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**Establishing Large Foraminiferal Biostratigraphic Evidences for Paleocene–
Eocene Boundary on Kakinada Terrace, K.G. Basin, India.**

INTRODUCTION:

The Paleocene-Eocene boundary is one of the difficult and debated levels world-over. The Paleocene Epoch characterized by equable climate exhibits increased faunal diversity and productivity as regards both the marine as well as terrestrial biota (Berggren et al. 1998). The Eocene epoch was warmest interval with significant changes in global climate and considerably affected both marine and terrestrial faunal / floral populations and their extinctions. The Paleogene Period is characterized as gradual climatic transition time between the warm, ice-free Cretaceous and the much colder Neogene (Zachos et al. 1993). PETM i.e. Paleocene-Eocene Thermal Maxima (Thomas et al. 2000) is widely considered as the first major Paleogene climatic event of sudden global warming which occurred at the Paleocene-Eocene boundary. This episode is also referred by other authors as LPTM i.e. Late Paleocene thermal maxima (Zachos et al. 1993) and IETM i.e. Initial Eocene Thermal Maxima (Thomas et al. 2006). The Paleocene / Eocene boundary is marked in the GSSP (Dababiya section, Luxor, Egypt) at the LO biochron of *A. sibaiaensis* (\equiv Chron C 24r, ca. 2 Myr) in the planktic foraminiferal scale. P/E boundary is also considered at the onset of a pronounced negative carbon isotope excursion (CIE) (Stott et al. 1996). Planktic foraminiferal 'excursion' taxa such as *A. sibaiaensis*, *A. africana* and *M. allisonensis* that appeared in response to the Initial Eocene thermal maximum (IETM) in the carbon isotope excursion (CIE) interval are reported to occur globally. These short lived planktic foraminiferal 'excursion' taxa (PFET) are proxy indicators for the CIE and may be used in identifying the Paleocene / Eocene boundary (Kelly et al., 1998).

In India, the Paleocene epoch is characterized both by marine and non-marine sediments along with occasional volcanic activity. Rich foraminiferal occurrences (planktic as well as larger benthic) have been noticed in Pondicherry Formation (Cauvery Basin); Modi Formation (K.G. Basin) and foraminiferal limestone (Meghalaya), on the eastern Indian shelf, during Paleocene. Marine Paleocene and younger sequences have also been widely reported under various formation names, in several parts of western Indian shelf stretching from the Kerala-Konkan in the south through Mumbai offshore to Barmar basin in the north. Among the planktic foraminifera, besides short lived planktic foraminiferal 'excursion' taxa (PFET) such as *A. sibaiaensis*, *A. africana* and *M. allisonensis* which have also been reported from Rajasthan, India (Kalia et al, 2008), usually *Globorotalia (Morozovella) velascoensis* Zone was widely recognized as the youngest zone in Paleocene, also corresponding to the ostracoda zone: *Anommatocythere*

indica Range Zone (Bhandari, 2008). However, in the case of larger foraminifera, an assemblage represented by *Discocyclina ramaraoi* and other associated larger foraminifera is believed to correspond to the top of Paleocene in India and underlies *Miscellanea miscella* Zone roughly equivalent to P5. In view of this, an attempt was made to evolve biostratigraphic criteria for defining Paleocene-Eocene boundary by larger benthic foraminifera and index larger foraminifera for Paleocene and Eocene were restudied from selected intervals in wells **KG-T** (interval 1251-3400m) and **KG-B** (interval 1060m to 2759m), over Kakinada terrace, K.G. basin (Fig.1).

MATERIAL & METHODS:

Standard methods of sample processing and examination were followed. About 126 samples from wells KG-T (1251-3725-30m) and KG-B (1060-2759m) referable to Pallakollu, Pasarlapudi and Bhimanapalli formations were studied with special reference to important larger benthic foraminifera. A number of oriented sections were prepared for the important larger foraminifera. The concept of normal order of stratigraphic superposition was followed for studied well sections to know various species of larger foraminifera, successively falling in an evolutionary sequence with their entry (FAD) and exits (LAD) being important events. The ranges of selected larger foraminifera and other fossils have been shown in Figs.2-3. Biostratigraphic subdivision of the two wells showing the position of the Paleocene-Eocene boundary against the foraminiferal zones is provided. The main objective of the study has been to evolve biostratigraphic criteria for defining Paleocene-Eocene boundary by larger foraminifera. In view of this, index larger foraminifera for Paleocene have been marked; compared and possible criteria for the Paleocene-Eocene boundary by planktic microfossils are also discussed.

