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Science of establishing identity - Past, present and future

MW PANDIT AND LALJI SINGH*

Centre for Cellular and Molecular Biology, Hyderabad, INDIA.
Email: lalji@ccmb.ap.nic.in

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INTRODUCTION

CRIME is as old as human civilisation and so is man's ingenuity to investigate crime. King Solomon's legendary dilemma in identifying who is the real mother of the child and his decision based on the psyche of the motherhood is well known. World, however, has made tremendous progress since then in the science of identification. Identification process plays a crucial role in various day-to-day activities of human life. Be it the identification of heir to the estate or be it a suspected criminal charged with an offence of murder or rape, it becomes essential that identity of the person concerned be established beyond doubt in the interest of justice. The scientific and technological advances in the process of identification of an individual, therefore, are of utmost importance specially in a forensic set up. Over the last 150 years or so, several techniques have been developed for this purpose, most of them being a reflection of scientific progress and advancement of knowledge and understanding in the field of human biology; a simple example is the fingerprints of an individual. Whatever may be the origin of a man, there can be no doubt that human beings are individualised by their fingerprints. Man realised this quite early and developed an identification system based on the fact that fingerprints of every human being are unique. Practice of making fingerprints on legal documents is also very old. To begin with, it would be worthwhile to look at the historical perspective of this well documented popular and most commonly used method for identification.

Fig. 1—Two photographs of Sir William Herschel's fingerprint of the same thumb, taken thirty years apart; *left* : taken in 1860; and *right* : taken in 1888 showing no difference except a little bit of wear and tear.

THE PAST

Fingerprints : Indicator of absolute individuality

The distinction of being the first person to document his findings about the ridges on the hands goes to the 17th Century English Botanist Dr Nehemiah Grew, Fellow of the College of Physicians and of the Royal Society. He published a paper in 1668 in Philosophical Transactions. Grew at that time had absolutely no idea that over 200 years later these ridges would be used to identify criminals at crime scenes (Geral Lambourne 1984 in the 'fingerprinting story', pg. 25 published by Harrap Limited, London). However the individuality of fingerprints was first realised in 1860 by Sir William Herschel, a British

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Sixth Jubilee Lecture delivered by Dr Lalji Singh, Director, Centre for Cellular & Molecular Biology (CCMB), Hyderabad on 10th September, 2002 on the occasion of Foundation Day at Birbal Sahni Institute of Palaeobotany, Lucknow.

Administrator. He made an important observation that fingerprints of each individual were unique; hence, none of the fingerprints of two individuals matched. When he sent his observations for publication in Nature, one of the leading scientific journals, it rejected his paper with the objection that what is the guarantee that the fingerprint of a person remains the same throughout the life span of that individual. Sir William Herschel pursued his observations for 28 years and demonstrated that fingerprints taken of an individual in 1860 is the same as that taken in 1888. There was no difference in the fingerprint except a little bit of wear and tear (Fig. 1). His paper was finally published in Nature on 28th June, 1888.

This attracted the attention of a famous British biologist, Francis Galton, who did detailed study and wrote a book called "Fingerprint" in 1892. The first instance in which the person was hanged on the basis of the evidence of fingerprints took place in 1892 in Argentina. This classical approach for the identification of an individual is in vogue even today in many countries. The probability of two unrelated individuals having identical fingerprints is 1 in 10^{10} whereas the world population is about 6 x 10^9. Therefore no two unrelated individuals with identical fingerprint pattern can be found in the world. The Britishers made use of fingerprints all over the world wherever they had their empire but they never used it on themselves, until Edward Henry, another British scientist did a detailed survey of fingerprints from variety of people and classified them into various sectors and groups. This pioneering classification is used in fingerprint analysis even today. Identification through fingerprint is no doubt a powerful technique; but what if criminals do not leave any fingerprints on the scene of crime? Investigating authorities become absolutely helpless when no fingerprints of an individual suspected to be involved in the crime are available at the crime scene.

Blood as an identifier

Is it possible to identify an individual from his blood alone? It was believed earlier that the blood of every human being is the same and therefore it can be transfused from one individual to any other individual. However, such transfusion resulted in large number of deaths, the reasons for which were not immediately understood. It was Dr Karl Landsteiner who announced in 1901, one of the major medical discoveries of the century, later became known as blood group system. Dr Landsteiner demonstrated in 1901 that human blood can be classified into four distinct groups i.e., A, B, AB and O. Dr Landsteiner proposed the existence of these groups on the basis of the presence or the absence of both of the two antigens in the blood (i.e., the substances against which antibodies react) which he named A and B.

As soon as blood groups were discovered, forensic scientists adapted these characteristics for establishing identity of individuals for catching criminals. The problem with the blood group has been that if the blood group does not match, it can be said with 100% certainty that so and so cannot be the biological father of a particular child; or so and so cannot be the person whose blood was found at the scene of crime, and all this is valid even today. In fact in case of mismatch this itself could be enough and one does not have to do any more tests. But this happens very rarely. If the blood group matches, one cannot say with certainty that a particular person is a biological father of the child or he is the person whose blood stain was found at the scene of crime. This is because the probability of two people not being related and having the same blood group is very high. In a group of five, two are likely to have the same blood group. Therefore, this approach cannot be used for positive identification – one of the limitations of the blood group analysis.

In 1940, Dr Landsteiner at the age of 70 years announced the discovery of Rhesus (Rh) factor responsible for the consequent serious illness or death of 200 white babies. With the discovery of Rh factor, one has a little better probability of positive identification.

Today we know that there are more than 100 different factors in our blood, which can differ from individual to individual (Trowsdale, 1993). Most important of these factors are immunological proteins such as human lymphocyte antigens (HLAs). These antigens are found on the surface of white blood cells. By conducting about 32 different tests, including HLAs, one can have exclusion with 100% certainty; but the positive identification will again be only with a certainty of 99.7%. Can a person alleged for a crime be hanged with 99.7% probability of his being criminal? Obviously that would not be enough.

THE RECENT PAST

Besides, most of the forensic tests are based on proteins which are very labile molecules and under the environmental conditions as well as with the passage of time they get degraded. By the time forensic samples are brought to the laboratory, it takes a long time (several days) which causes degradation of proteins and therefore they become unsuitable for doing the test. Taking into account all these limitations, there was a necessity to identify biological material which on one hand is highly stable and on the other, it is so variable that is individual—specific. This dream of forensic science was fulfilled by the discovery of DNA fingerprinting in 1985 by Professor Alec Jeffreys, Leicester University, UK. Although the technique of DNA fingerprinting was pioneered by Alec Jeffreys (Jeffreys *et al.*, 1985), and is also popular amongst the developed countries such as USA, India was the third country in the world to develop its own DNA fingerprinting probe and technique in 1989 (see Singh, 1991). DNA fingerprinting would not have become so popular, had it not found its use in

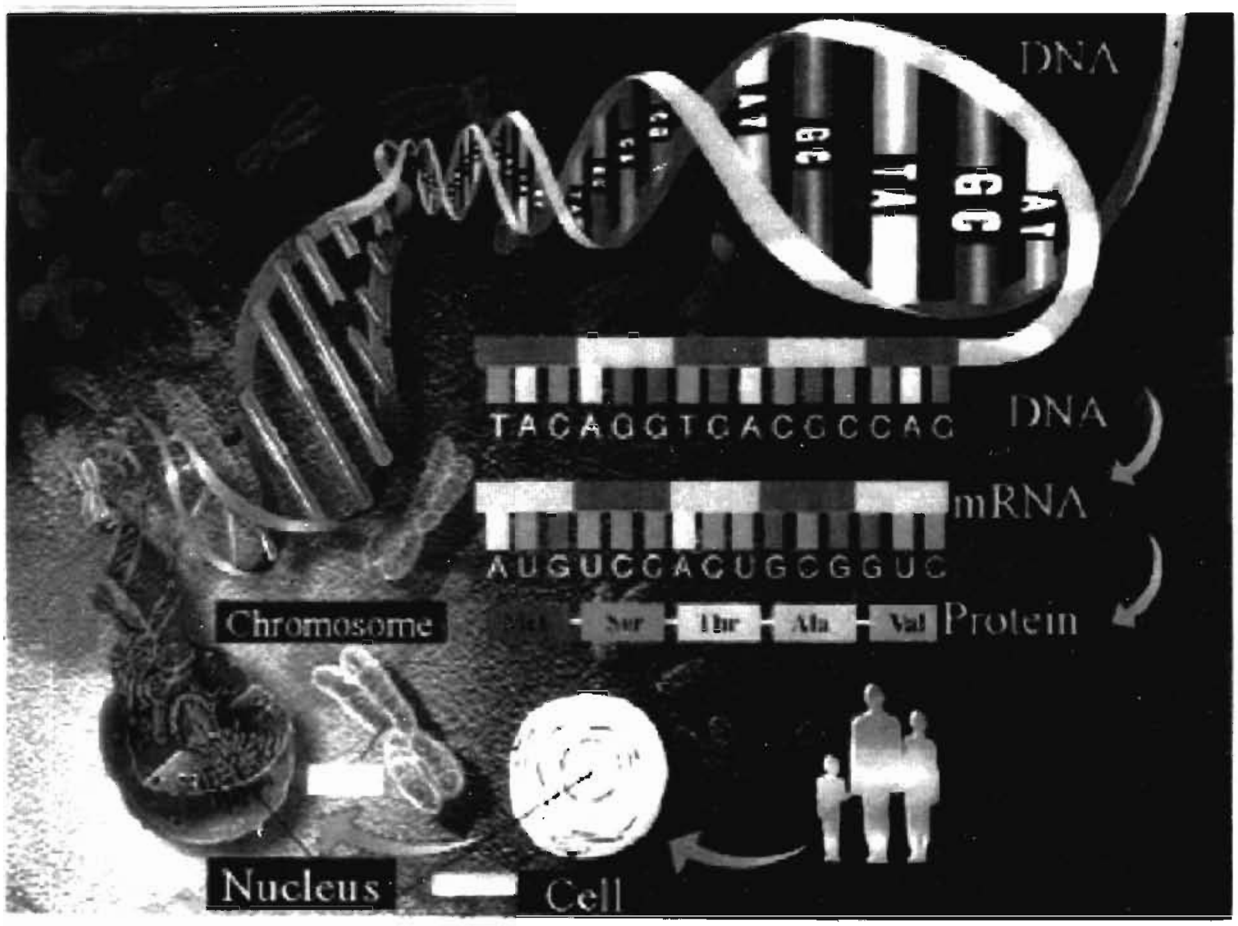

Fig. 2—Schematic diagram showing cell from human body, its nucleus, chromosomes and DNA coding for protein through mRNA as an intermediary.

identification of mutilated bodies, missing children, establishing paternity or maternity, in the field of agriculture, wildlife conservation, in cases of assassinations and murders, cases of rapes, etc. It particularly became known because of its use in forensic investigations and its ability to establish the identity of an individual.

