E-PG PATHSHALA IN EARTH SCIENCE

Content Writers Template

1. Details of Module and its Structure

Module details	
Subject Name	Earth Science
Paper Name	Stratigraphy and Sedimentology
Module Name/Title	**Biostratigraphy**
Module Id	ES 273
Pre-requisites	Before learning this module, the users should be aware of • Fundamental litho, bio and chronostratigraphy units • Macro and microfossils and its relation to time and environment • Geological time scale • Applications of fossils in sedimentary basin studies
Objectives	The objectives of learning this module are to understand • Macro and microfossil clues in decipher the Paleoenvironment of sedimentary basins • To evaluate depositional history with biochronogical framework
Keywords	Biostratigraphy, Foraminifera,

2. Structure of the Module-as Outline : Table of Contents only (topics covered with their sub-topics)

1.0 Introduction to Micropaleontology	
2.0 Biostratigraphy	
	2.1
	2.2
3.0 Principles and Concepts of Biostratigraphy	
	3.1
	3.2
4.0 Principle of Faunal succession	
	4.1
5.0 Concept of Stage	
	5.1 Concept of Zone
6.0 Historical review	
7.0 Biozonation	
8.0 Biozone correlation	
9.0 Applied Biostratigraphy	

10.0 Sequence biostratigraphy	
11.0 Biosteering	
12.0 High-impact biostratigraphy	
13.0 Ecobiostratigraphy	
14.0 Graphic Correlation	
15.0 Biotic Mass Extinctions	
16.0 Future perspective	

3. Development Team

Role	Name	Affiliation
National Co-ordinator		
Subject Co-ordinators (em: epgearth640@gmail.com)	Prof. A. Balasubramanian Prof. K. N. Prakash Narasimha Prof. B. Suresh Kumar	Centre for Advanced Studies Dept of Earth Science University of Mysore, Mysore-6
Paper Co-ordinator	Prof.R.Nagendra	Department of Geology Anna University, Chennai-25
Content Writer/Author(CW)	Dr.A.N. Reddy	(R) Chief Geologist,ONGC
Content Reviewer (CR)		
Language Editor(LE)		

4. E-text (as per table of contents)

Headings	Sub-headings with para-wise contents

1.0 Introduction to Micropaleontology

The study of microfossils is known as Micropaleontology. All microfossil groups are genetically unrelated but require the aid of microscope and hence included under Micropaleontology (fig.1).