PREVIOUS STUDIES:

Some of the more important works over the Paleocene-Eocene boundary problem are summarized below:

Davies and Pinfold (1937) recorded *Nummulites nuttalli*, *N. thalicus*, *N. sindensis*, *N. globulus*, *N. sp. cf. N. mamilla*, *Assilina dandotica*, *Miscellanea stampi*, *M. miscella*, *L. haimei*, *Lepidocyclina (Polylepidina) punjabensis*, *Discocyclina ranikoti*, *Alveolina vredenburgi* and others from the Ranikot beds of Punjab Salt Range, Pakistan. These strata are commonly referred to the Late Paleocene. Adams (1970, 1987) regarded *Actinosiphon punjabensis*, *Assilina dandotica*, *Discocyclina ranikotensis*, *Fasciolites (including F. vredenburgi)*, *F. glomalveolina*, *Lockhartia spp.*, *Miscellanea miscella*, *Nummulites nuttalli* (= *Ranikothalia nuttalli*), *N. spp.*, *Operculina sindensis*, *O. canalifera* and *Saudia labyrinthica* as the diagnostic fauna for Late Paleocene in Indian areas. To refer Adams (1970); while reconsidering the East Indian letter classification of the Tertiary, stated that no continuous carbonate succession across the Ta1/Ta2 (=Paleocene / Eocene) boundary has been described and there exists a faunal break between the youngest Ta1 and oldest Ta2 larger foraminiferal assemblages everywhere in the south-

east Asian region. In west Pakistan where strata of Ta 2 age rest over Ta1 beds e.g. Dungan Hill and Mehrab Tangi, Baluchistan and at Thal, N.W.F.P., still the faunal sequences are either undescribed or need detailing” Later on, Adams (1987) redescribed important Paleocene genera *Actinosiphon* and *Orbitosiphon* and suggested that additional data on the morphology, variation and stratigraphic levels of these taxa will be needed to establish their true relationships to the other groups. Commenting on the evolutionary history of the Tertiary orbitoidal foraminifera, he believed that the Cretaceous orbitoids became extinct at the end of Maastrichtian times and were replaced by new larger foraminiferal faunas in the Tertiary. The earliest Paleocene larger benthic foraminifers are still not fully known and in places where both Maastrichtian and Paleocene larger foraminiferal faunas occur (e.g. the Middle East and Pakistan) the Cretaceous / Tertiary boundary (KTB) is marked by pronounced facies changes. In the later part of Middle Paleocene, a low diversity larger foraminiferal fauna is occurring e.g. primitive Tertiary alveolinids such as *A. (Glomalveolina) primaeva* Reichel, simple nummulitids and rotaliids such as *Lockhartia*. Few orbitoidal foraminifera occur before the Late Paleocene when *Actinosiphon* and *Orbitosiphon* are found with discocyclinids in the circum-tropical region. Discussing the evolution of lepidocyclinids and related genera, Adams regarded *Actinosiphon* to be less likely ancestor of *Lepidocyclina*. The occurrence of *Miscellanea* and / or *Ranikothalia* has never been proved to be confined to the Paleocene owing to the absence of any form of control over their extinction levels. Adams considered *Orbitosiphon* and *Actinosiphon* to be restricted only to Paleocene.

Schaub (1968) while discussing some Paleocene and Eocene stages of Paris basin observed that in the Mesogean marine series, there are five biozones in the stage “Illerdian” i.e. above the Thanetian and below the zone of *N. planulatus*, whereas, the three biozones between the Illerdian and the inferior Lutetian at *N. laevigatus* represent the “Cuisian” stage. Probably the Sparnacian and the Ypressian s.s. are correlated to the upper zone of the Illerdian, but the exact correlation was not possible. Amard and Blondeau (1979) described the appearance of *Ranikothalia bermudezii* in the Upper Paleocene of Sahara in association with *Lockhartia sp.*, *Miscellanea miscella* and other fossils. They traced the limit of Paleocene / Eocene not only with the appearance of true *Nummulites* but also with the disappearance of *Ranikothalia* and above all by the microfaunal assemblage of upper Paleocene.

