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Late Paleocene to Early Eocene Larger Foraminiferal Biostratigraphy of the Nammal Formation in the Central Salt Range, Pakistan

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ABSTRACT

In order to establish a shallow benthic zonation scheme, the larger foraminiferal assemblages (Late Paleocene to Early Eocene) from the upper most beds of the Patala Formation to the top of the Nammal Formation were investigated at five localities of the central Salt Range. Semi-quantitative distribution of 20 species related to the genera *Alveolina, Assilina, Dictyokathina, Lockhartia, Miscellanea, Nummulites, Operculina, Ranikothalia* and *Sakesaria* are graphed. For a segment of the Late Paleocene to Early Eocene time, three benthic foraminiferal zones i.e. Zone SB4, Zone SB5 and Zone SB6 are recognized. Due to the variations in the stratigraphic ranges of certain larger foraminiferal species, minor amendments in the zonal definitions are proposed. However, the zonal boundaries seems coeval to that of the standard shallow benthic zonation. For the *Alveolina* based zonation, the zonal boundaries are better defined by the FOs of the subsequent younger species. Based on the larger foraminiferal extinction, the Zone SB5 is proposed to subdivide into older SB5a and younger SB5b subzones. This subdivision is used to facilitate the definition of Paleocene/Eocene boundary which stratigraphically lies in the lower part of the Nammal Formation in the study area. Both, lower and upper boundaries of the Nammal Formation in the Salt Range are dichronous, and are getting younger towards the west. The study also helped to establish the lower Ilerdian stage in Pakistan.

INTRODUCTION

Recent trends in the basin analysis have increased the role of precise biostratigraphic and chronostratigraphic control. One of the methodologies "Sequence Stratigraphy" readily needs the depositional timeline system which is furnished by the biostratigraphic correlation among the strata of varying lithologies distributed within a basin covering a shallow shelf to deep depression. An efficient biostratigraphic framework of inter-linked biozones based on various fossil groups is a prerequisite for such correlation. European biostratigraphic framework that has attained a mature stage is recently being applied and tested in Pakistan. The group "Foraminifera", because of its vast distribution and adaptation to a wide range of ecological conditions, is the most widely used fossil group to meet such requirements. Therefore, the present study related to the Nammal Formation representing a carbonate-siliciclastic system of shallow shelf setting was undertaken. The formation was investigated for its larger foraminiferal content exclusively within the central Salt Range that has demonstrated the applicability of standard benthic zonation scheme and dating of various sedimentary layers as well.

PREVIOUS WORK

To establish the Tertiary chronostratigraphy of the oil producing Potwar Depression, efforts were focused on the western Salt Range where the Nammal Gorge section (type section of Nammal Formation) due to its easy access and good exposure has attracted a number of experts of different specialities. Various fossil groups in the western Salt Range were used, for example larger foraminifera (Davies and Pinfold, 1937; Gill 1952; Weiss, 1988, 1993), smaller benthic foraminifera (Haque, 1956), planktonic foraminifera (Weiss, 1988, 1993; Afzal and von Daniels, 1991; Gibson, 1993), nannofossils and dinoflagellates (Haq, 1971; Koethe et al., 1988; Koethe and Ashraf, 1989; Ashraf and Bhatti, 1991; Bybell and Self-Trail, 1993). Afzal (1997) has established a biochronostratigraphic frame undertaking a fresh investigation based on planktonic, smaller and larger foraminifera duly compared with the nannofossil data which revealed that Nammal Formation is Early Eocene in age ranging from zone P6b-P9 of the planktonic foraminifera, zone NP10-NP13 of the calcareous nannofossils while zone SB8-SB11 of the larger foraminifera.

In the central Salt Range, the Nammal Formation is devoid of planktonic foraminifera and calcareous nannofossils but rich in the larger foraminifera. For this area only two references worth mentioning were available. Hottinger (1971) investigated a few samples and placed the formation in his *Al. cucumiformis* Zone (=SB5 Zone). The second one is the monograph of Sameeni (1997) who studied the genus *Alveolina* and he placed the Nammal Formation within zone SB5-SB7. This work is in fact a valuable addition to the stratigraphy of the Salt Range to establish a shallow benthic zonation scheme of Serra-Kiel et al., (1998), however, this study provides a little information regarding litho and biostratigraphic linkage. Litho-biostratigraphic likage is very important for stratigraphical analysis required for the basin modelling. Therefore, a fresh study was needed which could provide a reasonably good comparison between lithostratigraphy and biostratigraphy.

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MATERIAL, METHOD AND OBJECTIVES

The aim of this study is to establish the paleogeographic setting of the Nammal basin through the biostratigraphic and sedimentological inputs. In the present investigation shallow benthic zones based on different groups of larger foraminifera e.g. *Alveolina, Nummulites, Assilina, Lockhartia, Ranikothalia* and *Miscellanea* were established so that different layers of Nammal sediments in all the studied sections can be identified and correlated. This will help to get an insight into the nature of the sedimentation in the central Salt Range and to provide a solid base for the correlation of the Nammal strata to reconstruct the depositional history of the basin for the Late Paleocene to Early Eocene time. In two field trips to the Salt Range HDIP-BGR geoscientists recorded the field information, measured the sections and collected more than 80 samples from top Patala Formation to base Sakesar Limestone at five localities. However, the first author takes the responsibility for the foraminiferal investigation presented here. The localities from east to west are Badshah Pur, Nilawahan, Khura, Athal and Kuraddi which lie along the strip of the Salt Range (Figure 1). The general Cenozoic stratigraphic sequence is given in figure 2. Two sections viz. Nilawahan and Kuraddi were measured and sampled in detail whereas the remaining three sections were measured only for the lower part. The information and samples for the upper part of Nammal Formation in Khura section were borrowed from Jurgan et al., (1988). The larger foraminifera upto specific level were investigated in random thin sections, oriented thin sections and in isolation. Conventional techniques were applied for the sample preparation.

LITHOSTRATIGRAPHY

Before establishing the biostratigraphy, an essential prerequisite is to define the lithostratigraphy, especially the boundaries of the Formation. The lower boundary of the Nammal Formation with the underlying Patala Formation is quite distinct, sharp and easily recognisable. It is placed at the horizon where the dark gray shale of Patala lies below the light gray to light bluish gray limestone or marly limestone of the Nammal Formation. This contact is well exposed in Kuraddi section whereas in all other sections it is covered. The upper contact with the overlying Sakesar Limestone used to present great confusion in literature. In certain areas the contact is easy to distinguish, for instance in Nammal Gorge section of the western Salt Range where light bluish gray, smoothly bedded limestone (mudstone) of the Nammal Formation is followed by light gray to whitish gray, fossiliferous, irregular, nodular limestone (wackesotne to grainstone) of the Sakesar Limestone. In other areas the Nammal Formation changes gradually into the Sakesar Limestone. Several authors have placed this boundary at different stratigraphic horizons with little or inadequate explanation. The boundary is also difficult to recognize exactly according to Stratigraphy of Pakistan (Shah, 1977). As this paper does not exclusively deal with the Nammal/Sakesar boundary problem, the topic is still open to critics for a better solution, and thus deserves to be dealt with separately. In this study the boundary has been referred to the stratigraphic level where light gray to creamish, compact and nodular limestone of the Sakesar Limestone without any argillaceous material begins. The maximum variation in the lithofacies of the Nammal Formation was observed in the Nilawahan section where the lowermost part of the formation is gray limestone (mudstone) and argillaceous skeletal wackestone. The middle part is alveolinal grainstone whereas the upper part is argillaceous, nodular wackestone. The nodularity of the Nammal Formation is less pronounced as compared with that of the Sakesar Limesotne. Most of the Nammal lithofacies were persistently observed in the whole central Salt Range except for the upper one. The argillaceous, nodular limestone facies is not observed in the sections west of the Nilawahan area.

BIOSTRATIGRAPHY

As the major part of larger foraminiferal population consists of the genera *Alveolina, Nummulites, Assilina,* therefore, for the finer biostratigraphic resolution the larger foraminiferal zonation schemes of Hottinger (1960) and Schaub (1981) were the most suitable to be established and tested. These two zonation schemes together with fresh inputs were combined by Serra-Kiel et al., (1996 and 1998) to give a multiple criteria and numerical annotation to each zones which was followed in this study. Planktonic foraminifera are completely absent in this area. The semi-quantitative distribution of the larger foraminifera from the five localities are given in detailed species check lists (Figures 3, 4, 5, 6, & 7). In total 20 species were identified. A slight modification in the zonal definition is proposed due to the local variation in the foraminiferal assemblages and stratigraphic ranges of certain taxa (Figure 8). The zones are defined as below:

SB4 Zone

Original Definition: Interval characterized by the stratigraphic range of *Glomalveolina levis, Hottingerina lukasi, Miscellanea meandrina, Daviesina garumnensis, Dictyokathina simplex, Nummulites catari, Assilina azilensis,* and *A. yvettae* (Serra-Kiel et al., 1998). The FO of *Ranikothalia sindensis* is another evidence for the base of this zone.

Emended Definition: Interval characterized by the stratigraphic range of *Dictyokathina simplex* or from the FOs *Ranikothalia sindensis* and *Kathina selveri* to almost simultaneous FOs of *Alveolina globula, Al. vredenburgi (=Al. cucumiformis)* and *Al. dolioliformis.*

Remarks: Most of the taxa nominated in the original definition are not present in this area. The significant representatives of the foraminiferal assemblage at this horizon are *Miscellanea miscella, Lockhartia haimei, Ranikothalia nuttalli, R. sindensis, Kathina selveri* and *Dictyokathina simplex*. The latter three are tentatively used to define the base of this zone subject to the confirmation through further investigation of the underlying lithologic units. This assemblage except *D. simplex* is persistent into the next younger zone. In Nilawahan, Khura and Kuraddi sections appearance of *Al. globula* and *Al. dolioliformis* in abundance, slightly after the LO of *D. simplex,* is most likely due to ecological factors.

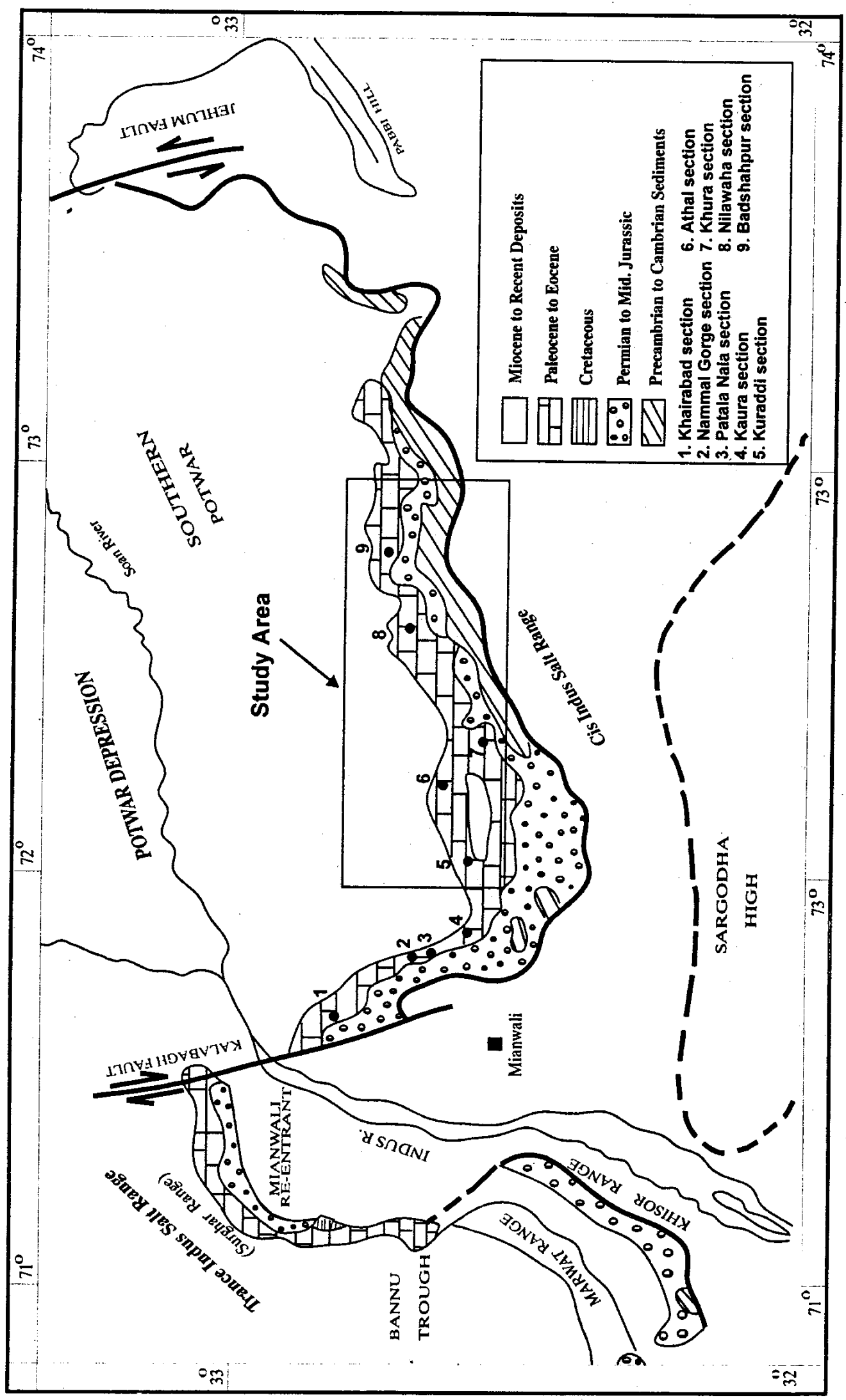

Figure 1- Location map of the study area with studied sections of the Salt Range.