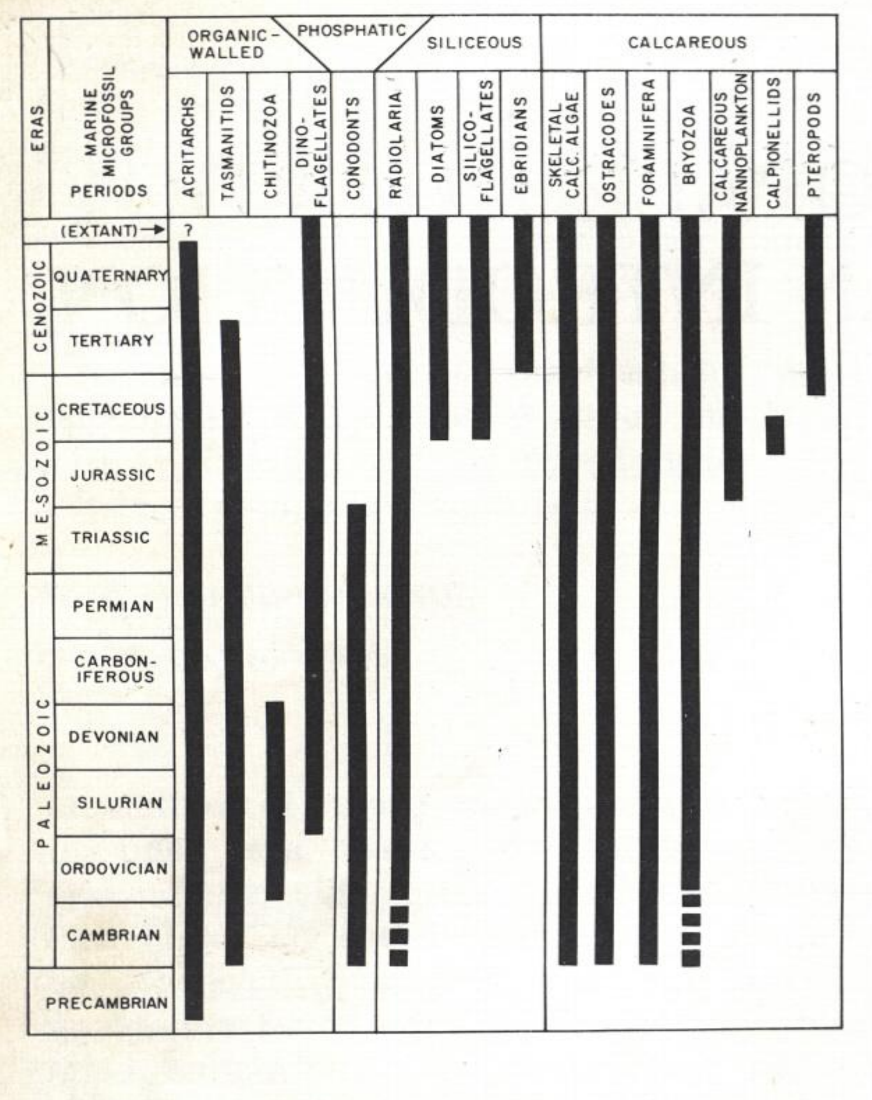

Fig. 1. Stratigraphic distribution of the major marine microfossil groups.

Microfossils (foraminifera, calcareous nannoplanktons, spore and pollen, dinoflagellates and radiolaraians) are abundant and widely distributed in all the environments. Their evolutionary rates are rapid and therefore provide better resolution for **biostratigraphic** correlations. Microfossils are widely used in stratigraphic correlations and depositional modeling, because small amount of sediment sample can yield large quantity of data required for statistical analysis. Available sample size is generally small in oil well drilling, seabed coring and shallow sedimentary cores and thus microfossils are better suited for analysis of this kind of sediment samples. This is one reason why microfossils score over macrofossils especially when sample size is small. The most frequently used fossil groups in biostratigraphy are listed below, together with their use as stratigraphic and environmental indicators.

Fossil group Time indicator	Environment resolution	Stratigraphic (practical use)	Time range	Time x106yr
Spore/pollen	Poor-medium	Medium	Devonian - recent	400 - 0
Nannofossils	Poor	Medium - high	Jurassic - recent	210 - 0
Foraminifera	Good	Medium - high	Carboniferous -recent	360 - 0
Dinoflagellates	Poor	Medium - high	Permian - recent	260 - 0
Diatoms/radiolarian	Medium	Medium - high	mostly Tertiary	65 – 0

Modern micropaleontology is the basis for understanding events in Earth History. No major environmental events can be explained without micropaleontology and its contributions to age dating, regional and global correlation, and the tempo and nature of environmental changes. The latter includes studies of sea level, climate and ocean circulation changes based on what we now know from benthic and planktic species depth habitats and environmental preferences. Micropaleontology is the main biostratigraphic tool in hydrocarbon exploration. In unexplored/complex areas good biostratigraphy can be a very important tool for field mapping, well drilling, testing structural interpretations and correlating reservoir zones.

2.0 **Biostratigraphy**

Biostratigraphy is the branch of stratigraphy which focuses on correlating and assigning relative ages of rock strata by using the fossil assemblages contained within them. It can assign a numerical age to rock strata by correlation to a geochronologically calibrated reference time scale. Biostratigraphy is fundamentally concerned with the recognition of fossils and the relative position of their occurrences in space and time. Various fossil groups can be found in different sedimentary environments. The two main environments are land (terrestrial) and ocean (marine).