Berggren, Kent and Flynn (1986) opined that the exact location of Paleocene-Eocene boundary has been a subject of controversy since Schimper (1874) originally defined the Paleocene. Alternative placements have spanned the extremes of basal Illerdian (= base of *Nummulites deserti / frassi* Zone) to the base of Cuisian (= base of *Nummulites planulatus* Zone) with intermediate positions including the base and top of the Sparnacian, base of Ypressian, top of the Landenian stages. Marine micropaleontologists have drawn the Paleocene-Eocene boundary at various levels ranging from the *Planorotaloides pseudomenardii-Morozovella velascoensis* (P4-P5) boundary to the *Morozovella formosa – M. aragoensis* (P7-P8) boundary, with intermediate positions including the P5-P6 boundary, the *Pseudohastigerina* Datum (within zone P6), base of Zone NP9, base of Zone NP10, middle of zone NP10, base of the *Apectodinium hyperacanthum* Zone, base of *W. astra* Zone, etc. Berggren et.al.

considered Paleocene to be consisting of two stages, the Danian and the Thanetian and have also suggested a Paleocene time scale. They summarized the data on Paleocene-Eocene boundary and suggested the boundary to lie-

1. Between *A. hyperacanthum* (Sparnacian) – *W. astra* (Ypressian) dinocyst Zones.
2. Between calcareous nannoplankton zones NP9 (Thanetian) and NP10 (Ypressian) or within zone NP10.
3. Between zones P6a and P6b (planktic foraminifera).
4. Within the lower part of chron C 24 R corresponding biostratigraphically within the tuff series of North Sea and N.W Europe; near the base of Division A2 of the London Clay Formation; and near the base of Lepar Formation (Belgium) and the Cuisian s.l. (France).

Mohan and Pandey (1971) discussed the Paleocene-Eocene boundary in Indian basins and suggested that the recommendations of the Eocene Colloquium (Paris, 1968) for delineation of Paleocene-Eocene boundary by means of planktic and larger foraminifera are not well applicable in the Indian region. They opined that in the Indian region *Nummulites* and *Assilina* first appear in the lower part of *G. pseudomenardii* Zone. Pandey and Ravindran (1988) discussed the boundaries and subdivisions of the Indian Paleocene based on foraminiferal controls and related aspects and suggested a tie-up of planktic foraminifer zones and benthic assemblages. Shukla (2008) considered the first appearance of *Nummulites*, *Assilina*, *Discocyclina*, *Lockhartia*, *Daviesina*, *Miscellanea* and *Alveolina* nearly at the same level in the Indian late Paleocene, in association with initiation of extensive carbonate deposition on the shelf. Top of *Globorotalia* (*M.*) *velascoensis* Zone and *Discocyclina ramaraoi* (*seunesi*) Partial Range Zone coinciding with the P6a / P6b boundary have been regarded as the good choice for the Paleocene / Eocene boundary in the Indian region.

CASE HISTORY: FAUNAL OCCURRENCES AND AGE ASSIGNMENTS:

Well KG-T:

Foraminiferal record between intervals 1251-3400m was studied for faunal controls, occurrence and diversity of index larger benthic taxa (Fig.2). The former level corresponds to Eocene and the later Cretaceous on the basis of occurrence of *Globotruncana* spp. Lithologically, the section comprises mainly the clastic sediments with minor carbonates and represented by sandstones, siltstones, clays, claystone, minor shale and occasional limestone, however, the dominance of clastic over other types of sediments is significant. Almost continuous record / succession of certain larger benthic foraminifers were observed during Late Paleocene-Eocene coinciding with the gradually changing paleobathymetry. In order to understand faunal succession through geological time, a bigger interval was taken up and a few observations over the studied interval are as follows:

