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THIRTIETH SIR ALBERT CHARLES SEWARD MEMORIAL LECTURE

PALYNOLOGY, ORGANIC PETROLOGY AND PETROLEUM — A PALAEOBOTANISTS VIEW

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It is not my intention to present here new and exciting results of palaeobotanical research. Indeed, the topics named in the title may appear to be departures from palaeobotany in the sense most people like to think of that subject, with the exception of palynology which has become a respectable branch of palaeobotany. Still, what I shall be dealing with has with fossil plant material to do.

One aspect of my presentation, at least, appears to bring something new to this lecture series: as far as I can see, the word petroleum has not before appeared in any title. I hope to show that there are aspects of petroleum geology which can be of interest in a wider palaeobotanical sense.

For the last two-three decades, petroleum exploration has been a major driving force behind geological activities throughout the world. It is my view that palaeobotany, taken in a broad sense, has been, and will continue to be, affected by this development. Palynology and organic petrology are key words in this connection.

Petroleum geology is a complex subject, embracing many fields of study. One of these is the study of dispersed organic matter in sediments, the acknowledged source of petroleum. This organic matter is almost entirely derived from the plant kingdom. Therefore, teaching and research in this field has to be based to a considerable extent on biological and not least botanical knowledge, hence it also enters the palaeobotanist's sphere of interest, and particularly that section of palaeobotany which is known as palynology. Organic petrology is merely a further development of palynology.

I shall first comment on developments in palynology. The 4th Seward Memorial Lecture was given by Gunnar Erdtman, who spoke on the development and growth of palynology. That was in 1956. Since then, and especially during the last 15 years, there has been a more dramatic development than any palynologist could possibly have foreseen. This expansion has taken place particularly within the field which we may call non-spore-pollen palynology. The force behind the expansion is application in petroleum geology. Palynology has become the most commercialized branch of palaeobotany. However, if we take a look at the situation from an academic point of view, I think it is a perfectly defendable statement that research and teaching in palynology has not kept pace with the applied aspects of the subject.

This is not the place for a comprehensive updating of Erdtman's review of palynology in 1956. I shall only point out two major areas of development:

1. Dinoflagellate studies played only a minor role in palynology in 1956. Since then, the volume of dinoflagellate studies has been growing steadily. As an aid in correlation and age determination of marine sediments, particularly in oil well studies, dinoflagellates have moved from a position of being resorted to when other fossils fail to becoming the first microfossil group to be studied in many instances. The stratigraphic resolution of dinoflagellates is in no way inferior to other microfossil groups. Furthermore, they have the advantage of producing adequate assemblages from samples of only a few grams. Dinoflagellate biostratigraphy is clearly going to be a significant growth field for some time to come, and as palaeoenvironmental indicators dinoflagellates have a considerable potential. However, the challenges presented by fossil dinoflagellates and their biostratigraphic application are not at the moment adequately met by teaching and research in universities.

2. Studies of dispersed organic matter in sediments started in the 1960's and since the early 70's they have been rapidly growing in volume and diversity. Prominent key words here are kerogen and organic maturation. It is this area of development in palynology for which the term organic petrology is now being applied. Previously, dispersed organic matter was only considered a nuisance in palynological preparations.

A brief review of programmes of some past international palynological conferences serves to illustrate the development of studies on dispersed organic matter. Titles and abstracts for the 2nd I.P.C. in Utrecht in 1966 contained no such topics as kerogen and organic maturation. Although industry palynologists were present, petroleum aspects of palynology hardly made a noticeable impact on the programme in Utrecht.

However, there was one remarkable exception: An invited paper entitled " Palynology and the oil industry ". The author was originally a palaeobotanist, Charles Hopping, a former student of John Walton in Glasgow who had become one of the early palynologists in the oil industry. The emphasis of Hopping's paper was on pollen/spore stratigraphy and environmental interpretations, particularly of deltas (Hopping, 1967). Kerogen and maturation were not mentioned in his paper.

If we move one decade and two conferences ahead to the memorable conference in Lucknow six years ago, we find that the programme had some ten papers devoted to kerogen studies. Finally, at the last I.P.C. in Cambridge 1980, not only was an entire section devoted to kerogen and maturation studies, but this section was one of the largest and most active during the conference. The position of this field is further illustrated by the fact that the proceedings of the section were the only to become published from that meeting (Brooks, 1981). The proceedings also give an indication of where the greater part of the activity in this field takes place. The addresses of the contributors show as many as 2/3 of them affiliated with oil companies or commercial and applied research institutions.

