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Biostratigraphy of Kirthar Formation (Middle to Late Eocene), Sulaiman Basin, Pakistan

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ABSTRACT

A foraminiferal (planktonic and larger) biostratigraphic investigation based on the 70 samples of the Kirthar Formation from five surface sections (one complete and three selective) in the eastern margin of the Sulaiman Range and one in subsurface of Mari Gas Field (southern Sulaiman Basin) were investigated. These new findings together with the re-evaluation of the previous biostratigraphic information, where needed, were synthesized to develop a chronostratigraphy of the Kirthar strata. The present study revealed that in most of the previous studies, the lower lithologic boundary of the Kirthar strata carried on varying at different stratigraphic levels, additionally a flexible taxonomical definition of some of the larger foraminiferal species was adopted which resulted contradicting age of the Kirthar Formation. Our investigation for a unified lithology of Kirthar Formation (*sensu strato* Shah, 1977) reflected that it range in age from the Middle to Late Eocene in the eastern part of the Sulaiman Range. Eight planktonic foraminiferal zones from P10 to P16/17 have been identified and compared with larger foraminiferal and calcareous nannoplankton zonations. The base of the Kirthar Formation (the base of Habib Rahi Limestone) on the shallow part of the shelf (inner shelf) has been found to lie within the larger foraminiferal *Assilina spira abrardi* Zone whereas in the deeper part of the basin (middle to outer shelf) it lies within upper part of zone P10 to ?P11. The regressive unit "Domanda Shale member" representing restricted marine and brackish water environments is P11 in age. Pir Koh Limestone and Marl member indicate that the basin attained a maximum depth (outer shelf to upper slope) during P12 to P13 time. Drazinda Shale member as a whole represents an inner to middle shelf environments during P14 to P16/17 time. Five correlative time lines emerged which showed almost isochronous time/facies relationship throughout the study area. However a slight degree of northward time transgressive nature of the Pir Koh Limestone has been observed. Based on the faunal association, two minor hiatuses, one at the base of Kirthar (between zones P9 and P10) and second between Pir Koh Limestone and Pir Koh Marl (between zones P13 and P14) are recognized. For the Habib Rahi Limestone and Pir Koh Limestone and Shale member our data shows a good time/sequence type consistency with the global sequences of Haq et al., (1987) whereas a time/sequence type discrepancy exists for the Domanda Shale member.

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INTRODUCTION

The present biostratigraphic study of the Kirthar Formation in Sulaiman Province was initiated to support the HDIP-BGR project "Evaluation of Zindapir Anticline" by providing exact age of the Formation based on the biostratigraphy. The study was initiated from the Thak section. The age of the Kirthar Formation in Sulaiman Basin, was disputed. Most of the workers have designated Early to Late Eocene age. As the study progressed, the curiosity to determine the exact age over a broad region increased, therefore, additional samples from the other sections were also investigated (Figure 1).

The Kirthar Formation is widely distributed throughout the Indus Basin having its northern limit upto Kohat and Waziristan (Shah, 1977). In the Sulaiman Basin, contradictory ages to the Kirthar Formation not only in the various sections but even in the single section have been assigned by different authors. Consequently, a number of discrepancies were emerged (Figure 2). These discrepancies might be a result of 1) variable lithological boundaries of Kirthar Formation, 2) flexible taxonomical definition of the age diagnostic taxa, 3) reworked element and/or missing of in-situ fauna and 4) advancement in the basic knowledge of biostratigraphy. Therefore, in the surface and subsurface of the Sulaiman Basin, a fresh biostratigraphic investigation together with the review of the previous litho and biostratigraphic data has been synthesized to establish a chronostratigraphic setup of the Kirthar Formation having a standard definition of (*s.s.* Shah, 1977) lithostratigraphic boundaries in the study area.

MATERIAL AND METHODS

Fifty one samples drawn from the shaly/marly and limestone intervals of the Kirthar Formation in the Thak section, 16 samples of the Habib Rahi and Pir Koh Limestone members from Domanda section, 1 sample of the base of Habib Rahi from Zao River section, three samples, one of Pir Koh Limestone and 2 of the shale and limestone between gypsum and Habib Rahi Limestone from the Rakhi Nala section have been investigated for the planktonic and larger foraminifera. The available literature on the Kirthar Formation was surveyed for re-evaluation and interpretation of the results. Conventional techniques were used for sample preparation.

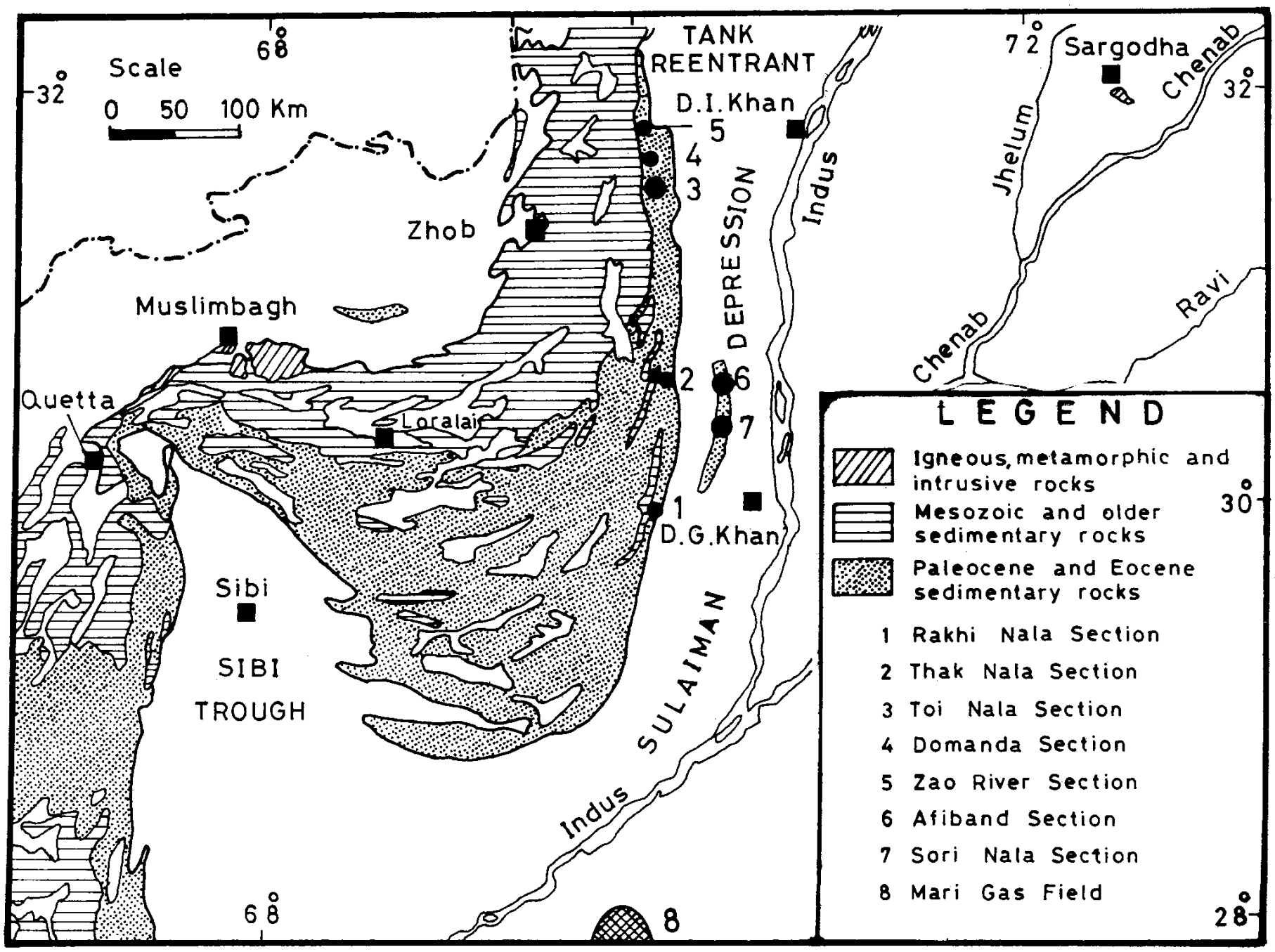

Figure 1- Location map of the study area (Modified after Weiss, 1993).

PREVIOUS WORK

Several researchers have worked on the Kirthar Formation and have recognized the formation with different lithologic boundaries and designated different ages to the formation (Figure 3). Based on the lithology and fauna, Eames (1952a, b) described and classified the sediments referred here under Kirthar Formation into two time-rock units and five lithostratigraphic units. The lower four units, Platy Limestone, Lower Chocolate Clays, White Marl Band and lower half of the Upper Chocolate Clays, he placed within the Kirthar Series (Middle Eocene) whereas the upper half of the Upper Chocolate Clays including *Pellatispira* bed placed within Tapti Series (Late Eocene). Bayliss (1961) measured and sampled the Rakhi Nala section which was later on studied for the larger foraminifera (Bayliss, 1961) and for the planktonic foraminifera (Latif, 1961 and Samanta, 1973). The above mentioned authors dated it as Early to Late Eocene. Fritz (1963; *fide* William, 1973) mentioned the presence of some larger foraminifera from the Habib Rahi Limestone member and Domanda Shale member at Toi Nala and north of Domanda. He commented that the lower age of these members is as old as Early Eocene (Late Ypresian). However, near Zinda Pir area, Rahman & Dunkle (1966) based on the marine fish fauna from the Habib Rakhi Limestone determined the age as Middle Eocene. Haq (1972) through the calcareous nannoplankton analysis datad Kirthar Formation as Middle Eocene (NP16).

Under HDIP-BGR project, Kirthar was investigated for the planktonic and larger foraminifera (Weiss, 1988, 1993), calcareous nannoplanktons and dinoflagellates (Kothe et al., 1988) from a number of localities of the Sulaiman Range. Weiss (1988, 1993) reported Early Eocene larger foraminifera from the Habib Rahi Limestone (his *Assilina* Cliff) from the Zao River and Toi Nala sections. At Rakhi Nala section, the base Habib Rahi was reported barren of foraminifera (Weiss, 1988, 1993) whereas Kothe et al., (1988) from the same beds recovered nannoplanktons of top NP14-NP15 Zone (Middle Eocene) whereas at the Toi Nala section she dated the base of Kirthar as NP12, Early Eocene.