1. Well section below 3000m is frequented by planktic foraminifer species referable to Paleocene. Sporadic / inconsistent occurrence of larger benthic foraminifers is also noted. Important planktic species in the interval 3000-3400m include *Globorotalia velascoensis*, *G. pseudomenardii* and others.
2. Interval 2600-3000m shows fairly good occurrence of larger foraminifer species but with lesser diversity. Planktic foraminifers are either absent or rare. A significant change in the preservation type, relative abundance, colour and to some extent size of the larger index species is observed below 2560-65m. Here the fauna is dark, some times pyritized and relatively smaller and more abundant.
3. Interval 1251-2600m is represented by a rich and diversified larger foraminifer population and a number of Paleocene and Eocene species range through it.
4. Considering the first down hole appearance (=LAD) of index taxa, the LAD of *Assilina dandotica* was marked at 2000-05m. The LAD of *A. pustulosa* was at 1950-55m, and could not be recorded in the side wall core sample at 1978.5m. Almost consistent record of *A. dandotica* has been made further below up to 3000m.
5. Considering the *A. dandotica* top as the Paleocene top along with other Paleocene index foraminifers the Paleocene/Eocene boundary in the well was suggested at 2000m. The faunal occurrences and ranges are shown in Fig.2.
6. Other significant Paleocene larger foraminifers include *Actinosiphon sp.*, *Lockhartia sp. aff. L. haimei*, *Daviesina langhami*, *Discocyclina seunesi*, *Nummulites frassi*, *N. solitarius* and *Assilina sp. aff. A. ranikoti*. *A. aff. Arenensis* and *A. pustulosa* although quite abundant in the Paleocene also range into Eocene.
7. Non-typical occurrence of *Ranikothalia sp.* does not help to mark the Paleocene / Eocene boundary firstly because the typical *Ranikothalia* seems to be absent and secondly the ranikothaline *Nummulites* ranges above the extinction level of definite Paleocene taxa. *Ranikothalia* itself may well range into the basal Eocene (Adams, 1987).
8. Predominant Eocene forms include *A. papillata*, *A. exponens*, *N. acutus*, *N. douvillei*, *N. anomalous*, *N. chavannessi*, *Pellatispira sp.*, *Fasciolites (Alveolina) sp.* and species of *Discocyclina*.

Summarizing, lithologically the studied interval (1251-3400m) comprises mainly the clastic sediments with minor carbonates. A continuous succession of important larger benthic foraminifers was observed during Late Paleocene through Eocene and foraminiferal occurrence and diversity suggests Paleocene and Eocene ages. Interval 1251-2600m is represented by a rich and diversified larger foraminifer population and a number of Paleocene and Eocene species range through it. Significant Paleocene larger foraminifers in well **KG-T** include *Assilina dandotica*, *Actinosiphon punjabensis*, *Lockhartia Haimei*, *Daviesina langhami*, *Discocyclina ramaraoi*, *Nummulites frassi*, *N.*

solitarius and *Assilina Ranikoti*. *A. sp. aff. A. arenensis* and *A. pustulosa* although quite abundant in the Paleocene, also range into Eocene. The first down hole appearance (=LAD) of index taxa: *Assilina dandotica* was recorded at 2000-05m and continues up to 3000m. *A. pustulosa* although appears for the first time in 1950-55m, however, is not recorded in the underlying core sample (at 1978.5m SWC). Almost consistent record of *A. dandotica* has been made further below up to 3000m. Typical *Ranikothalia* seems to be absent, however, the ranikothaline *Nummulites* occurs which ranges above the extinction levels of definite Paleocene taxa. Prominent Eocene forms include *Assilina papillata*, *A. exponens*, *Nummulites acutus*, *N. douville*, *N. anomalous*, *N. chavannessi*, *Pellatispira sp.*, *Fasciolites (Alveolina) sp.* and species of *Discocyclina*.

Well KG-B:

Foraminiferal record between intervals 1060-2759m was examined for faunal diversity, controls and occurrences of larger foraminifera (Fig.3). The former level corresponds to Eocene while the later to Paleocene. The interval is characterized by clastic dominated facies with intermittent carbonates and is represented by sandstones, shale, siltstones, clays (Claystone) and limestone/dolomite. Below 2340m, shale occurs as the dominant lithological constituent. Almost consistent occurrence of important larger benthic taxa was observed in complete section excepting for the SWC at 2759m yielding only smaller benthic fauna. Following are a few observations made over the faunal occurrences-

1. Cutting interval between 1770-2505m is characterized by fairly consistent occurrence of *A. danotica* along with other prominent Paleocene assemblage. *A. pustulosa* and *A. sp. aff. A. arenensis* occur only in the upper part and continue into the Eocene section.
2. Development and abundance of *A. pustulosa* seems to be better in KG-B as compared to well KG-T, where the *A. pustulosa* is not abundant in the Eocene section; instead a single first down-hole occurrence is noticed at 1950-55m.
3. Late Paleocene section in the well KG-B is represented by *A. dandotica*, *A. sp. aff. A. ranikoti*, *A. sp. aff. A. arenensis*, *A. pustulosa*, *Lockhartia sp. aff. L. haimei*, *Actinosiphon sp.*, *Daviesina langhami*, *N. frassi*, *N. solitarius*, *N. sp. aff. N. precursor* and *D. ramaraoi* etc.
4. Most prominent among the Eocene larger foraminifera are *A. papillata*, *A. exponens*, *Nummulites acutus*, *N. chavannessi*, *N. douville*, *N. stamineus*, *N. laevigatus*, *N. anomalous*, *Lockhartia alveolata* and *Pellatispira sp. Fasciolites (Alveolina) sp.* *Fasciolites (Alveolina)* are fairly common at certain levels and are highly complex evolutionary group during lower Tertiary.
5. *Miscellanea* is not a typically developed genus in these wells and only rare occurrences have been noticed in the Paleocene sections. A comparison made with the