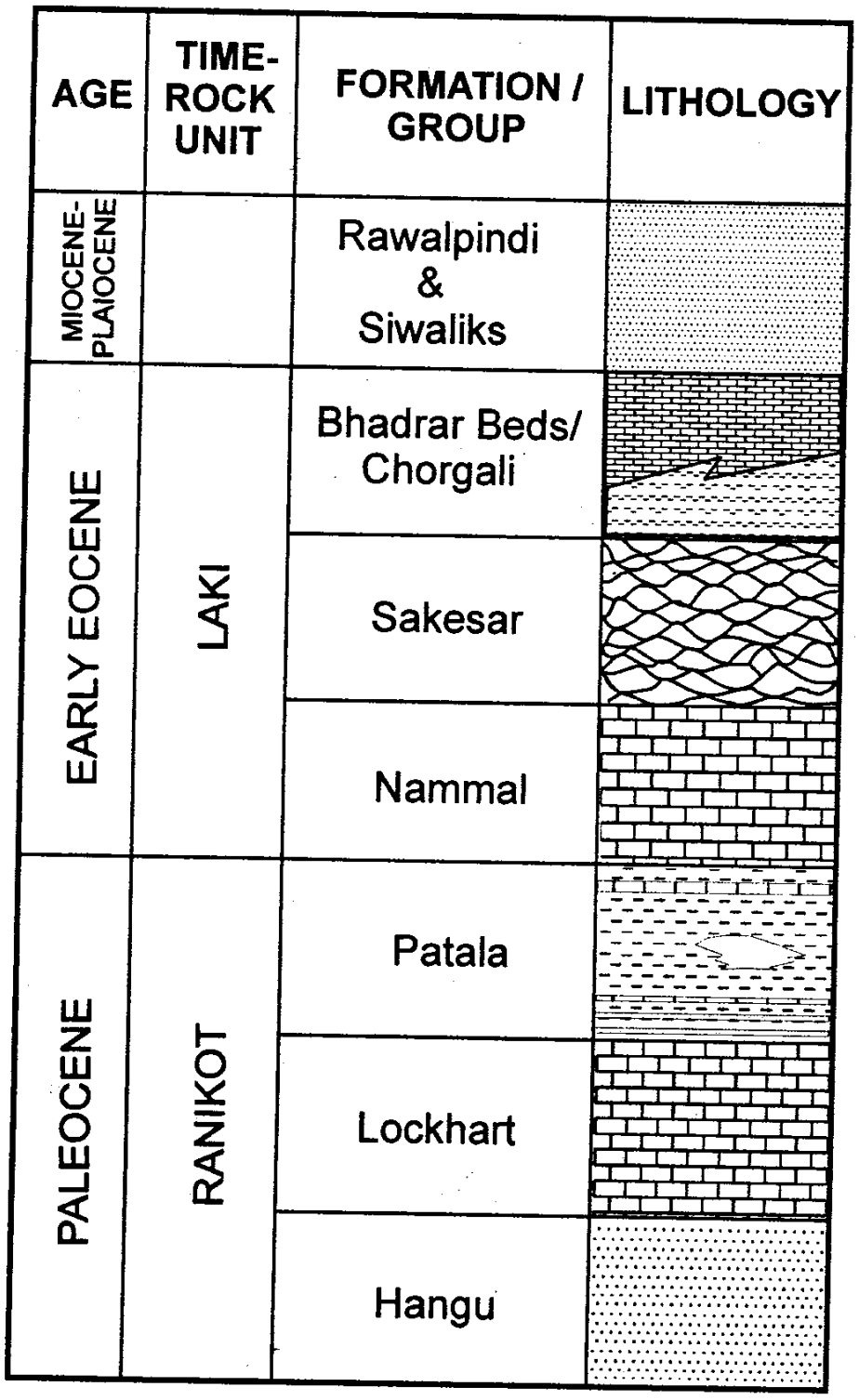

Figure 2- Tertiary stratigraphic sequence of the Salt Range and Potwar depression.

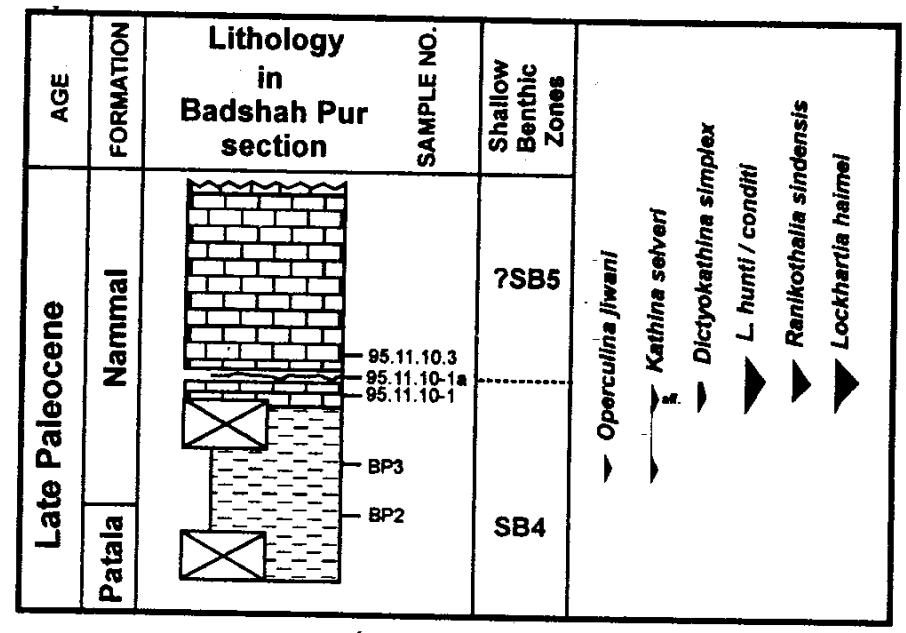

Figure 3- Larger foraminiferal species checklist in Badshah Pur section.

SB5 Zone

Original Definition: Interval characterized by the stratigraphic range of *Orbitolites gracilis, Daviesina tenuis, Al. vredenburgi, Al. avellana, Al. aramaea, Al. varians, Nummulites gamardensis, Assilina dandotica* and *A. prisca* (Serra-Kiel et al., 1998).

Emended Definition: Interval from the simultaneous FOs of *Al. vredenburgi, Al. globula* and *Al. dolioliformis* to the simultaneous FOs of *Al. pasticillata* and *Al. tumida* in juxtaposition with the LO of *Al. avellana.*

Remarks: In the study area and the western Salt Range, a distinct overlapping ranges of *Ranikothalia sindensis, Miscellanea miscella, M. stampi, Lockhartia haimei* and *R. nuttalli* were observed with the assemblages of Zone SB5 (Figure 7). Different views exit about the upper range of *M. miscella, L. haimei and R. sindensis* which according to Adams (1971) are restricted to the Late Paleocene. However, Hasson (1985) and Jones & Racey (1994) reported *M. miscella and L. haimei* from the Early Eocene of the Gulf region. Butt (1991) reported the rare occurrence of *R. sindensis* in the Early Eocene Margala Hill Limestone of the Kala Chitta Range. Likewise, Sameeni (1996) reported and gave a photograph of the axial section of *R. sindensis* from the Sakesar Limestone (Early Eocene) in the Nammal Gorge section. Afzal (1997) recognised a planktonic, benthic foraminiferal (smaller and larger) change within a very narrow stratigraphic interval representing SB5 Zone in the western Salt Range and Surghar Range. This change indicates that *R. sindensis, R. nuttalli* and *M. miscella* s.l. (a robust form) are restricted to the lower half of the SB5 Zone, whereas rare specimens of *M. stampi* s.l. (a complanate form) and *L. haimei* persist slightly above this level. A prominent feature of Zone SB5 in this area is the extinction of a similar assemblage comprising of 3 species i.e. *R. sindensis, M. miscella* and *L. haimei* almost in juxtaposition with the FO of *Sakesaria cotteri* in the middle of the zone. Several smaller benthics such as *Cincoreola patalaensis* and *C. ovoides* are also restricted to the same level. The smaller benthics will be dealt with separately. This extinction occurs in the middle part of the Zone SB5, stratigraphically related to the lower part of the Nammal Formation. Based on this event, Zone SB5 is subdivided into an older SB5a and the younger SB5b. This subdivision is considered to facilitate the definition of the Paleocene / Eocene boundary in this area. Recovery of *R. sindensis* from Early Eocene sediments looks very problematic which might have been a result of possible Eocene homomorph. Quite similar to *R. sindensis*, Boukhary (1994) established a new genus "*Decrouezina*" from the Cuisian of Egypt which was distinguished based on the evolute and laxer spire test especially at a latter stage in contrast to the completely involute *R. sindensis.* Although the figure given by Sameeni (1996) does not show very well preserved specimens, nevertheless is in accordance with the description of *Decrouezina*. Therefore, the forms related to *R. sindensis* reported from the Eocene sediments require a careful examination. In Athal and Kuraddi sections, *Alveolina vredenburgi* appears almost simultaneously with *Nummulites*

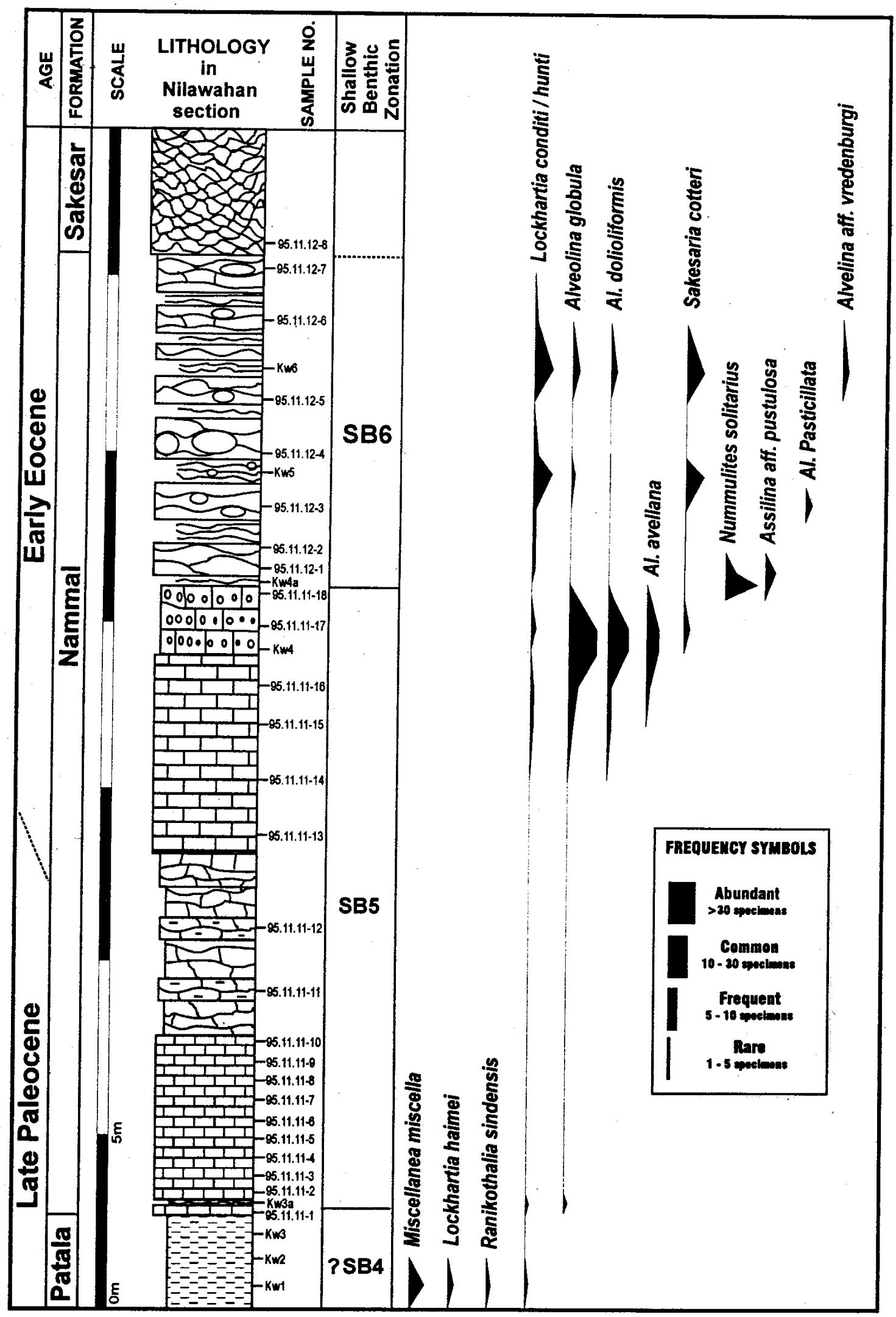

Figure 4- Larger foraminiferal species checklist in the Nilawahan section.