In 1985, when Alec Jeffreys demonstrated that the genetic material i.e., DNA can vary from individual to individual, it came as a surprise to the scientific community all over the world. Scientists, however, eventually confirmed that what Alec Jeffreys was saying was correct. Today, one knows that there are significant differences in the genetic material from each individual. When one does the DNA fingerprinting, which is described later, one gets the pattern something like barcodes on library books and food packets based on which the computer establishes the identity and all the details of the content. Similarly, the total number of bands mapped as per their sizes help in establishing the identity of the particular individual. By this technique it is possible to identify an individual in the entire world population, because the probability of having the same DNA fingerprint pattern for any two individuals is extremely low which could exclude the entire world population of 6 x 10^9 several times over, with the only exception of identical twins.

Fig. 3—Stretch of DNA sequence showing repeats of GATA.

Basis of DNA fingerprinting

All living organisms on this planet are made up of living units called cells. There are about 10 trillion cells in the human body. Each cell (Fig. 2) has a clear dense structure in the centre which is called nucleus. Nucleus contains thread-like structures known as chromosomes. There are 46 chromosomes in every cell of our body; 23 of these are inherited from the father through sperm and 23 from the mother through the egg. So the newborn child is a combination of chromosomes from both the parents. At the molecular level, chromosome is a complex entity consisting of proteins and deoxyribose nucleic acid (DNA). The DNA molecule is so small that it can be seen only when it is magnified to the extent of 200000 times under electron microscope. DNA from a single human cell measures about 2 meter in length. It is astonishing that this 2 meter long DNA is packed in a tiny nucleus, the diameter of which is barely 10 microns. This is one of the astonishing engineering feats of nature. The structure of DNA was discovered by James Watson and Francis Crick (1953) for which they were awarded the Nobel prize. They demonstrated that the DNA is made up of double helix consisting of two strands, the backbone of which is made up of sugar and phosphate groups. Thus two backbones of DNA are held together in a double helical form by four basic chemical units (bases) A, G, C & T. The structure of these bases is such that A pairs with T and G with C (Fig. 2). It is remarkable that these four bases and the sequence in which they occur in a piece of DNA essentially decide the function of this piece of DNA. Thus the piece of DNA which instructs a cell to perform a particular function is called a gene. Size of the gene is enormously variable; it can be a few hundred base pairs (RNA genes, Sry gene, etc.) or it can be several 1000 Kb in length (Muscular dystrophy gene). It is estimated that there are about 30,000-40,000 genes (International Human Genome Consortium, 2001) which are necessary and sufficient to perform each and every function of a cell of our body. However, it is interesting to note that these genes constitute only less than 2% of the total DNA found in a cell. In other words, we do not know what the role of remaining >98% of DNA present in every cell is? It has been a challenging riddle that if all the genes code for proteins and all of us carry almost same genes, then why are we so different from each other? Probably the answer to the riddle would lie in that >98% DNA present in every cell of our body; and still we do not know

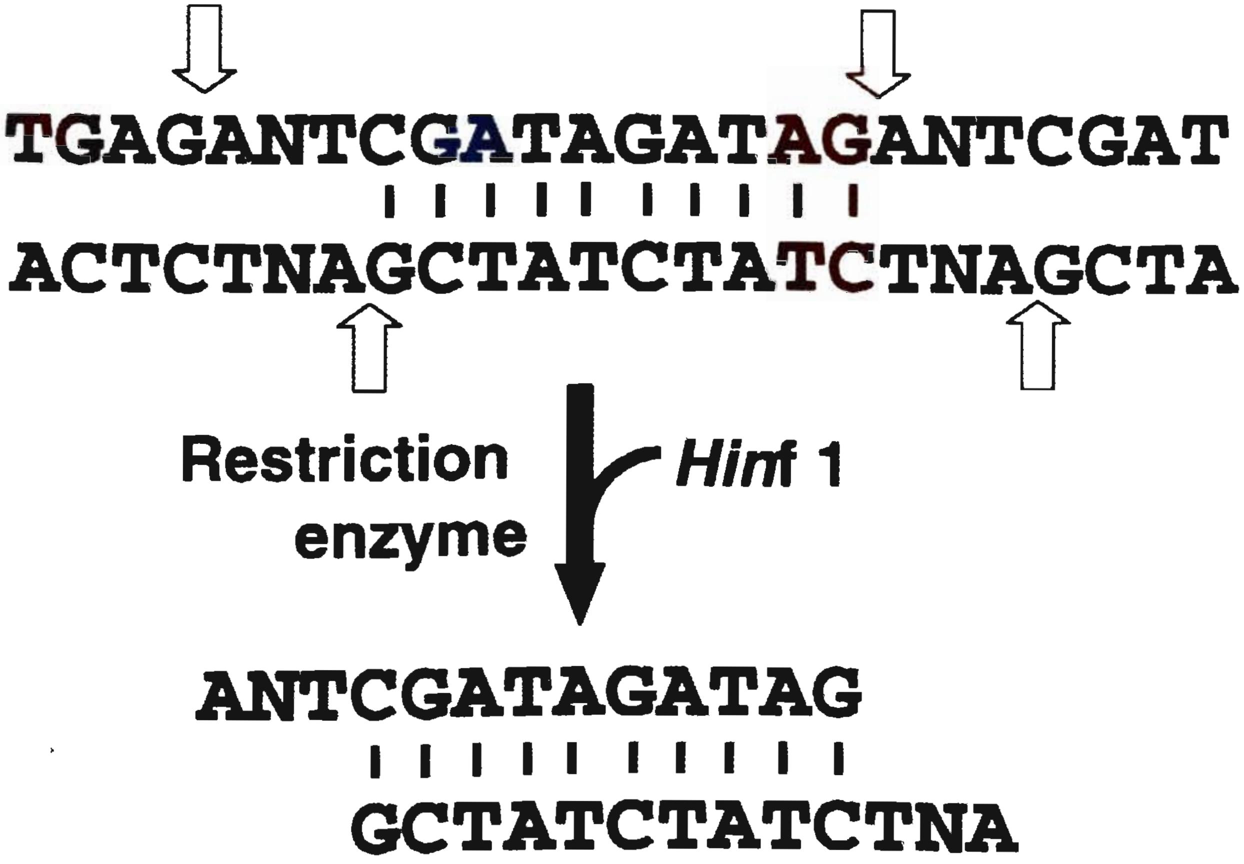

Fig. 4—Cutting of DNA at specific sites (shown by arrows) by restriction enzyme *Hinf* 1.

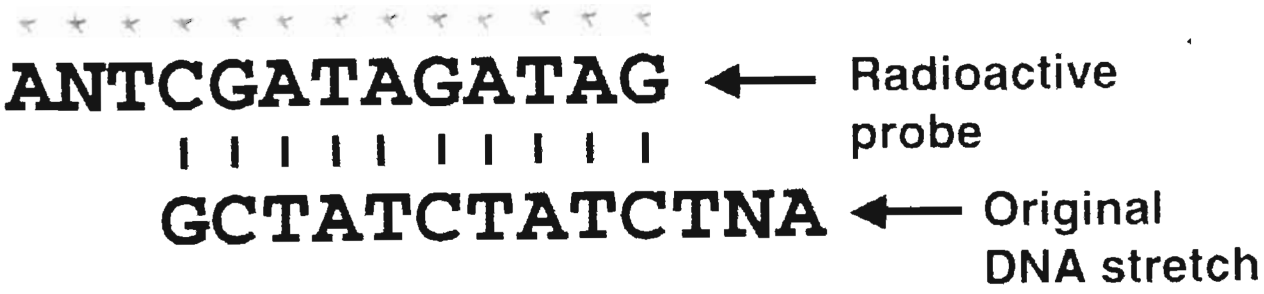

Fig. 5—Radioactively labelled DNA by the incorporation of labelled nucleotides (shown by stars).

what sense it makes for the existence of the organism. To assign function to so called Junk DNA is going to be a daunting task. It would require the help of all branches of sciences including physics, chemistry, biology, mathematics, computer science, etc. It is, however, interesting to note that a small part of this Junk DNA is repetitive in nature. Fig. 3 shows that a stretch of DNA made up of 4 nucleotides is repeated twice and there exist two copies of such repeats in the given sample. Such repeats are known as tandem repeats. These repeats could be of variable length from a few copies to several hundred copies at each location. Repeats of this kind are not known to make any biological sense. The nature of such repeats in terms of the number of copies and the frequency with which they occur in DNA varies from individual to individual. The technique by which we can detect the variation in copy number of such sequences is called DNA fingerprinting. The term DNA fingerprinting was introduced by Alec Jeffreys to emphasise that DNA from each individuals is as unique as his/her fingerprints.

HOW DNA FINGERPRINTING IS DONE

Step 1 – Isolation of DNA

Initial step of the isolation of DNA is always dictated by the source and the nature of the tissue. It depends upon whether one is isolating DNA from rocky fossils or from bones, hairs or soft tissue like kidney or liquid like blood. The crucial step in the isolation of the DNA is to break cells as well as nucleus so that contents of the cell become free; then one has to remove molecules like proteins, RNA and the cell debris from the mixture by treating with phenol and chloroform repeatedly by making use of centrifugation. DNA finally comes in the supernatant and is colourless. In a precipitated form DNA resembles cotton wool. It can then be dissolved again in appropriate buffer for further processing.

Step 2 – Fragmentation of DNA

DNA molecules are very large and they need to be cut further into smaller fragments. This molecular cutting is achieved by special chemical scissors known as restriction enzymes. The beauty of the restriction enzymes is that they have an ability to recognise specific sites consisting of their sequences and an ability to cut only those sites. For example, the restriction enzyme *Hinf* 1 recognises the sequence such

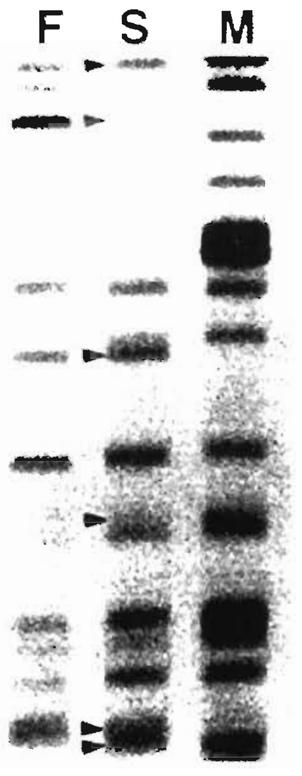

Fig. 6—Typical DNA-fingerprint patterns obtained from different related individuals using multilocus probe. Arrows indicate the paternally inherited bands in the son which are not present in the mother (F: father; S: son; M: mother)

as -GANTC- on DNA and cuts between G and A at this site as shown in Fig. 4. Several hundreds of such restriction enzymes have been isolated and are commercially available. About half a dozen of them are routinely used for DNA fingerprinting analysis.