From the Afiband area of Sulaiman Range, Sameeni et al., (1994) reported Early Eocene larger foraminifera from the Pir Koh Limestone member (White Marl Band). Ahsan (1994, *fide* Chaudhary et al., 1994) also reported Early Eocene larger foraminifera from the Rakhi-Gaj section of the Sulaiman Range. Ahsan et al., (1993) reported similar fauna also from

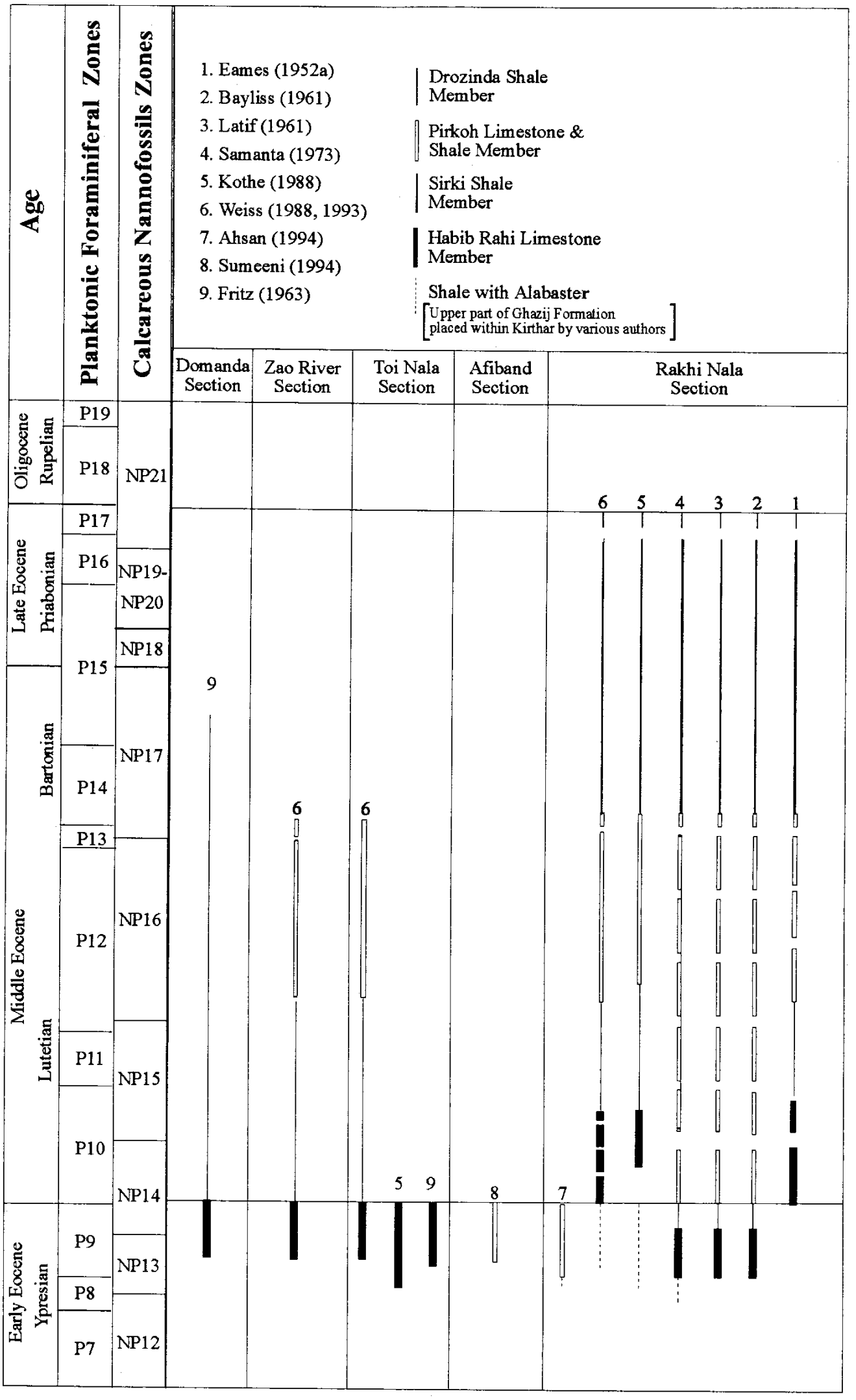

Figure 2- Summary chart representing the age of Kirthar Formation assigned by various authors.

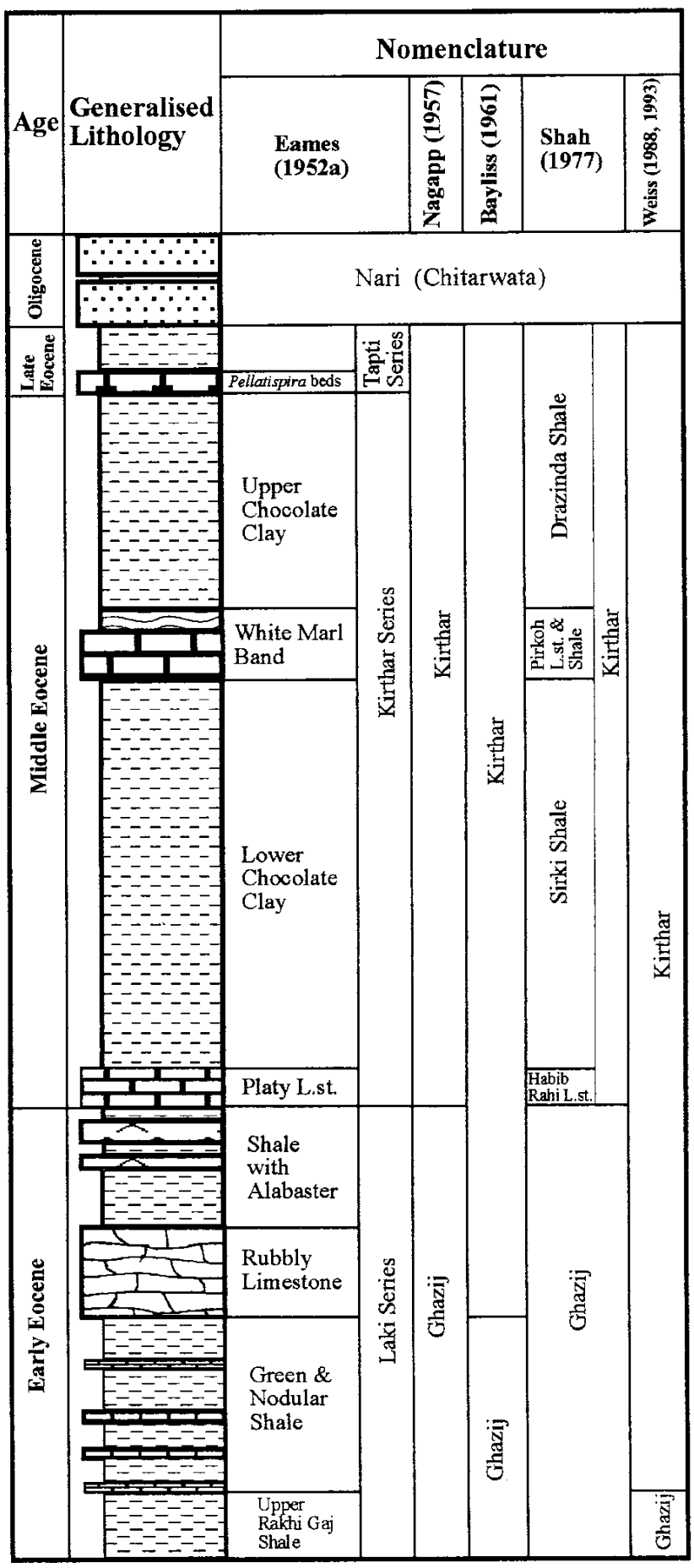

Figure 3- Lithostratigraphic nomenclature used for the Kirthar Formation by various authors in the Sulaiman Range with particular reference to the Rakhi Nala section.

the Pir Koh Limestone from Dhar and Taunsa area. Gingerich (1995a, b) studied the mammals from the Domanda and Drazinda Shales (Kirthar Formation). Taking into account the results of previous studies, he correlated all the four members of the Kirthar Formation with the global sequence of Haq et al., (1987).

KIRTHAR FORMATION

The term Kirthar (time-rock unit) was introduced by Blanford (1876) for the strata between the Ranikot Group and Chitarwata Formation in the western Sindh. Later on Noetling (1903) separated its lower part as Laki (time-rock unit) while for the upper part he retained the term Kirthar. For the Sulaiman Range, Nuttall (1926) further subdivided the term Kirthar into Lower Kirthar (Early to Middle Eocene) and Upper Kirthar (Middle to Late Eocene). This subdivision has been followed by the subsequent authors for the biostratigraphy of the Kirthar Formation. Eames (1952a) redescribed the lithologic units from the Rakhi Nala and Zinda Pir sections of the Sulaiman Range and used the term Kirthar for the Middle Eocene strata and for the Late Eocene he introduced a third time rock unit "Tapti". Hunting Survey (1961) defined another Early to Middle Eocene unit and named "Spintangi Limestone" for the Sulaiman Province and Calcareous Zone of Axial Belt. William (1959) designated the Gaj River section in Kirthar Range as a type locality and named it as Kirthar Formation for a limestone dominant sequence. In the previous literature the term Kirthar has been referred both for the rock unit and time rock-unit. The definition of the Kirthar Formation until Shah (1977) and even after, has remained a matter of confusion. A redefinition of the Kirthar strata in the Sulaiman Basin is required. In the Sulaiman Range the lithologic units of Eames (1952a) are easily recognizable and therefore, here referred as standard reference to define the Kirthar Formation. Stratigraphic Committee of Pakistan has accepted the four fold subdivision of the Kirthar Formation i.e. from base to top as, Habib Rahi Limestone member, Domanda Shale member, Pir Koh Limestone and Marl member and Drazinda Shale member. These units are briefly described below.

The lower most member "Habib Rahi Limestone" is equivalent to the "Platy Limestone" of La Touch (1893) and Eames (1952a), massive limestone of William (1973). It is a pale gray to buff, platy limestone having more dark gray to black argillaceous intercalations and some thin bands of black chert. Presence of oil shale has been observed within this unit Porth & Raza (1990). The "*Assilina* bed" of Eames (1952a) described from the Rakhi Nala area is not included here within the Kirthar strata. Replacing the previous Sirki Shale of Eames (1952a) by "Domanda Shale" of Hemphill and Kadwai (1973) has been now adopted for the "Lower Chocolate Clays" of Eames (1952a) in the Sulaiman Range (Rakhi Nala). It consists of reddish brown, greenish gray, at places gypsiferous shale with gray to brown, thick to thin bedded calcareous sandstone, limestone and claystone. The Pir Koh Limestone and Shale member is equivalent to the "White Marl Band" of Eames (1952a). It consists of light gray to chalky white, thin bedded, argillaceous, Discocyclina marl whereas the subordinate beds of light gray to chalky white shale, limestone and marl at places containing black chert. This unit also showed the presence the oil shale (Porth & Raza, 1990).