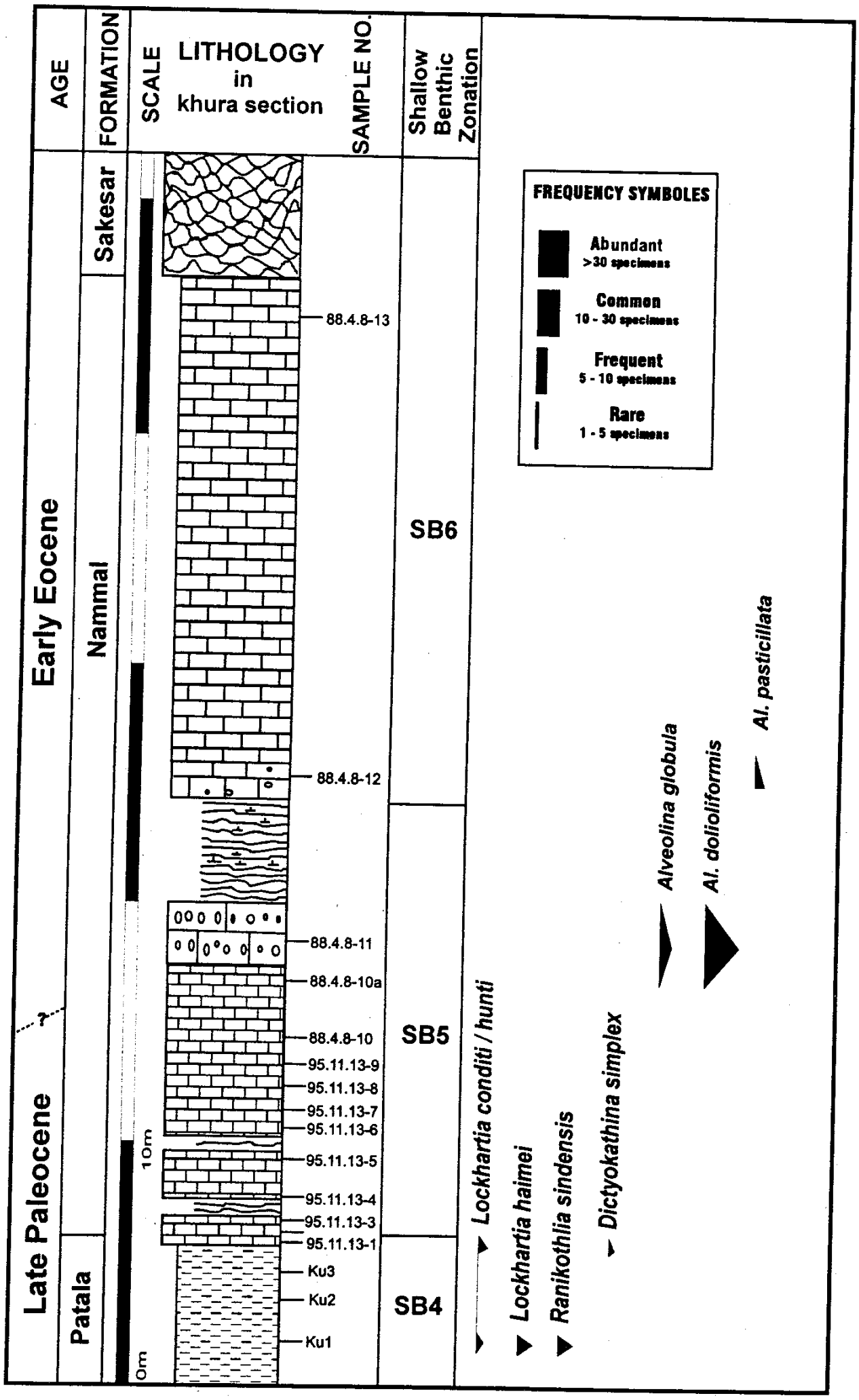

Figure 5- Larger foraminiferal checklist in Khura section.

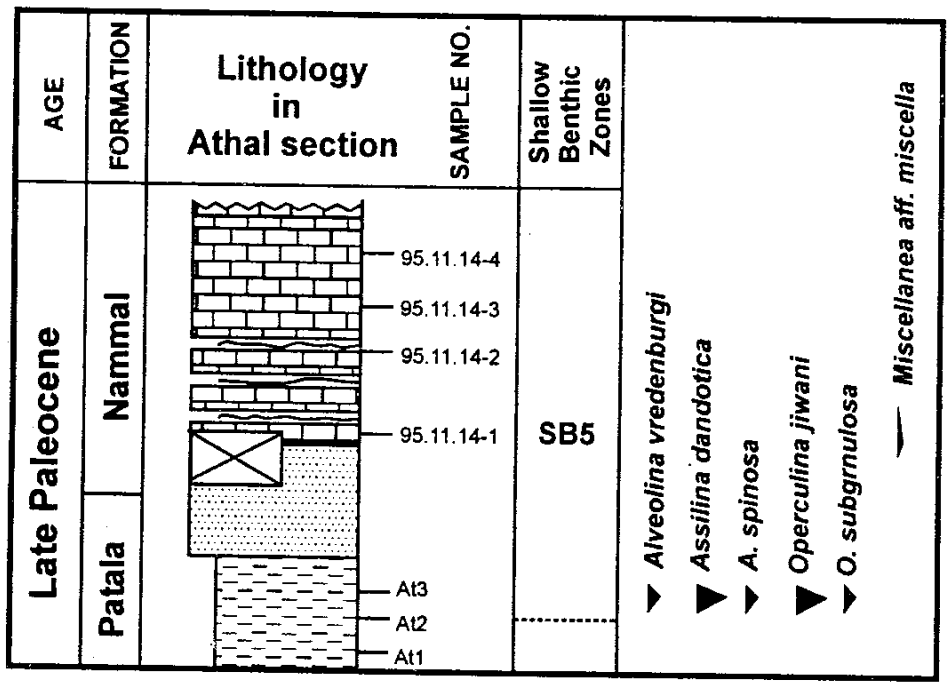

Figure 6- Larger foraminifera in Athal section.

deserti and *Assilina dandotica*. The latter two are not used here to define the base of the SB5 Zone because in the western Salt Range the *Nummulites* and *Assilina* assemblage including *N. deserti, N. thalicus, A. dandotica* and *A. spinosa* appear well before the FO of *Al. vredenburgi* within Zone P4c and Zone NP8 (Afzal, 1997). Likewise, the appearance of small and elongate shaped alveolinids (*Al. vredenburgi*) prior to the spherical forms (*Al. globula, Al. dolioliformis* and *Al. avellana*) is considered to reflect a result of ecological factors. Distribution of alveolinids is mainly controlled by the water depth, however, elongate forms are shown to have a greater affinity with muddy substrates (Luterbacher, 1970).

SB6 Zone

Original Definition: The interval characterized by the range of *Al. ellipsoidalis, Al. daniensis, Al. pasticillata, Al. solida*, and *N. minervensis* (Serra-Kiel et al., 1998).

Emended Definition: Interval from the almost simultaneous FOs of *Al. pasticillata, Al. tumida* and LO of *Al. avellana* to the FO of *A. pustulosa*.

Remarks: The assemblage observed around this horizon comprises of *Al. pasticillata, Al. globula, Al. dolioliformis, Al. tumida, Al,. vredenburgi, N. solitarius, Assilina aff. pustulosa* and *Sakesaria cotteri*. From the argillaceous limestone facies of the upper part of the Nammal Formation in Nilawahan section, a few compressed specimens quite close in size and general shape to *Al. vredenburgi* were recovered.

The SB5/SB6 zonal boundary is problematic in the Salt Range. One of the taxa defining the Zone SB6 is *Al. pasticillata* appearing in juxtaposition with the LO of *Al. vredenburgi* in Europe (Serra-Kiel et al., 1998). In Nilawahan section occurrence of a few specimens of *Al. vredenburgi* above the FO of *Al. pasticillata* caused a confusion and offered a choice to mark the SB5/SB6 zonal boundary either at the LO of *Al. vredenburgi* or at the FO of *Al. pasticillata*. In the Nilawahan section, the first appearance of abundant *Nummulites* spp. including *N. solitarius* and *Assilina aff. pustulosa* (a form with less pronounced central depression) concomitant with the FO of *Al. pasticillata* is observed, and soon followed by the LO of *Alveolina aff. vredenburgi*. As *N. solitarius* first appears at the horizon equivalent to Zone SB5 (Serra Kiel et al., 1998), it is not used for the definition. The LO of *Al. dandotica* is not recommended to mark the SB5/SB6 zonal boundary because of its taxomomic problems with *Assilina aff. pustulosa* (Afzal, 1997). The form *Al. avellana is the* only representative of Zone SB5 which did not show overlapping range with *Alveolina pasticillata*. These results are in accordance with Sameeni (1997) and Serra-Kiel et al., (1998). Therefore, the LO of *Al. avellana* in juxtaposition with the FOs of *Al. pasticillata* and *Al. tumida* are used to define the SB5/SB6 zonal boundary. *Alveolina vredenburgi* occur sporadically but its stratigraphic range is likely to extend into Zone SB6. Hottinger (1996) has also mentioned the similar results. The FO of *Al. pasticilatta* is used to mark the base of Zone SB6 while the top is tentatively defined at the FO of true *Assilina pustulosa* after Serra-Kiel et al., (1998) which requires an investigation of the overlying Sakesar Limestone for further confirmation.

CORRELATION

At Badshah Pur section, the Patala Formation yielded abundant *Operculina jiwani* and rare *Kathina selveri* whereas the base of the overlying Nammal Formation yielded an assemblage rich in *Lockhartia haimei* and *Ranikothalia sindensis* (Figure 3). The Patala Formation in the Nilawahan section yielded *M.miscella-L.haimei-R.sindensis* assemblage (Figure 4). These assemblages have also been reported from the underlying Lockhart Limestone (Davies and Pinfold, 1937 and Weiss, 1993) and is equivalent to the *Miscelllanea-L. haimei-Dk. simplex* assemblage Zone of Weiss (1993). The above mentioned assemblages were interpreted as Late Paleocene SB4 Zone and are in accordance with Serra-Kiel et al., (1998). Complete non-evidence of any of the representatives of the *Alveolina-Nummulites-Assilina* assemblage fully supports this interpretation. The first occurrence of *Alveolina globula* lies within the basal beds of the Nammal Formation in Nilawahan section (this study and Sameeni, 1997). Similar faunal relationship exists in the Khura section. Therefore, in three of these localities SB4/SB5 zonal boundary lies closer to the Patala / Nammal boundary (Figure 9). In Athal and Kuraddi sections, the upper part of the Patala Formation yielded simultaneous FOs of *Al. vredenburgi, Nummulites deserti, A. spinosa* in association with *M. miscella, L. haimei, R. sindensis*. This assemblage indicates SB5 Zone, and therefore, the Patala/Nammal boundary in Kuraddi section lies within SB5 Zone. The top of the Nammal Formation is investigated in only two sections. In Nilawahan section, the upper part of the Nammal Formation due to the presence of *Al. pasticillata* is dated as SB6 (probably the upper most part), whereas in Kuraddi section the SB5/SB6 zonal boundary found close to Nammal/Sakesar boundary (Figure 9).

Following the route of several adjustments resulted through the subsequent studies in Europe, the correlation of the larger foraminiferal zones with the planktonic foraminiferal

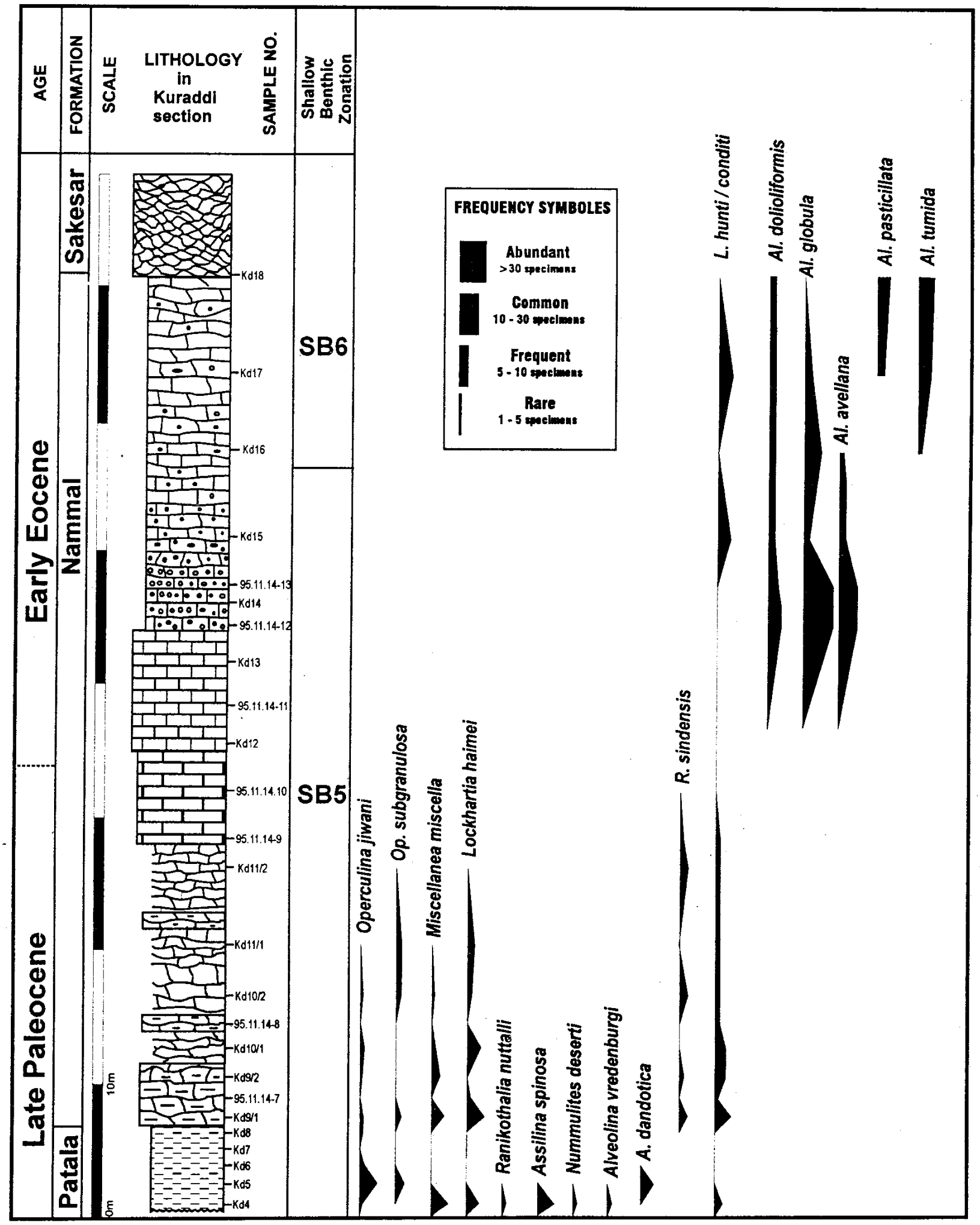

Figure 7- Larger foraminiferal species checklist in Kuraddi section.