The application of biostratigraphy has multifold purposes in petroleum industry both in exploration and development stages to realize commercial hydrocarbons. Biostratigraphy divides the stratigraphic column into chronostratigraphic biozones, which form primary units for basinal scale correlation. The integration of biostratigraphy with seismic data and well logs provides the basis for developing depositional models.

Biostratigraphy uses fossils for correlating and dating sediments. Sediments of the same age can look completely different because of local variations in the sedimentary environment. For example, one section might have been made up of clays and marls while another has more chalky limestones, but if the fossil species recorded are similar, the two sediments are likely to have been deposited at the same time. Different fossils work well for sediments of different ages. Microfossils specially foraminifera, calcareous nannoplanktons, dinoflagellates, spore and pollen are widely employed in biostratigraphy because of their high resolution, better preservation and more abundance for quantitative analysis.

3.0 Principles and Concepts of Biostratigraphy

Introduced here below, basic concepts and principles of biostratigraphy. The concept of biostratigraphy is based on the observations that organisms have undergone successive changes throughout geologic time. Thus, any unit of strata can be dated and characterized by its fossil content. That is, any stratigraphic unit can be differentiated on the basis of its contained fossils from stratigraphically younger and older units.

4.0 Principle of Faunal succession

An English civil engineer Wlliam Smith discovered the principle of faunal succession. He was evidently the first to utilize fossils as a practical tool for characterizing, subdividing, and correlating strata from one area to another. He found rock strata superposition, and also noted that each stratigraphic succession was characterized by the same distinctive fossil assemblage. Soon, this concept became known as the principle (law) of faunal succession. The fossils help to establish a stratigraphic succession and to subdivide the rocks into mappable units by a combination of lithologic characteristics and fossil assemblages.

5.0 Concept of Stage

A stage is a major subdivision of strata. Each strata systematically following the other bearing a unique fossil assemblages. Therefore, stages can be defined as a group of strata containing the same major fossil assemblages.

Alcide d'Orbigny, a French paleontologist has introduced the concept of Stage. Around 1842, d'Orbigny recognized major subdivisions of strata, each systematically following the other and each bearing a unique assemblage of fossils. Like Smith, d'Orbigny recognized that similarity of fossil assemblages was the key to correlating rock units, and further proposed that strata characterized by distinctive and unique fossil assemblages might include many formations (lithostratigraphic units) in one place or only a single formation or part of a formation in another place. He defined groups of strata containing the same major fossil assemblages as stages. The stage boundaries of d'Orbigny' were defined by the last appearance, or disappearance, of distinctive assemblages fossils and their replacement in the rock record by other assemblages. Orbigny named stages after geographic localities with particularly good sections of rock strata that bear the characteristic fossils on which the stages are based.

5.1 **Concept of Zone**

The stage concept of d'Orbigny was useful in subdividing strata into major successions on the basis of fossils, but not effective to divide fossiliferous strata into small-magnitude. In 1876 Albert Oppel introduced the concept of zone and thus altered the practice of biostratigraphy forever. However, Oppel while working with Jurassic rocks in various parts of Germany conceived the idea of small-scale units defined by the stratigraphic ranges of fossil species irrespective of lithology of the fossil-bearing beds. By exploring the vertical ranges of each species, Oppel defined zones. A zone represents the time between first appearance and last appearance of a chosen species or different species. Each zone was named after a particular species, called an index fossil.

