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MIDDLE EOCENE STRATIGRAPHY AND MARINE MAMMALS (MAMMALIA: CETACEA AND SIRENIA) OF THE SULAIMAN RANGE, PAKISTAN

PHILIP D. GINGERICH

Department of Geological Sciences and Museum of Paleontology, The University of Michigan, Ann Arbor, Michigan 48109-1079 USA

MUHAMMAD ARIF

Paleontology and Stratigraphy Branch, Geological Survey of Pakistan, Islamabad

M. AKRAM BHATTI

Paleontology and Stratigraphy Branch, Geological Survey of Pakistan, Lahore

WILLIAM C. CLYDE

Department of Geological Sciences and Museum of Paleontology, The University of Michigan, Ann Arbor, Michigan 48109-1079 USA

ABSTRACT

Field work in the Sulaiman Range of southwestern Punjab has yielded four middle Eocene vertebrate faunas with marine mammals, principally archaeocete Cetacea. These are intermediate in age and bridge the temporal and morphological gap between two continental early Eocene faunas with amphibious archaeocetes in Kohat and northern Punjab (Pakistan), and later marine middle Eocene faunas with aquatic archaeocetes and sirenians in Kutch (India) and in Mokattam and Fayum (Egypt). The six Pakistan faunas are correlated to the geological time scale using global sea-level sequence stratigraphy, with planktonic foraminiferal and nannoplankton control (magnetization is weak where this has been sampled, with the present-day field predominating and little or no remanent Eocene primary magnetization). The two oldest faunas come from Kohat and northern Punjab: 1) the *Pakicetus* fluvial fauna comes from the lower Kuldana Formation, which is latest Ypresian in age (about 49.0 to 49.5 million years before present on the Haq et al. time scale); and 2) the *Ambulocetus* transitional-marine fauna comes from the upper Kuldana Formation, which is earliest Lutetian in age (about 49.0 to 48.0 Ma). Four succeeding faunas come from the Sulaiman Range: 3) the Habib Rahi Formation deep-shelf marine fauna comes from platy limestones and is early Lutetian in age (about 48.0 to 46.5 Ma); 4) the lower Domanda Formation *Rodhocetus–Takracetus* middle-shelf marine fauna comes from green clays and limestones and is early middle Lutetian in age (about 46.5 to 46.0 Ma); 5) the middle Domanda Formation *Gaviacetus–Remingtonocetus–Dalanistes* shallow-shelf marine fauna comes from brown clays and is middle Lutetian in age (about 46.0 to 45.5 Ma); and 6) the middle Drazinda Formation *Babiacetus–Protosiren* middle-shelf marine fauna comes from green clays and is late middle Lutetian in age (about 43.5 Ma). The Drazinda Formation fauna is evidently younger than the long-known Egyptian *Protocetus–Protosiren* fauna of Gebel Mokattam (ca. 45.0 Ma), and the Indian *Indocetus–Remingtonocetus* fauna from Kutch probably lies in the interval spanned by these two (ca. 45.0 to 43.5 Ma). The six Pakistan faunas document successive stages of cetacean evolution through six million years of early and middle Eocene time in eastern Tethys that involved changes first in the dentition for feeding on fish, then in the basicranium and dentaries for hearing in water, and finally in the pelvic girdle and hind limbs for efficient tail-powered swimming.

INTRODUCTION

The first mammalian remains from Eocene strata of the Sulaiman Range of Pakistan were reported by Pilgrim (1940). Pilgrim described three specimens. The first was a maxilla that he identified as anthracotheroid, and the other two were a partial maxilla lacking teeth and a "bear-like" partial right pelvic bone or innominate, both identified as mesonychid creodont. These came from "blue-grey shales weathering olive-green of the lower Khirthar" at Safed Toba, three to five miles south of Toba Kund, south of Kaha Nala (Fig. 1). This "lower Khirthar" is the "lower Chocolate Clays" of Eames (1952*a*, 1952*b*), or, in modern terminology, the Domanda Formation of Hemphill and Kidwai (1973) and Shah (1977, 1991). In Pilgrim's time, the Khirthar stage of Indo–Pakistan was known to