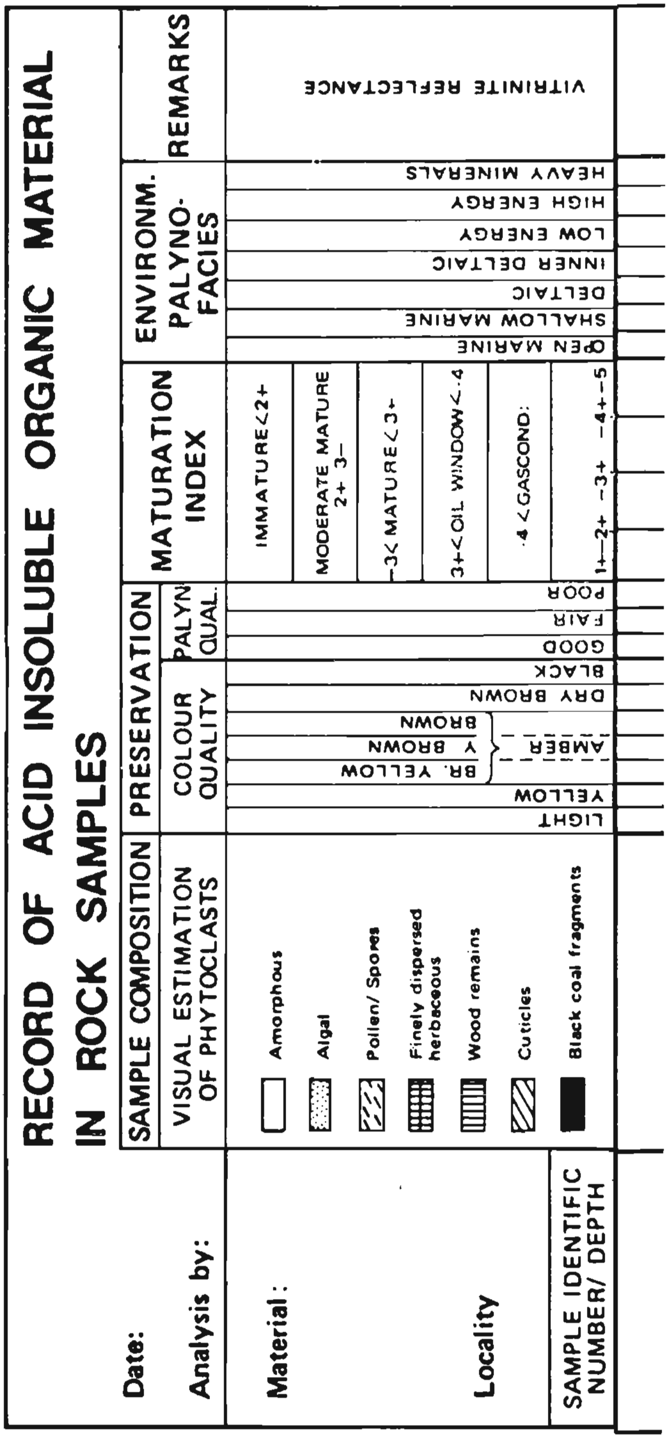
Organic petrology is the second key word in the title of this paper. By this I understand the study of solid organic constituents in rocks by microscopical methods. The term itself is easily associated to coal petrology to which it is in many ways related and owes certain basic principles.

Many palaeobotanists have contributed to the knowledge of coal and coal formation, and palaeobotanical thought and knowledge have had a significant impact on concepts and advances in coal petrology. The relations between organic petrology and palaeobotany are perhaps less evident at first view.

In order to illustrate what the organic petrologist is doing and what it is for, we may look at a log-sheet used in an applied research institution (Text-fig. 1). The design of the log-sheet will vary from one laboratory to another, but the kind of data recorded will be essentially the same. Most of the data entered in the log are from observations on palynological preparations.

Entries in the first column denote some structures which are familiar also to a palaeobotanist. The purpose of collecting the data, however, is not at all palaeobotanical. The two main purposes are seen from other columns: evaluation of the maturation level, which is an essential parameter in the assessment of a petroleum source rock; and interpretation of sedimentary environments.