6.0 **Historical review**

Micropaleontology is more a practical and utilitarian science which deals with taxonomy, biostratigraphy, paleoecology and paleobathymetry. It has grown over the years from a simple fossil describing medium to 'sequence biostratigraphy' a latest tool in hydrocarbon exploration. rneeIt is important to know the history of its journey to this day. W.A.Berggren has beautifully summarised the history of micropaleontology in his introductory chapter in the book "Introduction to Marine micropaleontology" edited by B.U.Haq and A.Boersma. The brief summary as given by Berggren is as follows. "The great pyramids of Egypt were built using shelly limestone blocks. Millions of tourists have visited the sites and are doing so even now but few have the sense of inquiry. Herodotus (5th Century BC), Strabo (7th Century BC), Pliny the Elder (1st Century AD) were among the first to record the unknown nature of the shells seen embedded in the limestone. The great painter Leonardo da Vinci (1452 – 1519) was the first to recognise the organic nature of the shells. From the historical perspective the period spanning from 5th century BC to 1660 can be designated as the primitive or early phase of paleontology.

Antonie van Leeuwenhoek discovered the microscope in 1660. This heralded the birth of systematic micropaleontology. With the introduction of 10th edition of Linne’s Systema *Naturae* in 1758, the binomial nomenclature became the basis of both modern biological and fossil taxonomy. Micropaleontology began to grow as a concrete science in four successive phases. The first was the descriptive phase. Alcide d’Orbigny (1802 – 1875) carried out detailed descriptive work on foraminifera which led to the first classification in 1826. He was the first to develop foraminiferal biostratigraphy of Paratethyan Tertiaries. C. G. Ehrenberg (1795 – 1876) was the first to discover and describe silicoflagellates, ebridians, coccoliths, discoasters, dinoflagellates and in addition numerous radiolarians, diatoms and foraminifera. Fundamental descriptive works include Reuss’s (1860’s and 1870’s) on Cretaceous and Tertiary foraminifera of Prussia. The contemporaneous “English school” consisted of N.C. Williamson, W.K. Parker, T.R. Jones, W.B. Carpenter, H.B. Brady and C.D. Sherborne. Major studies were carried out on Radiolarians by Ernst Haeckel (1862 – 1887) and on ostracodes by Sars (1886). The preparation of diatom atlas was initiated in 1875 by Schmidt. The 19th century H.M.S. Challenger voyage from 1873 to 1876 gave tremendous impetus to descriptive work. The monograph on foraminifera by H.B. Brady in 1884 remains to this day one of the most fundamental works in micropaleontology.

The second phase in the growth of micropaleontology was the analytical phase. This is the period from last decade of 19th century to 2nd world war. Most of the studies during this period involved the analysis of basic biologic structures, morphogenetic studies and creation of classificatory systems and biostratigraphy. Deep sea drilling programs JOIDES in 1965 and DSDP in 1968 lead to the most important phase in the history of the growth of micropaleontology called the synoptic phase. Voluminous data on both fossil and living organisms was generated throughout the world based on the cores from these programs. Great strides were made in the understanding of the planktic and benthic foraminiferal evolution. This has lead to greater understanding of the evolution of the oceans themselves. Biostratigraphic zonations, paleoecological interpretations and paleobathymetric reconstructions were the major advances during the synoptic phase. And this was possible because of the enormous data base that was created from worldwide marine biosphere. Some of the most important catalogues of various fossil groups such as foraminifera, ostracoda and others were made available in 1970’s and 1980’s.” The birth of economic or commercial micropaleontology can be attributed to the advent of oil industry. This signalled the present ‘Application phase’ of micropaleontology. The application of biozonations in the petroleum exploration for dating, correlation and interpretation of sea level cycles brought new awareness among the geoscientists. Most of the biozones were integrated with paleomagnetic and radiochronologic schemes and an integrated time scale was made available. Geological Time Scale 2012 is a case in example.

7.0 **Biozonation**

The fundamental unit of biostratigraphy is the biozone. Biozones are units of stratigraphy that are defined by the fossil taxa (usually species and subspecies) that they contain. These biozones are extremely useful in the exploration realm, where basinwide correlation is of interest. But at the reservoir scale, this coarse resolution needs much more precision. According to W. A. Berggren, interpretations of earth's history depend on two different systems of logic, which arrange geological observations into sequences of events. 1) *logic of superposition*: orders events iteratively in a system of variant properties by determining the physical relationship of features in the rock. 2) *ordinal progression*: which links a series events in a system of ireversibly varying characteristics.