The term Drazinda Shale of Hemphill and Kadwai (1975) was adopted for the "Upper Chocolate Clays" including "*Pellatispira* bed" of Eames (1952a). It consists of dark brownish gray to chocolate shale, claystone, siltstone and marl, gypsiferous near the upper part. The top most part is light bluish gray marl and argellaceous limestone. In the eastern margin of the Sulaiman Range, the lower contact with the

Ghazij Formation is transitional. The top most member of the Ghazij Formation (Baska Shale with Alabaster member) is a sequence of shale, gypsum and thin limestone beds which is overlained by the Habib Rahi Limestone. The presence of the gypsum beds has been observed throughout the eastern Sulaiman Range. In the calcareous zone of Axial Belt the formation rests unconformably upon many Early Eocene and Mesozoic rocks marked by the thin leteritic shale or pebbly conglomerate bed (Shah, 1977). In the study area we refer the base of Kirthar Formation at the consistent limestone sequence i.e. Platy Limestone of Eames (1952a) at Rakhi Nala area. The underlying thin sequence consisting of shale and thin limestone beds (=*Assilina bed* of Eames, 1952a; observed at Rakhi Nala, Toi Nala etc.) lying within the gypsum and Habib Rahi Limestone is considered as the top most part of Ghazij Formation *sensu strato* Eames (1952a) and Shah (1977).

BIOSTRATIGRAPHY

For the planktonic foraminiferal taxonomy, Bolli (1957b), Stainforth et al., (1975), Postuma (1975), Blow (1979) and Tomarkine & Luterbacher (1985) are followed whereas for the biostratigraphyic zonation, scheme of Berggren et al., (1995) in comparison with the nannoplankton zonation scheme of Martini (1971), is generally followed. For the larger foraminiferal taxonomy following references are concerned: Nuttall (1926b), Davies (1940), Bayliss (1961), Adams (1971), Schaub (1981) and Raecy (1995).

Habib Rahi Limestone Member

For the Habib Rahi Limestone member, 16 samples from the Thak section while 12 samples from the Domanda section and only one from the Zao River section were investigated (Figures 4, 5 and 6).

At the Thak section, only the basal bed yielded larger foraminifera (Figure 5) whereas the overlying beds yielded frequent planktons. The larger foraminifera include *Assilina papillata, Nummulites* cf. *mamillatus* and *Lockhartia conditi.* This assemblage possibly is equivalent to the A. spira abrardi Zone of Schaub (1981). Among the planktonic forams, only one species was recognizable i.e. *Subbotina frontosa* ranging P9 to P12, while other belonging to the *Globigerina* and *Chailoguembelina* stock, are not identifiable up to species level.

At Domanda and Zao River sections, the Habib Rahi Limestone, yielded abundant larger foraminifera. The assemblage consists of *A. papillata, A. spira abrardi, Nummulites sp., N. mamilaltus, Operculina aspensis* (Figure 6). Based on the above assemblage, Middle Eocene (Lutetian) age has been assigned to it and placed within *Assilina spira abrardi* Zone of Schaub (1981), equivalent to the top NP14 to NP15 zones (Kothe et al., 1988 in Rakhi Nala) and planktonic foraminiferal P10-P11 zones of Berggren et al., (1995).

Abbas (1992) described the lithofacies of Kirthar Formation in the subsurface of the Mari Gas Field. Some of his plates show the presence of *A. spira abrardi, A. papillata, Nummulites aff. kugleri* near the base of the Habib Rahi Limestone member, fitting within *A. spira brardi* Zone of Schaub (1981). At the higher level *N. beaumonti* and *Alveolina elliptica* are present that fit within *A. aspira spira* Zone of Schaub (1981) or *Alveolina munieri* Zone of Hottinger (1961). Therefore, confirmed the Middle Eocene age of the base Kirthar also in the subsurface.

Two samples, one from the *Assilina* bed and second just above this in RakhiNala also analyzed which yielded only the non age diagnostic agglutinated fauna. The thin limestone bed (= *Assilina* bed) lying within the shale of Ghazij Formation (above gypsum) shows the presence of *A. aff. daviesi, Nummulites sp.* (aff. *atacicus), N. mamillatus*. This assemblage indicates that most likely age is the top most part of Early Eocene. A similar level in the Toi Nala section has been dated as NP12, Early Eocene (Kothe et al., 1988).

Domanda Shale Member

Thirteen samples from the Sirki Shale were investigated from the Thak section (Figure 4). The lower part is completely barren of all kind of foraminifera whereas the upper part yielded only non age diagnostic agglutinated fauna consisting of *Haplophragmoides, Trochamina, Glomospira, Ammodiscus.* Therefore, age can not be designated to this part, however, according to the age of the lower unit, it should not be older than zone P11 (=NP15). Whereas in the other sctions it is not investigated where it may cross the P11/P12 zonal boundary.

Pir Koh Limestone and Marl Member

In total twelve samples, 6 from Thak section, 5 from Domanda section and only one from the Rakhi Nala section are investigated. This unit provided maximum yield of all groups of foraminifera i.e. planktons, smaller and larger benthic foraminifera, therefore, provided a precise age control for this unit. Three planktonic foraminiferal zones are recognized from this interval (Figure 4, 5 and 6).

Morozovella lehneri (P12) Zone
Age: Middle Eocene, Lutetian
Category: Interval Zone
Author: Bolli (1957b)

Horizon: Pir Koh Limestone in Thak section (Sample No. 95.2.20-14 to 95.2.20-17), at Domanda section (Sample No. 95.11.11-11 to 95.11.11-14)

Definition: An interval between the LAD of *M. aragonensis* to the FAD of *Globigerinopsis beckmanni.*

Other assemblage: Among the planktonic foraminiferal assemblage, *Morozovella spinulosa, Truncorotaloides topilensis, T. rohri, Acarinina bullbrooki, S. frontosa, S. inaequispira, Globigerinoides hagginsi, Globigerinatheka* spp., whereas among the larger foraminifera *Discocyclina dispansa, D. sowerbyi, D. dorreeni, Operculina sp. and N. vanderstoki* were recovered.

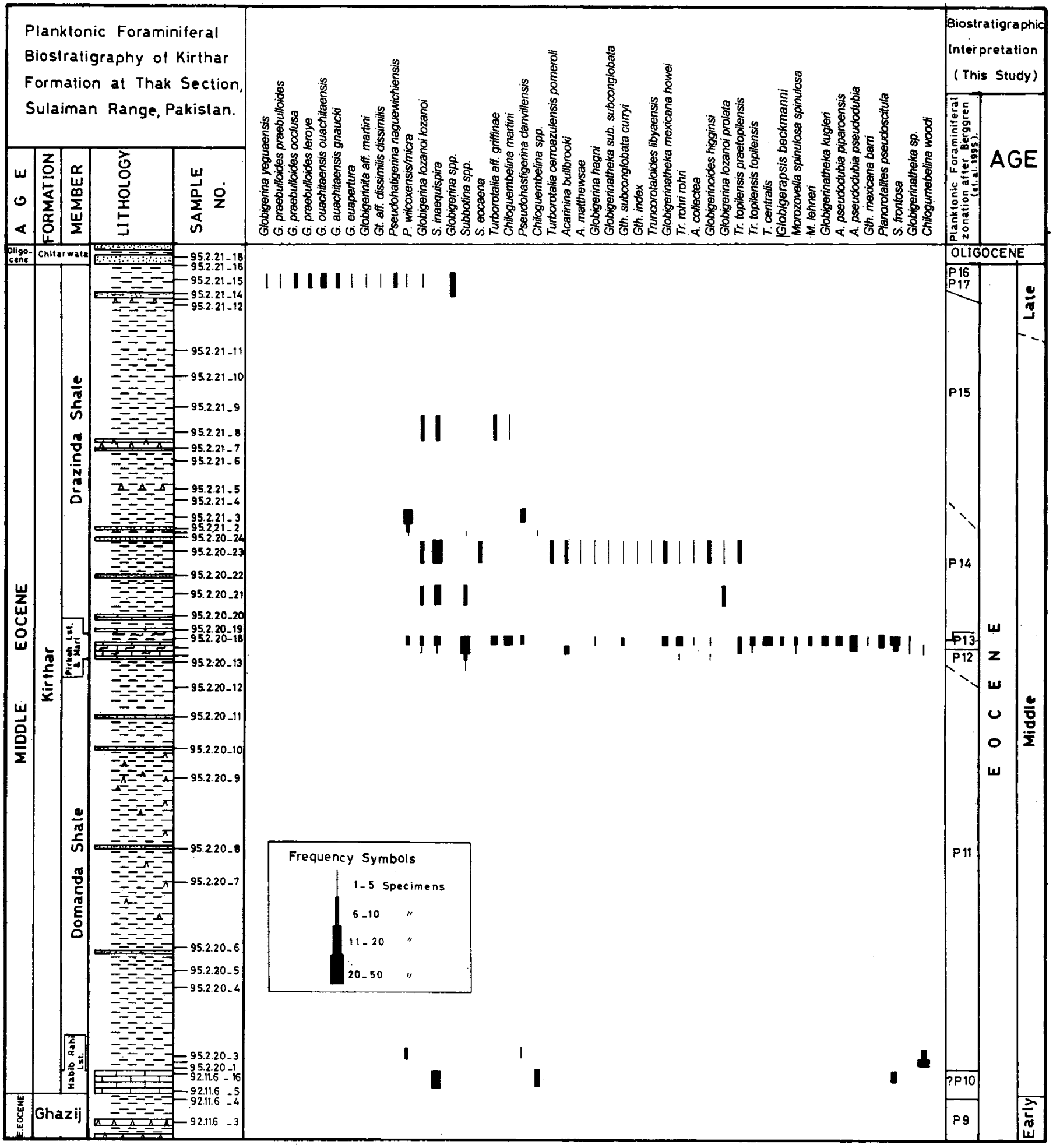

Figure 4- Distribution chart of the planktonic foraminifera in the Thak section, Sulaiman Range.

Remarks: The top of this zone is clearly distinguished in all the sections mentioned above whereas the base is not defined due to the lack of diagnostic fauna, nevertheless, the base may lie close to the Pir Koh Limestone.