The sample composition data recorded in the first column represent the bulk of organic matter which may be extracted from the sediments by means of acid solution of the mineral matrix. This is a medley which has been given many different names: acid insoluble organic material immediately conveys the right information, but is obviously too long for general use. Phytoclasts, meaning broken pieces of plant origin, is a good term, also descriptive in its concept. The term was proposed by Bostick (1971) but is used less than it deserves. The most widely used term is kerogen, hence visual kerogen analysis for the observations recorded. However, kerogen is an old term, older than the palynological method of acid digestion of sediments. It was proposed in 1912 by Crum Brown to designate the solid, in organic solvents insoluble residue of Scottish oil shales, which produced hydrocarbon distillates when heated (for ref. and further discussion, see Brooks, 1981, pp. 1-3). In palynology and organic petrology the term kerogen is used for the organic residue left after palynological methods of extraction,



RECORD OF ACID INSOLUBLE ORGANIC MATERIAL IN ROCK SAMPLES

Date:

Analysis by:

Material:

Locality

SAMPLE IDENTIFIC NUMBER/ DEPTH

SAMPLE COMPOSITION

VISUAL ESTIMATION OF PHYTOCLASTS

- ☐ Amorphous
- ░ Algal
- ▨ Pollen/ Spores
- ▦ Finely dispersed herbaceous
- ▥ Wood remains
- ▧ Cuticles
- ■ Black coal fragments

PRESERVATION

COLOUR QUALITY

- LIGHT
- YELLOW
- BR. YELLOW
- Y BROWN
- BROWN
- AMBER
- DRY BROWN
- BLACK

PALYN QUAL.

- GOOD
- FAIR
- POOR

MATURATION INDEX

- IMMATURE<2+
- MODERATE MATURE 2+ 3−
- 3< MATURE <3+
- 3+< OIL WINDOW<4
- 4<GASCOND:
- 1+ —2+ —3+ —4+ —5

ENVIRONM. PALYNO-FACIES

- OPEN MARINE
- SHALLOW MARINE
- DELTAIC
- INNER DELTAIC
- LOW ENERGY
- HIGH ENERGY
- HEAVY MINERALS

REMARKS

VITRINITE REFLECTANCE

TEXT-FIG. 1 — Head of log-sheet for visual kerogen analysis (Continental Shelf Institute, Norway).

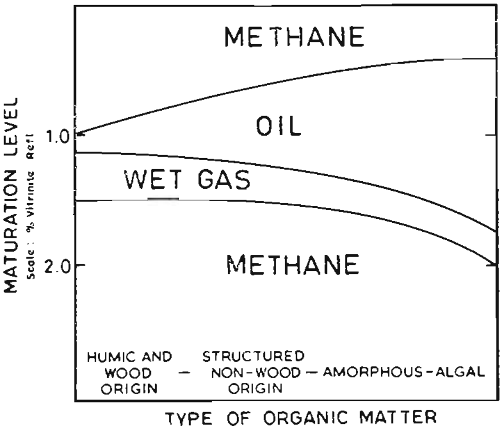
i.e. HCl nad HF treatment of sediments. This is the most widely used meaning and the one adopted here. We do well, however, to be aware that organic geochemists tend to prefer a definition more in line with the original.

So far I have been dealing with the more familiar palynological methods to study dispersed organic matter. But organic petrology includes a variety of other methods, all microscopical. The last column in Text-fig. 1 indicates one of these methods: vitrinite reflectance. This means the study of polished organic particles by incident light with the application of a photometer to measure their reflectivity. By still other methods, the fluorescence of organic particles on UV and blue light excitation is studied, both qualitatively and quantitatively. In all these various methods we can observe a rapid development towards higher level of technical sophistication with the objective of obtaining more quantitative data and reliable interpretations.

For the assessment of the hydrocarbon source quality of a sediment, three sets of observations on the organic particles are essential:

1. The total amount of organic matter in the sediment.
2. The composition of the organic matter; often called the " organic type " or " kerogen type ".
3. The maturation level. This means the degree to which chemical transformations have taken place in the organic matter; these transformations are controlled by temperature as a result of deep burial of the sediments, hence the terms thermal alteration and thermal maturation are widely used.