The evolution of organisms through time has provided a framework for system of zonations by which discrete units of time represented by material accumulation of sediments can be recognized. Biozones may generally be grouped into various categories depending on their characteristic features (fig.2).

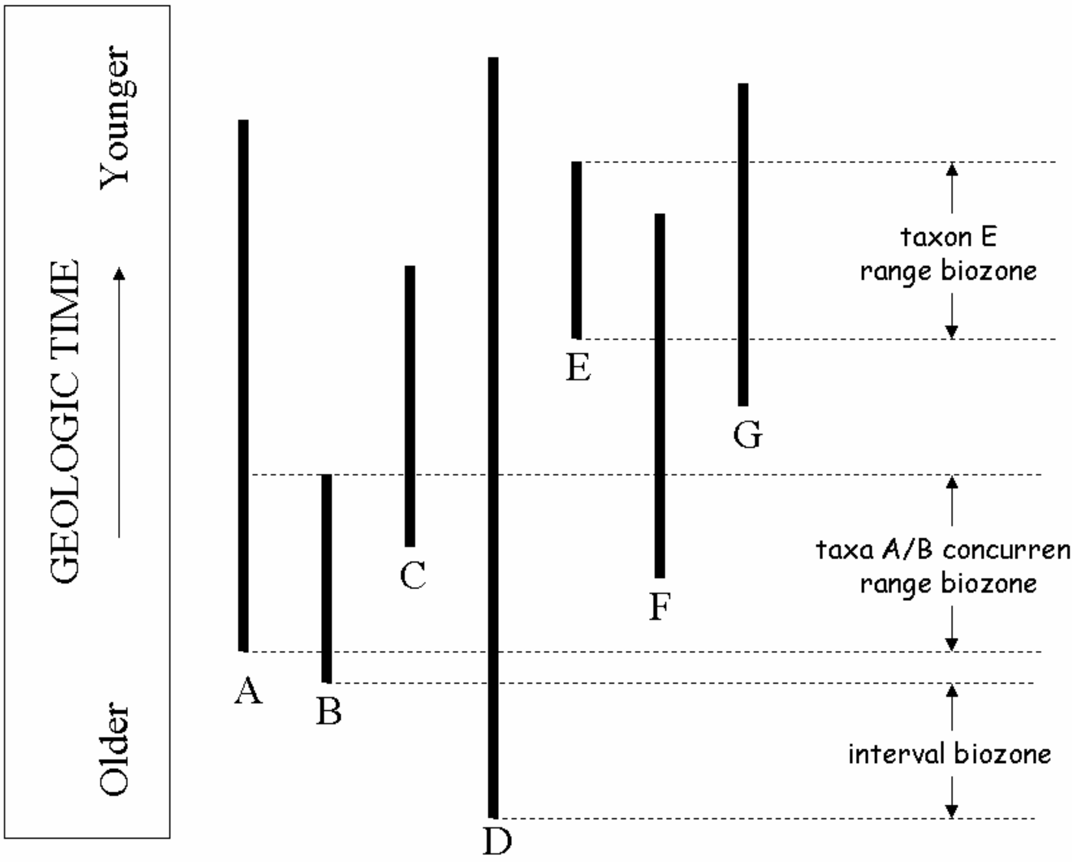

Figure 2. Different kinds of biozones defined on the basis of stratigraphic ranges of hypothetical fossil species A–G

The zone is the fundamental biostratigraphic unit. Its thickness range from a few to hundreds of metres, and its extant range from local to worldwide. Biostratigraphic units are divided into six principal kinds of biozones:

- *Taxon range biozone* represents the known stratigraphic and geographic range of occurrence of a single taxon (species or genus).
- *Concurrent range biozone* include the concurrent, coincident, or overlapping part of the range of two specified taxa.
- *Interval biozone* include the stata between two specific biostratigraphic surfaces. It can be based on lowest or highest occurrences.
- *Lineage biozone* are strata containing species representing a specific segment of an evolutionary lineage.
- *Assemblage biozones* are strata that contain a unique association of three or more taxa.