typical *Miscellanea miscella* from the western offshore well KD-1 attributes the non typical nature of KG. Basin species to the substratum / provenance conditions or the paleobathymetry.

Summarizing, larger foraminifera between intervals 1060-2759m were examined for faunal diversity, controls and occurrence of index species. The section is characterized by clastic dominated lithofacies with intermittent limestone / dolomite. Almost consistent occurrence of key larger benthic taxa was observed excepting for the SWC at 2759m yielding only smaller benthic fauna. Cutting interval between 1770-2505m is characterized by fairly consistent occurrence of *Assilina dandotica* along with other prominent Paleocene assemblage comprising *Assilina ranikoti*, *A. sp. aff. A. arenensis*, *A. pustulosa*, *Lockhartia haimei*, *Actinosiphon sp.*, *Discocyclina ramaraoi (seunesi)*, *Daviesina langhami*, *N. frassi*, *N. solitarius*, *N. sp. aff. N. precursor* and *Discocyclina sp* etc. (Fig.3). *A. pustulosa* and *A. sp. aff. A. arenensis* occur only in the upper portion of the interval and continue into the Eocene. Prominent among the Eocene larger foraminifers are *A. papillata*, *A. exponens*, *Nummulites acutus*, *N. chavannesi*, *N. douvillei*, *N. stamineus*, *N. laevigatus*, *N. anomalus*, *Lockhartia alveolata* and *Pellatispira sp. Faciolites (Alveolina) elliptica*. Genus *Miscellanea* is not a typically developed in these K G wells and only rare occurrences have been noticed in the Paleocene sections.

ESTABLISHING FORAMINIFERAL BIOSTRATIGRAPHIC EVIDENCES FOR LATE PALEOCENE:

Lower Paleogene over Kakinada terrace is generally characterized by good larger foraminiferal diversity and control. A fairly continuous evolutionary series among the faunal assemblages can be traced in these wells from Upper Cretaceous-Lower Paleocene to Upper Paleocene-Eocene levels. With the gradually changing bathymetry in **Well KG-T**, the older Upper Cretaceous-Lower Paleocene section is dominated by planktonic and smaller benthic faunas indicative of deep water outer shelf to bathyal environments. Occurrence of index planktonic species such as *Globorotalia pusilla*, *G. velascoensis*, *G. pseudomenardii* and others at 3205-3210m is considered equivalent to planktic datum: zone P4. Overlying about 200m section does not indicate very good larger or planktonic foraminiferal controls and is also characterized by less diversity and less abundance of the taxa. Consistent occurrence of important Paleocene and Eocene larger foraminifers in the younger sequence in **well KG-T** suggests shallow water inner shelf stable environments of deposition with gradually increasing larger foraminifer diversity. In **well KG-B**, however, the larger foraminifera are occurring through out the studied interval and abundance of certain taxa is much better than in **well KG-T**.

Taking into account the present status of index larger foraminifera during Late Paleocene and Eocene in KG basin wells, rich assemblage comprising of *Assilina dandotica*, *A. ranikoti*, *A. leymerie*, *Discocyclina ramaraoi (seunesi)*, *Actinosiphon punjabensis*, *Actinosiphon sp.*, *Daviesina langhami*, *Nummulites solitarius*, *N. indicus*, *N. sp. aff. N. precursor*, *Lockhartia haimei*, *Ranikothalia sp* and *Miscellanea spp* as indicative