Globigerapsis beckmanni (P13) Zone
Age: Middle Eocene, Bartonian
Category: Total Range Zone

Author: Bolli (1957b, 1966) renamed by Cardey (1968), Blow & Cita (1968) and Blow (1979)

Horizon: Pir Koh Limestone at Domanda section (Sample No.92.11.11-15), Pir Koh Marl at Thak section (Sample No.95.2.20-18) and at Rakhi Nala section (Sample No. 95.3.11-14)

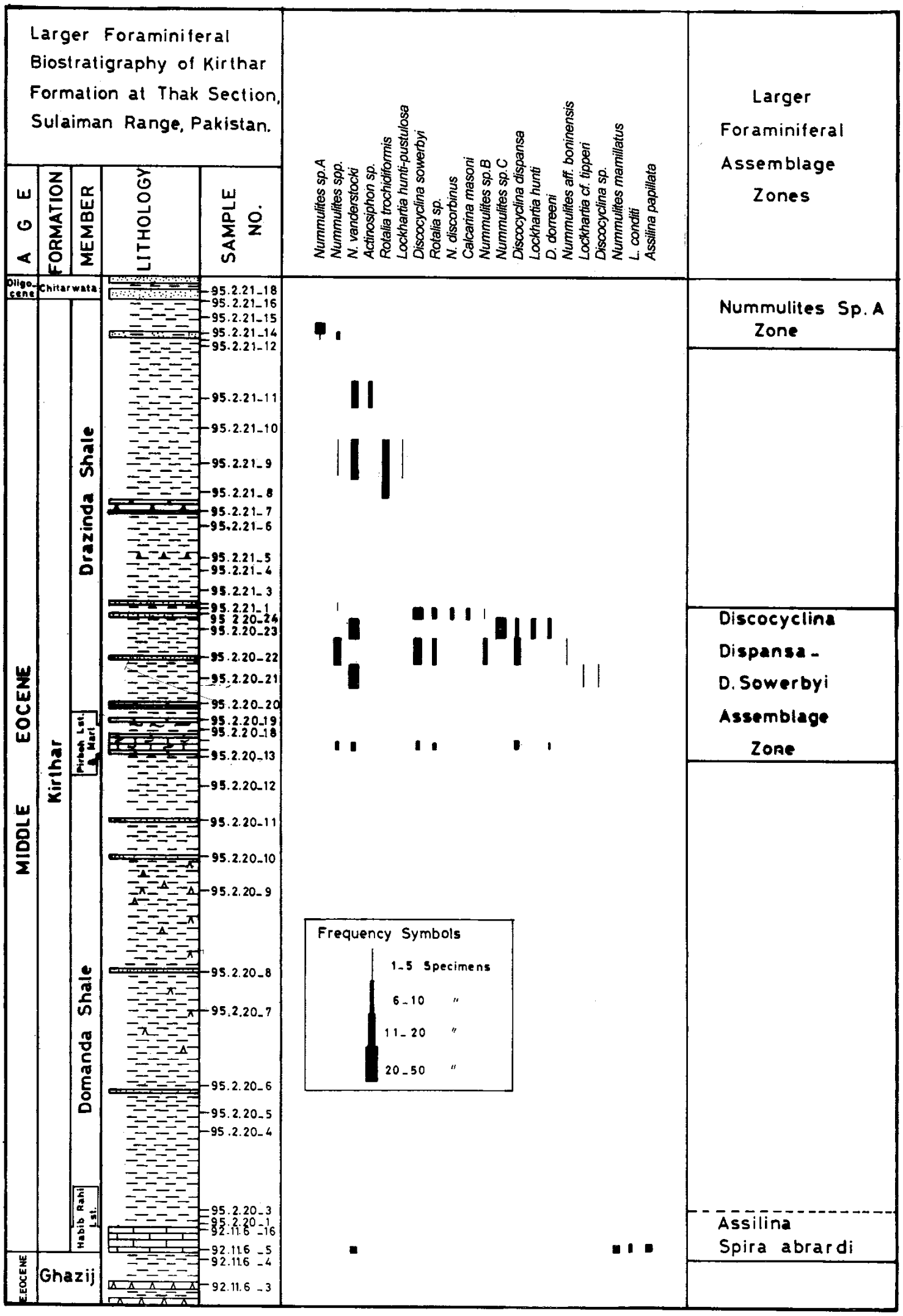

Figure 5- Distribution chart of the larger foraminifera in the Thak section, Sulaiman Range.

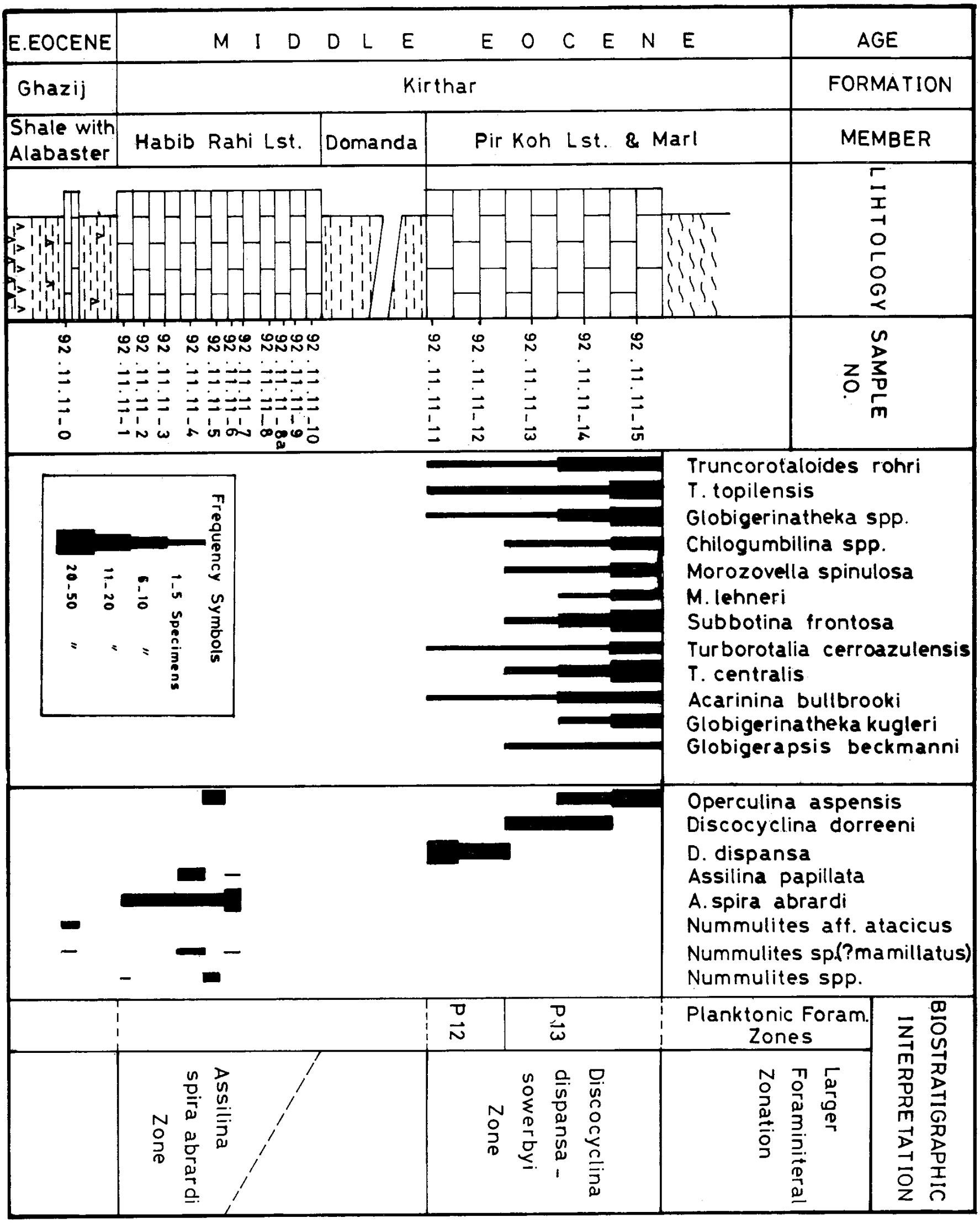

Figure 6- Distribution chart of the planktonic and larger foraminifera in the Domanda section, Sulaiman Range.

Definition: A total range zone of the nominated taxon.

Other assemblage: The planktonic foraminifera include *Globigerina lozanoi, G. prolata, Pseudohastigerina naguewichiensis, P. micra/wilcoxensis, P. danvillensis, S. frontosa, S. inaequispira, Turborotalia griffinae, T. centralis, T. cerraozulensis pomeroli, Truncorotaloides rohri, Tr. topilensis praetopilensis, Tr. topilensis topilensis, A. pseudodubia piparoensis, Globigerinatheka mexicana barri, Gth. mexicana howei, Gth. kugleri, A. bullbrooki, A. collactea, Globigerina hagni, Globigerinoides higginsi, Chiloguembelina woodi, Planorotalites pseudoscitula, Morozovella spinulosa, M. lehneri.* Among the larger foraminifera, *Operculina aspensis, D. dispansa, D. dorreeni* are observed.

Remarks: In the Thak and Rakhi Nala sections, this zone lies at the base of Pir Koh Marl whereas at the Domanda section this zone has been identify within the top most beds of the Pir Koh Limestone. The stratigraphic ranges of the *T. griffinae* and *G. lozanoi* are either prolonged in this area or may be reworked, however reworking based on the preservation could not be proved. This zone for the Rakhi Nala section is equivalent to the *G. yeguaensis* to *C. unicavus* zones of Latif (1961) and *T. topilensis* to *G. crassata* zones of Samanta (1973) and *Gth. subconglobata* to *M. lehneri* zones (Weiss, 1988, 1993) (Figure 7).

Drazinda Shale Member

This unit comprising of 21 samples from Thak section is investigated which yielded common to frequent planktonic, smaller and larger foraminifera. Two planktonic and three larger foraminiferal zones are recognized (Figures 4, 5).

Tr. rohri-M. spinulosa (P14) Zone
Age: Middle Eocene
Category: Partial Range Zone
Author: Blow (1979) and Berggren & Miller (1988)

Horizon: Drazinda Shale in Thak section (Sample No. 95.2.20-19 to 95.2.21-5)

Definition: Concurrent partial ranges of the nominated taxa between the LAD of *G. beckmanni* and FAD of *Porticulaspaera semiinvoluta.*

Other Assemblage: The planktonic foraminifera include *S. inaequispira, S. eocenae, P. danvillensis, A. bullbrooki, A. metthewsae, A. collactea, G. hagni, Gt. higginsi, G. prolata, Turborotalia centralis, T. libyaensis, T. cerrazulensis pomeroli, Truncorotaloides rohri, Globigerinatheka index, Gth. mexicana boweri, Gth. index ruberiformis.*

The larger foraminiferal assemblage consists of *N. vanderstoki, N. discorbinus, R. trochidiformis, Actinosiphon sp., Lockhartia hunti-pustulosa, L. tipperi, D. dispansa, D. dorreeni* and *Calcarina masonai* and several species of *Nummulites.* This assemblage also indicates Middle Eocene (Lutatian) age.

