Application of palynology and micropalaeontology in hydrocarbon exploration

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ABSTRACT

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Palynology and micropalaeontology have developed into multifaceted disciplines with new applications in oil industry. These techniques provide precise age of rock samples derived from hydrocarbon exploration and development drillings, as well as from outcrops. The microfossils are also used for determining hiatusus/unconformities, stratigraphic correlation, interpretation of depositional environment, reconstruction of palaeogeography, and recognition of source rocks. The methods involve the microscopic analysis of palynomorphs, organic remains, foraminifera, calcareous nannoplankton, ostracoda, etc. Palynology is often used in conjunction with the analysis of calcareous nannoplankton and foraminifera. The value of micropalaeontological and palynological analysis for resolving stratigraphic and palaeoenvironmental problems has increased multifold after the development of sequence stratigraphy in identifying source rock, oil or gas bearing strata and geometry of pay sands and other applications. The data derived from these microfossils are incorporated with other geological and geophysical evidences to assist in the exploration for hydrocarbons and in the more efficient utilization of existing hydrocarbon discoveries.

Key-words: Applied palynology, micropalaeontology, hydrocarbon exploration.

INTRODUCTION

There are many areas in oil exploration where palynology and micropalaeontology play an important role. The significant ones are: dating of sediments, high resolution biostratigraphy for finer zonation, correlation of terrestrial and marine sediments, palaeoclimatic and palaeogeographic reconstructions, sea level changes, sequence biostratigraphy and hydrocarbon source rock evaluation.

BIOSTRATIGRAPHY

Biostratigraphy is the differentiation of rock units based on fossils which they contain. Palaeoenvironmental analysis is the interpretation of the depositional environment in which the rock unit was formed, based upon the fossils found within the unit. The three microfossil groups, most commonly used in oil exploration, are foraminifera, calcareous nannofossils and palynomorphs.

Foraminifera are protists that make a shell or test, by secreting calcium carbonate or gluing together grains of sand or silt. Most species of foraminifers are bottom-dwellers (benthic), but during the Mesozoic Era a group of planktonic foraminifera appeared. These forms are free-floating in the oceans and are more widely dispersed than benthic species. After death, the planktonic foraminifers settle at the bottom and can be fossilized in the same rocks as contemporaneous benthic species. Benthic foraminifera tend to be restricted to particular environments and as such provide information to the palaeontologist about the environment where the rock containing these fossils was formed. For example, certain species of foraminifera prefer turbid water near the mouths of rivers while others live only in areas of

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very clear water. These preferences are recognized by two methods: (i) studies of the distribution of modern foraminifera; and (ii) analysis of the sediments containing ancient microfossils. In the first case, if the modern species has a fossil record, one can reasonably assume that the fossil ancestors had similar modes of life as the living organism. However, if the species in question is extinct then one examines modern forms, resembling the fossil ones, inferring that the fossil forms had similar environmental preferences. In the latter case, studies of the rock containing the fossils give further clues to the environment of deposition. While drilling for hydrocarbon in deltaic reservoirs, such information can be very useful by helping to locate ancient deltas both in time and space. Planktonic foraminfera provides less information concerning the environment of deposition, since they lived floating in the water column, but they have other advantages. While benthic foraminifera are restricted to certain environments, planktonic foraminifera are dispersed over a much broader part of the world oceans and are often found in large numbers. On the geologic time-scale, events such as the first appearance of a particular species or its extinction can happen very quickly. For the palaeontologists, these events are useful for dating and stratigraphic correlation.