Step 3 – Separation of DNA fragments

DNA which has been cut into smaller pieces in the previous step is separated for further examination by a process called gel electrophoresis. The matrix of the gel is prepared from agarose derived from a seaweed. The agarose is liquified by melting it and then poured in a thin glassware tray. Gel is set when it cools. DNA samples are loaded in previously made slots and voltage is applied across the gel. As DNA is negatively charged because of its phosphate groups, it moves towards the positive node when electric current is passed through the gel. Smaller size fragments move relatively faster and reach towards the positive pole earlier; the larger fragments remain behind. In between these two extremes, fragments of intermediary sizes align themselves according to their lengths.

Step 4 – Denaturation of fragments

Separated fragments are now denatured with the help of alkali (sodium hydroxide solution). These fragments are then transferred on to a membrane which is positively charged. Hence we now have essentially a single stranded fractionated DNA stuck on a positively charged membrane.

Step 5 – Detection of specific fragments

As DNA is colourless, we need some method by which we can detect all the fragments of DNA on the membrane. Therefore new complementary strands labelled with radioactivity are used. Formation of complementary base pairs with the existing single strand DNA fragments makes its detection possible with the help of radioactivity (Fig. 5). For example, if the fragment composed of ATGCG is on the membrane then we should provide radioactively labelled complementary strand such as TACGC which will form a duplex DNA by complementary base pairing. These radioactively

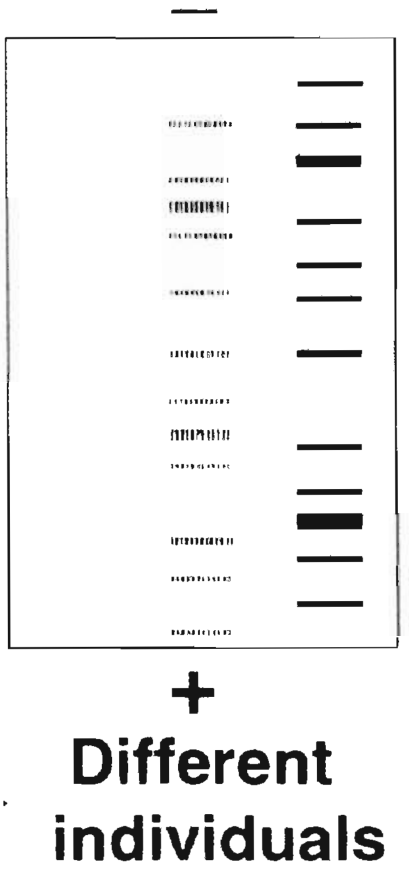

Fig. 7—DNA-fingerprints of three different unrelated individuals showing individual-specific patterns

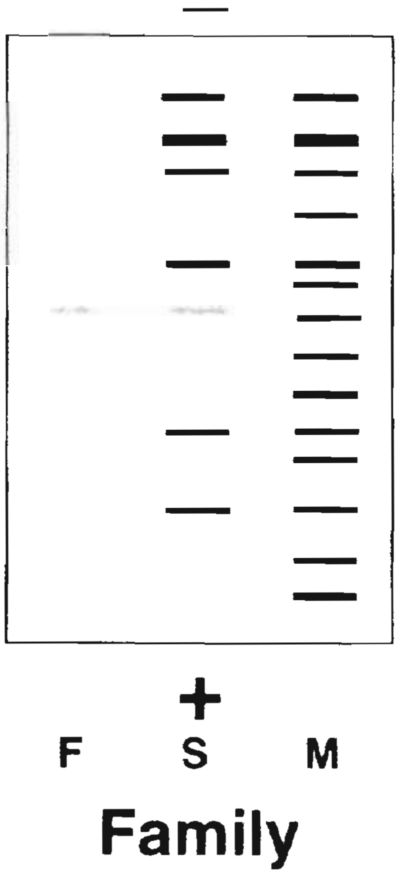

Fig. 8—DNA fingerprints of members from one family (F : father, S : son, M : mother). Every band present in the son is accounted for either being present in the father (grey bands) or in the mother (black bands). There is not a single band which is unaccounted for.

labelled sequences are called probes. When the membranes are incubated with probes under a proper set of conditions, radioactive probes will find their complementary partners to form duplex DNA. These membranes are subsequently put on the X-ray film in a dark room for a couple of days and bands can be seen on the X-ray film at positions where the radioactive complementary sequences have formed the duplexes. Typical DNA fingerprinting is shown in Fig. 6.

Uniqueness of DNA

There are certain important characteristics of DNA which make this material suitable for identification of an individual. Firstly, DNA remains the same all throughout the life span of human being; it does not change with age. Secondly, no matter from which tissue one isolates DNA (kidney, brain, hair, blood, semen, bone, sputum, urine, skin or from any other tissue) all give the same DNA fingerprinting pattern as long as tissue belongs to the same individual. Because of these reasons, it is immaterial which tissue is compared for DNA analysis. For example, the DNA from the semen found at the scene of crime in case of rape could be compared with the DNA isolated from the blood of the suspect. There is another remarkable property of DNA which is very essential for forensic investigations; DNA is very stable molecule. One can heat it or even boil it only to see that DNA strands are separated; this process is known as denaturation. The moment appropriate buffer conditions and temperature are provided, the strands come back and form a double helical structure. Thus DNA is comparatively more stable than other important functional biological molecules such as proteins, carbohydrates, etc. This could be one of the reasons why nature has selected DNA as a genetic material. DNA is so stable that it has been isolated from the remains of bones which were thousands of years old. It has also been isolated from some several million years old fossils. For example, DNA was isolated from insect fossils trapped in amber. Of course occasionally one finds that DNA is degraded into small pieces. However, scientists have invented ways and means to cope up with such a situation, which are described later.

Nature of DNA fingerprinting patterns

1. First generation of DNA fingerprinting probes : Multi-locus probes

A subset of minisatellites share a common 'core' sequence embedded in each repeat unit which is involved in the generation of hypervariable tandem repeated loci by serving as polymerase slippage signal. These are distributed all over the genome covering most of the chromosomes. These core-sequence probes detect variable number tandem repeats (VNTR) in the genome (Fig. 6). Some of the multi-locus probes (MLPs) that have been extensively used are Bkm (Banded krait minor satellite DNA) and Bkm-derived clone 2(8), and 33.6 and 33.15 (Tandemly repeated core-sequence downstream to ∝-globin gene, see Singh, 1991, 1995).

DNA fingerprinting patterns are normally reflections of existence of variable lengths of tandem repeats. As these variable regions are unique for every individual, DNA fingerprinting patterns can help in identifying a particular individual. The DNA fingerprinting patterns obtained from three different individuals are given in Fig. 7. The patterns are schematically generated on a computer for the convenience. DNA fragments in case of each individual are arranged from top to bottom in a decreasing order of length. It can be seen that these patterns are drastically different from each other and they are individual specific. None of the two individuals has all the bands exactly in the same position. However, occasionally there is a matching of one or two bands with one another but this could be purely coincidental. Another interesting example where three DNA fingerprinting patterns come from the members of the same family, the mother, the son and the father are given in Fig. 8. In these patterns, careful observation brings out certain facts such as (1) The patterns from the sample of mother and the father are entirely different and they hardly match in terms of their positions (sizes of fragments); (2) At a glance pattern from the son appears different from that of the parents, but on careful scrutiny one finds that every band present in the child is accounted for either being present in the mother or in the father. One cannot find a single band in the son which is not accounted for by his parents. This happens because 23 of the chromosomes in a child are inherited from the father and 23 from the mother which are carriers of genetic material and these bands originate from DNA. Therefore, theoretically speaking, approximately 50% of the bands present in every individual come from the father and 50% from the mother. One can also notice that every band present in the father is not inherited by the son; and every time the child is borne, 50% bands are inherited from the father in a completely random fashion. That means if one looks at the patterns from brothers and sisters, or two sons for that matter, their patterns are somewhat similar but not identical. But in each case, inheritance of the bands are accounted for by looking at the patterns of both the parents. In such cases like brother and sister, investigators make use of another parameter which is called co-efficient of band sharing. This parameter is based on the total number of bands and how many bands are common between two individuals. In such a case one should normally find a little more than 50% bands common between brother and sister; while in case of unrelated individuals, this could be 30% or less. Therefore, when one finds more than 50% bands common between two individuals, one can certainly say that these individuals are brothers and sisters. However, one cannot extend this parameter to cousins

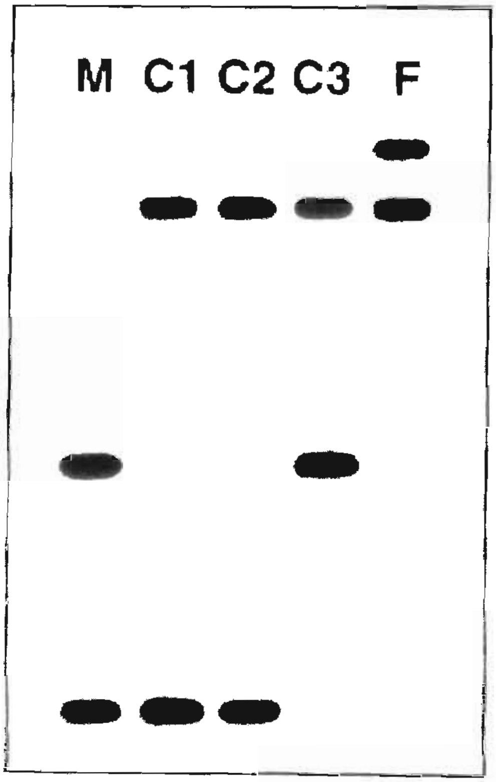

Fig. 9—DNA fingerprint patterns obtained using single locus probe. F : Father, M : Mother and C1, C2 and C3 are the children from the same family. Each child shares one band each from mother and one from father.

or cousin brothers because such individuals could be as good as unrelated ones.

DNA fingerprinting of identical twins

Identical twins are a special case where DNA fingerprinting patterns are absolutely identical and they match perfectly. Hence two identical twins cannot be differentiated from each other on the basis of DNA fingerprinting pattern. In a forensic set up, a challenging situation would be the case where one of the two identical twin brothers has actually committed a murder. Even if we know one of them is a suspect, it would be difficult to prove by DNA fingerprinting which one of the twin brothers has actually committed the crime – one of the serious limitations of this technology. Obviously, in such a case, normal fingerprints, if available, may be of help in identifying which of the two twin brothers has actually committed the crime. Researchers are in search of finding such probes where the differences between two identical twins could also be mapped with certainty.