- *Abundance biozone* are strata in which the abundance of a particular taxon or group of taxa is significantly greater than in the adjacent part of the section.

8.0 Biozone correlation

Stratigraphic correlation is accomplished by matching distinct stratigraphic surfaces or horizons recognized in a stratigraphic succession at one locality to their equivalent counterparts in a succession at another locality. This allows the extension of recognized stratigraphic units and surfaces into new geographic areas and potentially to areas around the world. One of the main goals of correlation is to establish an approximate time-stratigraphic correlation framework so as to allow facies relationships to be determined and predictions of facies occurrences to be made. Interpretations of depositional history and paleogeographic evolution also depend upon such a framework built by the correlation of stratigraphic surfaces that have a low diachroneity or are time barriers. Low diachroneity surfaces are often delineated in **biostratigraphy**, magnetostratigraphy, and chemostratigraphy.

Index fossils are more useful in stratigraphic correlation of strata which are located at a distance. Because, index fossils are easy to identify, rapidly evolving, independent of environment and geographically widespread and therefore invaluable in correlation.The first and last occurrences of fossils are examples of unique events that can be used for correlation between stratigraphic sections. Biostratigraphic events are geologically instantaneous changes to the stratigraphic distribution (range) of a fossil species. Terminologies describing these events include Top, extinction horizon, last occurrences(LO), last appearance datum (LAD), first downhole occurrence (FDO). Others are acme events, abundance peak, increase, pulse, influx, flood, coiling change, second occurrence, base, bottom, inception horizon, first occurrence (FO), first appearance datum (FAD) and last downhole occurrence (LDO).

9.0 Applied Biostratigraphy

From what we have understood from the historical perspective, micropaleontology has a long, glorious path of evolution into a concrete science. From a primitive beginning to descriptive, analytic, synoptic and application phase, micropaleontology has made a long journey. Biostratigraphy virtually provides solutions to every geological problem in marine sedimentary basins. Biostratigraphy and applied micropaleontology are essential tools in exploration activities for oil and gas industry. Microfossils, such as foraminifera, are of high importance since they occur in a variety of marine environments and through the geological time.

Biostratigraphy has been playing a dominant role in every aspect of hydrocarbon exploration. In seismic interpretation, foraminiferal data is employed in constraining the age of major seismic horizons. Foraminifera are used to develop depositional models based on paleobathymetric interpretations. The advent of sequence stratigraphy in 1977 demanded a major role by micropaleontologists specially in characterizing sequence parameters. This is so because seismic is indirectly derived information while microfossils provide direct observations. Fossil data is imperative in authenticating any indirectly obtained geological information such as seismic in petroleum exploration.

10.0 **Sequence biostratigraphy**

The principal horizons used in sequence stratigraphic analysis are the sequence boundary, a trangressive surface and the maximum flooding surface. These regionally correlative surfaces can be identified in seismic reflection profiles, on wireline logs, in outcrop stratigraphic sections and from checklists of microfossil abundance and diversity.

The relative sea-level fall leading to the formation of a sequence boundary causes a basinwards shift in facies and the development of an unconformity on the shelf. This should be reflected in a dramatic change in microfossil assemblages, together with missing biozones. Maximum flooding surface (MFS) is often be recognized by a paleontological abundance peak, especially of planktic microfossils together with condensation of biozones. This surface is wide spread in nature and thus has significant correlation potential, and one of the most critical surfaces to recognize in the sequence stratigraphic analysis of a succession. Systems tracts could be characterised by particular assemblage (that is the composition, diversity and density of asssemblages and the morphology and size of individuals) that are themselves are response to relative sea-level change. opportunistic taxa may charcterise a transgressive systems tract, whilst species diversification takes place during the highstand systems tract.