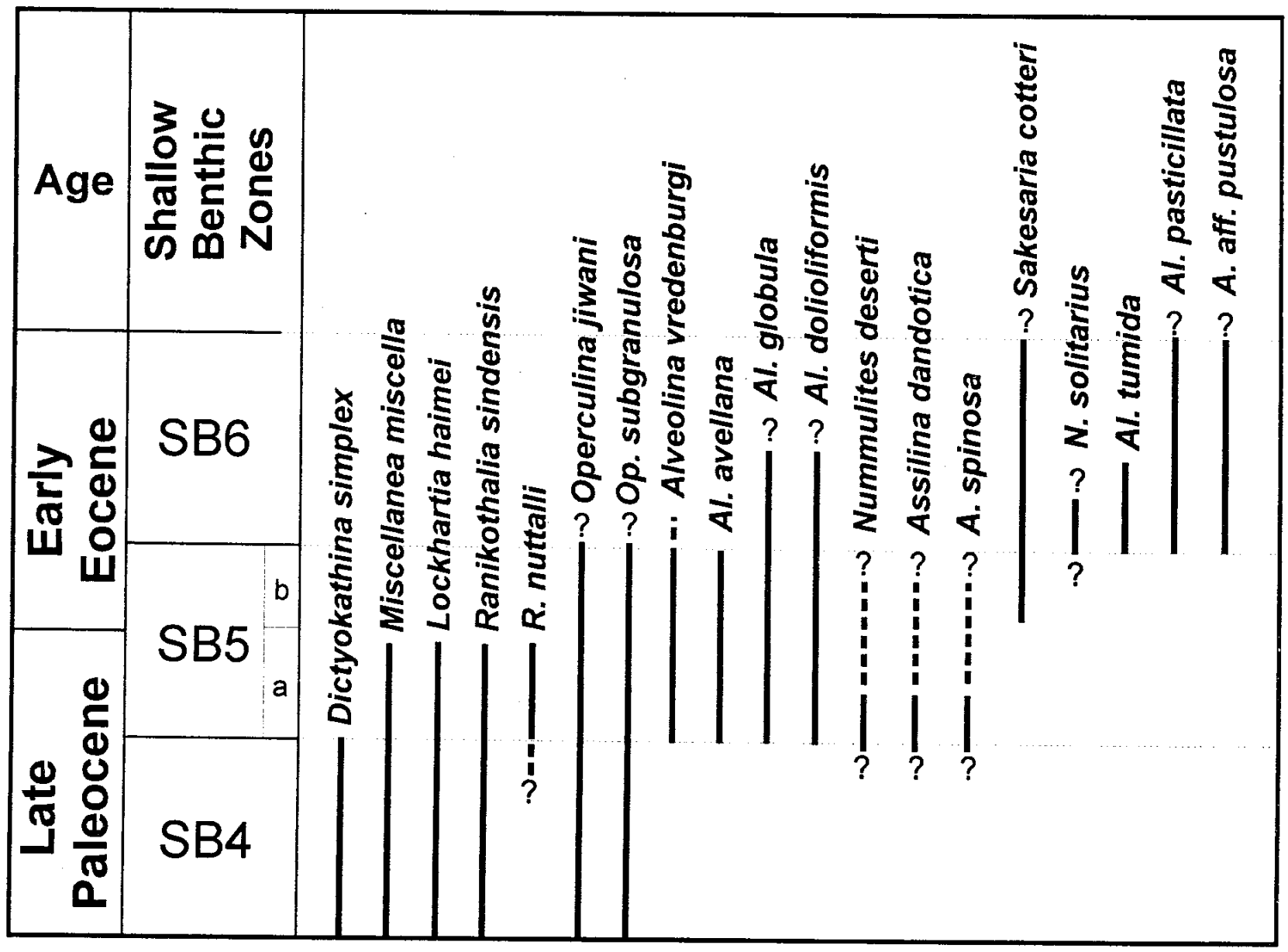

Figure 8- Generalized stratigraphic ranges of some of the larger foraminiferal species in the central Salt Range.

and calcareous nannofossils zones have attained a mature stage. Recently, Serra-Kiel et al., (1996 and 1998) presented a fresh correlation model of shallow benthic zones with Paleogene biochronology of Berggren et al., (1995). The correlation model showes that both SB4/SB5 and SB5/SB6 zonal boundries lie within Zone P5 of the planktonic foraminifera and Zone NP9 of the calcareous nannofossils. To prove the applicability of this model in areas like Salt Range, a complete revision of the different fossil groups is a prerequisite. In Pakistan little attention was paid to this topic. Recently, in the western Salt Range, the appearance of the *Nummulites / Assilina* stock has been observed within Zone P4c and NP8 which is prior to the FO of *Al. vredenburgi* having FO within Zone P5 and Zone NP9 (Afzal, 1997). Several definitions for the Zone SB5 were possible e.g. (1) based on FO of *Nummulites deserti, Assilina dandotica*, or (2) based on the FO of *Al. vredenburgi* to the FO of *Al. pasticillate*, and (3) based on total range of *Al. vredenburgi*. The definition no. 2 is considered an appropriate solution. In the Salt Range, the interpretation of the shallow benthic zonal boundaries appears comparable to those of Serra-Kiel et al., (1996 & 1998) (Figure 10).

According to the above mentioned assemblages and interpretations, both Patala/Nammal and Nammal/Sakesar boundaries in the central Salt Range are slightly dichronous with tendency to become further younger in the west. The biostratigraphic comparison of these units with the results from the western Salt Range indicates a high degree of diachroneity where the Nammal Formation ranges in age from Zone SB6 to at least Zone SB11 (Afzal 1997). The SB8 age of the Sakesar Formation in central Salt Range (Sameeni, 1997), and the Early Eocene age (P7 and NP11) assigned to most of the underlying Patala Formation in the Khairabad section, western Salt Range (Weiss, 1988, 1993; Afzal and von Daniels, 1991; Koethe et. al., 1988; Ashraf and Bhatti, 1991) fully supports the general result that the whole Tertiary sedimentary package over the entire Salt Range is dichronous in nature.

DISCUSSION

The form *Al. vredenburgi* was originally described and figured by Davies (1937) from the Makarwal area of the Surghar Range. Hottinger (1971) noted that morphologically *Al. vredenburgi* might be related to *Al. cucumiformis* HOTTINGER. Prof. Hottinger under the Project IGCP 286, visited the type locality of *Al. vredenburgi*. Comparing a large number of topotype specimens with the holotype and other specimens of *Al. cucumiformis*, he concluded that there is insuffient morphological discrepancies between these two forms, therefore, he placed *Al. cucumiformis* as a

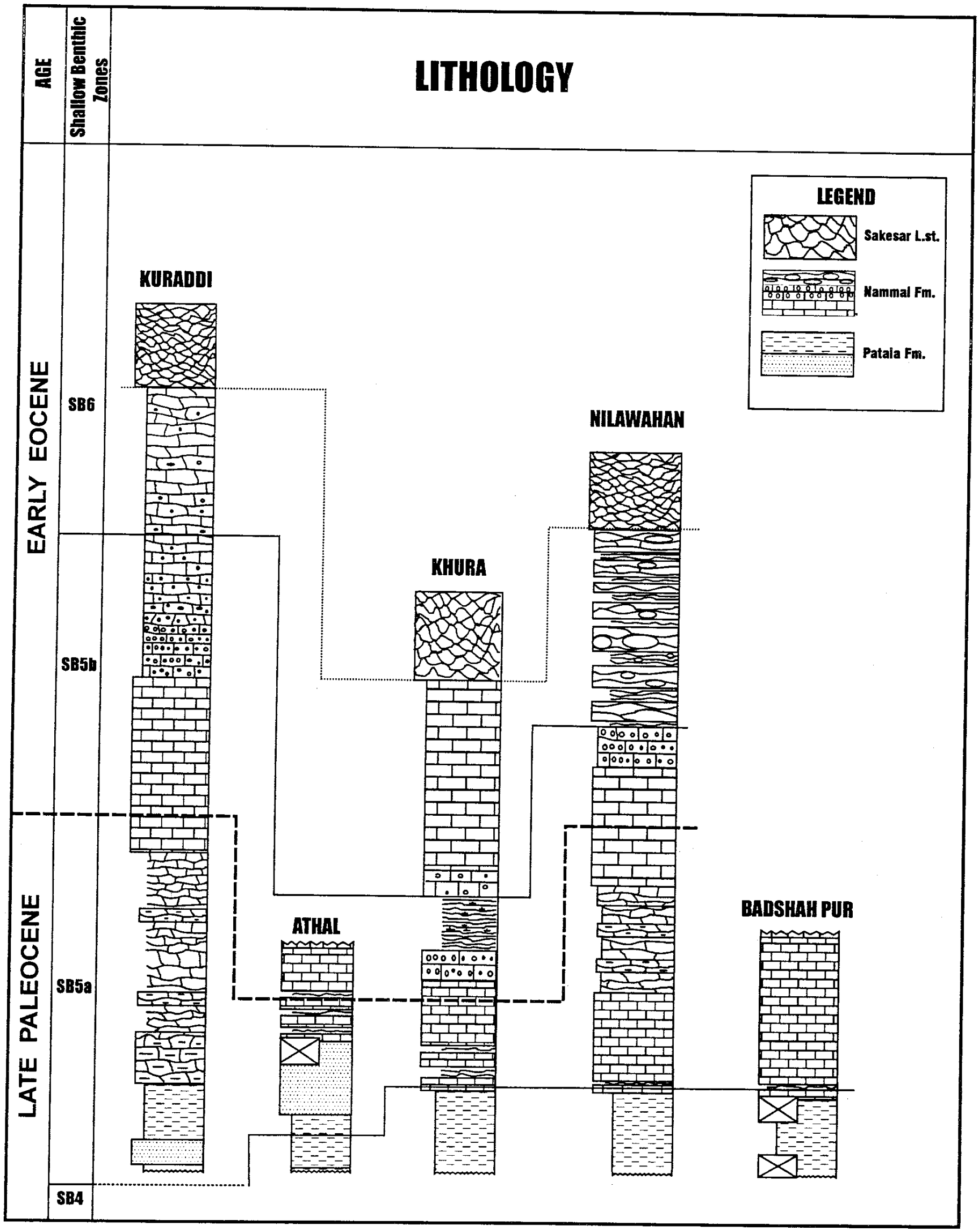

Figure 9- Biostratigraphic correlation of the Late Paleocene to Early Eocene Nammal Formation in the central Salt Range.

synonym of *Al. vredenburgi* (Hottinger, 1996). His co-workers at the University of Punjab also studied topotype specimens of *Al. vredenburgi* and achieved the same result (Sameeni and Butt, 1996; Sameeni, 1997). These authors did not find *Al. vredenburgi* outside the type area. However, Afzal (1997) previously reported rare occurrences of the same species from Makarwal, Chichali Pass, Nammal Gorge and Patala Nala sections. The specimens from the latter two localities were studied jointly by the first author and Prof. Hottinger at the Uinversity of Basel which provided further evidence in the favour of *Al. vredenburgi* as a senior synonym.

The age assigned to the Nammal Formation (zone SB5-SB6) is generally in accordance with that of Hottinger (1971) and Sameeni (1997). However, the SB7 Zone for the upper most beds of the Nammal Formation (Sameeni, 1997) based on the rare occurrence of specimens representing a transition form between *Al. dolioliformis* and *Al. subpyrenaica* without other typical representatives of this Zone may carry little weight. A similar form "*Alveolina aff. subpyrenaica*" has been reported from the Al. Ellipsoidalis Zone (=SB6) in the western desert of Egypt (Ulrike, 1996). Therefore, the Zone SB7 of Sameeni (1997), in the author's view, may be interpreted as the upper part of SB6 Zone.

According to the recent proposals the Paleocene/Eocene boundary is likely to corresponds to a horizon which represents a worldwide negative shift in the carbon isotopes (δC^{13}) associated with the benthic foraminiferal extinction (Berggren et al., 1997). This event in all the studied regions occurs within a time span representing Zone P5 of the planktonic foraminifera overlapping with Zone NP9 of the calcareous nannofossil and is termed as "Boundary Time span". In the western Salt Range such extinction in the benthic foraminifera (smaller and larger) is observed within P5, NP9 and SB5 zones (Afzal, 1997). A similar change in the larger benthic foraminiferal assemblage in the central Salt Range is observed within Zone SB5. The same event (SB5a/b zonal boundary) is proposed to mark the P/E boundary in the central Salt Range.