of Late Paleocene age on the Kakinada terrace. The extinction level of *Assilina dandotica* which is seen above the extinction levels of many associated taxa, has been considered as the Paleocene / Eocene boundary in these wells and may correspond to the short lived planktic foraminiferal 'excursion' taxa (PFET) zone comprising *A. sibaiaensis*, *A. africana* and *M. allisonensis* in areas of planktic foraminiferal dominance. It has also been observed that among the Paleocene genera *Actinosiphon* and *Orbitosiphon*, the former is well developed in these wells whereas the later could not be recorded. *Ranikothalia* although suspected of not being confined only to Paleocene, is non-typical in studied material and should be regarded as a good Late Paleocene marker species. *Nummulites* as such are rather well developed in the Late Paleocene-Eocene sediments and a number of species such as *N. frassi*, *N. solitarius*, *N. praecursor* provide supporting evidences to the Late Paleocene level. The abundance of and *N. exilis* (group) forms is evident in basal part of Early Eocene rather than in the Late Paleocene. Genus *Alveolina* (*Fascoilites*) is non-typical and less abundant in K G wells; however, several species of *Alveolina* such as *A. ellipsoidalis* and *A. pasticillata* etc are excellent markers for the Late Paleocene over Indian shelf. On the contrary, the Eocene larger foraminifers are very highly diversified and represented by several genera and species such as *Nummulites acutus*, *N. discorbinus*, *A. papillata*, *A. exponens*, *Nummulites atacicus*, *N. chavannessi*, *N. douville*, *N. stamineus*, *N. laevigatus*, *N. anomalus*, *Lockhartia alveolata* and *Pellatispira sp.* *Alveolina* (*Faciolites*) *elliptica*, *Discocyclina spp* and many more. Shukla et al (2009) had clearly pointed out that Shallow Benthic Zones (SBZ 6 and 7) falling in the Paleocene-Eocene boundary time span and equivalent to basal Illeridian stage (Europe); equivalent to zone P-6a; and also referable to the Khasian stage (India) are the uppermost Paleocene bio-chronozones for Tethyan sedimentary basins in Indian subcontinent and adjacent areas. This level roughly corresponds to 54.2 Ma on the absolute geological age and lies at the top of the P/E boundary transition spanning about 1.3 Ma.