In the Krishna – Godavari basin, the sequence depositional model (fig.3) developed for the Miocene reservoirs using foraminiferal data practically explains the shifting patterns of depocentres as a response to transgressive and regressive cycles. This model explains what happens to reservoir facies during sea level rise and fall and how the reworking takes place during unconformities. This model is predictive in nature and guides the exploration strategy.

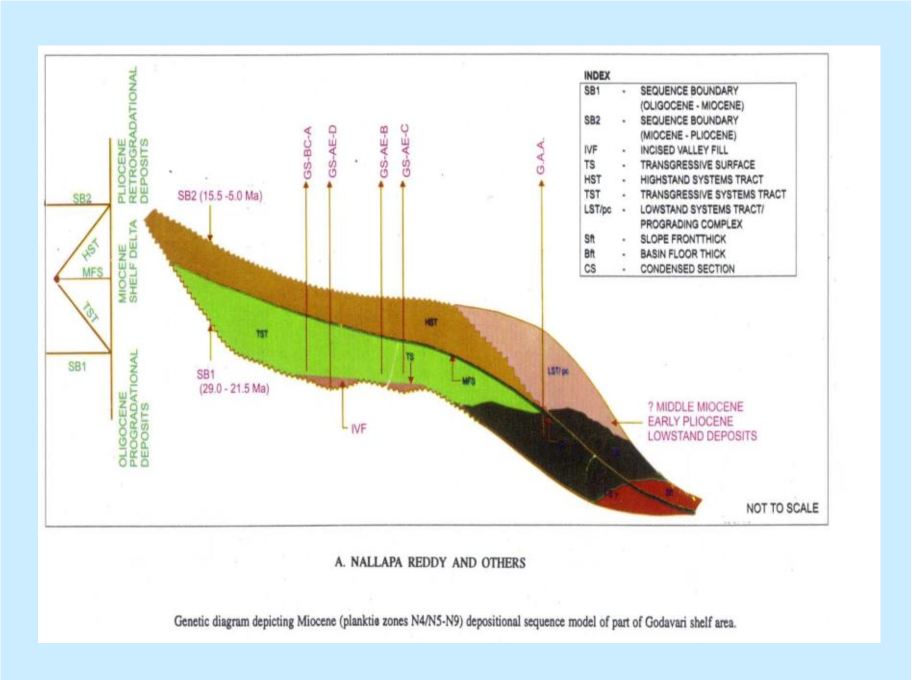

Figure 3. Sequence depositional model for Neogene of the KG Basin

Similarly, in the Cauvery basin, the paleobathymetric trends developed for the outcrops are extendable to sub-crops based on fossil markers. The sequence boundary surfaces recognised in the Ramnad sub basin are found to host reservoir facies during regressive phases at the end of middle Turonian and Santonian respectively.

11.0 **Biosteering**

'Biosteering' is the latest tool to control directional and horizontal drilling to maximise production potential of reservoirs. With these developments, micropaleontology became almost an integral part of multidisciplinary exploration strategies. Biosteering is a derivative of the high-resolution biostratigraphic techniques that attempts to resolve reservoir penetration challenges. Biosteering is intended to maximize reservoir penetration by biostratigraphically "fingerprinting" the reservoir-enveloping, non-pay package during drilling. If the well-bore encounters non-pay, having passed up through the top of the reservoir or down through the base, or passes out of the reservoir due to offset by faults (often of sub-seismic resolution), high resolution biostratigraphy provides a tool to steer the well bore-back into the reservoir.