The older concept of time-rock units e.g. the Ranikot (Paleocene) and the Laki (Early Eocene) is no more valid throughout this region. The rock types and boundaries of the rock units result from a complex combination of source, basinal configuration, tectonic activity, subsidence and eustatic sea level fluctuations. Any significant change in the basin architecture produced by the above mentioned factors may result a diachroneity in the lithofacies. However, tectonically stable and passive basin margins have a greater tendency towards resulting into an isochronous character of the lithostratigraphic units. For instance, the eastern margin of the Sulaiman Range represents quite a good example of the isochronous nature of the Middle Eocene Kirthar sediments over a broader area (Gingerich et al., 1997; Afzal et al., 1997). The high degree of diachroneity of the sediments of the Salt Range around P/E boundary suggests a tectonic activity which most probably is attributed to the Late Paleocene India-Asia collision (Beck et al., 1995). The Salt Range fauna in the Late Paleocene sediments provides supporting evidences which will be published later on.

Sameeni (1996, 1997) seems to project the ages of different formations established in the central Salt Range to the same lithologic units of the western Salt Range. He also reported a new assemblage of the larger foraminifera from the Sakesar Limestone (Early Eocene) of the Nammal Gorge section comprising of *Al. ellipsoidalis, Al. globula, N. mamillatus, A. spinosa,* and *R. sindensis*. This assemblage according to Serra-Kiel et al., (1996) is coeval to the SB4-SB6 horizon. However, in the same section the upper part of the Nammal Formation has yielded an assemblage of SB10 Zone and that of P9 of the planktonic Foraminiferal (Afzal, 1997), and has been placed in Zone NP11-13 of the calcareous nannofossils (Koethe et al. 1988 and Bybell and Self-Trail, 1993). It is, therefore, extremely important that before establishing a general age, the total range of the larger foraminifera in connection with other relevant fossil groups is to be well known.

CONCLUSION

The results presented here are exclusively based on the study of the larger foraminifera recovered from the five localities of the central Salt Range which are given as below:

- Because of the local variation in the stratigraphic ranges of certain larger foraminiferal taxa, definition of the shallow benthic zonal boundaries are slightly modified for the central Salt Range. The hard data related to alveolinids generated through the different studies in the Salt Range indicate that the first appearances of *Alveolina* species are coeval to that in Europe, whereas their total stratigraphic ranges in the Salt Range indicate a tendency towards a longer time span. It is, therefore, recommended that for the *Alveolina* based zonation, the zonal boundaries are better defined by the FOs of subsequent younger species.
- The SB4/SB5 zonal boundary is defined at the FOs of *Al. globula, Al. vredenburgi,* and *Al. dolioliformis*, whereas SB5/SB6 zonal boundary is defined at the FO of *Al. pasticillata* and *Al. tumida* in juxtaposition with the LO of *Al. avellana*. The definitions for the base of Zone SB4 and top of Zone SB6 need verification, subject to the thorough investigation of the Patala Formation and the Sakesar Limestone in the central Salt Range and also the Lockhart Limestone in the western Salt Range. Nevertheless, the zonal boundaries as defined here seem coeval to those of Serra-Kiel et al., (1998). Through this study the lower Ilerdian Stage has been established in the Salt Range, Pakistan which may facilitate worldwide correlation in future.
- In the middle of the Zone SB5, a larger foraminiferal turnover is observed, where three species i.e. *M. miscella, R. nuttali* and *R. sindensis* get extinct whereas *S. cotteri* originates, therefore, it is proposed to subdivide the Zone SB5 into SB5a and SB5b. This division is proposed to define the Paleocene / Eocene boundary which lies in the lower part of the Nammal Formation.
- The age of the Patala Formation in the central Salt Range is Late Paleocene (Zone SB4 to Zone SB5a), whereas the age of the Nammal Formation is Late Paleocene to Early Eocene (Zone SB5 to Zone SB6). Both lower and upper boundaries of the Nammal

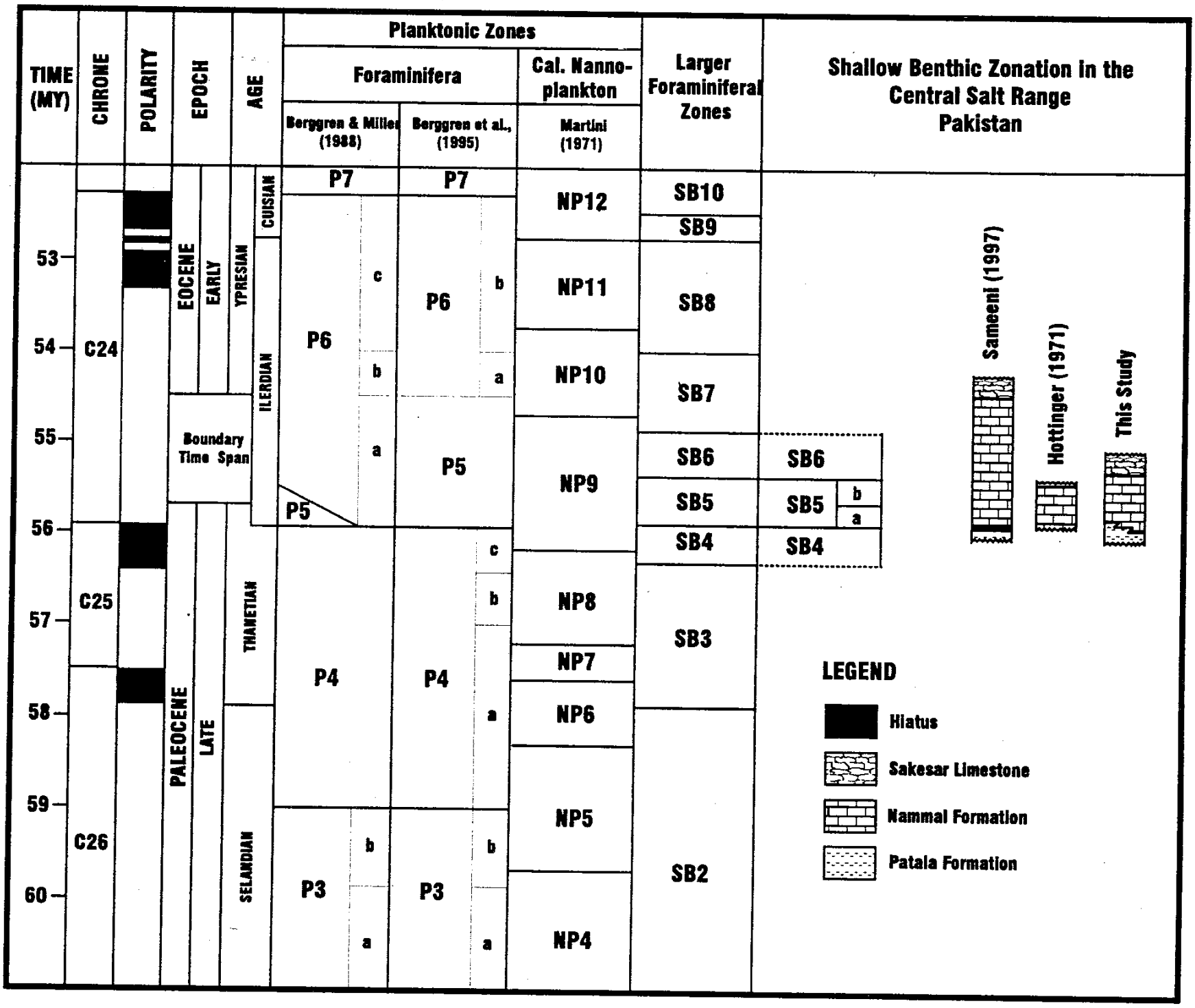

Figure 10- Correlation of the Shallow Benthic Zones interpreted in the Salt Range compared with the global biochronostratigraphy.

Formation are diachronous, which show a tendency to become younger in the west. A comparison of these results with those obtained from the western Salt Range indicates that a major facies change occurred around the P/E boundary in this area.

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PLATE 1
(each bar = 1mm)

1. ***Nummulites-Assilina*** assemblage: upper part of the Nammal Formation in Nilawahan section; Sample No. 95.11.12-17; Zone SB6. (a) ***Nummulites soliterius*** (b) ***Assilina aff. pustulosa.***
2. ***Ranikothalia*** assemblage: lower part of the Nammal Formation in Badshah Pur section; Sample No. 95.11.10.3; Zone SB5a. (a) ***Ranikothalia nuttalli.***
3. ***Ranikothalia*** assemblage: lower part of the Nammal Formation in Badshah Pur section; Sample No. 95.11.10.3; Zone SB5a. (a) ***Ranikothalia sindensis***.
4. ***Nummulites-Assilina*** assemblage: upper part of the Nammal Formation in Nilawahan section; Sample No. 95.11.12-1; Zone SB6.
5. ***Alveolina*** assemblage: middle part of the Nammal Formation in Nilawahan section; Sample No. 95.11.11.1; Zone SB5b. (a) ***Al. globula***, (b) ***Al. dolioliformis***, (c) ***Sakesaria cotteri***.
6. ***Sakesaria cotteri***, middle part of the Nammal Formation, Nilawahan section; Sample No. 95.11.11-17; Zone SB5b.

PLATE 2
(each bar = 1mm)

1. ***Lockhartia-Operculina-Miscellanea*** assemblage: lower part of the Nammal Formation in Kuraddi section; Sample No. Kd10; Zone SB5a. (a) ***Lockhartia haimei***, (b) ***Operculina sp.***, (c) ***Miscellanea miscella***
2. ***Operculina jiwani*** assemblage: lower part of the Nammal Formation in Kuraddi section; Sample No. Kd5; Zone SB5a.
3. ***Ranikothalia-Miscellanea-Lockhartia*** assemblage: lower part of Nammal Formation in Kuraddi section; Sample No. Kd9; Zone SB5a. (a) ***Ranikothalia sindensis***, (b) ***Miscellanea miscella***, (c) ***Lockharia conditi / hunti.***
4. ***Dictyokathina simplex***, base of the Nammal Formation, Sample No. 95.11.13.1, Zone SB4
5. ***Ranikothalia sindensis***, lower part of the Nammal Formation in Kuraddi section; Sample No. Kd9; Zone SB5a.
6. ***Miscellanea miscella***, lower part of the Nammal Formation in Kuraddi section; Sample No. Kd9; Zone SB5a.

7-8 ***Nummulites deserti***, upper part of the Patala Formation in Kuraddi section, Sample No. Kd4, Zone SB5a.

PLATE 3
(each bar = 1mm)

1-2. ***Alveolina avellana***, Sample No. Kd14, middle part of the Nammal Formation in Kuraddi section; Zone SB5b.

3-4. ***Alveolina globula***, Sample No. Nw4, middle part of the Nammal Formation in Kuraddi section; Zone SB5b.

5. ***Alveolina aff. avellana***, Sample No. Kd14; middle part of the Nammal Formation in Kuraddi section; Zone SB5b.
6. ***Alveolina tumida***, Sample No. Kd16; middle part of the Nammal Formation in Kuraddi section; Zone SB5b.
7. ***Alveolina vredenburgi***, Sample No. Kd4; upper part of the patala Formation in Kuraddi section; Zone SB5a.

PLATE 4
(each bar = 1mm)

1. ***Alveolina pasticillata***, Sample No. Kd17; middle part of the Nammal Formation in Kuraddi section; Zone SB6.

2-3. ***Alveolina pasticillata***, Sample No. Kd18; top Nammal Formation in Kuraddi section; Zone SB6.

4. ***Alveolina dolioliformis***, Sample No. Nw6; upper part of the Nammal Formation in Kuraddi section; Zone SB5b.

5-6. ***Lockhartia haimei***, Sample No. Kd11; middle part of the Nammal Formation in Kuraddi section; Zone SB5a.

7. ***Lockhartia conditi***, Sample No. Kd11; Middle part of the Nammal Formation in Kuraddi section, Zone SB5a.