Organic matter of marine or algal origin and so-called amorphous material are the best petroleum sources over a broad range of maturation. Organic matter of wood origin, on the other hand, mainly produces gas and only little oil (Text-fig. 2). If the organic matter of wood origin is not the most interesting from a petroleum point of view, it is interesting in our context for other reasons. It is this material which demonstrates most clearly the relationship between organic petrology and coal petrology, and it offers the best microscopical basis for determination of the maturation level.



TEXT-FIG. 2 — General relationships between type of organic matter, maturation and hydrocarbon potential.

In humic coals, degradation products of wood are the major constituents. The coal petrologists recognize several types of such coalified wood material, and one of these is vitrinite. Vitrinite is further subdivided into many finer categories, based among other criteria on the degree to which wood structures can be recognized, but these subdivisions are not essential to us here. A polished vitrinite surface reflects light with a low grey intensity. Another wood constituent in coals, the so-called mineral charcoal, or fusinite in the coal petrology terminology, reflects light much brighter than vitrinite.

A most significant point about the reflectivity of vitrinite is that it shows a steady increase with increasing coal rank. This is the basis for the use of vitrinite reflectance as the most reliable and widely used parameter of coal rank. While measurement of vitrinite reflectance has a long history in coal petrology, it is not much more than ten years ago that it was realized that particles of wood origin, equivalent to vitrinite, are widespread in sediments and that the method of reflectance measurements may be applied also to these particles (Bostick, 1971). Since the mid-70's, this method has become the most widely used for assessing the maturation level of dispersed organic matter in sediments. Previously, spore colour had been the most commonly used maturation parameter. It is still a quick and much used method, however, less objective than vitrinite reflectance measurements.

I have mentioned mineral charcoal, or fusinite, as another example of wood material in coal. Particles equivalent to fusinite also commonly occur dispersed in sediments. That is not surprising, since it is one of the most inert organic materials which exists.

Coal petrologists recognize a number of other coal constituents besides vitrinite and fusinite. Coal maceral is the general term for such constituents of coal which can be distinguished on morphological structures and other physical characters under the microscope. Macerals are therefore analogous to the minerals of the non-coal petrology.

Many palaeobotanists have contributed to the understanding of coal and coal formation. Thus, the concept of coal macerals is attributed to a well known palaeobotanist — Mary (1935). Her ideas and proposals some 50 years ago provided the basis for maceral differentiation, classification and terminology of modern coal petrology. The maceral concept and methods used in coal petrology can be profitably applied in organic petrology as we have seen from the example of vitrinite. However, it is not possible to make a general transfer of coal maceral classification and concepts to the field of organic petrology. The main reason for this is the differences in depositional environments of coal and clastic organic particles. Coal is an autochthonous deposit, the material is produced and fossilized in place. Clastic organic particles, on the other hand, have a different history of transportation, deposition and fossilization compared to their equivalents in coal; and indeed, many have no equivalents in coal.

Coal maceral classification has long ago reached the level of international standardization. The classification and definitions in organic petrology, on the other hand, are still rather unsettled. This is not only because the subject is still in its infancy, there are also great problems inherent in the material itself.

Let us consider a palynological preparation of a marginal marine sediment, say from the Early Tertiary. We will most probably find terrestrial plant fragments, wood and cuticles, to be dominating, besides conifer and angiosperm pollen and some dinoflagellate cysts. All the particles of terrestrial origin have had a complex history before they became extracted by the palynologist. They travelled a long distance, most likely in the order of hundreds of kilometers from their sites of origin. As palaeobotanists, we would certainly like to know something about their mother plants. The wood is taxonomically problematic, even if we have sizeable fossils for study, so here it does not offer a clue. The cuticle fragments are not much more helpful, small as they are. Still, I believe the cuticles have some potential of differentiation, but not much has been done in this direction. Differences in cuticle diversity might be a useful parameter in the palaeoenvironmental analysis in addition to others obtained from the kerogen analysis, even though it will not tell us much about the plant groups represented.

The question of the mother plants is only one of many which may be asked. Here are some others — What is the history of the fragmentation of the material ? Did it take place on the ground, or in the soil, or by abrasion during transport, or on a lake bottom or in the sediment ? These are only parts of the more general question: What were the agents and the environments involved in the formation of these particles ? Can we learn anything from these particles and their preservation regarding predepositional history and the depositional environments ? These are questions of why, rather than where from, about processes rather than origins. In our context again, we shall remember that part of these processes are biological in nature.

