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ABSTRACTS

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Symposium on Palynology in Fossil Fuel Exploration
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Theme Lecture

MULTIPLE APPLICATIONS OF PALYNOLOGY IN HYDROCARBON EXPLORATION

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In recent years, the subject of palynology has developed into a multifaceted discipline ranging from primary application of descriptive taxonomy, systematics and biostratigraphy to its direct application in hydrocarbon exploration. The significant role of palynology in hydrocarbon exploration is in the dating of sediments and high resolution biostratigraphy for finer zonation and recognition of hiatuses. In addition, it also plays significant role in correlation of terrestrial and marine sediments, sequence biostratigraphy, evaluation of hydrocarbon source rock potential, kerogen analysis and palaeogeographic reconstruction.

Various parameters of palynology, such as spore-pollen, dinoflagellate cysts, acritarchs, nannofossils, diatoms and silicoflagellates, are being presently applied by different oil companies for precise dating of sediments with high resolution sequence biostratigraphy. Presently, high resolution biostratigraphy for finer zonation is being attempted based on dinoflagellate cysts and calcareous nannoplanktons in Krishna-Godavari and Bombay Offshore basins within the range of 1 to 0.5 million years.

The study of organic contents of sediments, both from geochemical and particulate standpoint provides maturity [Thermal Alteration Index (TAI)], Total Organic Content (TOC) and also the subsidence history of the sedimentary basins with generative window that lead to the investigation of the genesis and pooling of liquid and gaseous hydrocarbons.

ROLE OF SOURCE ROCK PALYNOLOGY IN BASIN ANALYSIS

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Hydrocarbon is generated from organic-rich sediments (source rocks), containing organic matter, originating from biological materials. During burial of the sediments, the increase in temperature results in a series of geochemical reactions which lead the transformation of organic matter to kerogen, which is the precursor of hydrocarbons. The amount, type and composition of hydrocarbons generated can be reflected by the palynological expressions of the source rocks and geological history of the basins. The nature of the organic matter in the source rock and its maturity are governed by its time/temperature history.

Basin analysis is an integral part of any petroleum exploration programme which combines the use of all modern geo-scientific tools for its geological history, stratigraphic architecture, palaeogeographic evolution and existence of petroleum system. The aspects of hydrocarbon generation, migration and accumulation to evaluate the petroleum system, integrating with the geological development of the basin to predict the possible occurrence of hydrocarbons, are the essence of basin analysis.

This presentation attempts to demonstrate the understanding of origin and palaeoenvironment of hydrocarbon source rocks with a greater emphasis on palynofacies analysis and uses of other modern investigations to provide great value to the meaningful hydrocarbon exploration programme in the Indian Basins.

MODERN GEOCHEMICAL TECHNIQUES, TOOLS AND COMPUTER APPLICATIONS IN HYDROCARBON RESEARCH AND EXPLORATION

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The geochemical techniques have emerged as potential tools in hydrocarbon research, exploration and exploitation. In the early stage of exploration of a basin/ block, surface geochemical prospecting methods are used to demarcate anomalous hydrocarbon zones. The methods include adsorbed soil gas surveys; fluorescence, soil iodine and carbon isotope ratio studies. The surface geochemical data are integrated with geological, geophysical and remote sensing data to prioritize the prospects and drill location analyses.

The evaluation of the amount of organic matter, its type and maturity are used for the source rock characterization (immature or mature), which help in determining the prospects of the basin. The amount of organic matter is determined by total organic carbon analyzer and the type and maturity by optical, pyrolysis and physico-chemical methods.

Correlation of oil with source rocks, oil-oil, oil-gas-source rock, is used to understand the migration pathways of hydrocarbons. The techniques used are carbon isotope ratio measurements using continuous flow isotope ratio mass spectrometry (CF-IRMS) and characterization of biomarkers such as steranes, terpanes, hopanes, etc. using gas chromatography-mass spectrometry-mass spectrometry (GC-MS-MS).

Finally, geochemical basin modeling is employed to determine the amount of oil and gas generated (as kg per ton of the rock) and the time of hydrocarbon generation, etc. to evaluate the ultimate oil and gas reserves of a sedimentary basin. Details of modern geochemical techniques, tools and applications of computers and basin modeling for hydrocarbon prospect evaluation will be discussed and presented.