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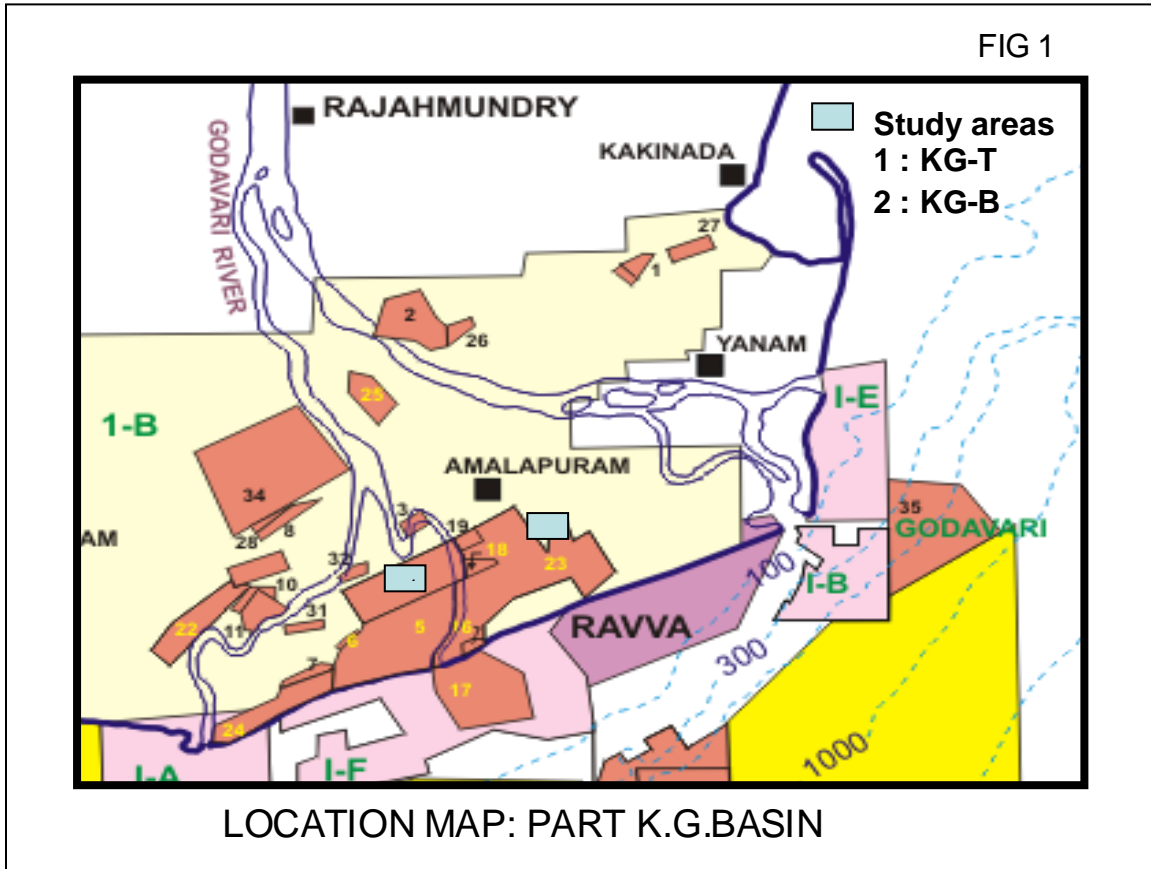
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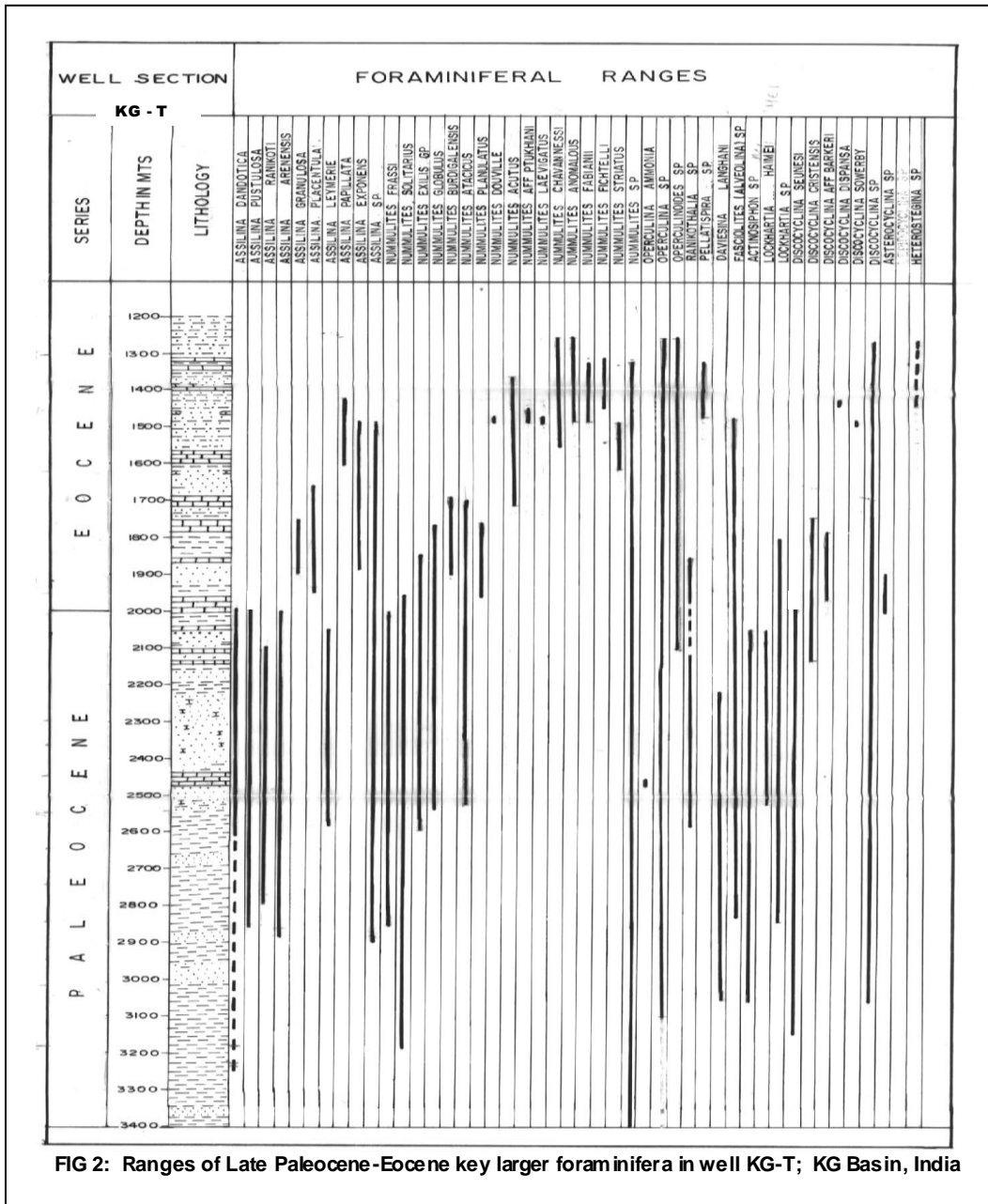