Organic petrology has one major aim: to obtain as much information as possible from the assemblages of plant debris and palynomorphs. Usually, data from a single sample are not of much use. Data are collected from series of samples through stratigraphic sections and attention is paid to the stratigraphic changes in the assemblages. It goes without saying that the quality of interpretations depends entirely on the level of understanding of origins and processes involved in formation of the kerogen. However, it must be admitted that a great deal is lacking in basic knowledge in order to give correct answers to the questions that were just asked. This field is probably the most neglected in organic petrology today. Advances in this field can only be made through interdisciplinary approaches, which will involve botany, invertebrate zoology, microbiology, organic chemistry, and aspects of palynology, palaeobotany and sedimentology.

We have an example of this kind of research in studies on plant litter decomposition in soils. Since this is of interest to pedology and agriculture, it has been studied extensively and a large body of knowledge exists. Major agents in the fragmentation process in soils are various invertebrate groups which are feeding, not on the plant litter itself, but on the saprophytic microflora thriving on it. Large quantities of plant fragments from soils are washed into the aquatic environment by rain storms and inundations.

The degradation processes in the aquatic environment are less well documented. Something has been learnt from cultures and experiments in the laboratory, but the natural environment is a far more difficult one to work in. To slove the problems of sampling and in situ experiments require technical skill and resources not commonly associated with palaeobotanists. It requires also combined biological and sedimentological insight at a level which is probably also unusual.

A recent study (Spicer, 1981) describes the degradation of tree leaves in stream and lake environments from the point of view of a palaeobotanist who is trying to relate a deposited leaf flora to its originating vegetation. The study illuminates the engineering problems of making sampling devices and experimental set-ups. Comprehensive studies with the scope of Spicer's are very much wanted on the microscopic fragments. The technical problem involved is probably one reason why such studies are so rare.

At the ultimate end of the degradation scale we face the amorphous issue. The clouds of finely dispersed particles have always casued some trouble to the palynologist, since it can be difficult to remove and impedes microscopical work. It is also troublesome to the organic petrologist because of its unstructured, nondescript nature which escapes all attempts at morphological classification and identification of its origins.

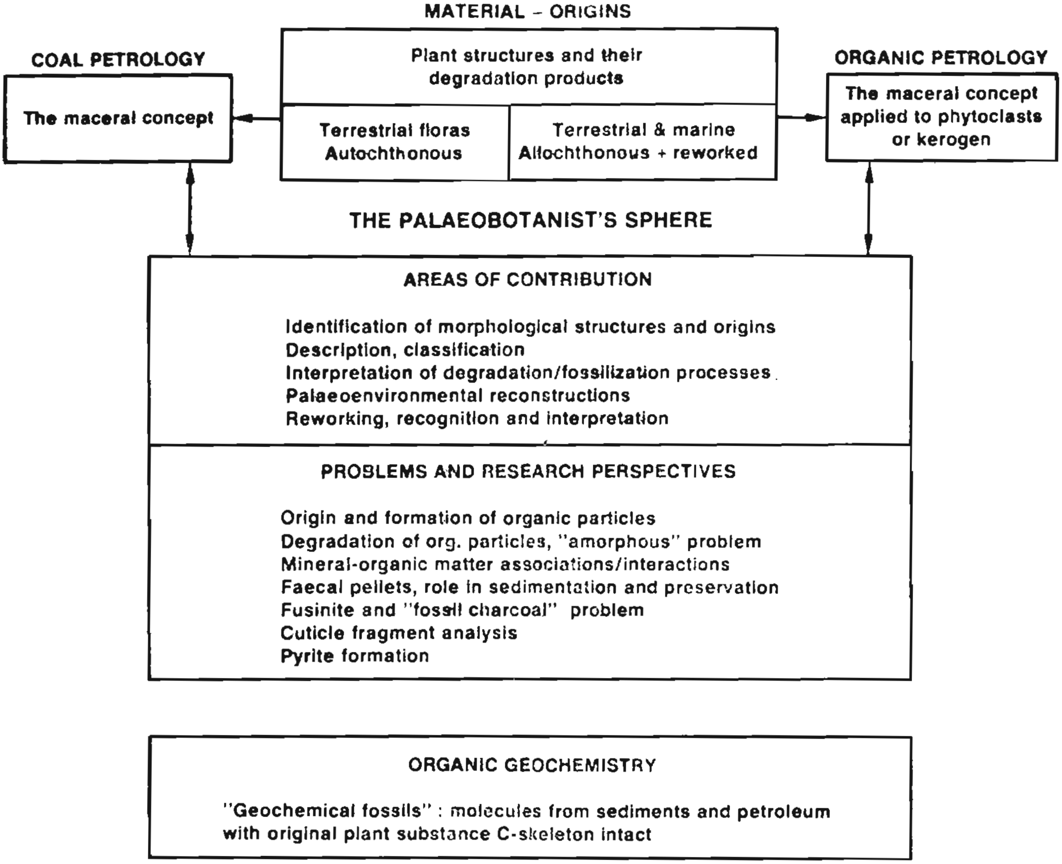
The coherence and lumping, quite often observed in the amorphous material, suggest that invertebrate ingestion and faecal pelletization play an essential role in its formation.