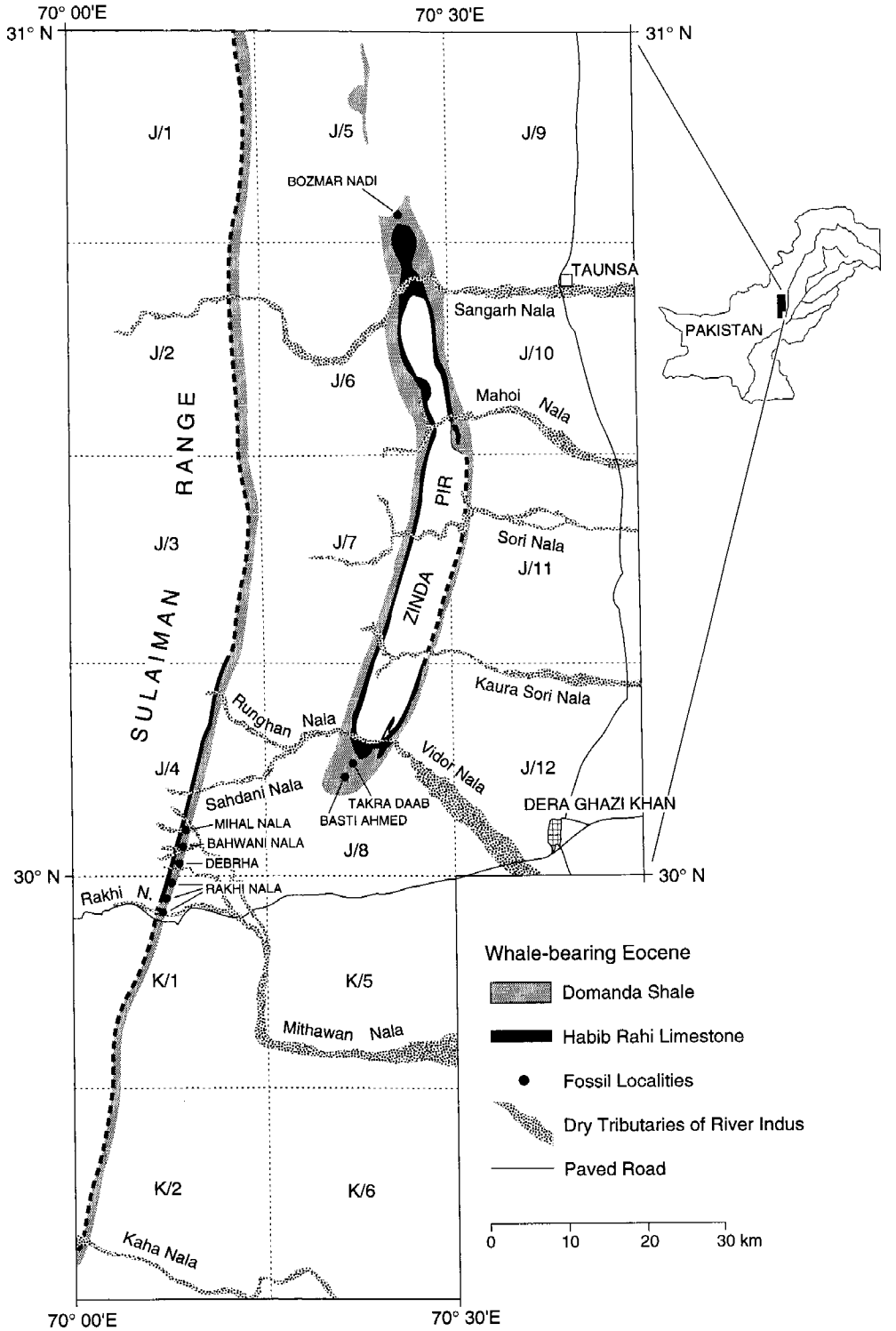