FIG 2: Ranges of Late Paleocene-Eocene key larger foraminifera in well KG-T; KG Basin, India

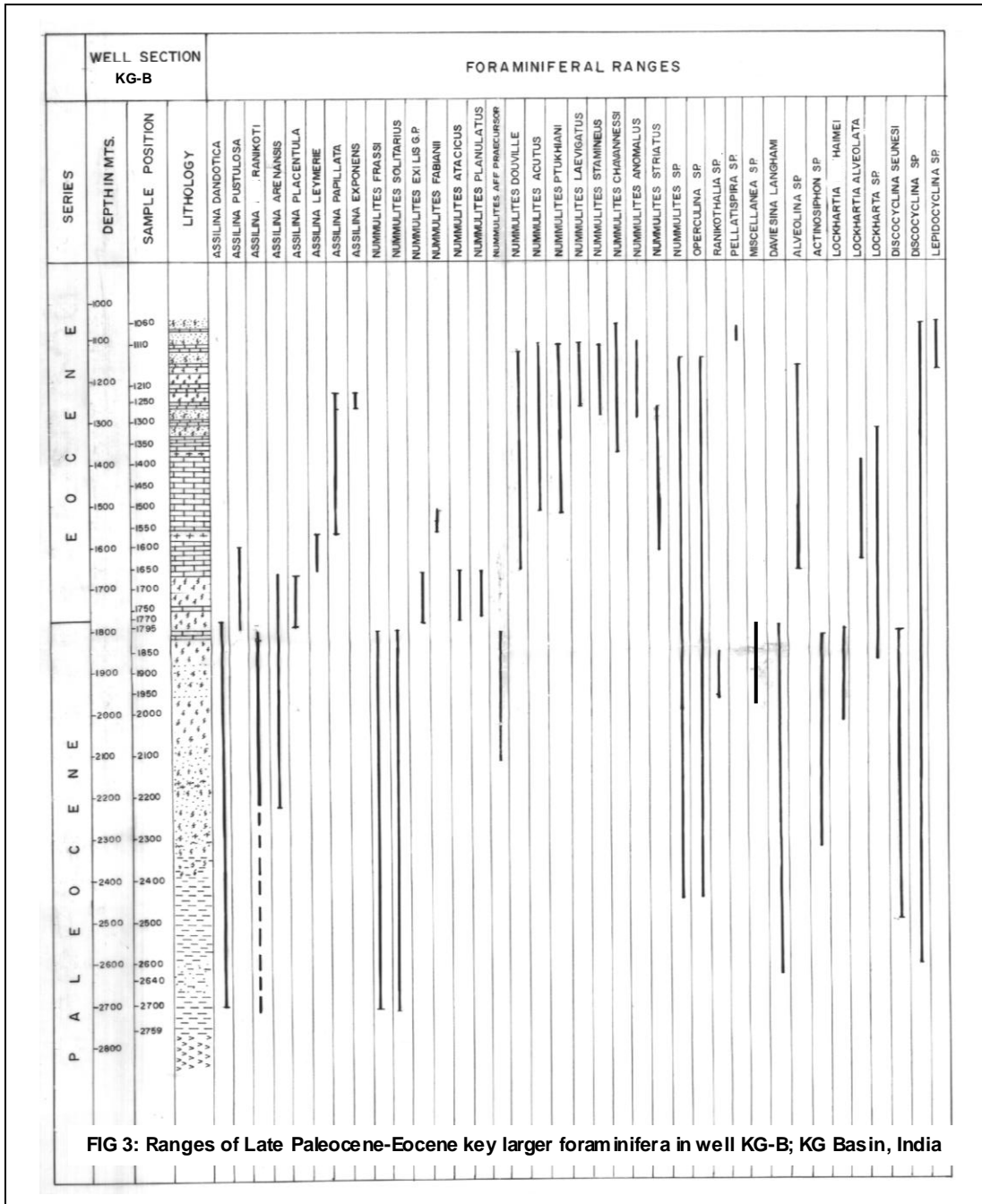


FIG 3: Ranges of Late Paleocene-Eocene key larger foraminifera in well KG-B; KG Basin, India