Remarks: Most of the assemblage is similar as observed within P13 Zone, The base of the zone is confirmed due to the non evidence of *G. beckmanni* whereas the top is not confirmed due to the shallowing upward sequence and complete absence of plaktonic and larger foraminifera. Only smaller benthic foraminifera are observed. This zone is equivalent to the *C. uncavus* to *Ch. aff. martini* zones of Latif (1961) and *T. rohri* Zone of Samanta (1973) in the Rakhi Nala section. Weiss (1988, 1993) introduced a larger foraminiferal assemblage zone "*Discocyclina dispansa-D. sowerbyi*" Zone equivalent to P12-P14 zones of the planktonic foraminifera which has also been identified in this study (Figure 7).

G. ouachitaensis ouachitaensis Zone (equivalent to ?P15-P17)
Age: Late Eocene, Priabonian
Category: Acme Zone
Author: This study

Horizon: Drazinda Shale at Thak section (Sample No. 95.2.21-15 to 95.2.21-16)

Definition: This zone is defined by the common occurrence of the G.*ouachitaensis* ouachitaensis.

Other assemblage: *G. yeguaensis, G. praebulloides praebulloides, G.preabulloides occlusa, G. praebulloides leroyi, G. ouachitaensis ganuki, G. euapertura, G. aff. martine martine, P. nagowichensis, P. micra/wilcoxensis.*The larger foraminifera species *Nummulites* sp.A having close similaritis with *N. praeswichianus, is frequently observed.*

Remarks: The above assemblege is recovered above a barren interval of planktonic foraminifera. No standard zonal marker was observed. The assemblage was of much smaller size and did not show good preservation, therefore, the most common and easily identifiable species "*G. ouachitaensis ouachitaensis*" is nominated for this zone. The zone, according to the stratigraphic ranges (Bolli & Sounders, 1985) may be equivalent to the ?P15-P17 zones of Berggren et al., (1995) and to NP19-NP20 zones of Martini (1971). In Rakhi Nala section, this zone is equivalent to the *G.* aff. *trilocularis-Ch. victoriana* Zone of Latif (1961) and *G. officinatis* Zone of Samanta (1973) (Figure 7). From the same sedimentary interval, Kothe et al., (1988) recognized NP18-NP19/20 zones of Martini (1971) (Figure 7). For this unit two larger foraminiferal zones have been identified. The middle part of Drazinda is barren of planktonic foraminifera. The most commonly present species observed within this part is *Nummulites vanderstoki*, therefore, nominated for this part equivalent to the lower part of P15 Zone of the planktonic foraminifera. In the upper part *Nummulites* sp. A has been commonly observed. This species have very close similarities with *N. praeswichianus*, therefore, nominated equivalent for the planktonic foraminiferal *G. ouachitanenensis* Zone (this study) and P15-P17 zones of Berggren et al., (1995) (Figure 7).

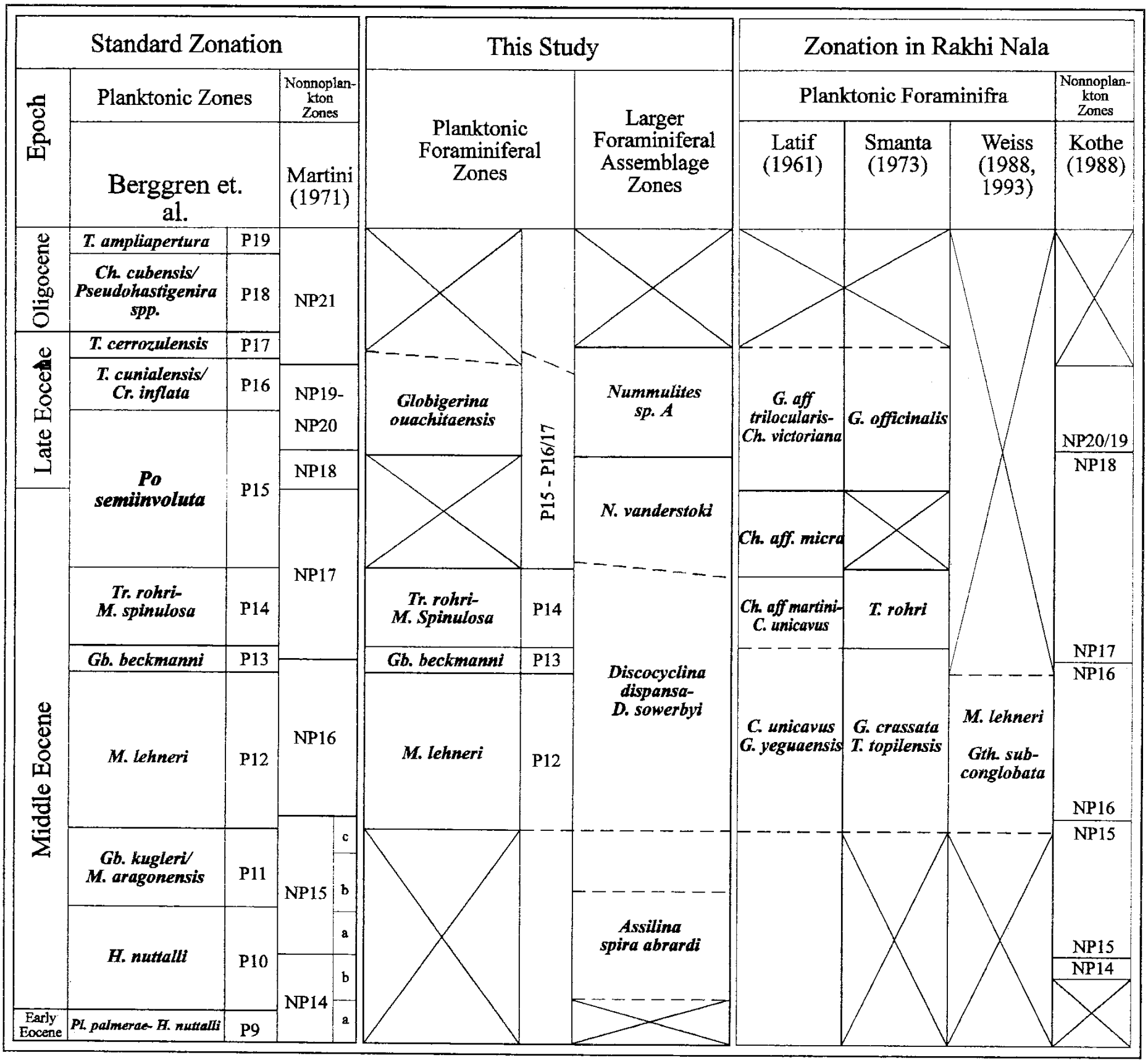

Figure 7- Standared correlation between planktonic foraminiferal and calcareous nannofossil zones after Berggren et al., (1995) in relation to the proposed and interpreted zonation in Rakhi Nala section by various authors.

BIOSTRATIGRAPHIC CORRELATION

A biostratigraphic correlation of the Kirthar Formation over a broad region of the Sulaiman Basin is attempted which is based on the recent investigation and previous biostratigraphic studies. This correlation is emerged in the form of five correlative time lines. These time lines are resultant of the combined agreement in the ages assigned to the Kirthar strata through the planktonic and larger foraminifera, calcareous nannoplankton and dinoflagellates (Figure 8). Each one of these is discussed in detail below:

Time Line-I

A world wide regression close to the Early Eocene, P9 Zone of the planktonic foraminifera (Haq et al.,, 1987) is represented in this area by gypsum while in the Axial belt area by the conglomeratic and letritic bed at the base of the Kirthar (Shah, 1977). The P9 age of the Ghazij Formation below the gypsum shale interval (Shale with Alabaster of Eames, 1952a) has been already proved at the Rakhi Nala section (Afzal, 1996). For this gypsum and shale interval, a broad Early to Middle Eocene age through the dinoflagellates i.e. Zone Pak-IX equivalent to the NP12-NP14 zones of the nannoplankton has been assigned (Kothe et al., 1988). The age of the Assilina bed in the Rakhi Nala section is most likely top most part of

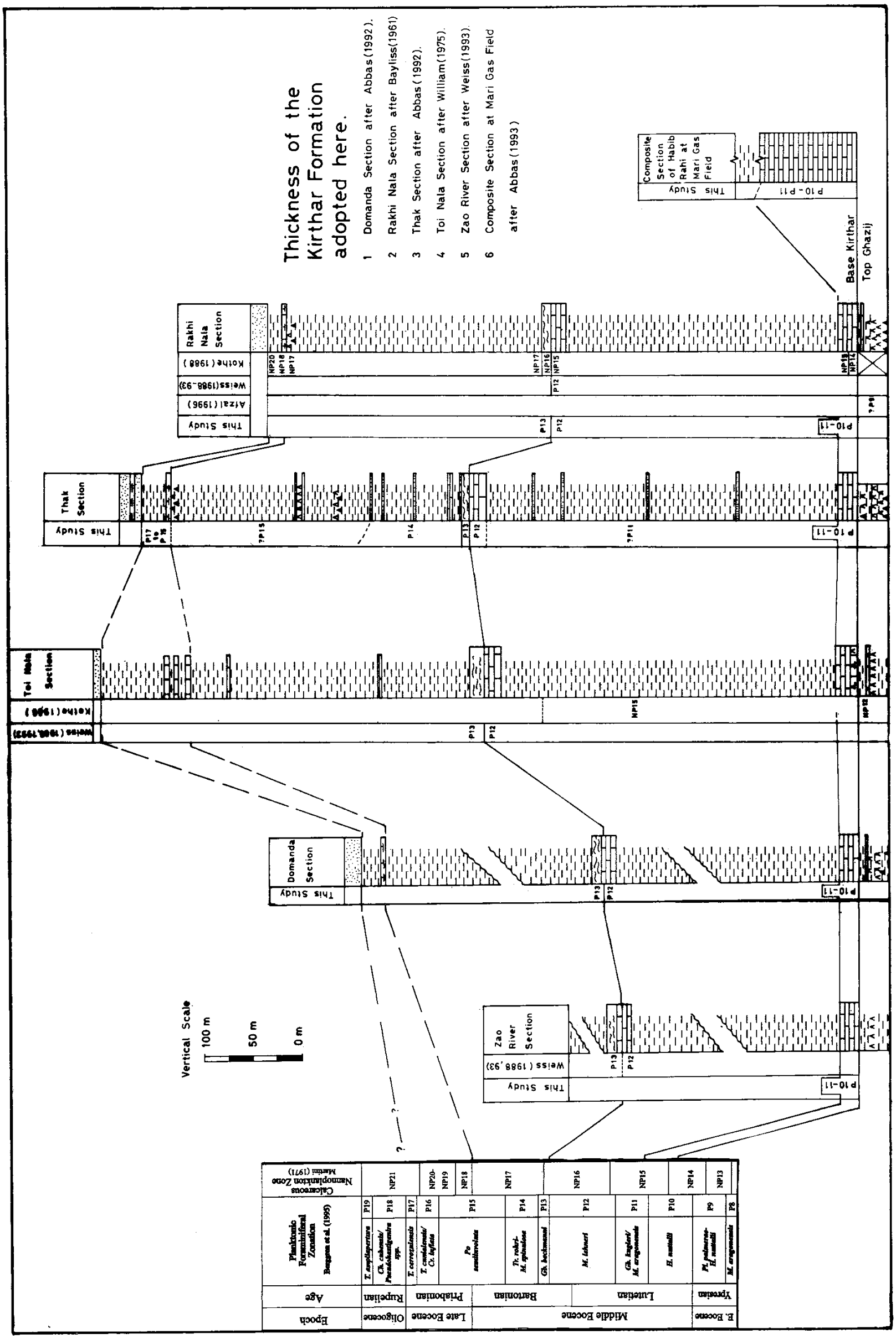

Figure 8- Biostratigraphic correlation of the Kirthar Formation in different sections of the eastern Sulaiman Basin.