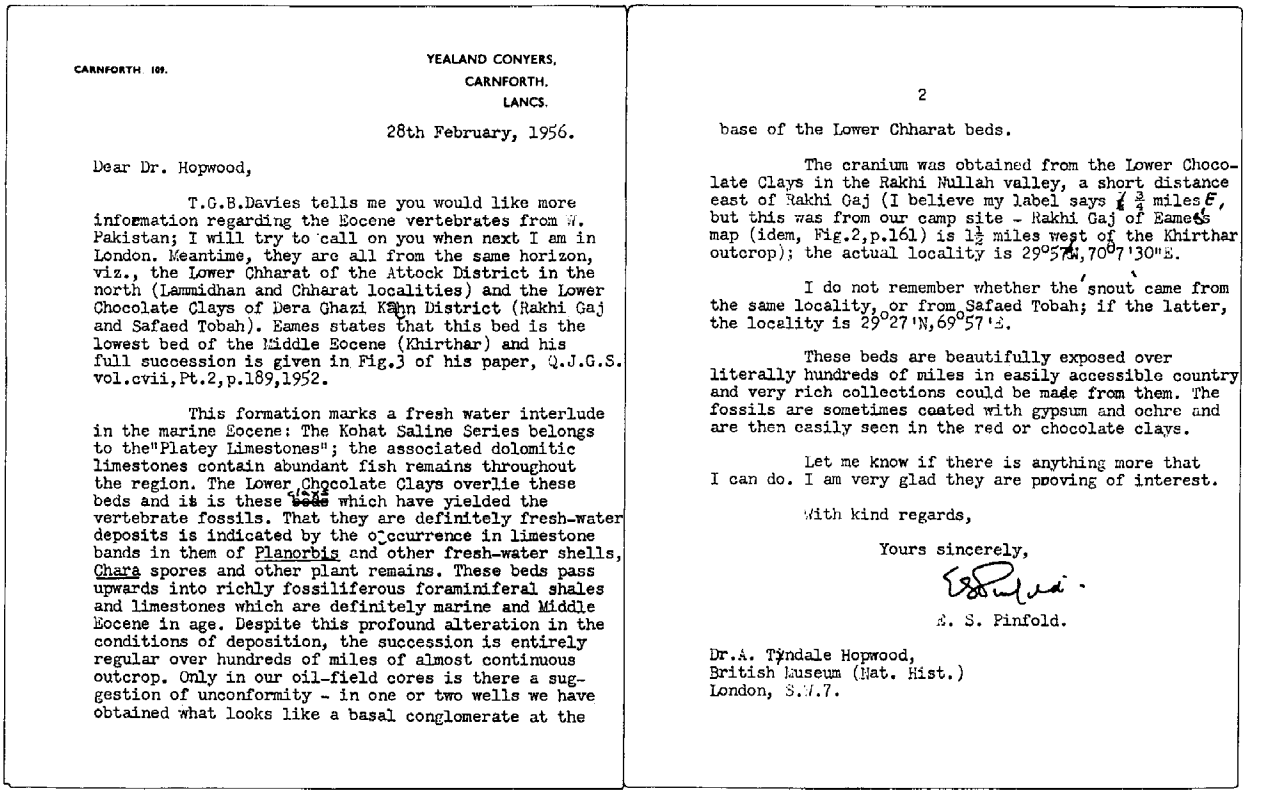