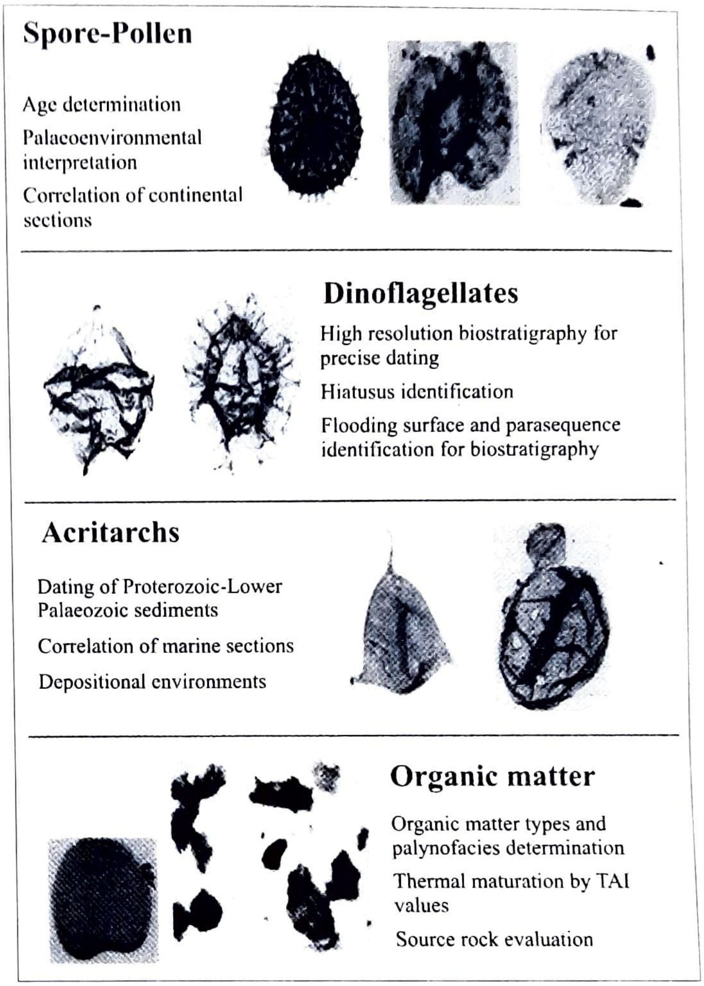

Figure 1. Palynofossils and their applications.

Calcareous nannofossils are extremely small objects (< 25 μm) produced by planktonic unicellular algae. They are made of calcium carbonate. Nannofossils first appeared during the Mesozoic Era and have persisted and evolved through time. The calcareous plates accumulate on the ocean floor, become buried beneath the later deposited layers, and are preserved as nannofossils.

Palynomorphs are organic walled fossils and include fossil pollen and spores, as well as certain marine organisms such as dinoflagellates (Figure 1). Pollen and spores are transported by wind and water and can travel long distances before final deposition. They are resistant to decay and are preserved as fossils and can be used for biostratigraphy. Fossil pollen and spores can also give us information about ancient climates. Additionally, the organic chemicals which comprise palynomorphs get darker with increased heat. Because of this color change they can be used to assess the temperature to which a rock sequence was heated during burial. This is useful in predicting maturation of organic matter indicating whether oil or gas may or may not have formed in the area under study.

APPLICATION OF BIOSTRATIGRAPHY

Biostratigraphy plays a critical role in building of geological models for hydrocarbon exploration and in the drilling operations to test those models. The fundamental principal in stratigraphy is that the sedimentary rocks in the Earth's surface are accumulated in layers, with the oldest on the bottom and the youngest on the top. The history of life on the Earth has been one of creatures appearing, evolving, and becoming extinct. Putting these two concepts together, we observe that different layers of sedimentary rocks contain different fossils (Figure 2). Dating and correlation of sediments are two main applications of biostratigraphy.

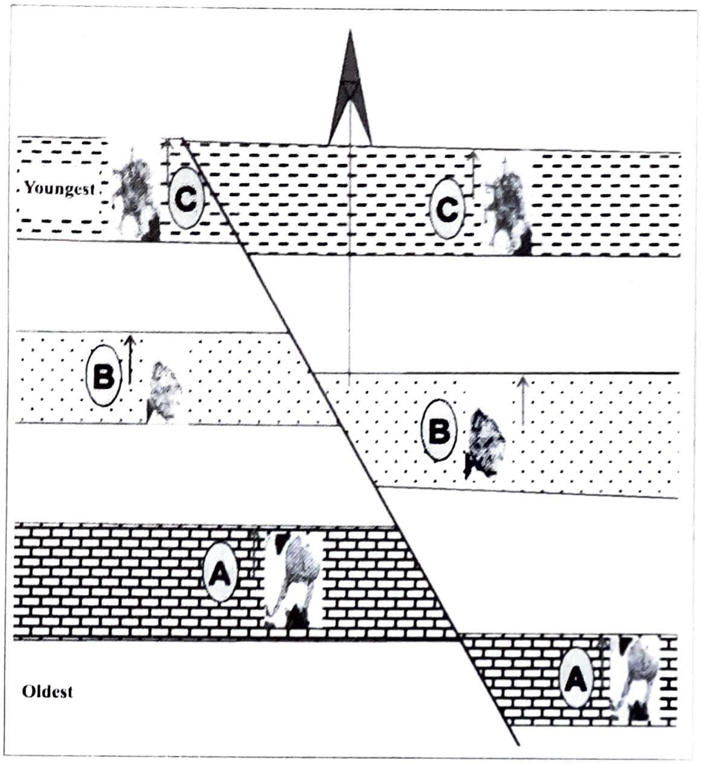

Figure 2. Schematic cross section showing rock units from oldest to youngest with biostratigraphic events (LAD of fossils A, B and C).

