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Micropaleontology in Petroleum Exploration

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Summary

One of the aims of micropaleontological studies is to unravel the geological history of the surface of the earth in a manner that can be achieved as reliably, in relatively quick time and at the same time be economically be reasonable. Oil companies, who invest hugely in this high risk business of oil exploration, have undoubtedly gained much from micropaleontological studies. This is because of the reasonable accuracy and speed with which the results are delivered. The two most common uses are: biostratigraphy and paleoenvironmental analyses. Biostratigraphy is the differentiation of rock units based upon the fossils which they contain. Paleoenvironmental analysis is the interpretation of the depositional environment in which the rock unit formed, based upon the fossils found within the unit. There are many other uses of fossils besides these, including: paleoclimatology, biogeography, and thermal maturation.

Introduction

In this ever-changing economic and political climate, petroleum explorationists and field development geologists are being asked to find more oil and develop older reserves. Concomitant with this demand comes the array of new computing, drilling and surface engineering technologies. Therefore, it is a welcoming challenge that geologists should look inward and rediscover how they can add more value to the exploration and production business. This has led biostratigraphers, usually niche service providers, to evolve new techniques and approaches, challenging old ones and aligning the science with the business needs. Microfossils, as the name implies, are those fossilized remains that require specialized methods of preparation and study. They normally cannot be studied by 'naked eyes' and require the use of a microscope. To give some historical account, the association of micropaleontology to petroleum exploration is almost a century old. The earliest use was demonstrated by Josef Gryzbowski of Poland in 1890 and many recall his pioneering effort in stratigraphy and correlation of beds. The commercial aspect of their importance was realized by many geological surveys, oil and gas and coal companies who employed teams of micropaleontologists to learn more about the rocks they were handling. These studies have also gained impetus and with systematic documentation world over by various oil companies, and have proved beyond doubt their predictiveness in local and geological analyses. Further oil companies also have been a major stimulus to the growth of micropaleontological studies. Assigning age to the rock is one of the primary requirements of micropaleontological studies as input to reconstruct stratigraphy. In marine sedimentary strata, foraminifera are known to occur abundantly (but at times not so abundant) and hence their usefulness as a tool for dating and correlating sediments in the realm of exploration. Apart from assigning age to the rocks the other central aspect of micropaleontological studies is the prediction of water depth and environment of deposition of the sediments. Such studies are vital to understand the depositional conditions and to prepare a depositional model with reasonable predictiveness.

Conventionally micropaleontological studies have remained largely a tool for exploration arena. In recent times, change in the mind set amongst many biostratigraphers is helping the studies to a gain foot hold as predictable means in the sphere of development geology and reservoir modeling. This is being achieved by way high-resolution biostratigraphy at reservoir scale. Scope of micropaleontology in the interpretation of paleo-water depth and paleoecology are also vital points to develop geological depositional models. Their application to biofacies studies has been proved beyond doubt especially while dealing at reservoir scale. Besides the roles discussed, the importance of micropaleontology in well site biosteering for real-time stratigraphic monitoring of drilling by way of predicting stratigraphic position of drill bit is another central point used by oil companies. This exercise is cost beneficial by way of maximizing reservoir penetration and production index in high angle and horizontal wells.

Micropalaeontological Techniques

For petroleum exploration, apart from the study of surface samples, subsurface samples are collected from exploratory wells, which may be of the following three types:

1. Cutting sample
2. Conventional Core (CC)
3. Side Wall Core (SWC)

The rock samples are either chunk like surface sample or core sample or small cuttings from well or small cylindrical sidewall core. In the case of coarser material it is broken, using a hammer, into smaller pieces of 0.5 to 1 cm, before processing. If the rock is too hard the sample is treated with dilute acetic acid to make it brittle. The steps for the processing of samples and study of microfauna are discussed below:

Processing of Samples

Samples are subjected to certain techniques in the processing laboratory for the recovery of micro fauna from them. The processing techniques are different for consolidated and unconsolidated samples and are elaborated below:

Unconsolidated Sediments:
The unconsolidated sediments are boiled in caustic soda for about half an hour. The material is then washed in running water over a 300-mesh size sieve so that the clay particles are removed from the sample. The sample is subsequently dried in an oven at a temperature of about 100^0C. These dried fractions are now put in plastic tubes on which proper labeling like name of the well, depth interval, weight of the initial sample etc. is written. The sample is now available for micro faunal sorting.