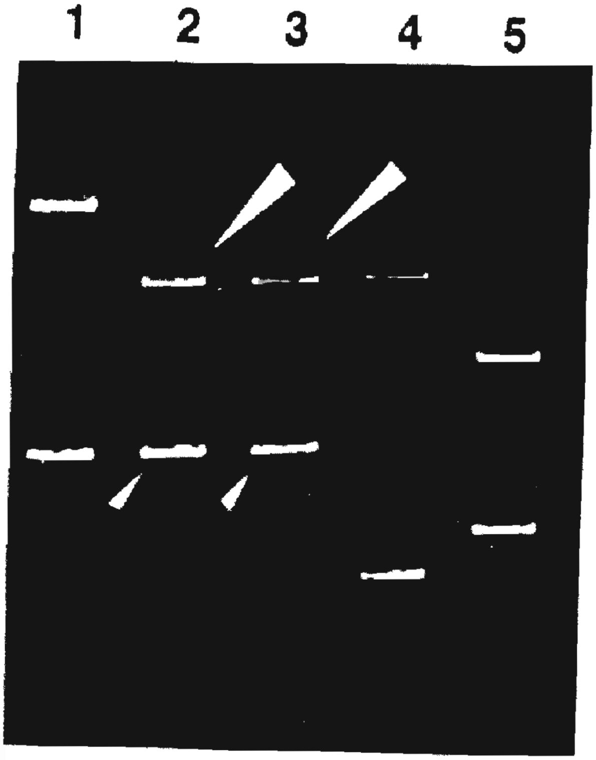

Fig. 10—PCR-based DNA fingerprinting carried out using teeth pulp and hair-roots and compared with the blood sample of the suspected parent. *Lane 1*: blood of suspected mother; *Lane 2*: teeth of the deceased; *Lane 3*: hair of the deceased; *Lane 4*: blood of suspected father; *Lane 5*: blood of unrelated individuals. Bands indicated by arrows testify that the deceased is the biological offspring of the suspected parents.

Advantages and disadvantages of MLPs

A single MLP provides sufficient number of variable bands to establish positive identity of an individual beyond reasonable doubt. An MLP cannot, however, be used reliably to type mixed samples for example in the case of multiple rape. It requires high-molecular-weight DNA in larger quantities and is technically demanding. The alleles are not well defined and their specific association with particular chromosomes is difficult to show.

2. Second generation of DNA fingerprinting probes : Locus-specific probes (single locus probes)

A probe that detects a single hypervariable locus originating from a specific region of a specific chromosome is called a locus-specific or single-locus probe (SLP). Each chromosome in an individual occurs in pair, one inherited from the biological mother and one from the biological father. If the locus is identical between mother and father, it gives only one

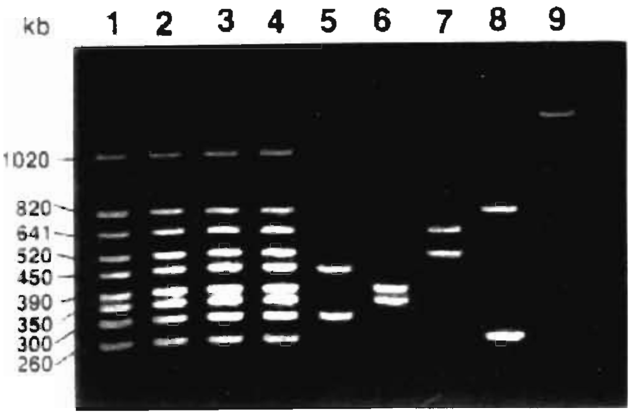

Fig. 11—Identification of various suspects from swabs of mixed blood by using PCR products from four cotton swabs (*Lanes 1-4*); four suspects (*Lanes 5-8*); and examiner as a control (*Lane 9*).

band and is designated as homozygous state and when the locus is different between the two parents, it gives two bands and is designated as heterozygous state. The hybridization patterns given by SLPs are very simple and consist of one or two fragments per individual (Singh, 1999). Loci with heterozygosities higher than 95% rarely show evidence of common alleles.

Advantages and disadvantages of SLPs

SLPs are simpler to use compared to MLPs (Fig. 9). They require comparatively little genomic DNA. Unlike in the case of MLPs, slightly degraded DNA can also be used. SLPs are most uniquely used in identifying mixed DNA samples in cases such as multiple rape, screening of large samples by pool typing to identify a serial rapist or most potential suspects. Patterns obtained are simple and easy to interpret in courts. Chromosomal locations of these probes are well defined. However, one has to use at last a set of five or six different probes to establish identity and it is technically highly demanding.

3. Third generation of DNA fingerprinting probes : SLP detection by DNA amplification using polymerase chain reaction (SLP by PCR)

The PCR is one of the most ingenious developments in molecular biology in recent years (Mullis, 1990). It allows amplification of a single copy of a target DNA sequence, defined by oligonucleotide primers flanking the ends of the sequence, to millions of copies in a short period.

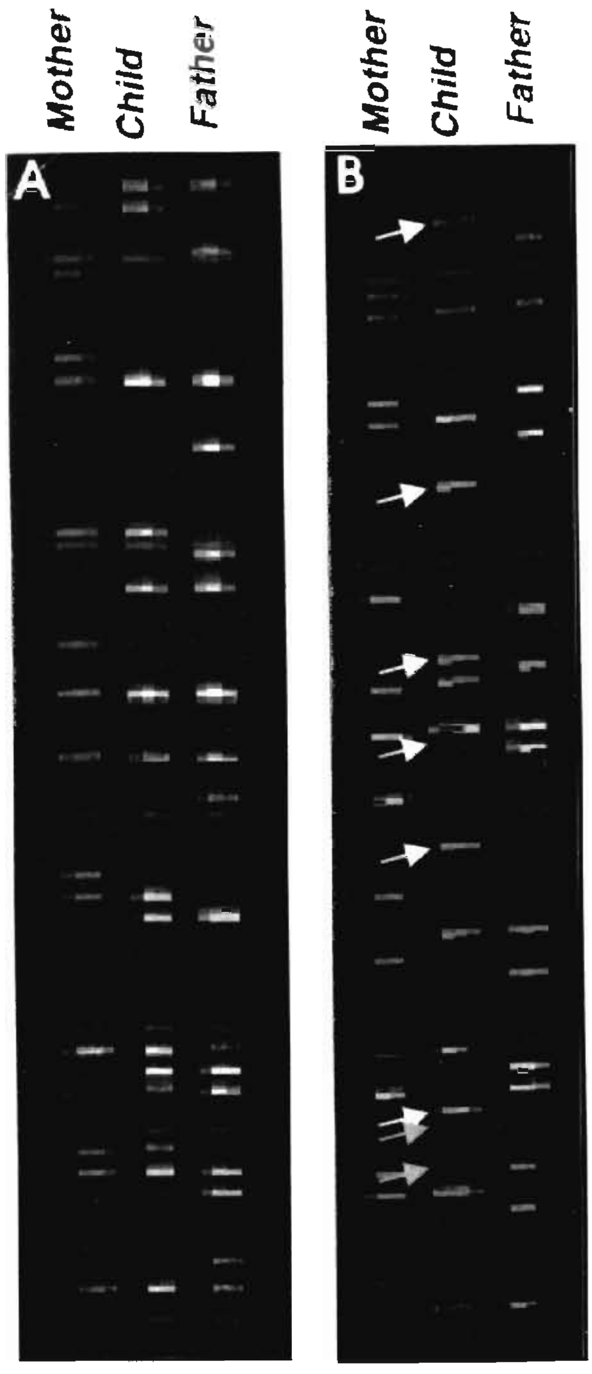

Fig. 12—STR analysis using Profiler Plus STR kit. Red color bands are the molecular weight markers, other color bands represent various STR alleles. (A) Every band present in the child is accounted for either being present in the mother or in the father, therefore they are the biological parents of this child. (B) Bands which are marked with the arrows are neither matching with mother nor with father, therefore they are not the biological parents of this child.

Advantages and disadvantages

This is ideally suited for forensic use because it allows DNA profiling of a single strand of human hair or a single drop of blood or semen or a minute blood stain or semen stain, which would otherwise be too small a quantity to be of value (Fig. 10). It also allows the typing of samples too degraded for MLP analysis. PCR-based DNA typing can be performed in a short time. It is useful in identifying mixed forensic samples and in cases of multiple rape (Fig. 11). However, one has to use at least a set of five to six pairs of different primers to establish identity; and being a very sensitive technique, contamination is a big problem, which may wrongly lead to exclusion. Therefore, utmost care is required while doing the DNA profiling. The HLA-DQ locus, with six typeable alleles was the first use of PCR in forensic case work.

Mitochondrial DNA (mtDNA) fingerprinting

Sequences of mtDNA hypervariable region are also highly polymorphic. Maternal inheritance of mtDNA makes it a unique tool in studies of populations (Thangaraj *et al.*, 1999). The use of PCR in association with restriction analysis and sequencing of any given piece of hypervariable mtDNA is ideally suited for forensic investigation, particularly in determining the maternity of any given child. mtDNA analysis was employed to determine the maternal relatives of children who were born in prison in Argentina during the military rule that lasted from 1976-1983.

THE PRESENT

4. Fourth generation of DNA fingerprinting probes : Short Tandem Repeats (STRs) in human identification - present method of choice

Short Tandem Repeats (STRs) commonly termed as microsatellites are interspersed in eukaryotic genome (randomly occurring every 6-10 kb) and are known to be highly polymorphic for their length (Hancock, 1999). STRs contain two to seven repeat nucleotide sequence. The most abundant microsatellites are $(GT)_n$ and $(CT)_n$ repeats. Allele size of STRs is generally less than 350 base pairs (bp) in length. Up to 9 sets of STRs can be co-amplified using PCR in a single reaction and the fluorescence-based PCR products can be separated by polyacrylamide gel electrophoresis using ABI Prism Automated DNA sequencer (Han *et al.*, 2000).