PALYNOFOSSILS AND HIGH-RESOLUTION BIOSTRATIGRAPHY: EXAMPLES FROM PETROLIFEROUS BASINS OF INDIA

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Palynology is the science dealing with the study of organic walled microfossils found in sedimentary rocks. It is only during the last two and a half decades that significant developments with regard to the application aspects of palynomorphs and palynofacies have taken place due to the increasing emphasis on hydrocarbon exploration in different on-shore and off-shore sedimentary basins. With the development of sequence stratigraphy in sedimentary geology, palynology and palynofacies have emerged as important components in integrated multidisciplinary studies. In the event of progressive developments of global bioevents for dinoflagellate cysts and calcareous nannoplankton and their precise stratigraphic ranges, the concept of high-resolution biostratigraphy using last appearance datum (LAD) and first appearance datum (FAD) of stratigraphically valuable species has been applied.

Significance of palynomorphs has been amply demonstrated for characterizing various sequence components, correlation of terrestrial and marine deposits and relative sea-level fluctuations. Studies on different palynofossil groups have helped in precise dating and correlation of sediments. For dating, they are used individually and also in combination to achieve fine time slicing. Correlation is made on the basis of both spores-pollen (for terrestrial) and dinoflagellate cysts, algae and nannoplankton (for marine sequence of sediments). Such studies help in the identification of onlap-offlap sequences in sequence stratigraphy. Statistical analyses based on ratios of spores-pollen versus dinocysts are utilized for deciphering marine transgressive/regressive (T/R) cycles. The integration of different ecological groups and organic walled microfossils helps to interpret palaeoenvironment. Identification of sequence boundaries, maximum flooding surfaces (MFS), characterization of systems tract components (highstand - HST, lowstand - LST, transgressive - TST and shelf margin systems tracts - SMST), condense sections and deciphering relative sea-level changes is the frontier field of palynological contribution for better understanding of hydrocarbon source potential facies in exploration.

Palynology has, therefore, proved its application in all the commercially producing sedimentary basins of India - Cambay, Mumbai Offshore, Krishna-Godavari, Cauvery and Assam (Mehrotra et al. 2002, 2005). Studies resulted into development of high-resolution biostratigraphy and standardization of palynozones by integrating with micropalaeontological data from various basins. Earliest (Neocomian) marine transgression in Cauvery Basin, demarcation of K/T boundary in Assam and Krishna-Godavari basins, 3.8 Ma span of Deccan volcanism in Krishna-Godavari Basin, existence of Carboniferous basin below the Deccan Trap in the Bombay Offshore region, demarcation of various hiatuses with their time span in Krishna-Godavari and Cauvery basins and Bombay Offshore, identification of two ‘Red Beds’ in Krishna-Godavari Basin, etc. are some of the highlights of palynological findings in the last decade. Based on the identification of globally recognized dinoflagellate cyst biohorizons at different stratigraphic levels during Cretaceous to Cenozoic, a fine stratigraphic resolution of 0.5 to 1 Ma has been achieved in some of these Indian

basins. These bioevents are correlatable at inter- and intra-basinal levels, which is helpful in recognizing hydrocarbon plays. One of the most important applications of biostratigraphy in hydrocarbon exploration is in identification of 3^{rd} and 4^{th} order cycles of sea level changes, which involve fine time slicing of 1-10 Ma and 0.2-1 Ma, respectively. These are key to development of source, reservoir and cap rock facies. Analyses of terrestrial palynomorphs and dinoflagellate cysts have helped to develop palaeoenvironmental models useful in basinal studies. Scope and limitations of palynological data in hand have been analyzed for more effective utilization in hydrocarbon exploration.

PALYNOFACIES AND ORGANIC MATURITY AS INDICATORS FOR DELINEATING SOURCE POTENTIAL FACIES IN SPACE AND TIME - A CASE STUDY

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The organic matter types, palynofacies and organic maturity play important role in the origin of hydrocarbons. Determination of hydrocarbon source capabilities of sedimentary rocks is possible by the qualitative and quantitative assessments of organic matter types and maturation. These include study of organic matter entities like: structured terrestrial matter, spores and pollen, biodegraded terrestrial matter, charcoal, amorphous organic matter, biodegraded aqueous organic matter and structured aqueous organic matter.

The data on qualitative aspects such as type of organic matter and palynofacies and quantitative aspects like total organic matter (TOM) and maturity are generated and interpreted. The data are integrated with various geochemical parameters like TOC, Tmax, S_1, S_2, S_3 and kerogen type along with petrological parameters like vitrinite reflectance (vRo) for precise assessment of source potential. The litho and biostratigraphic parameters are considered along with the environment to understand the spatio-temporal distribution of source potential facies.