Fig. 1.—Map of Sulaiman Range and Zinda Pir anticlinorium located on the west side of the Indus River in the southwest corner of Punjab, central Pakistan (inset). Northern fossil-bearing localities of Bozmar Nadi and Satta with specimens described by Gingerich et al. (1993, 1994, 1995*b*) are shown in relation to southern fossil-bearing localities of Takra Daab, Basti Ahmed, Debrha, Bahwani Nala, and Rakhi Nala with specimens described by Gingerich et al. (1993, 1995*a*). Stratigraphic sections shown in Figure 3 were measured on the north and south sides of the Rakhi Nala stream bed (southernmost Rakhi Nala locality shown here) and in nearby tributaries of Barghan Nala, the next drainage north of Rakhi Nala stream bed (middle Rakhi Nala locality shown here). Lithologies and thicknesses of middle Eocene formations studied here are very uniform over the entire map area, and the sections in Figure 3 are generally representative of sections studied throughout the field area.



CARNFORTH 109.

YEALAND CONYERS,
CARNFORTH.
LANCS.

28th February, 1956.

Dear Dr. Hopwood,

T.G.B.Davies tells me you would like more information regarding the Eocene vertebrates from W. Pakistan; I will try to call on you when next I am in London. Meantime, they are all from the same horizon, viz., the Lower Chharat of the Attock District in the north (Lammidhan and Chharat localities) and the Lower Chocolate Clays of Dera Ghazi Khan District (Rakhi Gaj and Safaed Tobah). Eames states that this bed is the lowest bed of the Middle Eocene (Khirthar) and his full succession is given in Fig.3 of his paper, Q.J.G.S. vol.cvii,Pt.2,p.189,1952.

This formation marks a fresh water interlude in the marine Eocene: The Kohat Saline Series belongs to the"Platey Limestones"; the associated dolomitic limestones contain abundant fish remains throughout the region. The Lower Chocolate Clays overlie these beds and it is these beds which have yielded the vertebrate fossils. That they are definitely fresh-water deposits is indicated by the occurrence in limestone bands in them of Planorbis and other fresh-water shells, Chara spores and other plant remains. These beds pass upwards into richly fossiliferous foraminiferal shales and limestones which are definitely marine and Middle Eocene in age. Despite this profound alteration in the conditions of deposition, the succession is entirely regular over hundreds of miles of almost continuous outcrop. Only in our oil-field cores is there a suggestion of unconformity - in one or two wells we have obtained what looks like a basal conglomerate at the

2

base of the Lower Chharat beds.

The cranium was obtained from the Lower Chocolate Clays in the Rakhi Nullah valley, a short distance east of Rakhi Gaj (I believe my label says ¾ miles E, but this was from our camp site - Rakhi Gaj of Eames's map (idem, Fig.2,p.161) is 1½ miles west of the Khirthar outcrop); the actual locality is 29°57'N,70°7'30"E.

I do not remember whether the snout came from the same locality, or from Safaed Tobah; if the latter, the locality is 29°27'N,69°57'E.

These beds are beautifully exposed over literally hundreds of miles in easily accessible country and very rich collections could be made from them. The fossils are sometimes coated with gypsum and ochre and are then easily seen in the red or chocolate clays.

Let me know if there is anything more that I can do. I am very glad they are proving of interest.

With kind regards,

Yours sincerely,

E. S. Pinfold.

Dr.A. Tyndale Hopwood,
British Museum (Nat. Hist.)
London, S.W.7.

Fig. 2.—Letter from E. S. Pinfold to A. Tyndale Hopwood, dated February 28, 1956, describing the promise of Eocene fossil vertebrate localities in the Domanda Formation or "Lower Chocolate Clays" of the Sulaiman Range of Pakistan. The cranium mentioned by Pinfold is M50719 in the Natural History Museum, London, United Kingdom, which is a partial cranium of *Dalanistes ahmedi* from the north side of Rakhi Nala east of Rakhi Gaj (locality shown in Figure 5). Safed Tobah, south of Kaha Nala on the map in Figure 1, is the source of the "mesonychid" maxilla described by Pilgrim (1940).

be an eastern-Tethys equivalent of the Lutetian stage of Europe, and the lower Khirthar was (and is) understood to be early middle Eocene in age.