Advantages and disadvantages

Small amount of DNA (2ng) is sufficient to co-amplify up to 10 STRs. A degraded sample can be amplified using small size STRs. STR alleles have defined size of amplification, which simplifies interpretation of the results. PCR-based STR analyses are very rapid. The ability to co-amplify and distinguish between multiple loci through the use of fluorescent multiple loci in a single reaction using fluorescent tags on markers with overlapping size ranges, and availability of automated detection technology enables STRs to be employed in high throughput situations because of which it has at present become the method of choice for genotyping (Fig. 12). More than 10 STRs can be amplified in a single tube and analysed in a single lane, provided one of the each STR primer pairs is fluorescently labelled. However, there are some disadvantages of this technology. For example, analysis of dinucleotide STRs has revealed that the Taq polymerase 'slips' during amplification resulting in the generation of artefactual stutter bands 2 bp apart; this leads to ambiguous allele designation and severely limits the reliable interpretation of such loci. Therefore, dinucleotide STRs are not generally employed in a forensic setting. Tetranucleotide repeat loci are more suitable for forensic identification.

THE FUTURE

Gene Chip Breakthrough

These world-changing biochips, formally known as DNA arrays, bear an uncanny resemblance to the chips that ushered in the information age. Instead of transisters, they are crammed with dense grids of molecular tweezers built to grip DNA. They give scientists the ability to analyse thousands of genes at once – in effect, to speed-read the book of life. Gene chips are being used in landmark studies on everything from the origin of cancer to gene mutations and genetic risks for scores of diseases. Gene chip also has potential to be used in forensic investigations for establishing identity of the suspect beyond any doubt by comparing the genetic variation using the entire genome rather than a few markers which are being presently used. For example, one of the most common forms of genomic variations is single nucleotide polymorphisms, or SNPs. The area where SNPs are receiving the most attention is their use as genetic markers for the study of complex human traits and pharmacogenomics. Genome-wide complements of SNPs are now being developed as genetic tools. Perhaps in future thousands of SNPs would be used to design oligo-microarray or a DNA chip which in turn would be used to hybridise with the fluorescence labelled DNA isolated from the forensic sample collected from the scene of crime and with the DNA of the suspect to determine the match or non-match. This will be the ultimate technology for establishing identity by comparison of thousands of variable sequences genome-wide instead of only a few marker bands used today.

Sex specific identification

Due to the lack of sensitivity and technical as well as statistical problems none of the traditional methods for male identification are being practiced for forensic applications. There are occasions when paternal or maternal lineage has to be established beyond doubt when one of the parents is absent. It has been shown that major part of the long arm of the human chromosome (Yq) is made up of polymorphic sequences which are organised into large interspersed tandemly repeated arrays. Therefore the development of Y-chromosome-linked STRs has become the system of choice for male identification (Jobling *et al.*, 1997). Y chromosome-specific STRs are more useful in rape cases to identify only the male DNA because vaginal swab of victim contains sperms as well as her own epithelial cells. Hence, DNA isolated from vaginal swab will also contain victim's DNA. In such case, Y-STR analysis is useful to detect only the culprit's DNA. Another application of Y-STRs is that if father of a male child is not available due to some reason, one can analyse his father's side male relatives to establish whether he belongs to that family or not.

To identify the maternal lineage is many a times crucial to the forensic investigation. In such a case, mitochondrial DNA (mtDNA) can be very useful because it is inherited only through maternal cytoplasm. It is known that the non-coding region of mtDNA is especially rich in polymorphism. This property of mtDNA can be used very effectively in the process of identification. However, it is also known that these regions are highly prone to frequent mutations and hence the investigator has to guard against any minor variations which he observes during the DNA fingerprinting tests.

DNA fingerprinting is now a well established technique. This is not only being used in several areas of research in modern molecular biology and genetics but also finding potential applications in our day to day life. A unique example is how the sophisticated scientific technology reaches to the common man and helps to resolve questions like establishment of paternity with accuracy which was hitherto not possible. There are several applications of DNA fingerprinting such as identification, crime investigations, wildlife conservation, authentication of plants and seeds, etc. Advances in the technology are leading to novel uses of DNA fingerprinting almost every day. It has potential to cover a range of applications such as from the identification of an individual to the conservation of biodiversity. Applications also cover various disciplines such as molecular biology, genetics, evolution, anthropology, medicine, judiciary, law, ethics, etc.

REFERENCES

Han GR, Lee YW, Lee HL, Kim SM, Ku TW, Kang IH, Lee HS & Hwang JJ 2000. A Korean population study of the nine STR loci FGA, vWA, D3S1358, D18S51, D21S11, D8S1179, D13S317 and D5S818. *International Journal of Legal Medicine* 114 : 41-44.

Hancock JM 1999. Microsatellite and other simple sequences : genomic context and mutational mechanisms. *In :* Goldstein DB & Schlotterer C (Editors)—*Microsatellites Evolution and Applications*: 1-9. Oxford University Press, UK.

Jeffreys AJ, Brookfields JFY & Sermeomoff R 1985. Positive identification of an immigration test case using human DNA fingerprint. *Nature* 317 : 818-819.

International Human Genome Sequencing Consortium 2001. Initial sequencing and analysis of the Human Genome. *Nature* 409 : 860-921.

Jobling MA, Pandya A & Tyler-Smith C 1997. The Y-chromosome in forensic analysis and paternity testing. *International Journal of Legal Medicene* 110 : 118-124.

Mullis KB 1990. The unusual origin of the polymerase chain reaction. *Scientific American* 262(1-6) : 36-43.

Singh L 1991. DNA profiling and its applications. *Current Science* 60 : 580-585.

Singh L 1995. Biological significance of minisatellites. *Electrophoresis* 16 : 1586-1595.

Singh L 1999. DNA fingerprinting technology and emerging legal and ethical issues. *In:* Menon MGK, Tandon PN, Agarwal SS & Sharma VP (Editors)—*Human Genome Research – Emerging ethical, legal, social and economic issues*: 116-135.

Thangaraj K, Ramana GV & Singh L 1999. Y-chromosome mitochondrial DNA polymorphisms in Indian populations. *Electrophoresis* 20 : 1743-1747.

Trowsdale J 1993. Genomic structure and function in MHC. *Trends in Genetics* 9 : 117-122.

Watson JD & Crick FHC 1953. Molecular structure of nucleic acids. A structure of deoxyribose nucleic acid. *Nature* 171 : 737-738.

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New microfossils from the Meso-Neoproterozoic Deoban Limestone, Garhwal Lesser Himalaya, India

PURNIMA SRIVASTAVA AND S. KUMAR

Geology Department, University of Lucknow, Lucknow, 226 007, India.
E-mail: purnimasrivastava_51@rediffmail.com, surendra100@hotmail.com

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ABSTRACT

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Forty-five additional microfossils are being described from the Meso-Neoproterozoic Deoban Limestone (Formation). Microfossils are preserved in black bedded chert, occurring as thin lenses and bands intercalated with dolostones. The assemblage comprises both filamentous as well as coccoid forms. The assemblage is dominated by cyanobacterial population along with a number of microfossils belonging to other affinities represented by bacterial, algal, fungal and acritarchean forms. Out of the fortyfive forms there are forty-four species belonging to 33 genera and one micro-organism is informally described as Form 'A'. Five taxa are described as new genera.

Additional Deoban forms are as follows:

Cyanobacteria—*Archaeoellipsoides minor, A. major, Palaeopleurocapsa* sp., *Scissilisphaera gradata, Scissilisphaera* sp., *Coniunctiophycus gaoyuzhuangense, Archaeophycus* sp., *Gloeodiniopsis lamellosa, Palaeomerismopedia misrai* gen. & sp. nov., *Siphonophycus septatum, S. robustum, S. solidum, S. typicum, Polytrichoides lineatus, Oscillatoriopsis amadeus, O. obtusa, O. breviconvexa, Rhicnonema antiquum, Nostocomorpha* sp., *Eomicrocoleus crassus, Cyanonema* sp., *Palaeolyngbya catenata, Circumvaginalis* sp., *Obruchevella parva, O. valdaica, O. minor* and *Glomovertella glomerata.*

Incertae sedis—*Paleosphaeridium zonale, Germinosphaera* sp., *Myxococcoides chlorelloides, Myxococcoides stragulescence, Palaeococcus indicus* gen. & sp. nov., *Dumbellina deobanensis* gen. & sp. nov., *Maithea indica* gen. & sp. nov., *Eophycomyces herkoides, Bulgenia septata* gen. & sp. nov. and Form 'A'.

Acritarchs—cf. *Cymatiosphaeroides* sp., *Micrhystridium* sp., *Favosphaeridium favosum, Trachysphaeridium* sp., *Leiosphaeridia crassa, L. jacutica, Caudosphaera* sp. and cf. *Ovulum saccatum.*

The Deoban Microfossil Assemblage is characterised by dominance of mat building cyanobacterial population, exhibiting evolutionary conservatism. Extensive size variation from specimens of less than one micron to 265 microns in case of coccoids and from less than one micron to 48 microns among filamentous forms indicate the most favourable preservational conditions for silicification of the biota.

There are a number of forms, which show some resemblance with extant chlorophycean, bacterial and rhodophycean forms. Presence of large sized sphaeromorphs ranging in diameter from 105 to 265 µm and rare occurrence of acanthomorph or spinose acritarch (represented by *Micrhystridium* sp.) and small sized, moderately developed spirally coiled filaments of *Obruchevella* support a pre-Vendian age to the Deoban microfossil assemblage.

Key-words—Deoban Limestone, Meso-Neoproterozoic, Microfossils, Lesser Himalaya, Black chert, India.