Consolidated Sediments:
For the disintegration of consolidated sediments the sample is first granulated to 0.5 to 1.0 cm size with the help of a hammer. The processing of the sample is done in the following way:

- For a sample of 20gm, around 20ml of Hydrogen Peroxide and an equal quantity of Ammonia solution is used for soaking it. It is soaked for about an hour to overnight depending upon the sample. Sometimes if the sediments are very hard the material has to be boiled for about half an hour or so. The material is then rinsed with water.
- The material treated above is placed in QUAT-O solution (a mildly acidic reagent). Normally, 10gm of primary QUAT-O is diluted with 2.5 liters of water and 50 ml of this solution is used for treating the material. The material is soaked overnight in the QUAT-O solution.
- The QUAT-O solution is drained out and the sample is rinsed with water. The sample is then boiled with around 20gm caustic soda for around half an hour.
- The caustic soda solution is drained out and the material is rinsed with water.
- The material is put in a beaker and is about half filled with water. The material is now given ultrasonic treatment by putting the beaker in ultrasonic machine for about 30 seconds.
- After ultrasonic treatment the material is washed over 300 mesh sieve.
- If it is observed that the material has not disintegrated well and some source matrix is still clinging to fossils, the above-illustrated steps are repeated as per requirements.
- After ensuring that the material is now clean of matrix material it is dried in an oven at about 100^0 C.
- The sample is now divided into different fractions by sieving it with different sized sieves i.e. 100-60, 60-40 and 40+ mesh. The material is now ready for sorting.

Sorting

The processed sample has different grades of rock particles and fossils, which are divided into different fractions by sieving. This processed sample is now taken into a triangular copper tray and particles are spread as a thin layer on a sorting tray. The sorting tray which is a flat metal tray, with grid, on which the disintegrated rock material, spread as a thin coating gets divided into several square segments. The sorting tray is moved under a binocular microscope left to right, grid after grid. The fossils in the tray are picked by a wet hairbrush of 0 or 00 sizes and kept in twenty-four chamber assemblage slides. Occasionally, if the fossils are big, these are picked by forceps or hand and kept in twenty-four chamber slides. If the sample is poorly fossiliferous the picked specimens are also arranges in round punch slide.

Thin section identification

Thin sectioning is done to study the faunal content of a rock. For paleontological studies, the thin sections are made nearly 0.05 mm thick. However, while grinding, the section is checked frequently by viewing it under the microscope until a clear section depicting distinct features of the form is obtained.

Oriented thin sections:
For the study of larger foraminifera, as the external morphological features are not enough to identify them to species level, it is comparative to study their internal morphological features. Thin sections of foraminifera are normally made in two planes. One, known as equatorial section is in the plane of coiling and at the very equator of the spiral. The other one perpendicular to the equatorial section and passing through proloculus is known as the axial section. Section is made by slowly grinding the form on FF grade carborundum powder on a glass plate with little water. The smaller forms (1 to 5mm) are first fixed in desired orientation with Canada balsam on a glass slide and then ground in slow motion. Subsequently, the form is reverse mounted and ground to around 0.05mm.

Oriented splits:
Some larger foraminifera that have empty chambers or are filled with clay, good equatorial splits can be obtained by first heating the form in a flame by holding it with a forceps and then by dipping it in water. Sometimes, if the form does not break into halves by its own, little pressure is to be applied along the plane of equatorial section by a forceps.

Identification and Data entry

The microscopically observed attributes of microfauna are considered to separate the assemblage into broad groups like foraminifera and ostracoda. For each group type specimens are selected and their morphology is compared with generic or specific description and illustration given in various standard faunal treatises and catalogues. Thus identification up to generic and specific level is done and frequency is determined for all identified fossils. The data of faunal frequency vs. depth are plotted in a frequency chart.

Applications of Microfossils to Petroleum geology

Microfossils have many applications to petroleum geology. The two most common uses are: biostratigraphy and paleoenvironmental analyses.