The kerogen in many organic rich marine sediments is dominated by amorphous material. It has a high H/C ratio and various chemical parameters point to algal origin. Because of the relatively high hydrogen content, it is reckoned to be a good hydrocarbon source. However, amorphous material in marine sediments may apparently also derive from land plants. Land plant membranes (cuticles, exines) are composed of relatively H-rich substances. Wood and associated tissues, on the other hand, are composed of substances of carbohydrate nature with less hydrogen and more oxygen. These two different origins of substances would produce amorphous material of markedly different petroleum source potential.

Laboratory experiments of microbial degradation of various terrestrial and marine plant materials indicate that all is eventually broken down to instructured matter whose origins cannot be distinguished under the ordinary light microscope (Masran & Pocock in Brooks, 1981). Bacteria are important agents in degradation processes, particularly in the aquatic environment. Much amorphous matter is probably derived from bacterial cell materials, which would explain its seemingly homogeneous nature irrespective of differences in origin.

There is a further kind of unstructured material which contributes to the amorphous category: the mineral-organic associations of a gel-like nature which can have the property of resisting HF digestion.

A great deal has yet to be learnt before we can claim to understand the processes and original materials involved in the formation of the diverse amorphous category, which is so important in the petroleum context. Recent advances in fluorescence microscopy appear to be promising for differentiation of amorphous material under the microscope (Robert, 1981). But this is a chapter of its own which shall not be further pursued here. However, palynologists and palaeobotanists should be aware of the potential advantages of fluorescence in morphological studies. Fluorescence can reveal structures which are otherwise imperceptible.



TEXT-FIG. 3 — Synthesis of relationships between organic petrology, coal petrology and palaeobotany.

I have attempted to present an overview of recent developments in palynology and particularly some palaeobotanical aspects of the dispersed organic matter in sediments. Text-fig. 3 is a synthesis of some of the diverse topics which I have touched upon with regard to organic petrology. The study of dispersed organic matter and of coal shares with palaeobotany the aspiration of building knowledge about past plants, floras and environments from bits and pieces of plants preserved in sediments. A palaeobotanical sphere of interest therefore clearly exists in both coal and organic petrology. Within this sphere there has been contributions of various kinds from palaeobotanical and other biological ideas and knowledge. One of these contributions not mentioned earlier in the text is the recognition of reworking and the potential which reworked palynomorphs and some of the debris have of indicating the provenance of sediments. There are not many systematic studies in this field, however, they can offer considerable contribution to geological interpretations.

The list of problems named in Text-fig. 3 is not meant to be exhaustive. The last item, pyrite formation, is included because it appears that pyrite varies so much in form that I wonder if there would not be environmental information to be gained from studying it more carefully.

I have entered organic geochemistry in the synthesis for a few reasons. The field is primarily concerned with studying the formation of petroleum from the sedimentary organic matter. It does also have its " fossils ", molecules which have retained their carbon-skeleton from the original plant substances. Organic geochemical research is for a great part directed at plant substances and their derivatives in sediments. This field should have our attention as palaeobotanists since methods and results are of potential value to us.

Plant fragments dealt with in organic petrology are smaller by some orders of magnitude than those which a macropalaeobotanist would normally want to look at. At the same time, however, they occur in numbers which are many orders of magnitude higher than macrofossils. There is a great challenge in the large volume of data on this plant material which is accumulated, particularly through applied studies, from many parts of the world.

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