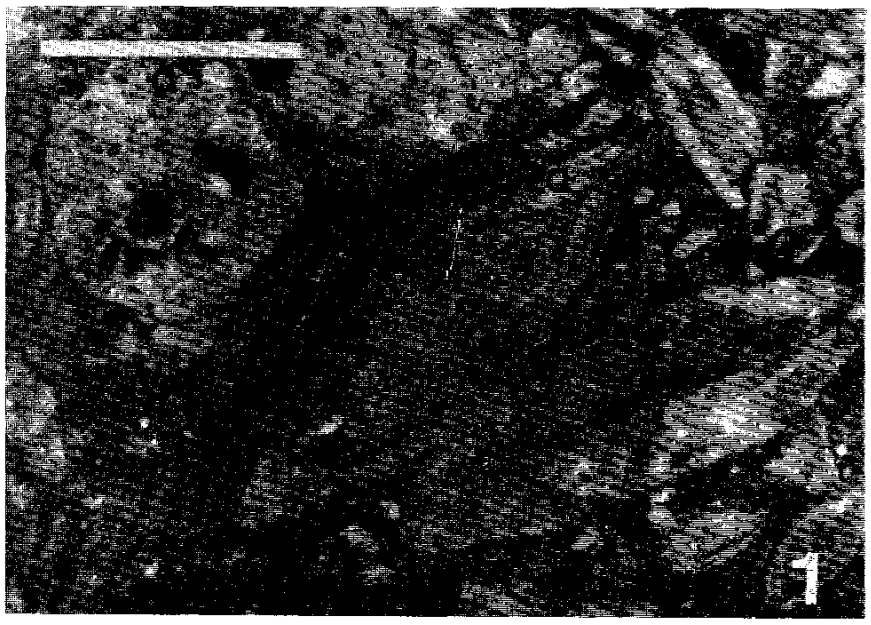
APPENDIX

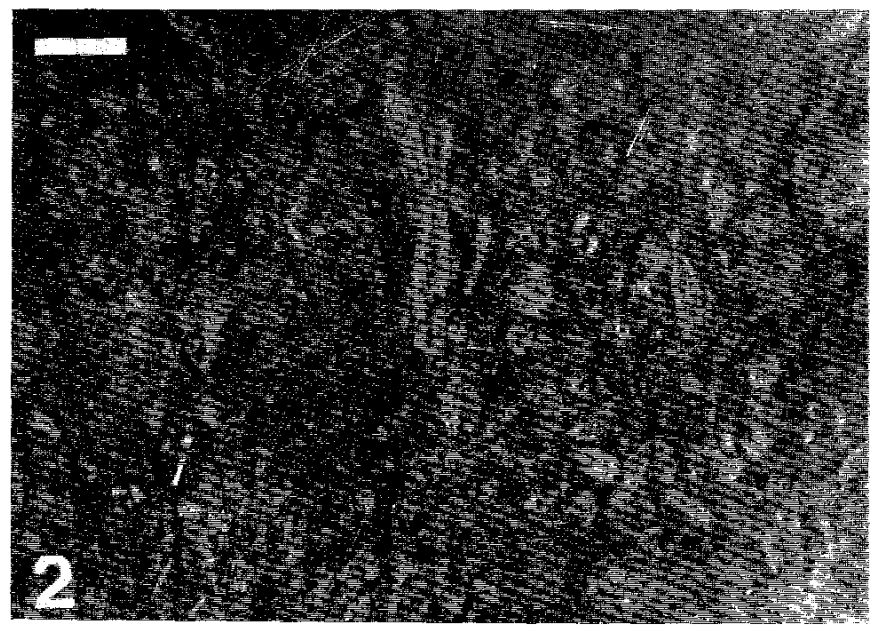
List of Larger Foraminiferal Species

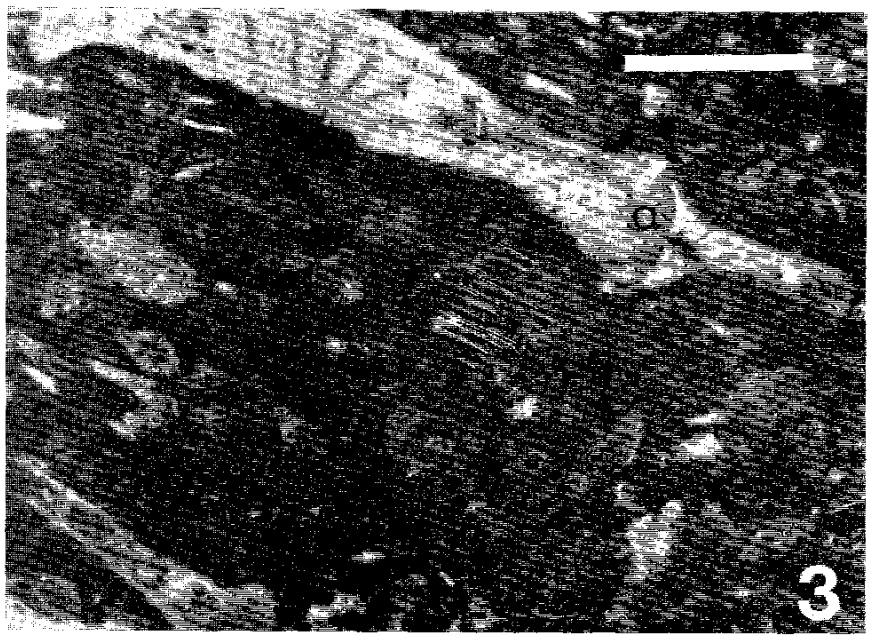
1. *Alveolina avellana* HOTTINGER, 1960
2. *Al. dolioliformis* SCHWAGER, 1983
3. *Al. globula* HOTTINGER, 1960
4. *Al. pasticillata* SCHWAGER, 1883
5. *Al. vredenburgi* DAVIES, 1937
6. *Al. tumida** HOTTINGER, 1960
7. *Assilina dandotica* DAVIES, 1937
8. *A. spinosa* DAVIES, 1937
9. *Dictyokathina simplex* SMOUT, 1954
10. *Lockhartia conditi* (NUTTALL, 1926)
11. *L. hunti* OVEY, 1947
12. *L. haimei* DAVIES, 1927
13. *Miscellanea miscella* (d 'ARCHIAC & HAIME, 1855)
14. *Nummulites deserti* de la HARPE, 1883
15. *N. solitarius* de la HARPE, 1881
16. *Operculina jiwani* DAVIES, 1937
17. *Op. subgranulosa* d'ORBIGNY, 1850
18. *Ranikothalia sindensis* (DAVIES, 1927)
19. *R. nuttalli* (DAVIES, 1927)
20. *Sakesaria cotteri* DAVIES, 1937

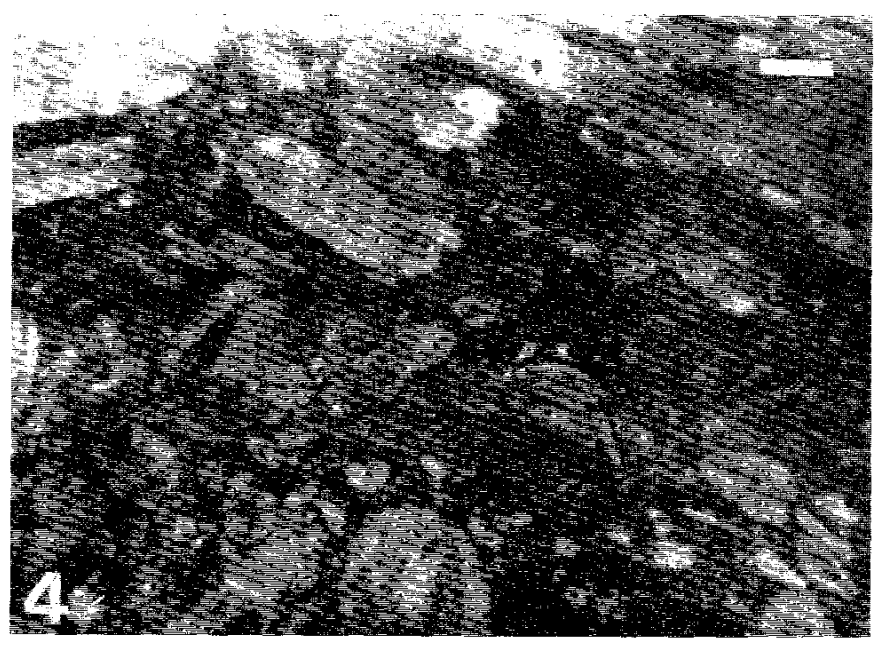
* Species first time reported in Pakistan