Pilgrim (1940) also described land mammals from what is now the Kuldana Formation at Lammidhan in the Kala Chitta Range of northern Punjab. Broader exploration of the Kuldana Formation in the Kala Chitta Range was organized by Dehm and Oettingen-Spielberg (1958), who added two named "mesonychids," *Gandakasia potens* and *Ichthyolestes pinfoldi*, to the Kuldana Eocene fauna. In 1972, one of us (P.D.G.) visited Kuldana localities in the Kala Chitta Range and examined Kuldana and other Pakistan specimens at the British Museum (Natural History) in London. Accompanying specimens in a drawer in the British Museum was a letter from the geologist E. S. Pinfold to A. Tyndall Hopwood. The letter (reproduced in Fig. 2) mentions Lammidhan and Chharat in northern Punjab and Rakhi Gaj and Safed Tobah (or Toba) in the Sulaiman Range, and, citing Eames, implies that the lower Chocolate Clays are "definitely fresh-water," and states that these are "beautifully exposed over literally hundreds of miles in easily accessible country" where "very rich collections could be made."

The Lammidhan and Chharat localities were examined in more detail in 1975, when discovery of a "*Gandakasia*" tooth led to the suggestion that this "mesonychid" might be an archaeocete (Gingerich, 1977). At this time a team from Howard University (S. T. Hussain), Utrecht (H. de Bruijn), and the Milwaukee Public Museum (R. M. West) began to prospect the Kala Chitta Eocene intensively (Hussain et al., 1978; West, 1980), and a cooperative Geological Survey of Pakistan–University of Michigan (GSP–UM) research project was organized by P. D. Gingerich and D. E. Russell of the Muséum National d'Histoire Naturelle (Paris) to follow up on Pinfold's letter with exploration of the lower Chocolate Clays and other formations in other parts of Pakistan having the potential to yield land mammals.

In the field in 1977 it quickly became clear, contrary to the implication of Pinfold's letter, that the

lower Chocolate Clays (now Domanda Formation) are predominantly or entirely marine, having been deposited in the Tethys Sea on the passively-subsiding northwestern margin of Eocene Indo–Pakistan before uplift of the Himalayas. Fragmentary cranial and postcranial remains of archaeocete cetaceans were found in 1977, and Pilgrim's edentulous "mesonychid" maxilla from Safed Tobah was reinterpreted as representing, possibly, an archaeocete rather than a land mammal (Gingerich et al., 1979). Several massive sacra and innominates with large acetabula found in 1977 were facetiously dubbed "walking whales" in the field, but such whales were then unknown and the specimens were consequently considered more likely to represent moeritheriid or other amphibious land mammals carried into the sea (as Sahni and Mishra, 1975, had interpreted a sacrum from Kutch). Subsequent study has shown that all of these are archaeocetes, as are Pilgrim's Safed Tobah innominate and "anthracotheroid" maxilla and Sahni and Mishra's sacrum. Although disappointing for land mammals, the Eocene of Pakistan showed promise for investigating the early evolution of whales.

Interest in archaeocetes was rekindled by three developments in the 1960s and 1970s. First, Van Valen (1966, 1968) combined the results of comparative immunological study of myoglobins showing Cetacea to be the sister group of Artiodactyla (Boyden and Gemeroy, 1950) with his own understanding of early Cenozoic condylarthran mammals and proposed that Mesonychidae (or later, Mesonychia) are the group from which cetaceans evolved. Second, an important new archaeocete fauna was found and described from the marine middle Eocene of Kutch in India by Tandon (1971, 1976), Sahni and Mishra (1972, 1975), Satsangi and Mukhopadhyay (1975), Trivedy and Satsangi (1984), and Kumar and Sahni (1986). Finally, the cranium of a new and very primitive archaeocete, *Pakicetus inachus*, was found in fluvial deposits now known to be early Eocene in age at Chorlakki in Kohat District in the North-West Frontier Province of Pakistan (Gingerich and Russell, 1981; Gingerich et al., 1983). All of these discoveries served to focus attention on the early-to-middle Eocene as the time of origin, and eastern Tethys as the place of diversification, of the earliest Cetacea.