1. Dating of sediments: When drilling a well into the Earth's crust in search of hydrocarbons, we encounter different fossils in a predictable sequence below the point in time where the organism became extinct. Biostratigraphic events can be used to subdivide geological time into biostratigraphic units. The point at which we last find a particular fossil is called its Last Appearance Datum (LAD). The LAD in one sequence of rock represents the same geologic moment as the LAD in another sequence. These are the points of correlation between wells. In addition to the LAD, another useful event is the First Appearance Datum (FAD). This may be difficult to recognize in a well, because rock from higher in the well bore may fall down and mix with rock from the bottom of the hole. However, in studies of rock units exposed at the surface of the Earth and in some cases from well bores, these FADs are extremely useful biostratigraphic events. By studying the fossils in many wells, a geologic model for the area can be built up.

Palynology is the study of organic microfossils, especially those in sediments, either of terrestrial, freshwater, or marine origin. These microfossils are very small, generally falling into the 5-500 μm range, and are found in rocks of all geological ages, beginning about 1.4 billion years ago in the late Precambrian right up to the present. Pollen grains have distinct shapes and ornamentation that allow palynologists to identify them according to the plants that produced them. The walls of pollen grains are made of sporopollenin, one of the most resistant natural chemical substances known. This explains why the pollen and spores are preserved so well and are still found relatively intact and identifiable even after millions of years of their burial. Most palynomorphs are produced by plants, including flowering plants, gymnosperms, algae and fungi or by animals, such as scolecodonts. Others are derived from dinoflagellates, which are of mainly marine algae. The most widely-studied group of microfossils is pollen grains and spores produced by plants. Pollen grains and spores are about the same size, are dispersed and deposited in similar ways, and are often found together.

Palynology has wide application in the earth sciences. For instance, it can be used to correlate and provide relative ages for layers of rock, mainly in oil exploration (stratigraphic palynology), recognition of hiatus or unconformity with its span, sequence biostratigraphy, source rock potential, to understand vegetation distributions and climate changes of the past (palaeoecology) and also for palaeogeographic reconstruction. The oldest palynomorphs are found in Precambrian sedimentary rocks, probably produced by simple aquatic algae. Palaeobotanists believe that the oldest terrestrial plants appeared in the Late Ordovician, about 440 million years ago. The spores produced by their descendants are abundant in rocks from the Late Ordovician to the Devonian. Many of these types of plants, such as ferns and horsetails, still exist today. The earliest types of pollen-producing plants were gymnosperms of which the best-known modern group is the conifers. Pollen-producing plants first appeared in the Late Devonian, about 360 million years ago, and became a dominant plant type over most of the earth.

Flowering plants or angiosperms first appeared somewhat later, about 120 million years ago in the early

Cretaceous Period. Because these plants have become increasingly abundant and diverse from the Cretaceous to the present, their pollen became more dominant in the geologic record.

Sedimentary rocks are important in constituting petroleum system, i.e. generation, migration and repository for the hydrocarbon accumulations. The knowledge on the subsurface configuration is build up through the information obtained from samples from the drilled wells.

2. Biostratigraphic Correlation: Since the palynofossil content in rocks is much higher than other populations which are of chronologic significance, Palynology has more advantage in comparison with other microfossils in biostratigraphy (Figure 3). It is also considered as a quick and practical method wherein the non-marine sediments can be correlated with marine sediments. Although spores and pollen largely relate their origin from terrestrial plants, their easy transportability facilitates in their wide distribution, both in marine and in non-marine depositional environments.

Assigning chronological datum to the strata involve determination of precise age of the sediments through various methods. Application of palaeontological and palynological methods provides reliable tools. Majority of fossils like foraminifera, ostracoda, spores, pollen, dinoflagellate cysts, acritarchs, calcareous nannoplankton and diatoms have been considered useful for precise dating and correlation.

High resolution biostratigraphy are carried out based on occurrences of dinoflagellate cysts. A high resolution, within a range of 1 to 0.4 million years, has been achieved in many basins of India.