The Palakollu Shale (Palaeocene) in the Bhimanapalli and Mori structures has good source potential to generate gas. The Pasarlapudi Formation (Eocene) has good potential to generate hydrocarbons. The Ravva Formation (Mio-Pliocene) in GS-3 structure has poor to marginal source potential to generate gas and the Early Eocene sequence in GS-21 structure is evaluated to have good source potential for gas.

PALYNOSTRATIGRAPHY OF EARLY PALAEOCENE-EARLY EOCENE SEDIMENTS IN DEEP WATER WELL KKD-AA, KERALA-KONKAN BASIN, INDIA

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Palynological study of Kasargod Formation in deep water well KKD-AA, Kerala-Konkan Basin has enabled dating of the sediments between 3520m and 1925m and interpreting environment of deposition based on dinoflagellate cysts and spores-pollen. The well was drilled down to 3772m and bottomed in the basalt.

Early Palaeocene (Danian) - Early Eocene palynofossil assemblages have been recorded from the studied section. The study details are described in the stratigraphic succession. The characteristic Early Palaeocene (Danian) dinoflagellate cysts and spores-pollen have been recorded in the intervals between 3520m and 3427m. The sedimentary section between 3427 and 3335m is devoid of palynoflora. However, some samples are poorly fossiliferous between 3335 and 3205m. The early Late Palaeocene age is assigned to the sediments between 3205 and 3180m based on diagnostic dinocysts and spores-pollen assemblages. Very poor palynofossil assemblage is recorded in the intervals between 3180 and 2035m. Significant assemblages of Early Eocene dinocysts and spore-pollen are recorded from the interval 2035-1925m. The overall dinoflagellate cysts recorded from Early Palaeocene (Danian: 3520-3427m), early part of Late Palaeocene (3205-3180m) and Early Eocene (2035-1925m) suggest prevalence of inner shelf environment in the studied area.

The record of Early Palaeocene (Danian) dinoflagellate cysts immediately above the trap wash (3524m) is significant to suggest that the rifting of Kerala-Konkan Basin had already started during the Danian, prior to the initiation of Mumbai Offshore Basin which was opened up in Late Palaeocene.

HIGH RESOLUTION BIO- CHRONO- AND BIO-SEQUENCE STRATIGRAPHY AND SEA LEVEL CHANGES: GLOBAL VS. INDIAN RECORD - PRESENT AND FUTURE OF MICROFAUNAL AND PALYNOLOGICAL RESEARCH

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Some of the breakthrough contributions on palynology and microfauna, valuable in stratigraphy, palaeogeography and understanding of the evolution of Indian plate, include: (i) record of Early Permian marine acritarchs from Palar, Cauvery and Krishna Godavari basins along East Coast of India; (ii) application of acritarchs in dating Late Proterozoic and Early Palaeozoic; (iii) record of shallow marine Triassic and Jurassic dinoflagellate cysts from the subsurface of Krishna-Godavari Basin; (iv) application of quantified dinoflagellate and spores-pollen data in reconstruction of Cretaceous and Cenozoic bio-sequence stratigraphy; (v) dating of marginal marine-very shallow marine source rocks exemplified from Panna Formation of Mumbai offshore; (vi) high resolution biochronostratigraphy based on foraminifera; (vii) reconstruction of high frequency and low amplitude sea level change of 3^{rd}, 4^{th}, 5^{th}/ 6^{th} order cycles/ sequences based on foraminifera; (vii) generalized relative sea level curves for Indian basins, based on foraminifera and palynofossils; (viii) estimation of duration and magnitude of hiatuses in Indian basins leading to build tectonostratigraphy; (ix) record of Oxfordian nannoplankton from K-G Basin and Ramnand subbasin of Cauvery Basin; and (xi) application of nannoplankton as a rapid tool for dating deep marine sediments. However, we are way behind by nearly a decade in basic research in establishing an integrated and independant multimicrofossil scales tied up with geochronology, isotope stratigraphy and magnetic polarity scale for Indian plate. It has to be realised that microfaunal and palynological events are of great utility in hydrocarbon exploration and there cannot be different sequences (system tracks, MFSs, etc.) for different specialists. A few case examples and a number of figures and tables are presented with a view that they will motivate further basic research.