BIOSTRATIGRAPHY is the differentiation of rock units based upon the fossils which they contain. Paleoenvironmental analysis is the interpretation of the depositional environment in which the rock unit formed, based upon the fossils found within the unit. There are many other uses of fossils besides these, including: paleoclimatology, biogeography, and thermal maturation. Recognition of unconformity in the subsurface is undoubtedly being done using geophysical techniques but they are also being done by biostratigraphic methods viz., absence of biozone(s). Indirect evidences like nature of preservation of foraminiferal tests i.e. abraded forms that at times are associated with lateritized material. However, these evidences have to be verified by other tools but are nevertheless thought provoking. Through biostratigraphy the hiatuses in geological history are being estimated routinely by many micropaleontologists. The fundamental principal in stratigraphy is that the sedimentary rocks in the Earth's surface accumulated in layers; with the oldest on the bottom and the youngest on the top (fig.1).The history of life on Earth has been one of creatures appearing, evolving, and becoming extinct (fig.2). Putting these two concepts together, we observe that different layers of sedimentary rocks contain different fossils. 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. In our simplified case (fig.1), the extant species C is present in the uppermost layers. Species B is only found in lower layers. The well does not penetrate any layers containing fossil A. The point at which you last find a particular fossil is called its LAD (Last Appearance Datum) (fig.2). In a simplified case, the LAD in one sequence of rock represents the same geologic moment as the LAD in another sequence. These are our points of correlation between wells. Another well drilled in this area should penetrate the same sequence, but most likely at different depths than the original well. 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 slough off the wall 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. Lastly from (fig.2), one can recognize that the range of the three fossils overlap for only a relatively short period of geologic time. As a consequence, if a sample of rock contains all three (A, B, and C), it must have been deposited during this interval of time (Concurrent Range Zone). This is yet another "event" which can be used to subdivide geologic time into biostratigraphic units. By studying the fossils in many wells, a geologic model for the area can be built up.

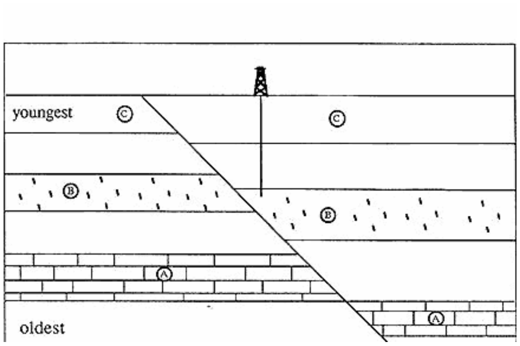

Fig.1-Schematic cross section showing rock units from oldest to youngest with LAD of hypothetical fossils A,B and C noted.

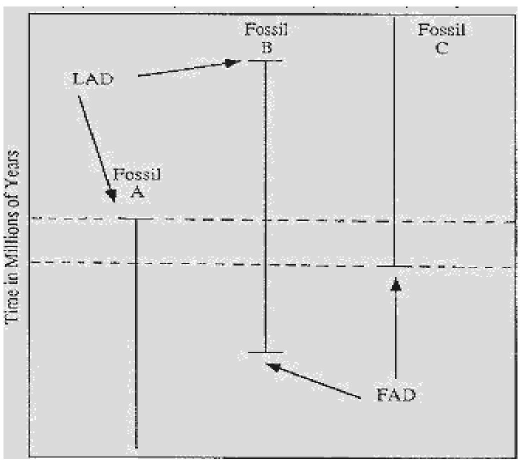

Fig-2 Schematic range chart showing the range of hypothetical fossils A, B and C.

PALEOENVIRONMENTAL ANALYSIS: Through this the fluctuation in sea level can be reconstructed by initially inferring the paleobathymetry and then integrating the same on a regional scale using seismic stratigraphy for reconstruction of transgressive/ regressive cycles within a time frame. Once this exercise is completed, based new techniques that have emerged over two decades the depositional sequences can be inferred. The sequences thus identified, depending on whether they form part of transgression, regression or a high stand of sea can be used for depositional models to surmise the disposition of likely reservoir and cap rock facies and thereby giving directions for a successful exploration campaign.