Early Eocene, P9 Zone. The shale bed that lies between the gypsum and *Assilina* bed was never investigated before. During this study one sample from this shale was also analyzed which yielded only the non age diagnostic agglutinated fauna. The same level in the Toi Nala section has been dated as NP12, Early Eocene (Kothe et al., 1988).

The base of Habib Rahi in Thak, Zao River, Domanda sections and in the subsurface of the Mari Gas field is well developed. In all these sections its basal bed shows the presence of *A. spira abrardi, A. papillata*, and in the Mari Gas Field additionally *Alveolina elliptica (A. elliptica nuttalli* of Davies, 1926) and *N. aff. qugleri* is confirmed in the upper part of Habib Rahi Limestone. Therefore, over the whole study area, the above mentioned assemblage found at the base of Kirthar is equivalent to the *Assilina spira abrardi* Zone of Schaub (1981) and *Alveolina stipes* Zone of Hottinger (1960). Above the massive gypsum beds, presence of gypseferous, brackish water shale overlained by *Assilina* bed of Early Eocene age indicates that new cycle of sedimentation started in the top most part of Early Eocene. But late NP14 age (Middle Eocene but not its basal part) of the base Habib Rahi Limestone in Rakhi Nala (Kothe et al., 1988) may indicate a minor break which might be due to sequence/parasequence boundary. This break is also evident by a sharp contrast of shallow to relatively deep marine fauna observed in Rakhi Nala and Thak sections.

Time Line-II

The Habib Rahi Limestone member is overlained by the Domanda Shale member which is completely barren of age diagnostics fauna (Figure 4). Based on the rare occurrence of dinoflagellates Kothe et al., (1988) in Rakhi Nala section identified Pak-DX Zone equivalent to NP15-NP17 zones of the nannoplanktons. Kothe et al., (1988) dated the overlying Pir Koh Limestone member as NP15 whereas through the planktonic foraminifera dated as P12 (this study). The depositional time of the overlying Domanda Shale may be NP15 (equivalent to P10-P12 of planktonic foraminifera). In terms of the planktonic foraminifera the appropriate time most likely be P11 because both the top of Habib Rahi and base of Pir Koh Limestone units have been dated as NP15. In the north of the study area, this shale is not investrigated. The upper age limit of this unit may cross P11/P12 zonal boundary. For the lower age limit a tentative line between P10 and P11 is marked within Habib Rahi Limestone or close to the contact between Habib Rahi Limestone and Domanda Shale.

Time Line-III

The third correlative time line emerged at the P12/P13 zonal boundary. This boundary is marked at the FAD of very characteristic and short range species, *G. beckmanni.* This line in Domanda section is clearly observed within the top most bed of the Pir Koh Limestone. In Thak and Rakhi Nala sections (this study), Toi Nala section (Weiss, 1988, 1993) and Rakhi Nala sections (this study and Kothe, 1988) this zonal boundary is observed at the basal layer of the Pir Koh Marl lying above the Pir Koh Limestone. At Rakhi Nala section, Kothe et al., (1988) marked the NP15/NP16 boundary at the contact between Pir Koh Limestone and Shale. This zonal boundary and the P12 age of the top Pir Koh Limestone (this study), when compared with the standard planktonic foraminifera and nannoplankton calibration chart (Berggren et al., 1995, fig.2) refers to the basal part of the P12 Zone. Just above this boundary, within the thin layer of Pir Koh Marl, Kothe (1988) marked NP16/NP17 zonal boundary equivalent to the middle of Zone P13 of the planktonic foraminifera (Berggren et al., 1995). This indicates that most of the upper part of Zone P12 and basal part of Zone P13, and most of the middle part of Zone NP16 is missing, therefore, a hiatus between the limestone and shale is most likely to exist (Figure 8, 9 and 10).

Time Line IV

In Thak section Late Paleocene (Bartonian) age is recognized within the *Pellatispira* bed having sediments above and below barren of foraminifera. Earlier workers in the Rakhi Nala section placed the Middle/Late Eocene boundary below the *Pellatispira* bed (Eames, 1952a; Bayliss, 1961; Latif, 1961). Kothe et al., (1988) in Raki Nala section marked NP17/NP18 boundary at the *Pellatispira* bed. The NP17/NP18 boundary lies within Zone P15 of the planktionic foraminifera. Therefore, to mark the Middle and Late Eocene boundary in the whole Sulaiman area we refer the base of the *Pellatispira* bed which shows the FO of genus *Pellatispira* a marker of Late Eocene (Adams, 1971) (Figure 8). But for the slight controversy between planktonic foraminifera and calcareous nannofossils further investigation is required.

Time Line V

The fifth one is simply a lithostratigraphic boundary between Kirthar Formation and overlying Chitarwata Formation (former Nari Fm.) Because of the unsuitable lithology for the age diagnostic fauna it is not investigated. However, most of the workers have considered its age as Oligocene (Shah, 1977; Porth & Raza, 1990).

PALEOENVIRONMENTS

The base of Habib Rahi Limestone taken as the base of Kirthar Formation in the study area overlies a massive gypsum deposits which represents a major regression. Whereas the base of Kirthar in the other areas rests above the leterite deposits indicating an unconformity (Shah, 1977). A thin bed of gypsiferous shale having brackish water fauna and a very thin limestone bed (*Assilina* bed) with Early Eocene larger foraminifera in its middle, seperates the massive gypsum and base of Habib Rahi. This thin sequence represents a new transgressive cycle in the top most part of the Early Eocene, P9 Zone. This transgressive cycle is comparable with the TA3.1 sequence of Haq et al., (1987), whereas massive gypsum and laterite deposits correspond to the major lowstand at the base of above mentioned sequence.

In the study area, the Habib Rahi Limestone represents variation in depositional environments from shallow to relatively deep marine. The lower part of Habib Rahi Limestone at the southern margin of study area (Mari Gas Field) and its whole thickness at the nothern margins (Domanda and Zao River sections) is full with larger foraminifera indicating shallow marine, inner shelf environments. Whereas in the middle of

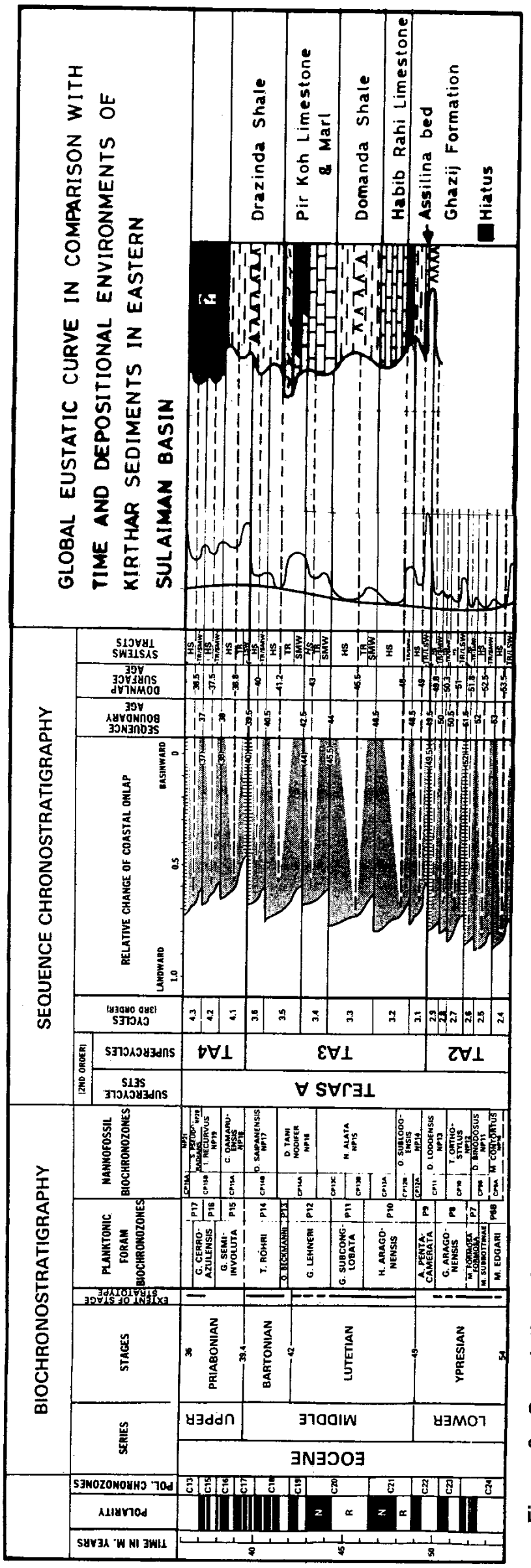

Figure 9- Correlation chart representing the age and paleoenvironments of different units of the Kirthar Formation in relation to the global sea level sequence stratigraphy of Haq et al., (1987).

the study area, in Rakhi Nala and Thak sections, the larger foraminifera are completely replaced by the planktonic foraminifera which indicates relatively deep marine, middle to outer shelf environments. According to the planktonic and larger foraminiferal correlation the base of shallow marine Habib Rahi Limestone in the north and the deep marine Habib Rahi (platy limestone) in the center of the study area are time equivalent (Figure 10). The hiatus observed at the base of Habib Rahi in Rakhi Nala, Thak and Domanda area could not be found in Mari Gas Field without proper investigation. The Habib Rahi Limestone with a hiatus at the base represents a new sequence correlatable to TA3.2 sequence of Haq et al., (1987)(Figure 9). The shallowing at the margins most probably is due to the Sargodha and Jacobabad highs which are the boundaries of the Sulaiman Basin.

The overlying gypsiferous Domanda Shale (age P11 and NP15) yielded only smaller benthic foraminifera especially the agglutinated forms typical of brackish water environments, therefore, indicating a regressive cycle or a lowstand. This interpretation supports the earlier interpretation as sabkha environments (Chaudhry et al., 1994). Whereas, against the same time interval Haq et al., (1989) mentioned a highstand at the top of his TA3.3 sequence. With respect to the global sea level curve a discripency in terms of time and sequence type exists in this area. The age of Domanda Shale in the north of the study area is needed to be investigated. This requires further studies to varify this result in the other areas of this basin.