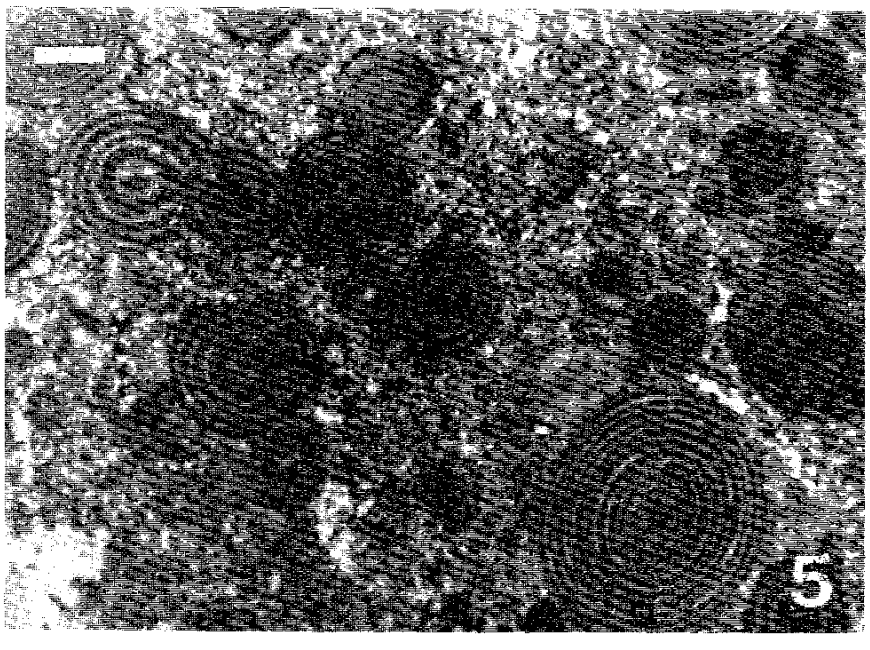
PLATE 1

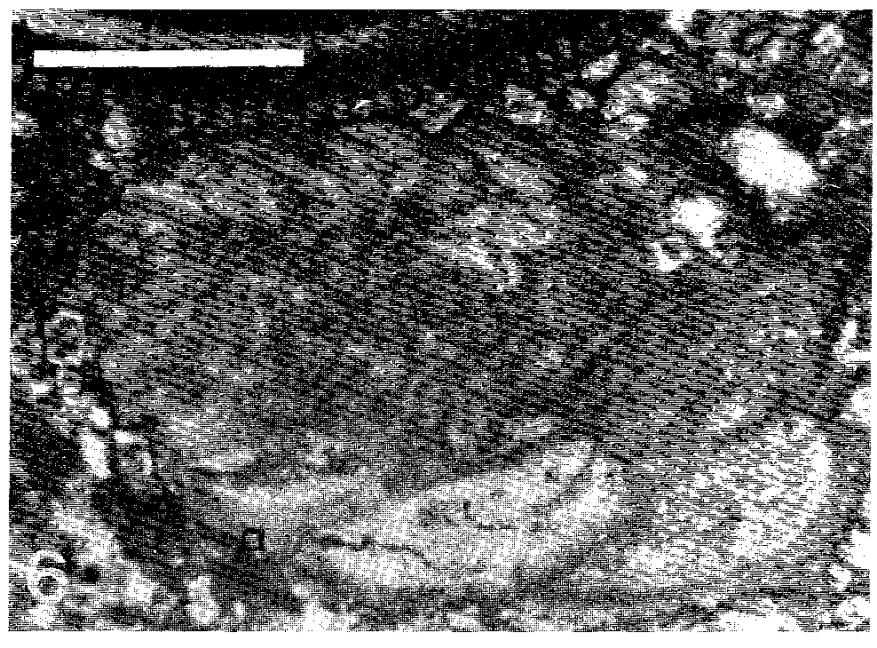












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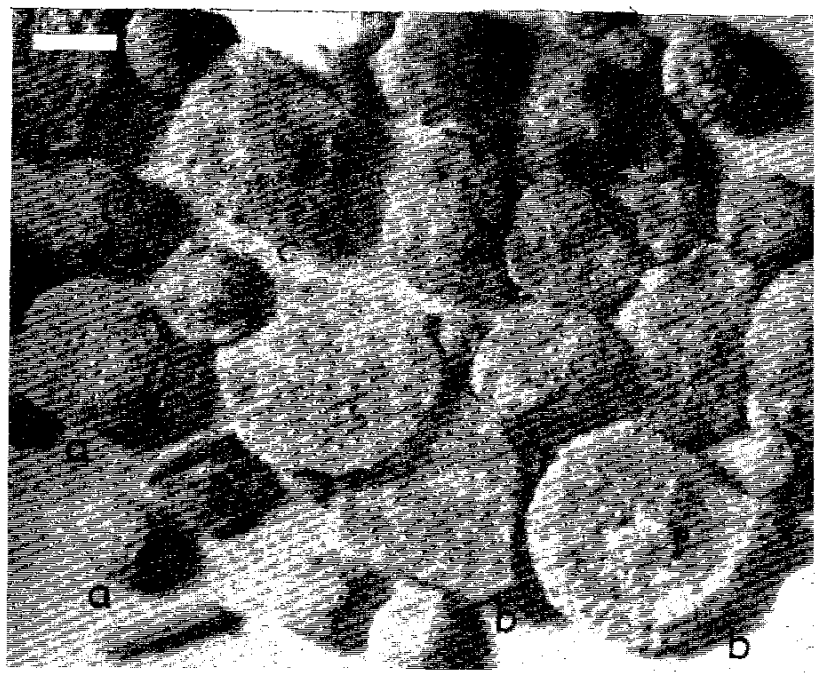
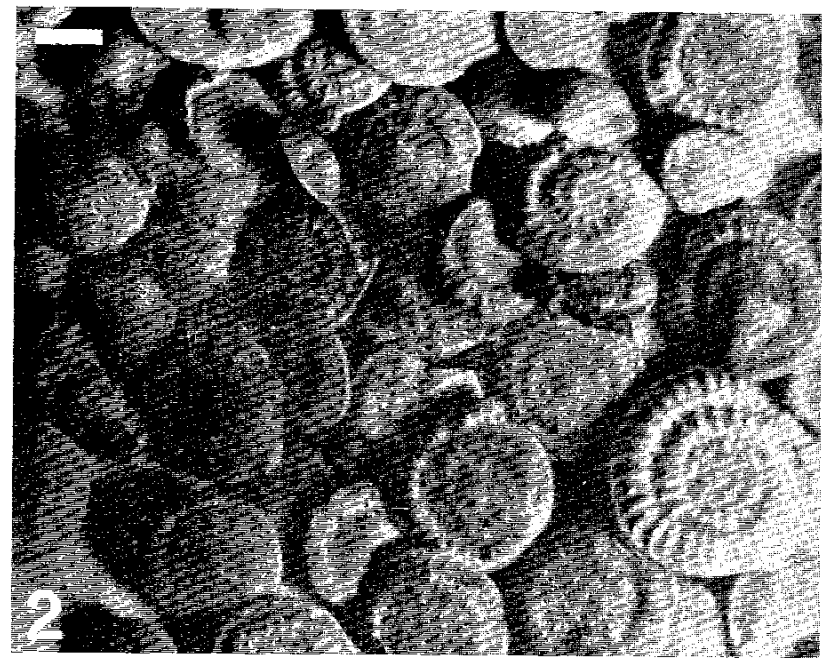
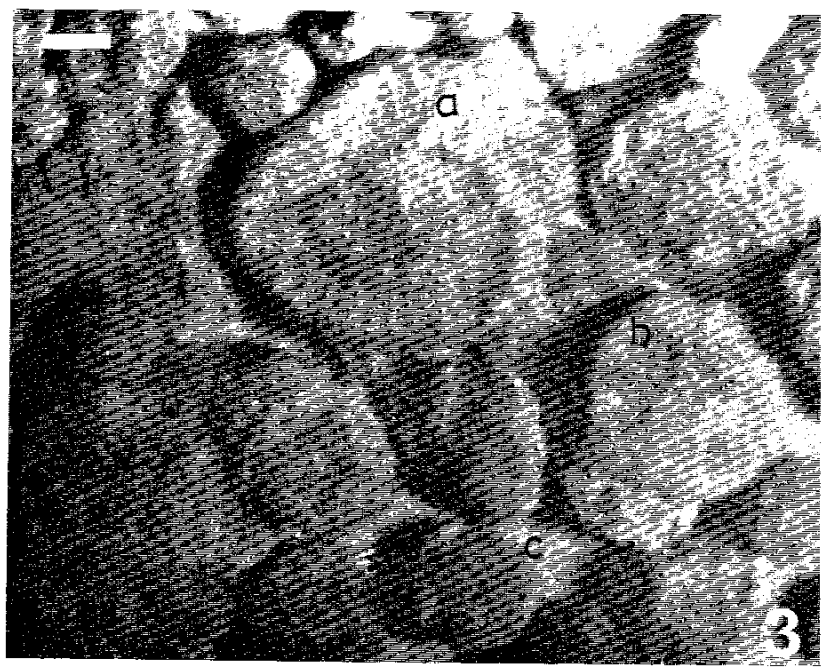
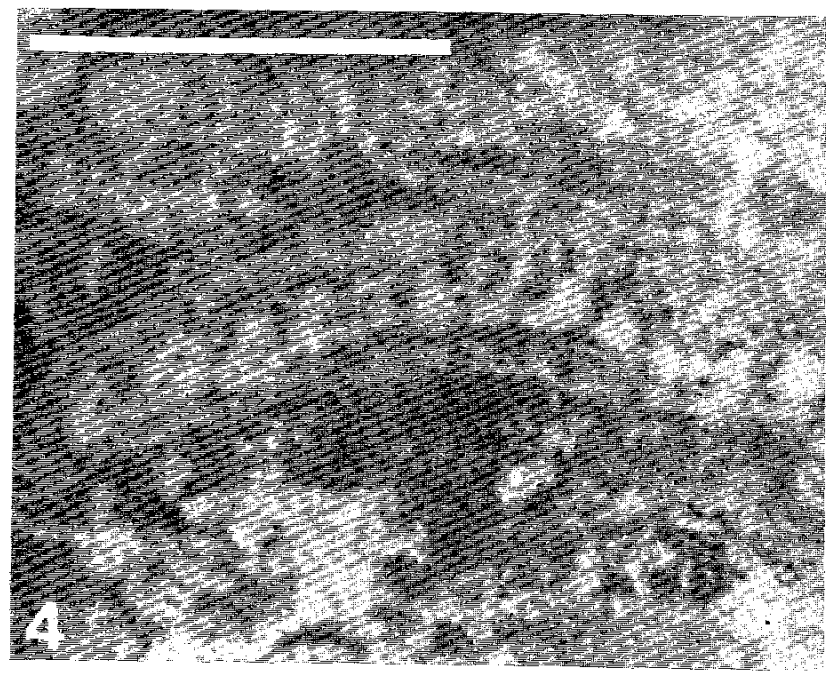
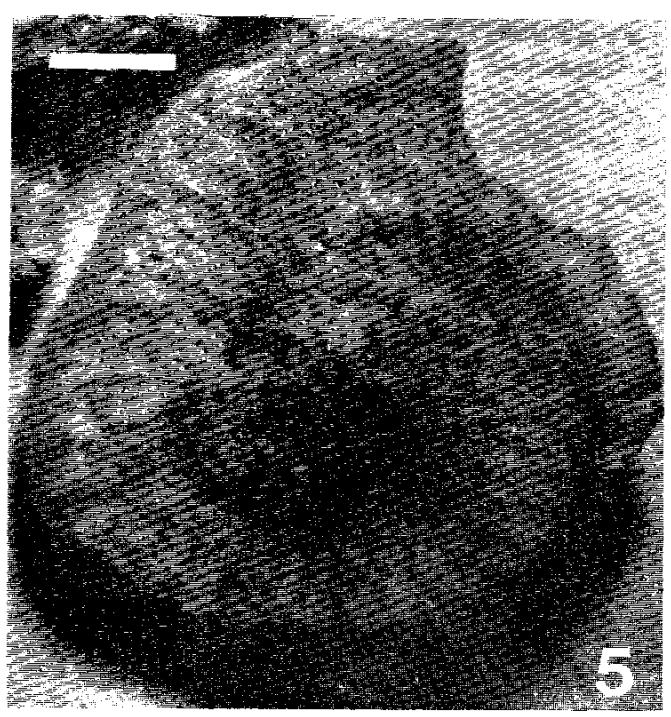
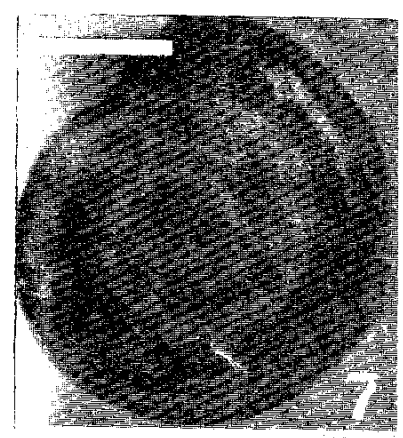












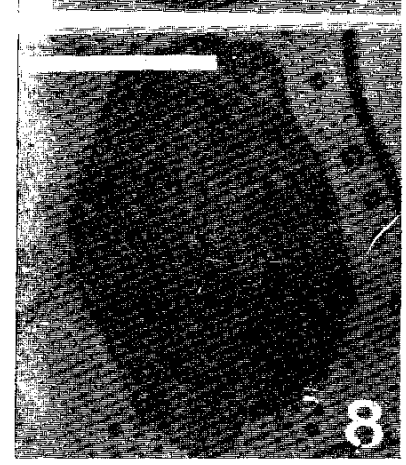
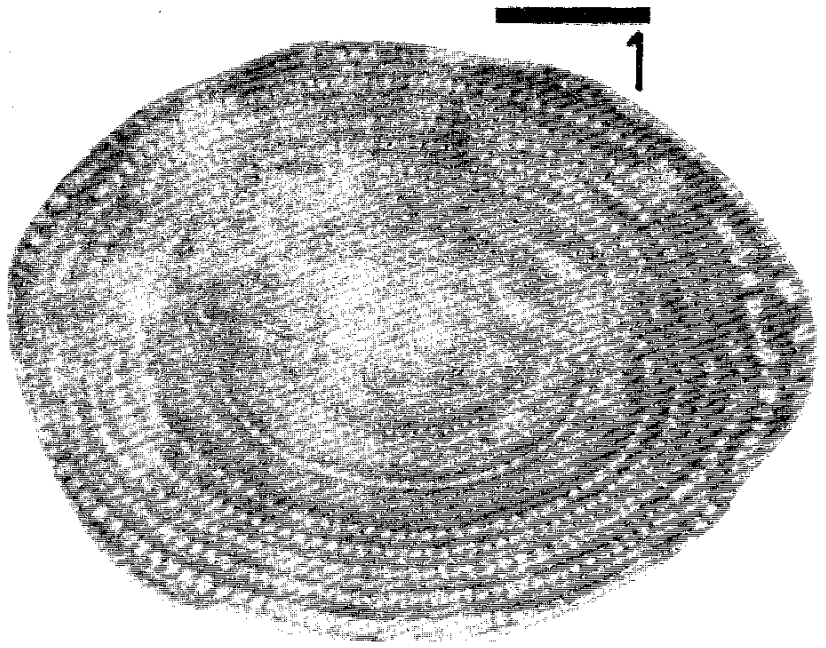
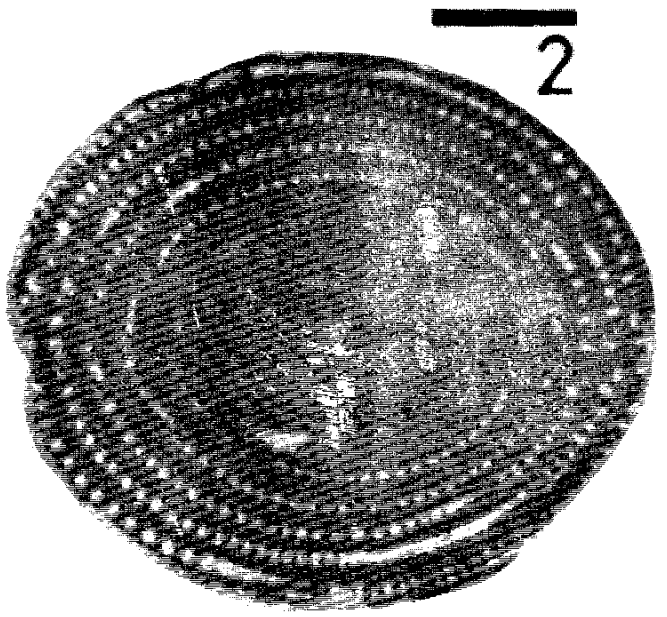
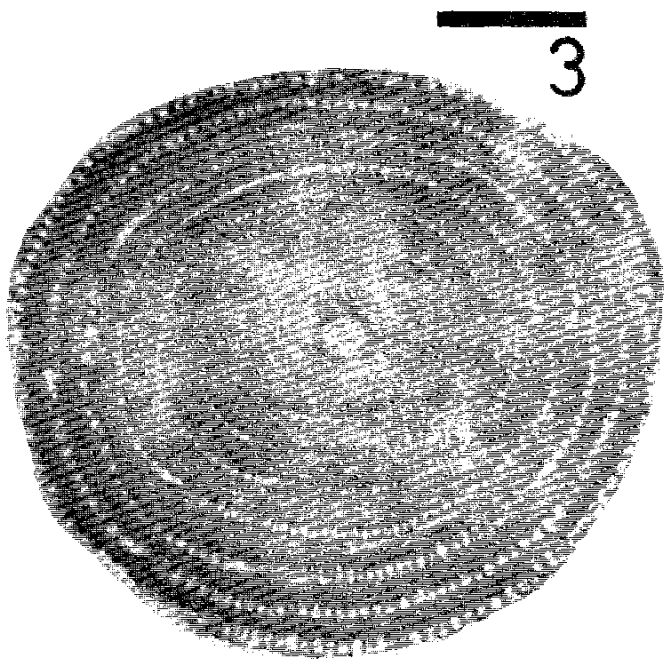
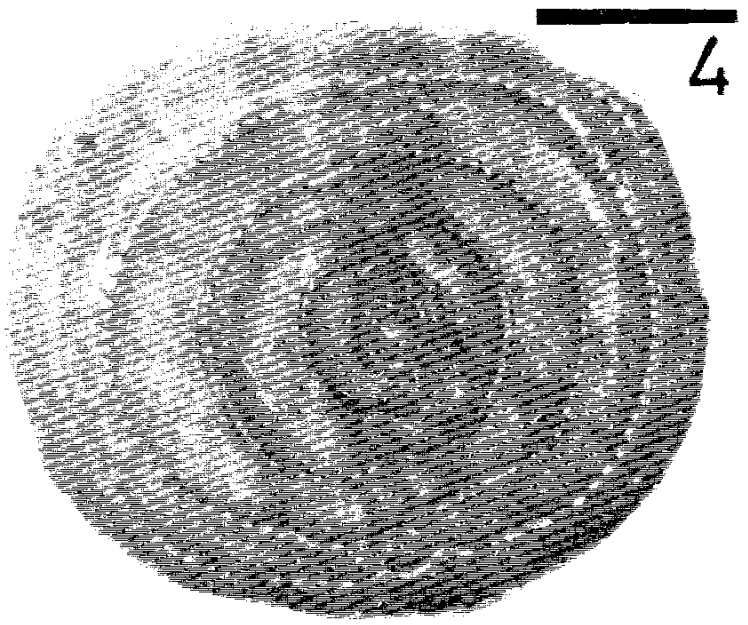