भारत के गढ़वाल लघु हिमालय के मीज़ो-निओप्रोटीरोजोइक देवबन चूना पत्थर से प्राप्त नवीनतम सूक्ष्मपादपाश्म

पूर्णिमा श्रीवास्तव एवं एस. कुमार

सारांश

मीज़ो-निओप्रोटीरोजोइक देवबन चूना पत्थर (शैलसमूह) से पैंतालीस अतिरिक्त सूक्ष्मपादपाश्म अभिलक्षणित किए गए हैं। ये सूक्ष्मपादपाश्म काले संस्तरित चर्ट में सुसंरक्षित हैं, जो डोलोस्टोन में अन्तर्विष्ट पतले लेंसों तथा पट्टियों की भाँति प्रतीत होते हैं। समुच्चय में तन्तुमय तथा गोलाभ दोनों ही रूप विद्यमान हैं। समुच्चय में जीवाणुविक, शैवालीय, कवकीय तथा एक्रीटार्क युक्त रूपों के साथ-साथ साइनोजीवाणुओं की प्रचुरता है। पैंतालीस रूपों में से चौवालीस प्रजातियाँ 33 वंशों से सम्बन्धित हैं तथा एक सूक्ष्मजीव रूप 'ए' की भाँति अनियमित रूप से अभिलक्षणित है। पाँच वर्गकों को नए वंशों के रूप में अभिलक्षणित किया गया है।

अतिरिक्त देवबन रूप निम्नलिखित हैं-

साइनोजीवाणु—*आर्कियोइलिप्सॉयडीज माइनर, ए. मेजर, पेलियोप्लूरोकैप्सा* प्रजाति, *सीजिलीस्फ़ेयरा ग्रेडाटा, सीजिलीस्फेयरा,* प्रजाति, *कोनिअंकटाइयोफ़ाइकस गाओयूझुआंगेन्सी, आर्कियोफाइकस* प्रजाति, *ग्लोइयोडाइनियॉप्सिस लैमेलोसा, पेलियोमेरिस्मोपीडिया मिश्राइ* वंश एवं नवप्रजाति, *साइफ़ोनोफ़ाइकस सेप्टेटम, एस. रोबस्टम, एस. सोलिडम, एस. टाइपिकम, पॉलीट्राइकॉयडीज़ लाइनिएटस, ऑसिलेटारियाप्सिस एमेडियस, ओ. ओबट्यूज़ा, ओ. ब्रीविकॉनवेक्सा, राइक्नोनीमा एन्टीक्कुम, नॉस्टोकामोर्फ़ा* प्रजाति, *इओमाइक्रोकोलियस क्रेसस, साइनोनीमा* प्रजाति, *पेलियोलिंगबिया कैटीनाटा, सरकमवेजाइनेलिस* प्रजाति, *ओब्रुचिवेला पार्वा, ओ. वाल्डेका, ओ. माइनर* तथा *ग्लोमोवर्टेला ग्लोमेराटा*।

अनिश्चित स्थानी—*पेलियोस्फ़ेयरीडियम ज़ोनेल, जर्मिनोस्फ़ेयरा* प्रजाति, *मिक्सोकोकॉयडीज़ क्लोरीलॉयडीज़, मिक्सोकोकॉयडीज स्ट्रागुलेसेंस, पेलियोइओकोकस इण्डिकस* वंश एवं नवप्रजाति, *डम्बेलिना देवबनेन्सिस* वंश एवं नवप्रजाति, *माइतिया इण्डिका* वंश एवं नवप्रजाति, *इओफ़ाइकोमाइसिस हक्वायडीज़, बुल्जीनिया सेप्टाटा* वंश एवं नवप्रजाति तथा रूप 'ए'।

एक्रीटार्क—*साइमेटियोस्फ़ेयरॉयडीज़* प्रजाति से तुलनीय, *माइक्रिस्ट्राइडियम* प्रजाति, *फ़ेवोस्फ़ेयरीडियम फ़वोसम ट्रेकीस्फ़ेयरीडियम* प्रजाति, *लेइयोस्फ़ेयरीडिया क्रासा, एल. जेक्यूटिका, कॉउडोस्फेयरा* प्रजाति तथा *ओव्यूलम सैक्केटम* से तुलनीय।

देवबन सूक्ष्मपादपाश्म वैकासिक संरक्षण प्रदर्शित करने वाले मैट निर्मित करने हेतु उत्तरदायी साइनोजीवाणुओं द्वारा अभिलक्षणित हैं। कोक्वायड्स के अन्तर्गत प्रादर्शों में परिवर्तनशीलता एक माइक्रॉन से लेकर 265 माइक्रॉन से कम है जबकि तन्तुमय रूपों के मध्य यह एक माइक्रॉन से लेकर 48 माइक्रॉन से कम है, जो जीवजात के सिलिकाभवन हेतु सर्वाधिक उपयुक्त संरक्षणीय स्थितियाँ इंगित करती है।

ऐसे अनेक रूप हैं, जो विद्यमान क्लोराफ़ाइसियन, जीवाणुविक तथा रोडोफ़ाइसियन रूपों के साथ सादृश्य प्रदर्शित करते हैं। 105 से 265 माइक्रॉन के व्यास के बड़े आमाप के गोलाशय रूपों (स्फ़ेयरोमार्फ़) की उपस्थिति तथा एक्रेन्थोमार्फ़ अथवा स्पाइनोज एक्रीटार्क (*माइक्रहिस्ट्राइडियम* प्रजाति द्वारा निरूपित) की अत्यल्प उपस्थिति तथा *ओब्रुचिवेला* का छोटे आमाप तथा इसके शनैः-शनैः विकसित सर्पिलतः कुण्डलित तंतुओं से देवबन सूक्ष्मपादपाश्म समुच्चय हेतु प्रारंभिक वेण्डियन आयु की पुष्टि होती है।

संकेत शब्द—देवबन चूनापत्थर, मीज़ो-निओप्रोटीरोज़ोइक, सूक्ष्मपादपाश्म, लघु हिमालय, काला चर्ट, भारत.

INTRODUCTION

THE Proterozoic successions occupy large areas in the Himalaya, which attain impressive thickness measurable in several kilometers. There are many reports of the presence of stromatolites in the carbonate horizons but microfossils are poorly recorded. The earliest record of microfossils from the petrographic thin sections of black-bedded cherts is by Kumar and Singh (1979) from the Meso-Neoproterozoic Deoban Limestone of the Garhwal Lesser Himalaya. Subsequently, Shukla *et al.* (1987) reported 14 species from the Deoban, most of which are of cyanobacterial affinity. Kumar and Srivastava (1992) gave a more detailed account of the Deoban Microfossil Assemblage and described 28 species belonging to sixteen

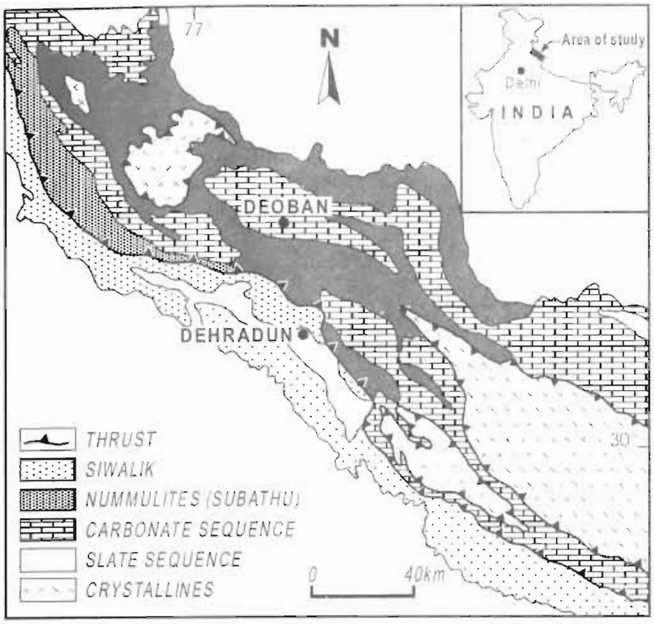

Fig. 1—Location and geological map of the Garhwal region, Lesser Himalaya, Uttaranchal Siwalik (Pliocene-Pleistocene, Subathu (Eocene), Carbonate sequence (Meso-Neoproterozoic), Slate sequence (Meso-Neoproterozoic), Crystallines (Palaeoproterozoic). Simplified after Gansser (1964).

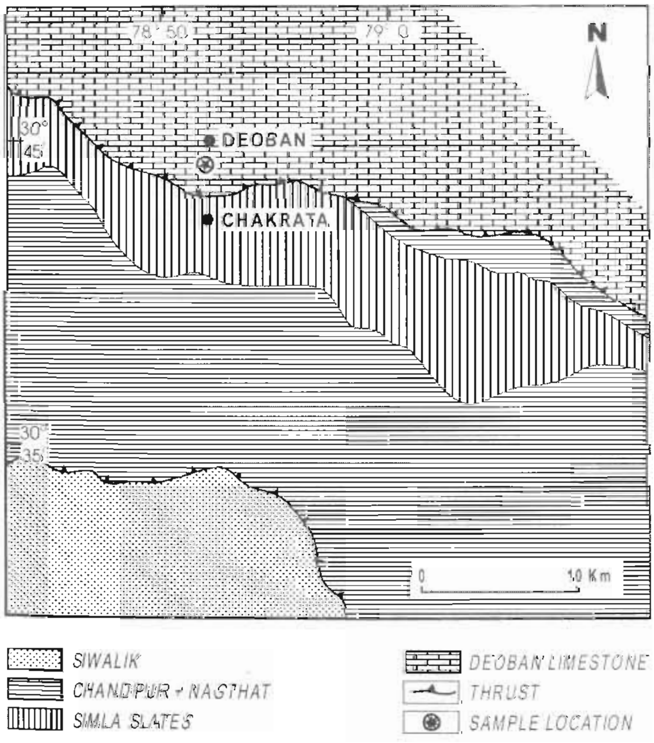

Fig. 2—Geological map showing stratigraphic units in the Chakrata area, Garhwal Himalaya, India and location of the fossiliferous chert-bearing horizon (After Sinha & Raaben, 1981).

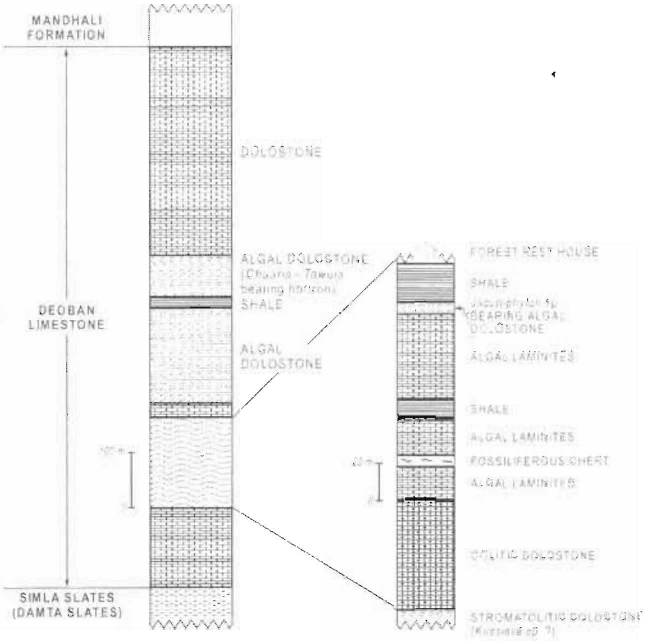

Fig. 3—Litho-column of the Deoban Limestone showing the position of the fossiliferous chert-bearing horizon (Simplified after Tewari, 1998; Kumar & Srivastava, 1992).

genera and also described two forms of uncertain affinity. The assemblage is made up of both coccoid and filamentous forms, dominated by forms of cyanobacterial affinity. Srivastava and Kumar (1997) described two forms of possible animal affinity (annelida and nematoda) and one form they interpreted as a back filled burrow. In the light of this a more detailed study of the Deoban Chert was undertaken. A fresh collection of chert samples was made in Chakrata area, Dehradun District, Uttaranchal. Fifty new thin sections were prepared and studied in detail for microfossil assemblage. All available slides referred in Kumar and Srivastava (1992) which were deposited in the museum of the Department of Geology, University of Lucknow, are also restudied for present paper. The paper incorporates a detailed account of the additional taxa from the Deoban Limestone.

