DBC 2)

Genus	Z 108	Y-GSP 417	DBC 2
Baluchimys	+	+	+
Lindsaya	+	+	
Lophibaluchia	+	+	
Hodsahibia	+	+	+
Asterattus	+	+	
Large taxon	+	+	+
Zindapiria	+		+
Downsimys	+	+	+
Fallomus	+	+	+
Atavocricetodon			+
Pseudocricetodon			+
Allosminthus			+
Oligopetes			+
gen. et sp. nov.			+++

from the Bugti Hills. On that evidence, they attributed an Early Miocene age to both localities. Because of the strong faunal similarity between the Y-GSP 417, Z 108 and Paali (C2) localities (see previous Section; Table 1), it is our view that the biochronology initially proposed for the Chitarwata Formation in the Zinda Pir anticline needs to be re-evaluated. The levels containing the described baluchimyine rodents in the Zinda Pir Dome are now attributed to the Early Oligocene.

3.b.2. Implications for the magnetostratigraphic interpretation in Zinda Pir Dome

Our current temporal reinterpretation of the Bugti Member in the Bugti area has implications for the magnetostratigraphic setting proposed for the lower Chitarwata Formation in the Zinda Pir Dome (Friedman *et al.* 1992). Indeed, it constrains an Oligocene age for this lower section (including the Z 108 locality) previously assigned to the Early Miocene (Aquitanian) and therefore implies important stratigraphic gaps according to the number of anomalies recorded, the number of anomalies being extremely low compared to the expected duration of sedimentation. The selected best choice correlation (Friedman *et al.* 1992) with the magnetic polarity time scale (Harland *et al.* 1990) should also be revisited. The geomagnetic polarities of the lower Chitarwata Formation must be correlated with the 'Oligocene' reference time scale (Cande & Kent, 1995).

4. Conclusions

Several multi-disciplinary investigations confirm significant Eocene orogenic deformations capable of producing mountainous relief and abundant clastic sediments (Chamberlain, Zeitler & Erickson, 1991; Sorkhabi & Stump, 1993; Clift *et al.* 2000), although results of the Deep Sea Drilling Project and Ocean Drilling Program suggest that high accumulation rates of Himalayan-derived sediments in the Indian Ocean started in Early Miocene times (Davies, Kidd & Ramsay, 1995). Our stratigraphic and palaeontological studies in the Bugti Hills from western Pakistan demonstrate that the Bugti Member of the continental lower Chitarwata Formation contains only Early and Late Oligocene micro- and macromammals. These different Oligocene mammalian faunas occur in five successive and distinct levels, which testifies to the existence of detrital deposits throughout the Oligocene. The review of the Bugti biostratigraphy consequently allows us to update the biostratigraphy of the Zinda Pir Dome, showing that the lowermost continental levels of the Chitarwata Formation in this latter area are coeval and Oligocene in age. These results demonstrate that the continental Oligocene hiatus does not occur in the Sulaiman geological province, as traditionally accepted. This geological province provides a unique opportunity to study a major Oligocene deltaic system occupying a vast floodplain. The region received Oligocene sediments from an important palaeo-fluvial system that drained Palaeogene highlands.

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