The overlying Pir Koh Limestone showed a moderate to high diversity and abundance of the planktonic and smaller benthic foraminifera, at places associated with larger foraminifera too. This assemblage suggests a deepning of the basin corresponding to the highstand in the upper part of TA3.4 cycle of Haq et al., (1987). An assemblage with maximum diversity and abundance of the planktonic and smaller benthic foraminifera within the Pir Koh Marl of P13 age indicates that the basin attained maximum depth (outer shelf to upper slope) during this time. This data forms a sharp peak during this short time interval of P13 Zone. This peak chronostratigraphically is slightly prior to a similar peak of Haq et al., (1987) within his TA3.5 cycle. The regression at the base of above mentioned cycle may corresponds to the hiatus identified between Pir Koh Limestone and Pir Koh Marl in the middle of the study area. The P13 age of the Pir Koh Limestone and absence of hiatus in the north of the study area indicates its northward time transgressive nature (Figure 10).

Within Drazinda Shale alternating fossiliferous and barren intervals were observed in Thak section. The fossiliferous levels contain planktonic smaller and larger foraminifera indicating inner to middle shelf environments. This unit as a whole may tentatively correspond to the TA3.6 cycle to TA4 supercycle of Haq et al., (1987). A detailed investigation is proposed to establish a better sequence stratigraphic interpretation. The overlying Chitarwata Sandstone may indicate the sequence boundary in this area (Figures 9, 10).

DISCUSSION

The base of Kirthar Formation has been disputed among the different workers, therefore, the biostratigraphic age is also

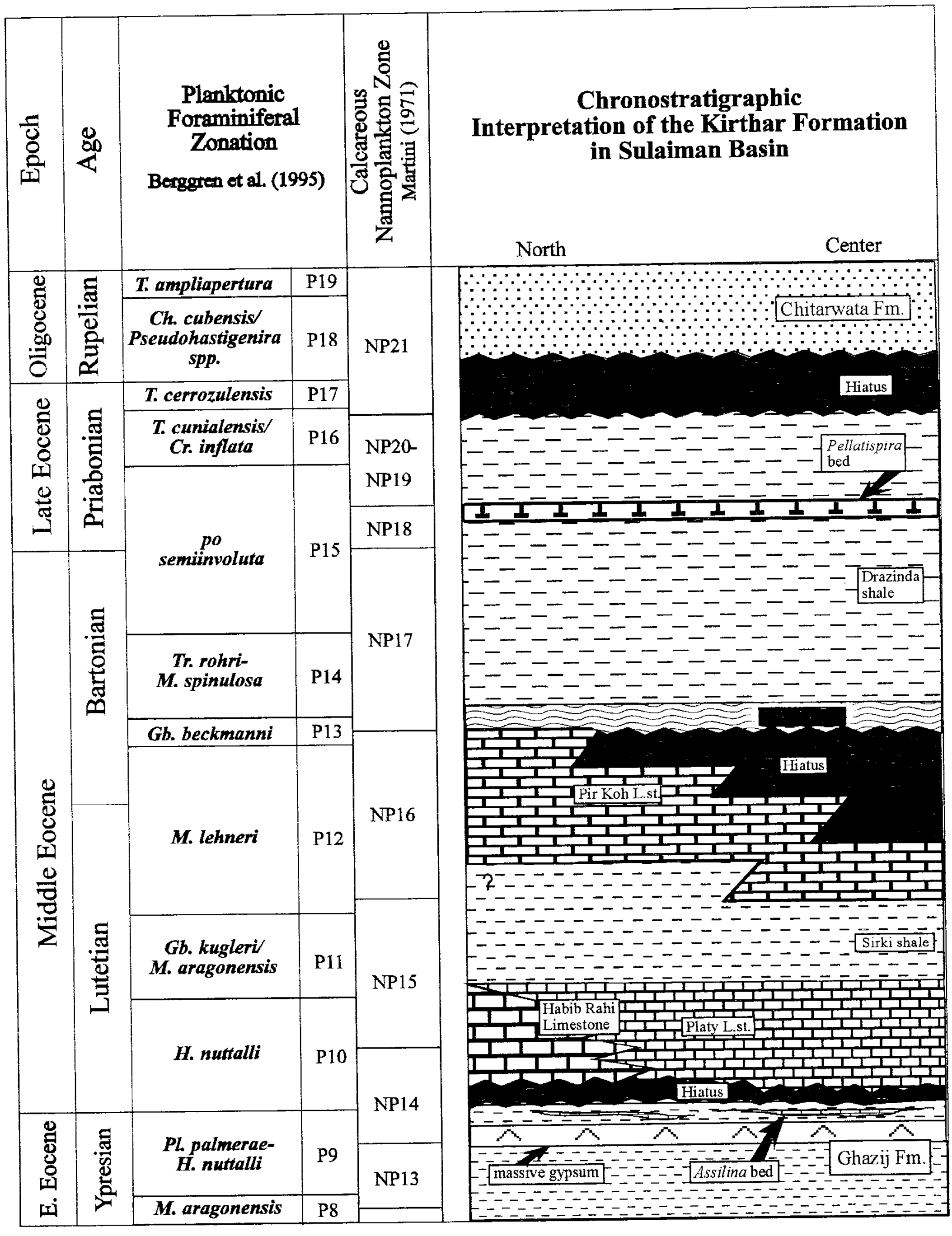

Figure 10- Chronostratigraphic picture of the Middle to Late Eocene Kirthar Formation in the eastern margin of the Sulaiman Range.

disputed. Nuttall (1926) placed the base of Lower Kirthar at the base of his Massive Limestone and divided the Kirthar in to lower, middle and upper Kirthar. Eames marked the base of Kirthar at the base of Habib Rahi (his platy limestone). Nagappa (1959) established a correlation and compared the different units of the Kirthar Formation of Nuttall (1926) and Eames (1952a). This correlation shows that most of the lower part of the Kirthar Formation of Nuttall (1926) belongs to the upper part of Laki (Ghazij Formation). Shah (1977) for the definition of lithostratigraphic units followed Eames (1952a) whereas the biostratigraphers such as Bayliss (1961), Latif (1961), Samanta (1973), Kothe (1988, not in Rakhi Nala), Weiss (1988, 1993) have been found to followed Nuttall (1926), therefore, assigned an Early Eocene age to the Kirthar Formation. Our base Kirthar *s.s.* Shah (1977) has been found to lie on the shallow part of the shelf within *A. spira abrardi* Zone of Schaub (1981) and within P10 Zone of planktonic foraminifera on the deeper part of the shelf.

All the sections investigated here have been found to lie approximately along the strike of the shelf, therefore, almost isochronous age/facies relationship has been observed whereas towards the basin some variations are expected. Hunting Survey (1961) formulated another lithostratigraphic unit "Spintangi Limestone" lying between the gypsum and Habib Rahi in the other areas of the Sulaiman Basin and Axial Belt. It is recommended to investigate this unit also where an age variation of the Kirthar strata may exist.

Another discrepancy exists about the Early Eocene age of the Pir Koh Limestone in Afiband section (Sameeni et al., 1994) and at Rakhi-Gaj section (Ahsan, 1994, *fide* Chaudhry, 1994). These authors reported *N. atacicus, N. mamillatus, A. spinosa, A. subspinosa, A. granulosa, D. dispansa and D. ranikotensis. L. conditi, L. tipperi, Ranikothalia solimani* from the Pir Koh Limestone member. Many of these species are long ranging and have been confirmed in this study. The Early Eocene species and older age assignment is completely out of question and possibly is due to the highly flexible taxonomical criteria adopted. Previous investigations at Rakhi Nala section and our at Thak section which lies very close to the Afiband section clearly demonstrates that Pir Koh Limestone member is Middle Eocene, deposited during P12-P13 zones of the planktonic foraminifera and NP15-NP17 zones of the calcareous nannoplankton.

At the Toi Nala section Fritz (1963) mentioned the presence of *Assilina* aff. *davesi* (an Early Eocene form) in Habib Rahi Limestone. We have also observed this form in almost all the sections. Its abundance decreases upward and has been found in association with *A. papillata and A. spira.* Schaub (1981) considered this form as a synonym of *A. papillata.* It is therefore, needed to test the range of this species. Another group of larger foraminifera which offered a lot of difficulties is *Nummulites.* A number of different forms have been observed during this study but to use this group as an efficient biostratigraphic tool for this region, a systematic research is prerequisite.

CONCLUSION

The present investigation and the synthesis of the existing data reveals Middle to Late Eocene age for the Kirthar Formation in the eastern margins of the Sulaiman Basin.The base of the Kirthar Formation is defined at the base of Habib Rahi Limestone. This unit represents Middle Eocene age, *A. spira abrardi* Zone of the larger foraminifera and P10-?P11 zones of the planktonic foraminifera. It is shallow marine (inner shelf) on the margins to relatively deep marine (middle to outer shelf) in the middle of the study area. The age and paleoenvironmental data is completely in accordance with the highstand within TA3.2 cycle of Haq et al., (1987).

The overlying Domanda Shale member is barren of age diagnostic fauna, however based on the age of the underlying and overlying units, its age most probably is P11 to lower part of ?P12 representing brackish water environments. A discrepancy in the sequence type exists when compared with the sequence of Haq et al., (1987) within TA3.3 cycle. Further investigations are required to prove these results.

The age of the Pir Koh Limestone and Marl member is determined as P12-P13. The basin attained maximum depth (outer shelf to upper slope) during this time. Both subunits of this member are quite in accordance with the sequences of Haq et al., (1987) fitting within TA3.4 and TA3.5 cycles.

Drazinda Shale member is Middle to Late Eocene lying within zones P14-P17. The unit as a whole represents inner to middle shelf environments and tentatively related to the TA3.6 cycle to TA4 supercycle of Haq et al., (1987) but further investigations are required.

A biostratigraphic correlation and a chronostratigraphic picture have been established which show that Pir Koh Limestone is northward time transgressive.

Two hiatuses are recognized, first at the base of Habib Rahi and the second between Pir Koh Limestone and Marl.

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PLATE 1

Figure 1 *Globigerapsis beckmanni* x 125, Sample No. 92-11-11-15, Domanda section.

Figure 2 *Globigerapsis beckmanni* x 125, Sample No. 92-11-11-13, Domanda section.

Figure 3 *Morozovella spinulosa* x 125, Sample No. 92-11-11-15, Domanda section.

Figure 4 *Truncorotaloides topilensis* x 125, Sample No. 92-11-11-15, Domanda section.

Figure 5 *Turborotalia centralis* x 125, Sample No. 92-11-11-15, Domanda section.