Calcareous nannoplankton and foraminifera are used individually and in combination, i.e. 'multimicrofossil approach' for fine time slicing.

Correlation of terrestrial and marine sediments is made on the basis of both spores-pollen (for terrestrial) and dinoflagellate cysts, algae and nannoplankton (for marine sequence). Such studies help in the identification of onlap-offlap sequences in sequence stratigraphy. Statistical analysis based on ratios of spores-pollen versus dinoflagellate cysts leads to identification of marine transgressive/regressive cycles and in turn to reconstruct relative sea level changes.

The study of the organic content of sediments, both from a geochemical and particulate standpoint, yields data of value in the investigation of the genesis and pooling of liquid and gaseous hydrocarbons.

DEPOSITIONAL ENVIRONMENTS

Palaeoenvironment and palaeoclimate reconstructions are other areas in the field of hydrocarbon exploration. The integration of different ecological groups such as montane floral complex, low land complex, fresh water swamp and water edge association, mangrove and back mangrove complex, sand dunes and barrier island association leads to such reconstructions (Figure 4).

For palaeoenvironmental analyses, studies of the distribution of living benthic foraminifera provide an excellent database. Using these studies and others, palaeontologists construct models for interpreting past environments using fossil benthic foraminifera. Ancient marine environments are related to water depths (palaeobathymetry) which can be interpreted based on palaeontology. By using these fossils from the studied wells, it is possible to reconstruct the profile of the continental shelf and slope at various points in geologic time. Such palaeogeographic maps, combined with seismic profiles and other geologic data sets, are the tools used in the search for hydrocarbons. It is palaeontology that uniquely explains the element of geologic time and depositional environment to petroleum geology.

The problem of recognizing depositional environments in the stratigraphic record is basic to every aspect of research in sedimentary rock. It is of paramount importance in petroleum exploration too, where an understanding of the geometry and genesis of a sand-body can result into success or failure of an exploration venture. The understanding of the habitat of oil is also a direct consequence of the reconstruction of palaeogeographic and geologic history of a basin. In recent years, palynology has made important contributions in the interpretations of palaeoenvironments for the surface and subsurface sections in almost all sedimentary basins of India.

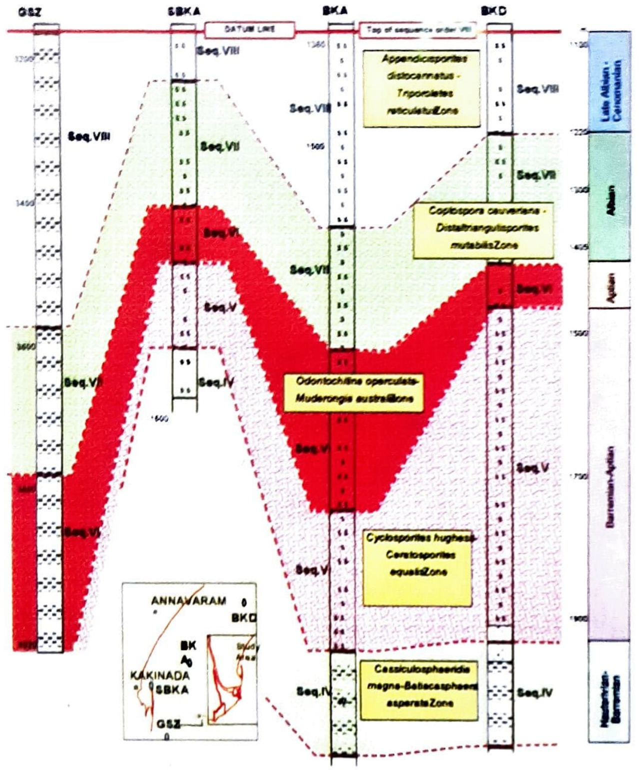

Figure 3. Palynostratigraphic correlation in Krishna-Godavari Basin, Andhra Pradesh.