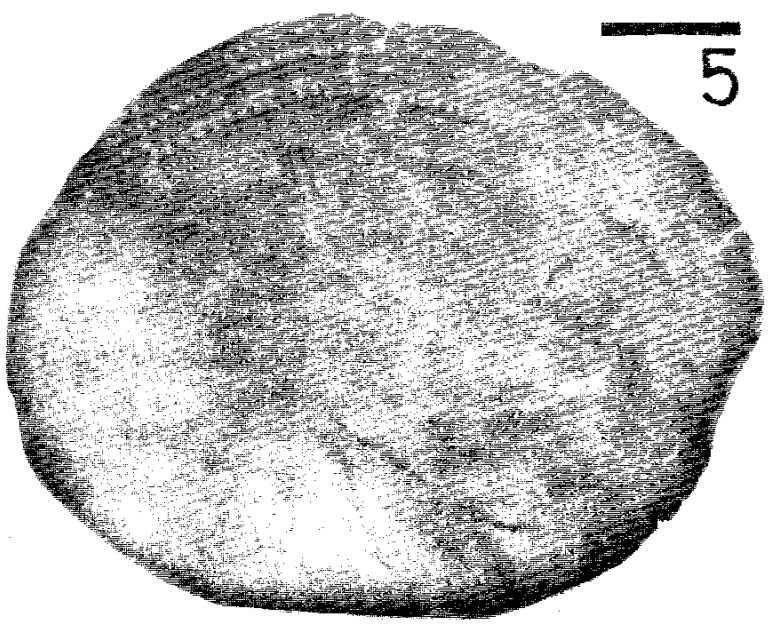
PLATE 3

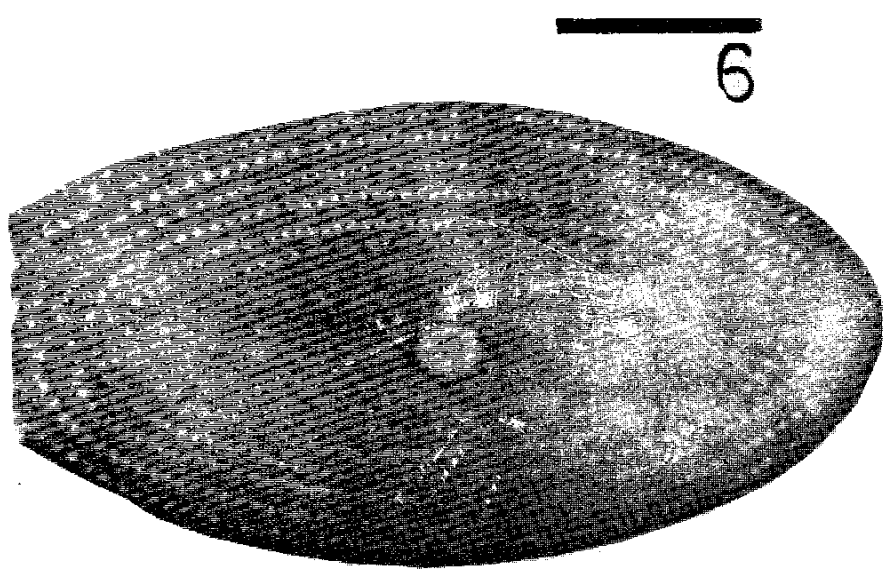












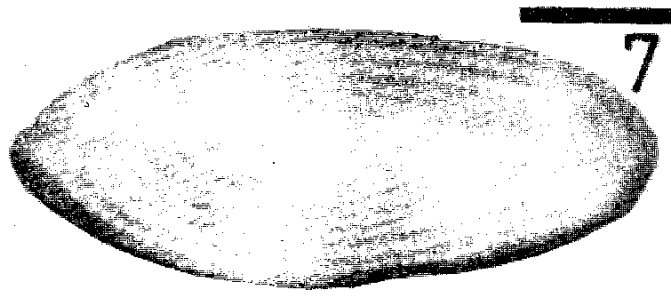
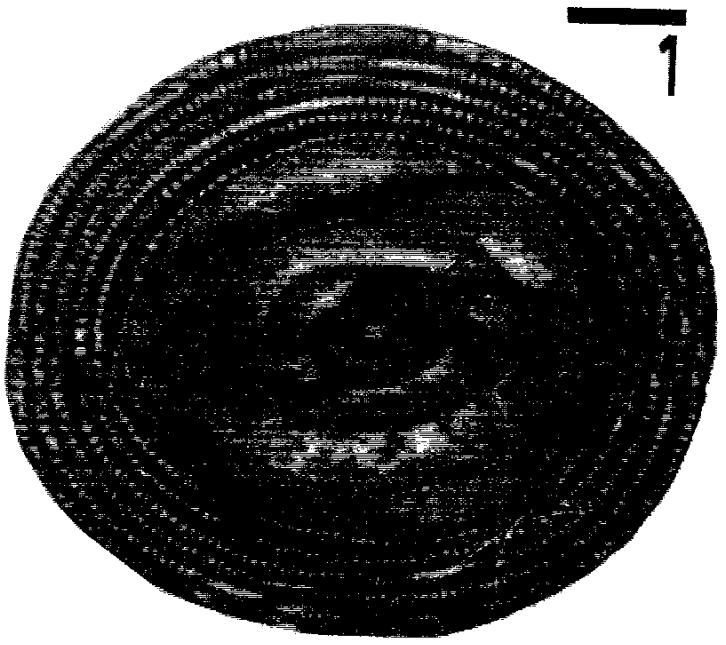


PLATE 4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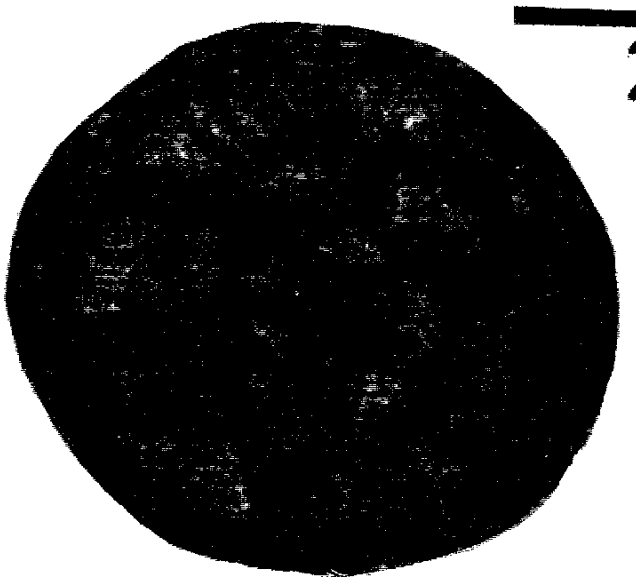
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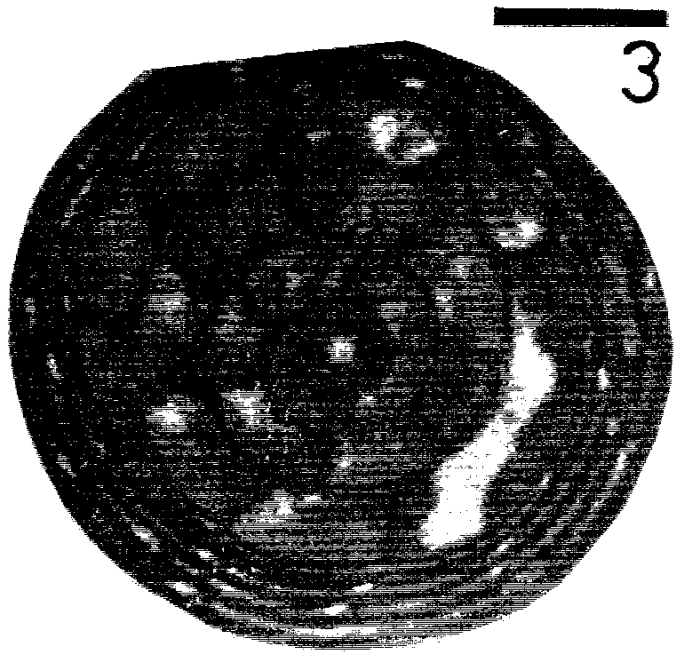
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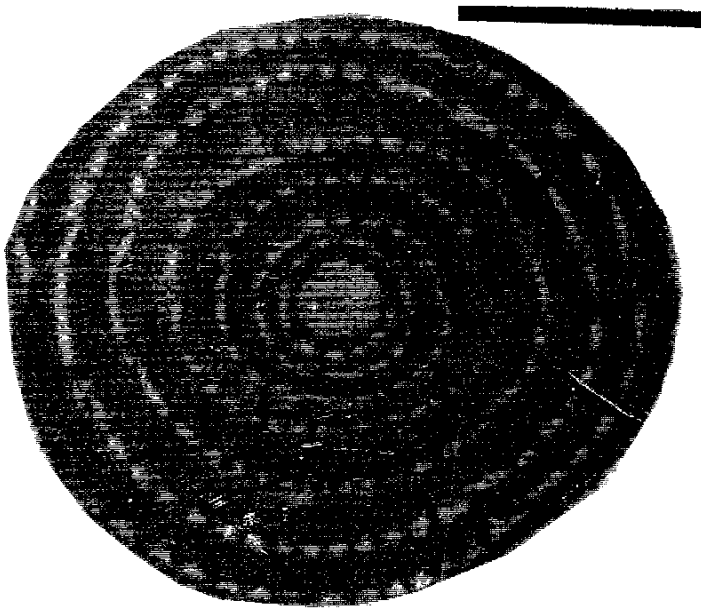
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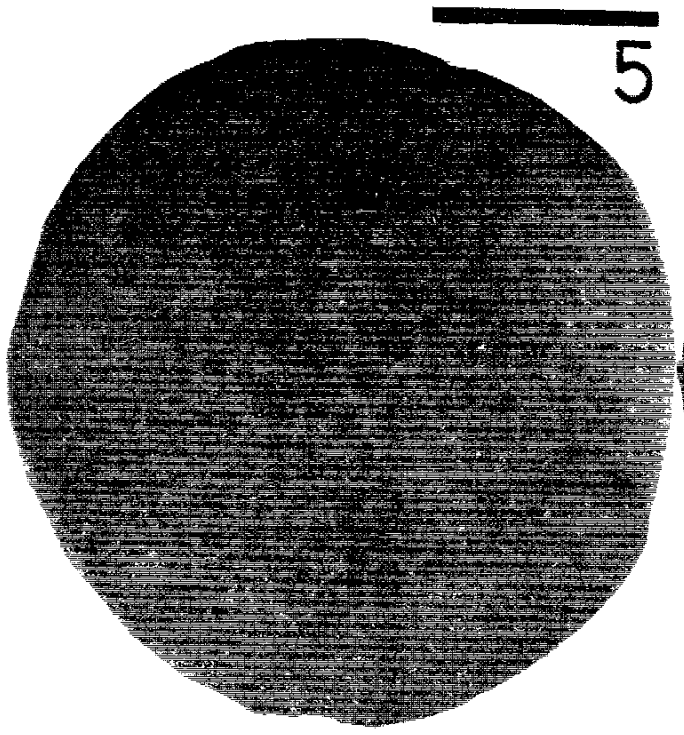
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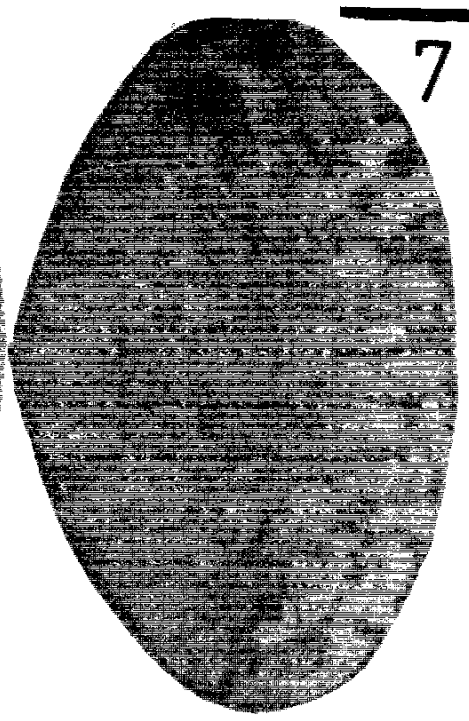
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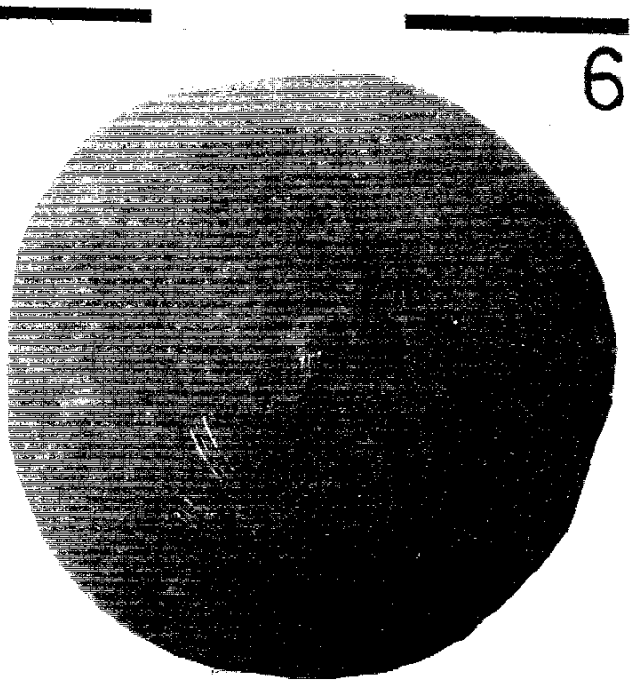
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