In 1981 a GSP-UM team including Neil Wells, Hassan Shaheed, David Bardack, and William Ryan returned to the Sulaiman Range to look for archaeocetes and other marine vertebrates. There, in addition to a substantial fauna of fishes, they found: 1) the skull included in *Indocetus* by Gingerich et al. (1993; now identified as *Rodhocetus*), 2) well-preserved dentaries described and named *Rodhocetus* by Gingerich et al. (1994), and 3) a partial skull of *Remingtonocetus* cf. *R. harudiensis* described by Gingerich et al. (1995*a*; identifications and re-identifications are explained in this paper). These specimens all came from the Domanda Formation. In addition, the GSP–UM team found a partially articulated skull and skeleton of a new archaeocete in the underlying Habib Rahi Formation (Gingerich, 1991), which Rahman and Dunkle (1966) had reported as yielding well-preserved marine fishes. Localities are described in Wells (1984) and in Gingerich et al. (1993, 1995*a*; see Fig. 1 here). The 1981 expedition proved that well-preserved archaeocetes can be found in the Domanda and other Eocene formations of the Sulaiman Range.

Further expeditions were organized in 1992 and 1994 to follow up on the 1977 and 1981 discoveries. Field work in 1992 was concentrated at the northern plunge of the Zinda Pir anticlinorium, particularly in the Domanda Formation of Bozmar Nadi (Fig. 1), and in the Drazinda Formation near Satta (north of Sangarh Nala, north of an area prospected by West et al., 1991; see also Case and West, 1991, and Nolf, 1991). Field work in 1994 was concentrated at the southern plunge of the Zinda Pir anticlinorium, particularly in the Domanda Formation of Takra Daab (Fig. 1). The 1994 field work yielded some ten cetacean skulls or partial skulls, including several with good associated postcranial remains. These show, when studied together with the Pilgrim–Pinfold specimens and our 1977, 1981, and 1992 collections, that there is considerable morphological and taxonomic diversity in early middle Eocene archaeocetes—much greater diversity than is known in late middle and late Eocene archaeocetes found in Egyptian Tethys or elsewhere. Diversity and its temporal succession are important for understanding the early evolution of whales. Six successive archaeocete faunas are now known from Pakistan, substantially improving our understanding of the timing and adaptive diversification of earliest Cetacea.

This paper combines results of Gingerich et al. (1995*a*, 1995*b*), with those of Sahni and Mishra (1975), Gingerich et al. (1983, 1993, 1994), Thewissen (1993), and Thewissen et al. (1994), using a stratigraphic framework to investigate the evolutionary chronology of cetacean evolution in eastern Tethys. Possible cetaceans from the early-to-middle

Eocene of Kashmir (Gingerich and Russell, 1994) are not considered here because of ambiguities concerning their age and identification.

Institutional acronyms used in text are: CGM, Cairo Geological Museum, Cairo, Egypt; GSI, Geological Survey of India, Calcutta, India; GSP–UM, Geological Survey of Pakistan–University of Michigan collection, Islamabad, Pakistan; H–GSP, Howard University–Geological Survey of Pakistan collection, Islamabad, Pakistan; LUVP, Lucknow University vertebrate paleontology collection, Lucknow, India; NHML, Natural History Museum, London, United Kingdom; VPL/K, Kumar collection, Vertebrate Paleontology Laboratory, Panjab University, Chandigarh, India; SMNS, Staatliches Museum für Naturkunde, Stuttgart, Germany.

EOCENE STRATIGRAPHY

Archaeocetes are known from three principal areas in Pakistan: the Kala Chitta Range in northern Punjab, the Kohat District in the North-West Frontier Province, and the Sulaiman Range in western Punjab. Extensive study of the micropaleontological stratigraphy and sea-level stratigraphy from various parts of the western Indo–Pakistan subcontinent has provided a means to correlate the archaeocete-bearing deposits from all three areas to the geological time scale.