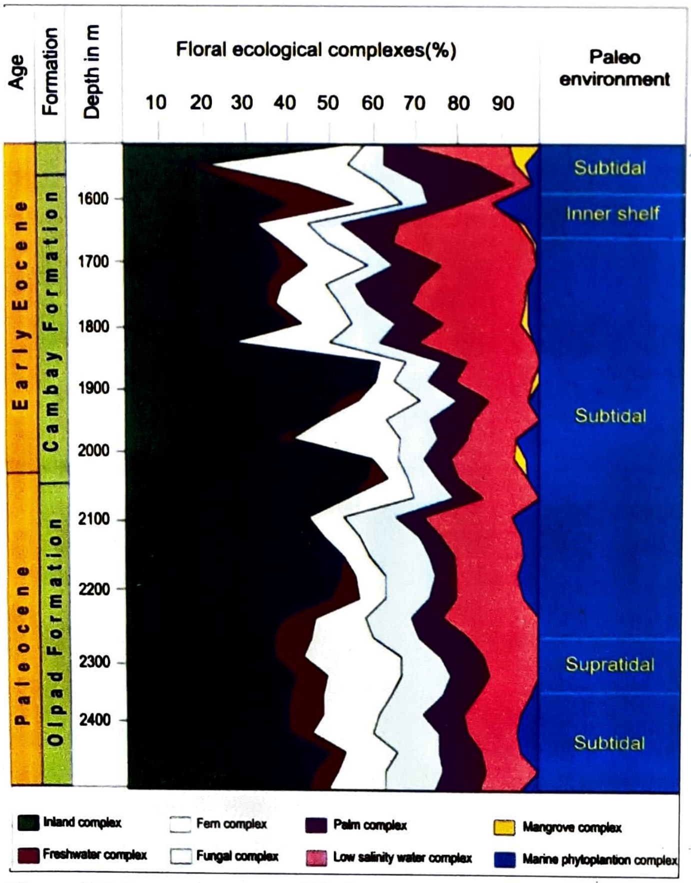

Figure 4. Palaeoenvironment of Early Palaeogene sediments of Asmali Well E, Cambay Basin, Gujarat.

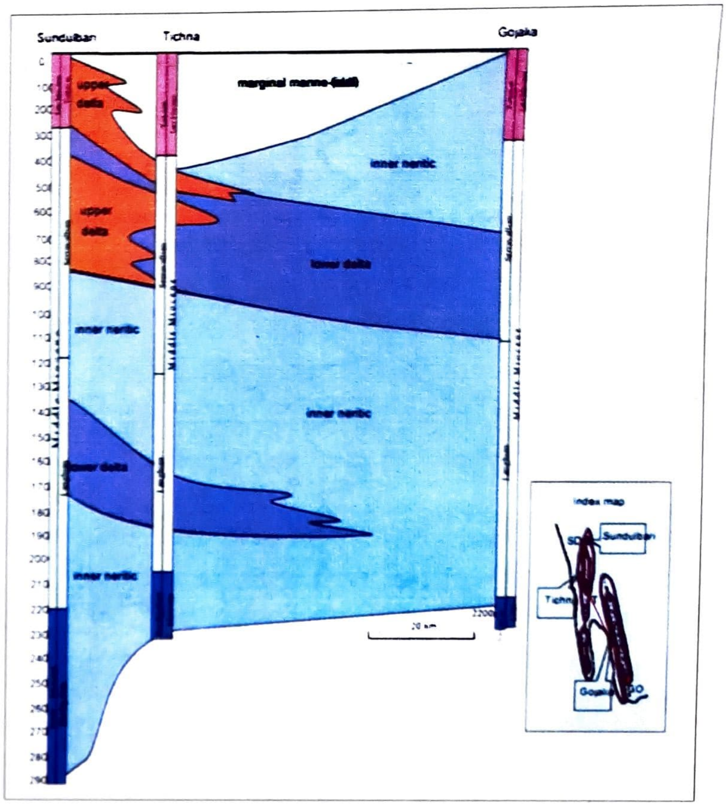

Figure 5. Depositional environments of subsurface Tertiary sediments of Tripura.

Figure 6. Humic and Sapropelic organic matter types.

Finding of evolutionary patterns in the Proterozoic fossil records implies the biostratigraphic utility of early microfossils. Acritrachs, in particular, are helpful for indicating proximity to shoreline.

Many workers have attempted to relate assemblage composition of acritarchs and other palynomorphs to depositional setting. In combination with a marine influence index that included non-acritarch palynomorphs, it is possible to trace transgressive/ regressive shifts in depositional settings.

Research on spatial and temporal distribution of buried cysts must be undertaken if acritarchs are to be useful as independent palaeoecological indices. If such palaeoecological models are to become useful in oil industry, assemblage data must be expressed in a quantified manner that is easily replicated in different sections.

Every type of sediments, ranging from fresh water to deep marine environment, has its own distinctive microfossil assemblages (Figure 5).