COAL BED METHANE GENESIS AND ITS STATUS IN INDIAN CONTEXT

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Genesis of methane in coal beds mainly occur during biochemical and geochemical stages of coal formation (throughout entire coalification series) and also during post depositional phases at the time of magmatic intrusions. Intrusions in Cretaceous Period baked most of the Indian Gondwana coal seams. Of course, geothermal gradient also played a significant role. High rank coals with intense magmatic ramification (in the form of sills and dykes) in Damodar Valley coalfields, having huge coal bed methane (CBM) reserves, are the good examples to prove the above contention. In early phases of coal deposition (peat to lignite), biochemical and further onwards geochemical stages are responsible for methane generation. From the in-depth analysis of the genetic path of coal and concept on its structural genesis earlier advanced, it is indicated that most of the occluded methane (CBM, coal mine methane-CMM, abandoned mine methane-AMM), formed today in Indian coalfields, had its origin mostly during the geochemical stage and magmatic intrusion periods. During the biochemical stage of coal formation, a lot of gases including methane (biogenic) were evolved due to transformation of plant entities, particularly cellulose and lignin, into humic acid and humus, the complex of which is called ulmin. During geochemical phases followed by volcanism, due to prevalence of high temperature and pressure the rank of coal enhanced and huge amount of thermogenic methane gas evolved.

Methane, previously supposed to be a hazardous gas, is nowadays considered a source of alternate energy in several countries, including India. In some developed countries, its share in national energy production is increasing significantly. Since India is almost ready to exploit the CBM for commercial usage in some of the coalfields, such as Jharia, Raniganj and others, it is high time to debate on the issues related to genesis and distribution of this eco-friendly fossil fuel resource. The present paper purports on the issues like: *how methane gassiness in the mines develops, how it is coal rank dependent, can methane gassiness be predicted even before mine development,* etc. Such studies may prove to be of immense help to industries engaged in CBM exploration and exploitation.

PETROGRAPHIC CHARACTERISTICS, MATRIX SHRINKAGE AND PERMEABILITY IN COAL BED METHANE EXPLORATION - CASE STUDIES FROM SOUTH KARANPURA AND BIRBHUM COALFIELDS, INDIA

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Borehole coal core samples, having different petrographic composition and technological properties, were collected from South Karanpura and Birbhum coalfields. The coal samples of South Karanpura coalfield are macroscopically distinguished by their brownish black colour and slightly greater cleat intensity in comparison to coal samples of Birbhum coalfield. The cleat attributes and lithotypes coal core samples from coalfields were studied. The lithotypes were found to be differentiated into vitrain, clarain, durain, duroclarain and clarodurain. The technological properties of coal samples were determined following standards. The moisture content (W^a), volatile matter content (V^{daf}) and ash content (A^d) of coal samples from South Karanpura are found to vary in the range of 1.27-1.67wt %, 34.14-36.89 wt % and 19.38- 20.74 wt % correspondingly. The coal samples of Birbhum coalfield indicate W^a, $V^{daf}$and A^d respectively varying from 1.31-2.25 wt %, 31.30-32.59wt % and 17.77-18.34 wt %. The coal samples of South Karanpura coalfield are characterized by large amount of volatile matter content, ash content and lower fuel ratio (FR) with respect to coal samples of Birbhum coalfield. The detailed micropetrographic lnvestigations (maceral group composition, maceral composition, microlithotype composition, maceral- microlithotype composition, distribution of microscopic pores, pore-walls and micro-cleats, relative distribution of empty pores, filled pores, empty micro-cleats and filled micro-cleats) were carried on polished coal samples and polished pellets. The vitrinite content (Vt^{mmf}) of South Karanpura and Birbhum coalfields vary in the range of 33.76-39.82 vol.% and 32.21-36.29 vol.% respectively. The inertinite content (I^{mmf}) of South Karanpura and Birbhum coalfields show their range 57.07-63.06 vol.% and 61.25-66.42 vol.% respectively FTIR (Fourier Transform Infra Red) analyses of coal samples were carried to identify chemical bonds. Methane adsorption isotherms were prepared to know about maximum sorption capacity of coals. The maximum sorption capacity of coals from South Karanpura and Birbhum coalfield varies from 11.36-12.36 cc/g and 12.48-12.84cc/g respectively. The permeability of coal samples was determined using gas/liquid permeameter and porosimeter. The permeability of coal samples from South Karanpura coalfield ranges from 0.633 to 0.753 md whereas the same of coal samples from Birbhum coalfield ranges from 0.588 to 0.925 md. The effect of

petrographic composition on permeability and matrix shrinkage was observed. The matrix shrinkage seems to affect the permeability of coal seams in a significant way. Authors have modeled coal matrix shrinkage influencing permeability which in turn may affect coal bed methane production