GEOLOGICAL SETTING

The Deoban Limestone named after ca. 3000 m high Deoban peak constitutes an important Proterozoic carbonate litho-unit of the Garhwal Lesser Himalaya (Fig. 1) and is best developed near Chakrata town ship. The terrain is marked by rugged high peaks and deep gorges. The Deoban Limestone unconformably overlies the Simla Slates and underlain by the Mandhali Formation (Fig. 2). The succession is highly deformed and several generations of folding and faulting have made the lithostratigraphy of the area and measurements of true thickness quite complicated. The dominant lithology is represented by dolomicrite, stromatolitic dolostone, oolitic and intraclastic dolostone and subordinate shales. Good exposures can be seen on Chakrata-Jadi and Chakrata-Buchkoti motor road. The dolostones in general are recrystallized. The fossil bearing black-bedded chert (maximum thickness measured about 15 cm), occurs as lenses and thin bands within the dolostones (Fig. 3), which could be traced up to several metres. The chert is greyish black to black with flat fracture and fenestral fabric. The chert horizon is associated with algal laminites, which are made up of intraclastic dolomite, conglomerate and breccia and dolomicrite. Therefore supratidal to intertidal zone can be suggested for chert bearing horizon.

Very little data has been added, since the publication of earlier report by Kumar and Srivastava (1992). Recently, the thickness of the Deoban Limestone has been estimated by Tewari (1998) as ca 1000 m. The lithology given by Tewari (1998), has been simplified and approximate position of the chert bearing unit has been shown in Fig. 3. Tewari (1998) has also given carbon and oxygen isotope data for 25 carbonate samples representing the entire thickness of the Deoban Limestone exposed in the Chakrata area. According to him the data is very close to Meso-Proterozoic isotope data.

AGE

No radiometric dates are available for the Deoban Limestone. Kumar and Srivastava (1992) have discussed the age of the Deoban Limestone on the basis of the available data and considered it to be of Early to Middle Riphean. Srivastava and Kumar (1995) have reported *Obruchevella* from the Deoban assemblage and have suggested Upper Riphean (Neoproterozoic) age for the chert- bearing horizon.

Tewari (1996) has recorded the presence of *Chuaria circularis* from the Deoban Limestone. The published photographs of *Chuaria circularis* were of very poor quality and because of this the samples available with Dr VC Tewari in the laboratory of the Wadia Institute of Himalayan Geology, Dehradun were re-examined by one of us (SK) and it is concluded that reported *Chuaria circularis* is simply an abiotic depression. However, presence of *Chuaria-Tawuia* association has now been noted by us in the upper part of the Deoban Limestone (see Fig. 3; Pl. 1.1, 2, 3, 4). This association also suggests rather Meso-Neoproterozoic age to fossil bearing horizon. Thus, on the basis of the presence of carbonaceous megafossils like *Chuaria-Tawuia* assemblage, organosedimentary structures like stromatolites (Raaben *et al.*, 2001), a spirally coiled cyanobacterial filamentous form *Obruchevella*, absence of trace fossils and very rare occurrençe of acanthomorphic acritarchs, the chert bearing horizon may be considered as Upper Riphean to Vendian in age. No age connotation can be given on the basis of isotope data as suggested by Tewari (1998).

METHODOLOGY AND REPOSITORY

The work is based on thin section study of black-bedded chert under Nikon opti-phot-pol, Leitz Orthoplan and Leica-Quantimat microscopes with the help of Agfa-copex Tri-13 films. All slides are deposited in the Museum of the Geology Department, University of Lucknow, Lucknow, Uttar Pradesh, India.

PRESERVATION OF DEOBAN MICROFOSSILS

The fossiliferous chert is greyish black to black in hand specimen, but appears brown in thin sections. Organic matter shows various degrees of preservation, which often shows clotting in the form of coalified lumps.

Microorganisms of Deoban Microfossil Assemblage lost their morphological details wherever the process of coalification took place. The internal structure is preserved only when it is not severe. In thin sections of chert the microfossils are seen preserved within the laminae, and also within the clasts. The clasts give a brecciated appearance to the chert when observed under the microscope and degree of preservation and degradation differ from clast to clast.

The Deoban microfossil assemblage as well as other Proterozoic microbiotas are highly facies controlled. It appears that several combinations of microbial populations flourished in a low energy lagoon-intertidal environment and produced algal laminites. Under high-energy conditions and/or under dry conditions, the algal mat was destroyed and algal clasts were produced. In favourable conditions, these clasts were again cemented by the second generation of microbial population dominated by filamentous communities.

One sample of black chert and one sample of associated dolomite were analysed for δ^{13}Corg and δ^{13}Ccarb. δ^{13}Corg values for chert and dolomite are -24.5‰ and -19.8‰ (PDB) respectively. δ^{13}Ccarb for dolomite is 3.2 ‰ (PDB) and δ^{18}O is -11.9‰ (PDB). The data suggests some enrichment in ^{13}C possibly due to somewhat evaporatic conditions.

DEOBAN MICROFOSSIL ASSEMBLAGE

Kumar and Singh (1979) discovered the microbiota from the petrographic thin sections of the black-bedded chert belonging to the Deoban Limestone. Later on Shukla *et al.* (1987) and Kumar and Srivastava (1992) described detailed account of microfossils. The reported assemblage is as follows:

Coccoid forms—*Myxococcoides minor, M. inornata, Eosynechococcus isolatus, Glenobotrydion aenigmatis, G. majorinum, Melasmatosphaera parva, M. media, Tetraphycus*

Fig. 4—Additional coccoid morphotaxa, their size distribution, relative abundance and affinity.

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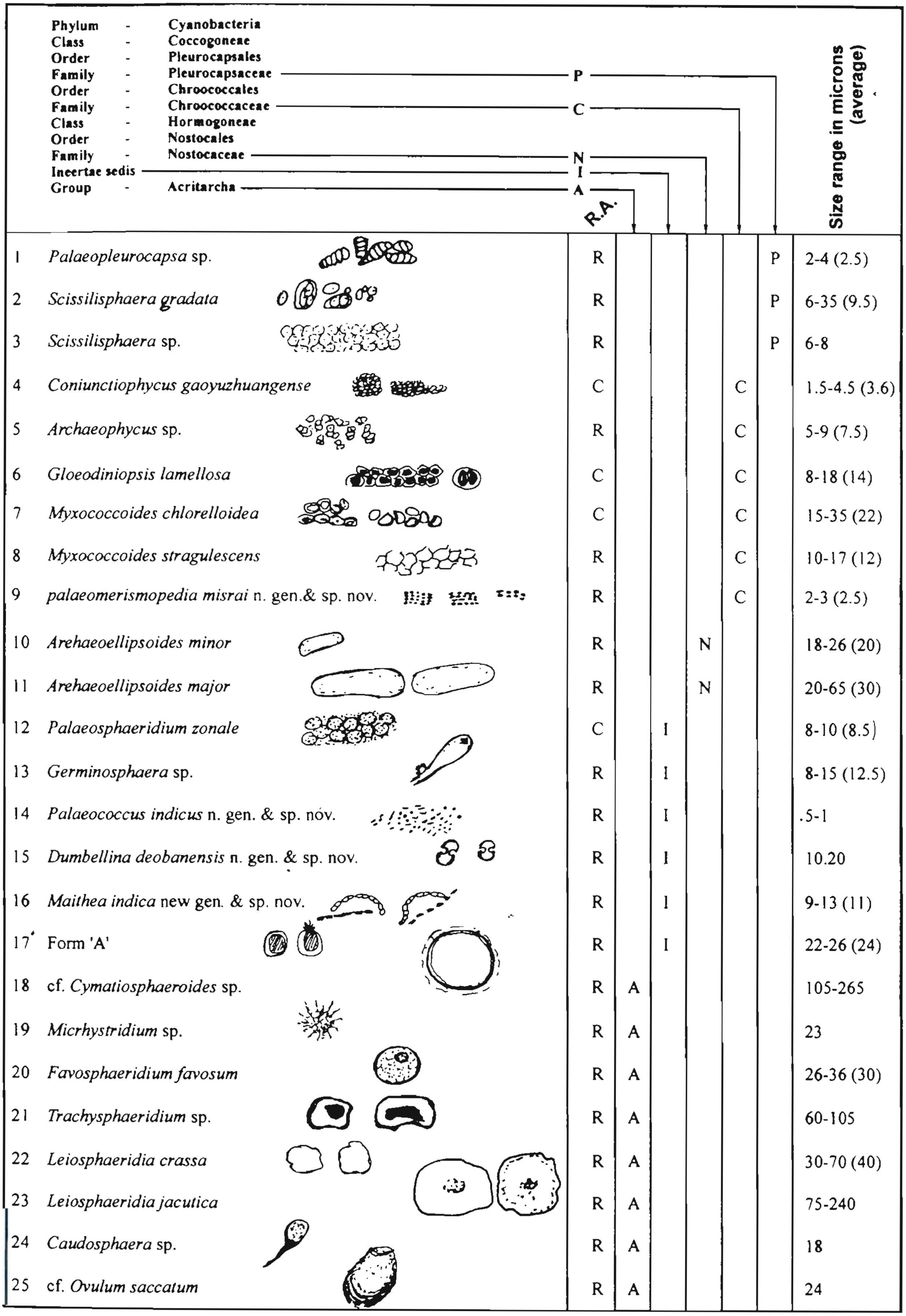


Phylum - Cyanobacteria
Class - Coccogoneae
Order - Pleurocapsales
Family - Pleurocapsaceae — P
Order - Chroococcales
Family - Chroococcaceae — C
Class - Hormogoneae
Order - Nostocales
Family - Nostocaceae — N
Incertae sedis — I
Group - Acritarcha — A

		R.A.	A	I	N	C	P	Size range in microns (average)
1	*Palaeopleurocapsa* sp.	R					P	2-4 (2.5)
2	*Scissilisphaera gradata*	R					P	6-35 (9.5)
3	*Scissilisphaera* sp.	R					P	6-8
4	*Coniunctiophycus gaoyuzhuangense*	C				C		1.5-4.5 (3.6)
5	*Archaeophycus* sp.	R				C		5-9 (7.5)
6	*Gloeodiniopsis lamellosa*	C				C		8-18 (14)
7	*Myxococcoides chlorelloidea*	C				C		15-35 (22)
8	*Myxococcoides stragulescens*	R				C		10-17 (12)
9	*palaeomerismopedia misrai* n. gen.& sp. nov.	R				C		2-3 (2.5)
10	*Arehaeoellipsoides minor*	R			N			18-26 (20)
11	*Arehaeoellipsoides major*	R			N			20-65 (30)
12	*Palaeosphaeridium zonale*	C		I				8-10 (8.5)
13	*Germinosphaera* sp.	R		I				8-15 (12.5)
14	*Palaeococcus indicus* n. gen. & sp. nov.	R		I				.5-1
15	*Dumbellina deobanensis* n. gen. & sp. nov.	R		I				10.20
16	*Maithea indica* new gen. & sp. nov.	R		I				9-13 (11)
17	Form 'A'	R		I				22-26 (24)
18	cf. *Cymatiosphaeroides* sp.	R	A					105-265
19	*Micrhystridium* sp.	R	A					23
20	*Favosphaeridium favosum*	R	A					26-36 (30)
21	*Trachysphaeridium* sp.	R	A					60-105
22	*Leiosphaeridia crassa*	R	A					30-70 (40)
23	*Leiosphaeridia jacutica*	R	A					75-240
24	*Caudosphaera* sp.	R	A					18
25	cf. *Ovulum saccatum*	R	A					24

major, T. cunjunctum, Globophycus rugosum, Huroniospora psilata, H. microreticulata, Caryosphaeroides pristine, Eoentophysalis magna, E. cumulus, E. belcherensis, Glooeodiniopsis lamellosa, G. gregaria, G. sp., *Sphaerophycus parvum,* Form 'A' and Form 'B'.