12.0 **High-impact biostratigraphy**

Any biostratigraphic event that is repeatable with potential field-wide chronostratigraphic significance is the basis for high-impact biostratigraphy. These bioevents can be used to "fingerprint" mudstones, which can then be integrated with wireline logs and tied around the field. Central to the application of high impact biostratigraphy is thinking at field scale and "pushing the data hard," but always integrating and iterating with other geoscience disciplines. This approach may call for dropping a formal biozonation in favor of the use of a series of finer scale bioevents. While it is still possible to relate the local bioevents back to a broader regional biozonation scheme, strong emphasis is placed on "anything goes" to develop a localized, field-focused scheme driven by any repeatable bioevent.

13.0 Ecobiostratigraphy

Analysis of source rock potential using oxic and anoxic events is another field where fossil data plays an important role. The concept of ecostratigraphy was introduced in 1973. This was a new approach that encompasses all the ecological (biotic and abiotic) aspects in stratigraphy. The basic premise is that genetic changes does not proceed on isolated taxa but in the frame of ecosystems and is, therefore, intimately associated with the ecological succession. Environmental factors, far from being distorting signals provide the basis for more accurate correlations. Events are restricted in space, but if the geographical domain in which they occur is known, a space-dependent stratigraphy is possible.

14.0 Graphic Correlation

Graphic Correlation is a quantitative, but non-statistical technique to determine the coeval relationships between two sections by comparing the ranges of taxa in both sections (fig.4). One of these (the most complete) is a designated Standard Reference Section. Graphic correlation compares the rate of sediment accumulation in one section with that of the other and thus enables (and forces) a stratigrapher to consider the sedimentological events along with the biostratigraphic events.

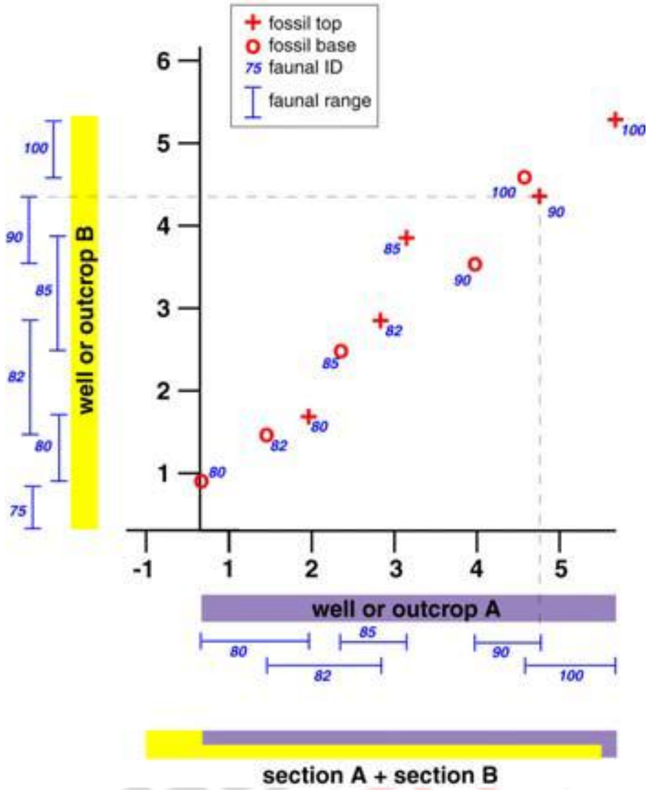

Figure 4. Showing the graphic correlation between locations A and B.

15.0 **Biotic Mass Extinctions**

The Cretaceous-Tertiary Boundary (KTB) is one of the most debated geological problems in the latter part of 20th century beginning in 1970's. Was it bolide impact or Deccan volcanism which caused the mass extinction? There are two schools of thought with impact lobby dominating the whole course of debate for more than three decades. Gerta Keller of Princeton University, USA and her team (includes A.N. Reddy and B.C. Jaiprakash from India) has used foraminiferal data and shown that the bolide impact was not the cause of KTB mass extinction and Deccan volcanism from India did the act. This is one example where fossil data has played a decisive role in understanding evolution and extinction patterns of life on earth.