Kala Chitta Range and Kohat District

The geology of Eocene deposits in the Kala Chitta Range of northern Punjab, whence Pilgrim (1940) and Dehm and Oettingen-Spielberg (1958) described Eocene land mammals, was studied by Cotter (1933). These Eocene deposits extend north and east into Hazara (Latif, 1970), and westward across the Indus River into Kohat District in North-West Frontier Province (Eames, 1952*a*, 1952*b*; Meissner et al., 1975). The principal land-mammal-bearing unit is the lower Kuldana Formation (or Mami Khel Formation), which is red mudstone with thin beds of calcarenite representing reworked soil nodules (Wells, 1983, 1984). These calcarenites sometimes preserve reasonably complete skulls (e.g., the holotype of *Pakicetus inachus*) and even skeletons of mammals (e.g., the *Diacodexis pakistanensis* skeletons described by Thewissen et al., 1983), and the entire vertebrate fauna is continental with no marine taxa (Pilgrim, 1940; Dehm and Oettingen-Spielberg, 1958; Buffetaut, 1978; Hussain et al., 1978; Russell and Gingerich, 1980, 1981, 1987; West, 1980; de Bruijn et al., 1982; Hartenberger, 1982; Gingerich et al., 1983; Thewissen et al., 1983, 1987; de Broin, 1987; Gayet, 1987; Rage, 1987; Roe, 1991), except, possibly, archaeocetes like *Ichthyolestes* and *Pakicetus*. Lower Kuldana red beds are interpreted as clastic low-stand wedge deposits that grade laterally and offshore into Bahadur Khel salt and Jatta gypsum in Kohat District, which are equivalent to Baska gypsum farther south along strike in the Sulaiman Range.

The upper Kuldana Formation is a thin unit of green shales with oyster beds and other indications of shallow marine deposition (Wells, 1984). Mammals are rare elements of the fauna, and these generally represent more amphibious groups like anthracobunids (Wells and Gingerich, 1983) and *Ambulocetus* (Thewissen et al., 1994). The upper Kuldana shales are overlain by nummulite-rich marine Kohat Limestone, which has not yet been found to yield mammalian fossils. The Kohat Limestone was probably deposited during the TA3.2 sea-level highstand, correlative with Habib Rahi deposition in the Sulaiman Range farther to the south (see below).

Sulaiman Range

In 1994 we spent ten days in the Sulaiman Range studying the classic Eocene stratigraphic section exposed in Rakhi Nala near Rakhi Gaj police post. Five formations were examined: 1) the 122 m-thick Baska Shale, "shales with alabaster," or Baska Formation, consisting of interbedded green shales and thin limestones with 10 m of bedded to massive gypsum near the top (Fig. 3, 4); 2) the 43 m-thick Habib Rahi Formation or "platy limestone" consisting of platy limestone and marl alternating with green shale, with limestones 10 cm thick at the base of the formation thinning and becoming more distantly spaced upward in the section (Fig. 3, 5); 3) the 303 m-thick Domanda Formation or "lower chocolate clays" consisting of green clay shale (sometimes fissile paper shales) at the base, brown clay shales in the middle, and brown shales with a lignite near the top (Fig. 3, 5); 4) the 12 m-thick Pir Koh Limestone or "white marl band" (Fig. 3, 6, 7); and 5) the 331 m-thick Drazinda Formation or "upper chocolate clays" consisting of green clay shales with some *Discocyclina*-rich limestones in the lower part and brown to red shales in the upper part (Fig. 6). The upper contact of the Drazinda For-