Micropaleontology in Sequence stratigraphy

To understand stratigraphic and paleoenvironmental aspects of the depositional sequences a correlation frame work is necessary. Age significant bioevents, identified by microfossils species FAD (First Appearance Datum) or LDO (Last Downhole Occurrence in oil exploration parlance) and LAD (Last Appearance Datum) or FDO (First Downhole Occurrence in oil exploration parlance) assume importance to form a high-resolution biostratigraphic framework. This framework when tied up seismic and wire-line log events provides a regional correlative framework. During the past decade or so micropaleontologists have attempted to emphasize on the application of micropaleontological data to reconstruct higher order (4^{th} – 6^{th} order) sequences. These new developments in sequence biostratigraphy are significant as they have great value in providing a high-resolution framework generally beyond the resolution of seismic stratigraphy and also wire line logs. The other aspect of providing a chronostratigraphic framework to sequence stratigraphy using condensed intervals is also well known. Condensed intervals are associated with regional transgressions and are expected to be widespread and they generally contain a rich assemblage of planktic foraminifera useful for age dating on a local and regional scale. To define the various internal architecture of a depositional sequence viz., lowstand (LST), highstand (HST) and transgressive systems tracts (TST); condensed interval and maximum flooding surface (MFS) associated with TST biofacies studies become very important. For e.g. in a clastic sequence, shallow water biofacies can be associated with laterally extensive delta or marine sand deposited under deltaic, shallow marine and near shore processes. Like wise deep-water biofacies are very often distinct associated with environments dominated by gravity driven processes in which sand prone channel fed fan deposits may occur.

Higher order transgressive – regressive (T-R) cycles are identified using paleobathymetric trends that are inferred from foraminiferal diversity. These higher order cycles are imprints of transgression-regression and they also reflect 0_2 supply to the benthic community. Organic carbon content also fluctuates with 0_2 supply and hence effects the distribution of foraminifera. All these indicate the importance of organic flux and dissolved 0_2 in the ecological distribution of foraminiferal. Therefore it is important to understand the dominance diversity foraminifera while reconstructing the T-R cycles, for e.g. high species diversities are generally associated with inferred where calcareous foraminifera predominate. Assemblage with high dominance of calcareous group and increased diversity are interpreted as reflecting normal 0_2 levels associated with showing of depositional area. On the contrary when diversity decreases it implies progressive change from normal environment is restricted condition (e.g. close to anoxia) associated with transgression. When the environment persistently turns into totally anoxic, the interval may contain a condensed interval including mfs. In the former case, i.e. close to anoxic (also associated with transgression), a reduction in diversity and increase in agglutinants and increase in the dominance occurs. Under totally conditions, reduced diversity high dominance and low frequency or absence of calcareous taxa can be anticipated.

Microfossils used for Hydrocarbon exploration

There are a great number of different types of microfossils available for use. There are three groups which are of particular importance to hydrocarbon exploration. The three microfossil groups most commonly used are: foraminifera, calcareous nannofossils, and palynomorphs. A brief introduction to each of these groups is included below:

Foraminifera- Foraminifera (fig.3&4) are protists that make a shell (called a "test") by secreting calcium carbonate or gluing together grains of sand or silt. Most species of "forams" are bottom- dwellers (benthic), but during the Mesozoic Era a group of planktonic foraminifera arose. These forms (fig.4) were (and are) free-floating in the oceans and as a result are more widely dispersed than benthic species. After death, the planktonic foraminifera settle to 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 paleontologist about what the environment was like where the rock containing the fossils formed. For example, certain species of foraminifera prefer the turbid waters near the mouths of rivers while others live only in areas of very clear water.