The palynological parameters considered for the interpretation of depositional environments and transgressive/regressive cycles are: (i) plant associations of upland, lowland, freshwater, ferns, fungi, coastal, mangrove swamp elements, acritarch and dinoflagellate cysts, (ii) organic matter types, (iii) relative abundance of organic matter in relation to the grain size of the sediments and depositional environments, and (iv) ratio of terrestrial to marine palynomorphs in relation to the grain size of the sediments and depositional environments. Besides, characteristic spore pollen and dinoflagellate cysts assemblages of the sequences are identified for the depositional model.

From the hydrocarbon exploration point of view, such attempts are useful in indicating the potential of a particular stratum as a generator of hydrocarbons, It is possible to assess environmental as well as source potential by palynologists, palaeontologists, organic petrographers or geochemists.

SOURCE ROCK EVALUATION

The main source materials for hydrocarbon are the vegetal debris; including those of phytoplankton, marine and terrestrial algae as well as lipid rich land plant remains. Direct application of these organic matter types for identifying hydrocarbon generation potential sequences lies in estimating the quality, quantity and maturity of organic matter (OM) present in the sedimentary rock. The palynofacies are of two types. Humic organic matter type comprises wood, spore-pollen, charcoal and biodegraded terrestrial organic matter and has mainly gaseous hydrocarbon potential (Figure 6). Sapropelic organic matter type consists of amorphous-terrestrial/marine (AMTM), finely divided organic matter, biodegraded algal and structured marine and has mainly liquid hydrocarbon potential.

The various source rock parameters are mapped along with palaeoenvironment, age, and structure and basin configuration on the same scale. These maps are superimposed to interpret distribution of source potential facies in space and time, thus enabling identification of hydrocarbon generative depocentres. Integrated study includes identification of source rock potential facies and its comparison with geological and geochemical parameters for better understanding of source potential. The study helps to understand the timing and duration of generation of hydrocarbons based on the subsidence history curves and Time Temperature Index (TTI) plots. This integrated approach of TTI with observed palynofacies considering its quantity, quality and maturation has enabled to confirming the validity of conceptual model based on TTI alone.

Fluorescence microscopic technique is used as a tool for quantitative estimation of organic matter maturation. It is a useful technique for determination of rank or maturity and is better suited in cases where vitrinite is not in sufficient quantities.

MICROPALAEONTOLOGY AND PALYNOLOGY IN SEQUENCE STRATIGRAPHY

Sequence stratigraphy is another field wherein the micropalaeontology and palynology and oil industry go together because it has the relationship of biohorizons and zones to depositional sequences. Sequence stratigraphy is a systematic way of looking at well established and familiar stratigraphic concepts, such as eustatic cycle, transgression and regression, diachroneity, and progradation, retrogradation and aggradation. It represents a powerful methodology and modeling and analyzing geometric, spatial and temporal patterns of sediment accumulation in sedimentary basins. Sequences and their systems tracts form according to eustasy, subsidence and sediment supply, changes in sea-level, and accommodation. The sequences may be of various magnitudes: first (> 50 Ma), second (3.0-50 Ma), third (0.5-3.0 Ma) and fourth order (0.08-0.5 Ma), etc.

Sequence boundaries can potentially provide a useful chronostratigraphic framework for correlating and mapping sedimentary rocks. These are surfaces produced by erosion or non-deposition and are interpreted to form in response to the interaction of the rates of eustasy, subsidence and sediment supply. The fundamental building blocks of sequences are 'parasequences'. Successive parasequences are arranged in 'stacking patterns' that are either progradational (migrating progressively basinward), or gradational (building upward only), or retrogradational (migrating or 'backstepping' progressively landward). Such sets of parasequences are termed 'Systems Tracts'. These are referred as the 'lowstand systems tract' (LST), the 'transgressive system tract' (TST), and the 'highstand systems tract' (HST).

CONCLUSION

The special nature of the habitat of oil in sedimentary sequences is such that many of the problems connected with the geological side of oil exploration can only be tackled by palaeontology and palynology. Microfossils have many applications to petroleum geology, viz. dating of sediments, high resolution biostratigraphy for finer zonation, correlation of terrestrial and marine sediments, palaeoclimatic and palaeogeographic reconstructions, sea level changes, and identifying hydrocarbon source rocks. Sequence biostratigraphy is another field wherein the micropalaeontology and palynology and oil industry go together which are of paramount interest for identifying locations of hydrocarbon in future.