Figure 6 *Globigererpsis kuglari* x 125, Sample No. 92-11-11-15, Domanda section.

Figure 7 *Truncorotaloides rohri x* 125, Sample No. 95-11-11-13, Domanda section.

Figure 8 *Ttuncorotaloides. aff. rohri* x 125, Sample No. 95-11-11-13, Domanda section.

Figure 9 *Morozovella lehneri* x 125, Sample No. 95-11-11-13, Domanda section.

PLATE 2

Figure 1 *Assilina spira abrardi* X 10, form B, Sample No. 92-11-11-2, Domanda section.

Figure 2 *Assilina spira abrardi* X 10, form B, Sample No. 92-11-11-6, Domanda section.

Figure 3 *Assilina spira abrardi* X 10, form B, Sample No. 92-11-11-2, Domanda section.

Figure 4 *Discocyclina dispansa* X 10, form B, Sample No. 92-11-11-12, Domanda section.

Figure 5 *Nummulites sp. (aff. atacicus)* X 10, form B, Sample No. 92-11-11-0, Domanda section.

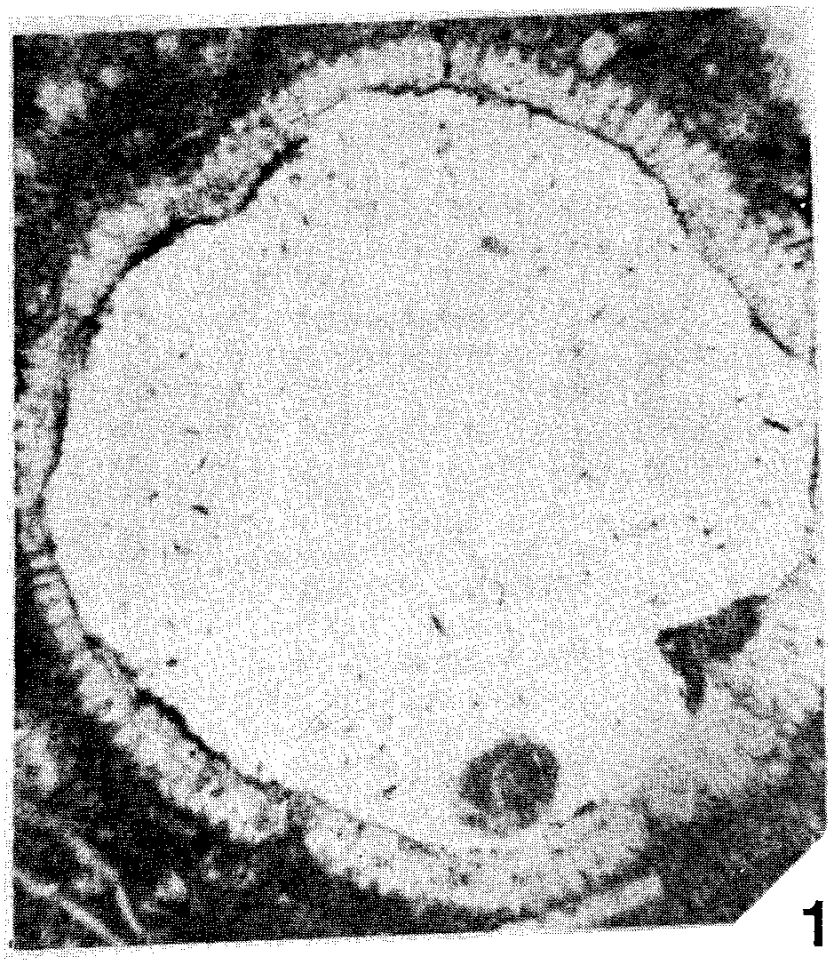
Figure 6 *Assilina aff. maior* X 10, form A, Sample No. 95-03-10-12, Rakhi Nala section.

Figure 7, 8 *Assilina spira abrardi* X 10, form A, Sample No. 92-11-11-4, Domanda section.

Figure 9 *Assilina papillata* X 10, form A, , Sample No.SmR214, Zao River section.

Figure 10 *Assilina aff. daviesi* X 10, form B, Sample No. 95-3-10-12, Rakhi Nala section.

PLATE 1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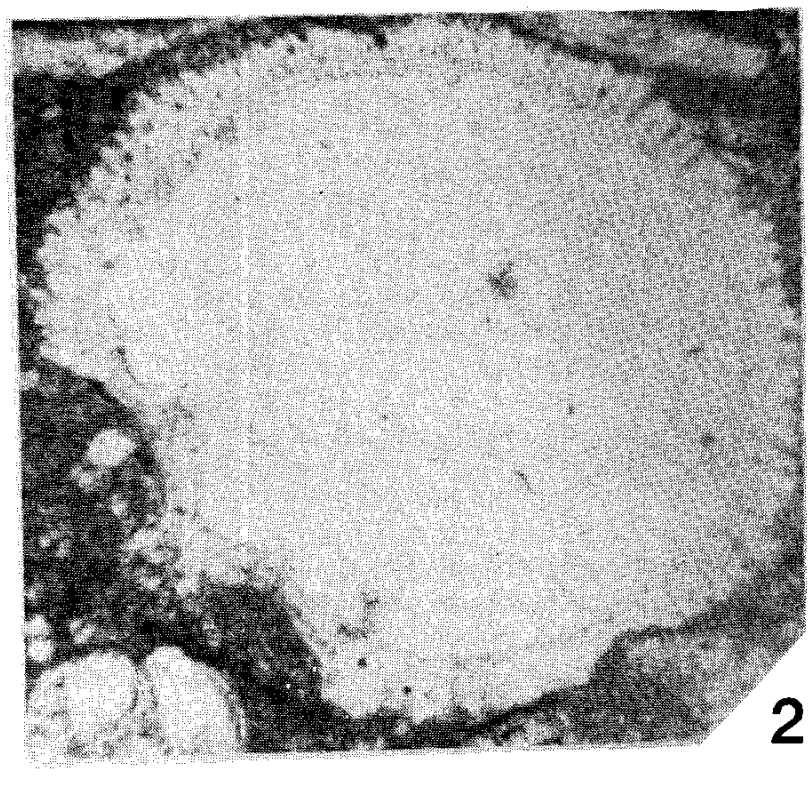
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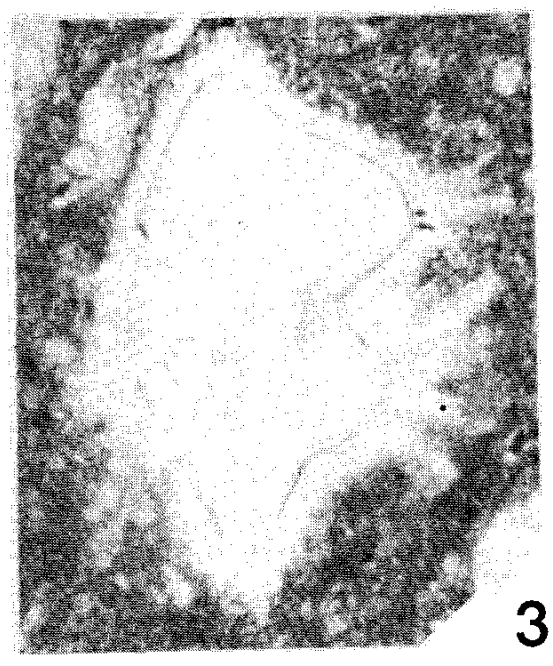
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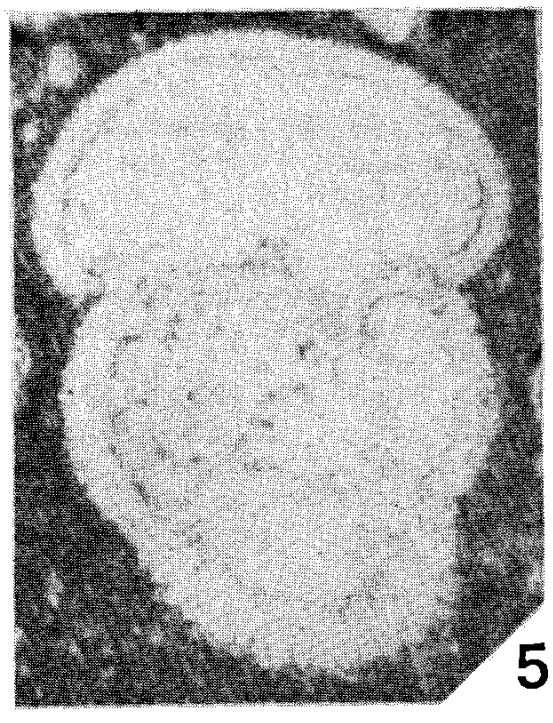
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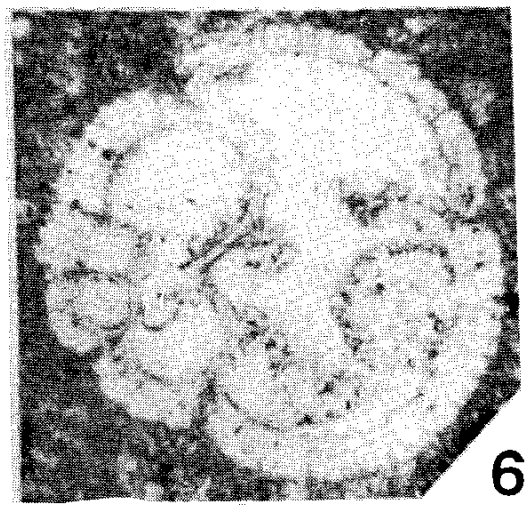
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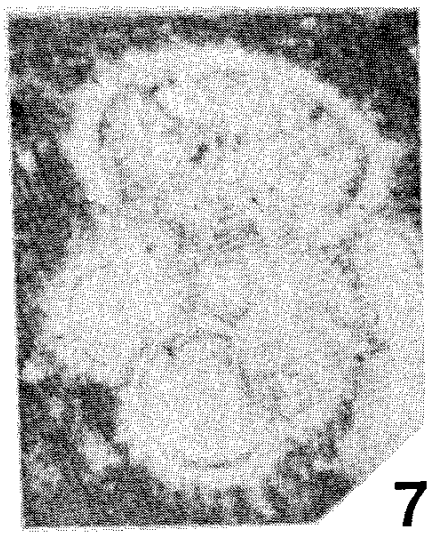
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8

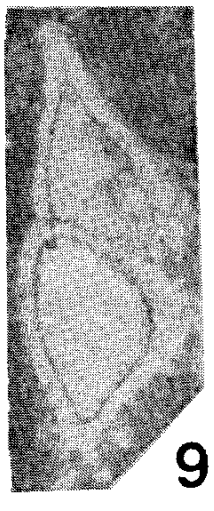
9

PLATE 2