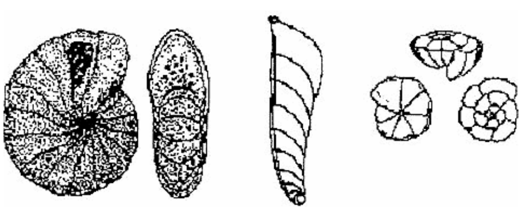

Fig.3-Benthic Foraminifera

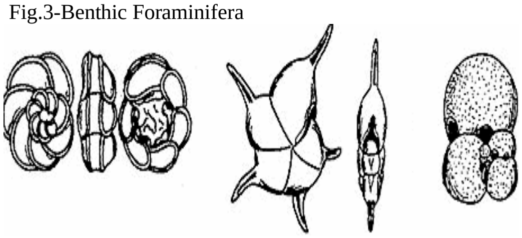

Fig.4-Planktonic foraminifera

Planktonic foraminifera provide less information concerning the environment of deposition, since they lived floating in the water column; but they have other advantages. Whereas benthic foraminifera are restricted to certain environments, planktonic foraminifera are dispersed over a much broader part of the world oceans and often are found in large numbers. On a geologic time-scale, events such as the first appearance of a given species or its extinction can happen very quickly. For the paleontologists, these correlate points in time and space across a depositional basin or even across whole oceans. However, local conditions may exclude a species from one area while it persists somewhere else. This gives a "suppressed" extinction point (i.e. the species disappears locally earlier in geologic time than it does in other parts of its range.)

Calcareous nannofossils- Calcareous nannofossils are extremely small objects (less than 25 microns) produced by planktonic unicellular algae (fig.5). As the name implies, they are made of calcium carbonate. Nannofossils first appeared during the Mesozoic Era and have persisted and evolved through time. The function of the calcareous "plates", even in living forms, is uncertain. One extant group that produces "nannofossils" is the Coccolithophorans, planktonic golden-brown algae that are very abundant in the world's oceans. The calcareous plates accumulate on the ocean floor, become buried beneath later layers, and are preserved as nannofossils. Like the planktonic foraminifera, the planktonic mode of life and the tremendous abundance of calcareous nannofossils make them very useful tools for biostratigraphy.

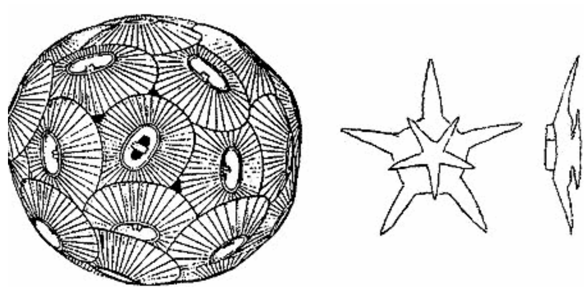

Fig.5- Calcareous nannofossils

Nannofossils are amongst the rare group of fossils which have been tied with chronologic time through magnetostratigraphy or rarely radiometric dates, during the vast amount of data gathered during the Deep Sea Drilling and Ocean Drilling Projects. This advantage along with the fine chronostratigraphic resolution of nannofossil zones and events make them one of the most potent tools for stratigraphic correlation. This is of prime importance in the hydrocarbon industry, where fine zonations are required to decipher pay zone level correlations. The added advantage of nannofossils is that where ever present, their distribution is largely independent of the depositional facies in which they occur, the only danger being diagenitic modification and destruction

Palynomorphs- Palynomorphs (fig.6) are organic walled fossils and include fossil pollen and spores, as well as certain marine organisms such as dinoflagellates (the red algae which make up the "red tides" in modern oceans). Pollen and spores are transported by wind and water and can travel long distances before final deposition. They are surprisingly resistant to decay and are common as fossils. Because of the long transport before deposition, they usually tell us little about the environment of deposition, but they 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 whether oil or gas may have formed in the area under study, because it is heat from burial in the Earth that makes oil and gas from original organic rich deposits.

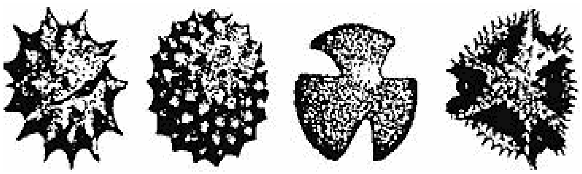

Fig.6-Palynomorphs

Conclusion

In petroleum exploration the biggest help through micropaleontology is to determine the precise age in outcrop or in the drilling well or to determine the correct stratigraphic position with the help of microfossils. Scope of micropaleontology in the interpretation of paleo-water depth and paleoecology are also vital points to develop geological depositional models. Their application to biofacies studies has been proved beyond doubt especially while dealing at reservoir scale. Besides the roles discussed, the importance of micropaleontology in well site biosteering for real-time stratigraphic monitoring of drilling by way of predicting stratigraphic position of drill bit is another central point used by oil companies. This exercise is cost beneficial by way of maximizing reservoir penetration and production index in high angle and horizontal wells.

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