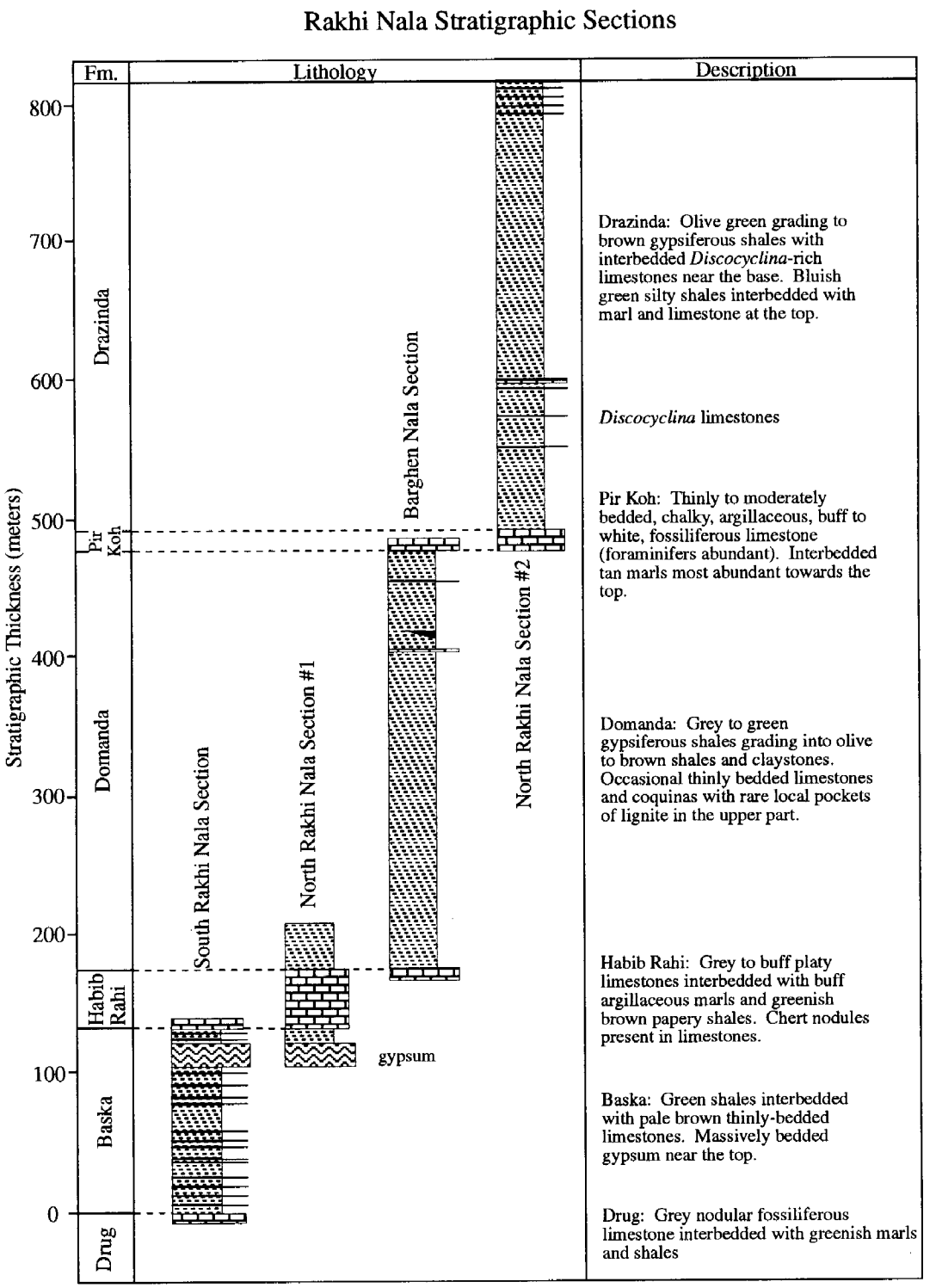


Fig. 3.—Diagrammatic summary of stratigraphic sections of lower and middle Eocene formations measured by the authors in and just north of Rakhi Nala in November 1994. Formational thicknesses are listed Table 1. Baska Formation is best exposed on the south side of Rakhi Nala (Fig. 4). Habib Rahi Formation is best exposed on the north side of Rakhi Nala (Fig. 5). Domanda Formation is best exposed in Barghen Nala just north of Rakhi Nala proper (Fig. 6). Pir Koh Formation (Fig. 7) and Drazinda Formation are best exposed on the north side of Rakhi Nala, where they are overlain disconformably by the continental Miocene Chitarwata Formation.