Filamentous forms*—Gunflintia minuta, G. grandis, Biocatenoides* sp., *Eomycetopsis siberiensis, E. robusta, E. filiformis, Siphonophycus kestron* and *Oscillatoriopsis* sp.

In present paper fortyfive additional forms are being described from the Deoban Chert. There are 44 species belonging to 33 genera and one form has been informally described as Form 'A'. Out of these, five taxa belong to new genera. The additional forms are as follows:

Cyanobacteria*—Archaeoellipsoides minor, A. major, Palaeopleurocapsa* sp., *Scissilisphaera gradata, Scissilisphaera* sp., *Coniunctiophycus gaoyuzhuangense, Archaeophycus* sp., *Gloeodiniopsis lamellosa, Palaeomerismopedia misrai* gen. & sp. nov. *Siphonophycus septatum, S. robustum, S. solidum, S. typicum, Polytrichoides lineatus, Oscillatoriopsis amadeus, O. obtusa, O. breviconvexa, Rhicnonema antiquum, Nostocomorpha* sp., *Eomicrocoleus crassus, Cyanonema* sp., *Palaeolyngbya catanata, Circumvaginalis* sp., *Obruchevella parva, O. valdaica, O. minor* and *Glomovertella glomerata.*

Incertae sedis—*Paleosphaeridium zonale, Germinosphaera* sp., *Myxococcoides chlorelloides, Myxococcoides stragulescence, Palaeococcus indicus* gen. & sp. nov., *Dumbellina deobanensis* gen. & sp. nov., *Maithea indica* gen. & sp. nov., *Eophycomyces herkoides, Bulgenias septata* gen. & sp. nov. and Form 'A'.

Acritarchs—cf. *Cymatiosphaeroides* sp., *Micrhystridium* sp., *Favosphaeridium favosum, Trachysphaeridium* sp., *Leiosphaeridia crassa, L. jacutica, Caudosphaera* sp. and cf. *Ovulum saccatum.*

SYSTEMATICS

Kingdom—EUBACTERIA

Phylum—CYANOBACTERIA

Class—COCCOGONAE

Order—PLEUROCAPSALES

Family—PLEUROCAPSACAE

Genus—PALAEOPLEUROCAPSA Knoll *et al.*, 1975

Type species—PALAEOPLEUROCAPSA WOPFNERII
Knoll *et al.*, 1975

Species—PALAEOPLEUROCAPSA sp.

(Pl. 3·1, 2)

Description—Colonial cells, subcylindrical in shape, arranged in rows of 3-4 cells in pseudoparenchymatous pattern. Terminal cell is hemispheroidal. Long axis of median cells ranges between 2-4 µm (2.5 µm average) and short axis ranges between 1·5-3 µm, 2 µm average (12 cells measured).

Discussion—General morphology and dimensions of Deoban forms are comparable to *Pleurocapsa* (?) sp. described by Hofmann (1976) from the Belcher Islands. This is a rare form of Deoban assemblage. Parenchymatous cells and endosporulation stages are not very well preserved, hence identification only up to generic level is possible. Arrangement of cells in chain like manner in *Palaeopleurocapsa* is comparable to *Eosynechococcus mooreii* Hofmann (1976). But the cells are joined together through their long axis in *Palaeopleurocapsa* and by their short axis in *E. mooreii.* From India *Palaeopleurocapsa* has been reported from the Fawn Limestone Member of the Kheinjua Formation (Newari locality of the Semri Group, Lower Vindhyan) by Kumar and Srivastava (1995). The genera has also been reported by Green *et al.* (1988) from the Eleonore Bay Group, East Greenland, by Knoll *et al.* (1989) from the Backlundtoppen Formation, Spitsbergen and from many other localities.

Genus—SCISSILISPHAERA Knoll & Calder, 1983

Type species—SCISSILISPHAERA REGULARIS Knoll & Calder, 1983

Species—SCISSILISPHAERA GRADATA Knoll & Calder, 1983 emend. Green *et al.*, 1989

(Pl. 2·6, 7; Pl. 6·7, 10)

Description—Spheroidal to ellipsoidal cell like units range in diameter between 6 to 35 µm, 9·5 µm average (20 cells measured). Occurring as solitary cells in clusters or as an irregular aggregates of 4-10 individuals, either with or without encompassing envelope. Intracellular mass may or may not be present.

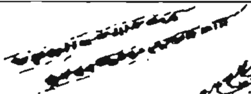
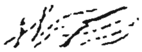
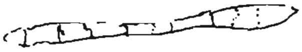
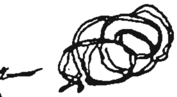
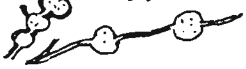
Discussion—Scissilisphaera gradata differs from *Scissilisphaera regularis* by a wide diameter range exhibited by former species. The form differs from *Gloeodiniopsis lamellosa* by a wide range of diameter where very small and quite large aggregates occur together. Smaller units are intrepreted as baeocytes (a characteristic feature of Pleurocapsalean affinity). A genus *Kheinjuasphaera* erected by McMenamin *et al.* (1983) from the Kheinjua Formation of India, also shows some resemblance with *Scissilisphaera gradata* in having wide diameter range, but the difference lies in multilamellate enveloping structure of latter taxa. Diameter range in Deoban form is narrow in comparison to the Greenland specimen described by Green *et al.* (1989). This is a rare form of the Deoban Assemblage.

Fig. 5—Additional filamentous morphotaxa, their size distribution, relative abundance and affinity.

→

RA = Relative abundance
C = Common
A = Abundant
R = Rare

Phylum - **Cyanobacteria**
Class - **Hormogoneae**
Order - **Nostocales**
Family - **Nostocaceae** — N
Order - **Oscillatoriales**
Family - **Oscillatoriaceae** — O
Incertae sedis — I

			R.A.	I	O	N	Size range in microns (average)
1	*Nostocomorpha* sp.		C			N	1.5-8 (5.5)
2	cf. *Circumvaginalis* sp.		R			N	10-11 (10.5)
3	*Siphonophycus septatum*		A		O		1-1.5
4	*Siphonophycus robustum*		A		O		3-12 (6)
5	*Siphonophycus solidum*		R		O		19-25 (21)
6	*Siphonophycus typicum*		C		O		3-10 (4.5)
7	*Polytrichoides lineatus*		R		O		2.5-4 (3)
8	*Oscillatoriopsis amadeus*		R		O		10-18 (13.5)
9	*Oscillatoriopsis obtusa*		R		O		4.5
10	*Oscillatoriopsis breviconvexa*		R		O		6-8μm (7)
11	*Rhicnonema antiquum*		C		O		6-9 (7.2)
12	*Eomicrocoleus crassus*		R		O		1.5-3 (2)
13	*Cyanonema* sp.		R		O		3-6 (4.5)
14	*Palaeolyngbya catenata*		R		O		8-16 (13)
15	*Obruchevella* aff. *parva*		R		O		5-6
16	*Obruchevella valdaica*		R		O		6
17	*Obruchevella minor*		R		O		2.5-3
18	*Glomovertella glomerata*		R		O		1.5-4.5
19	*Bulginia septata* new gen. & sp. nov.		R	I			3-15
20	cf. *Eophycomyces herkoides*		R	I			12-48

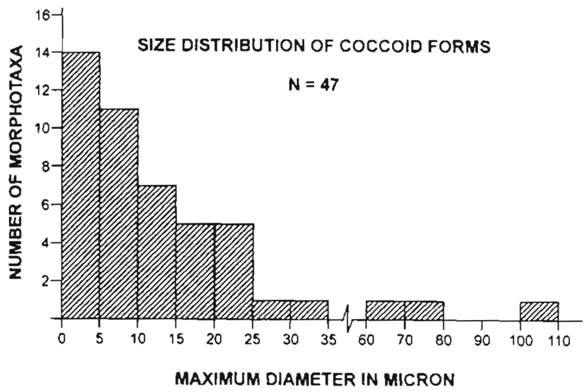


Fig. 6—Histogram for shorter diameter of coccoid forms including those, which have been described by Kumar and Srivastava (1992).

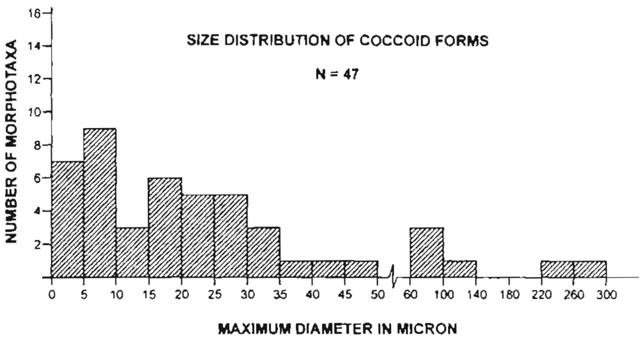


Fig. 7—Histogram for longer diameter of coccoid forms including those which have been described by Kumar and Srivastava (1992).

cf. **SCISSILISPHAERA** sp.

(Pl. 2·2)

Description—Spheroidal to polyhedral cells arranged in rosette like clusters. Cell diameter ranges from 6-8 µm, size of the cluster varies between 28-45 µm (45 cells measured). Intracellular mass may or may not present.

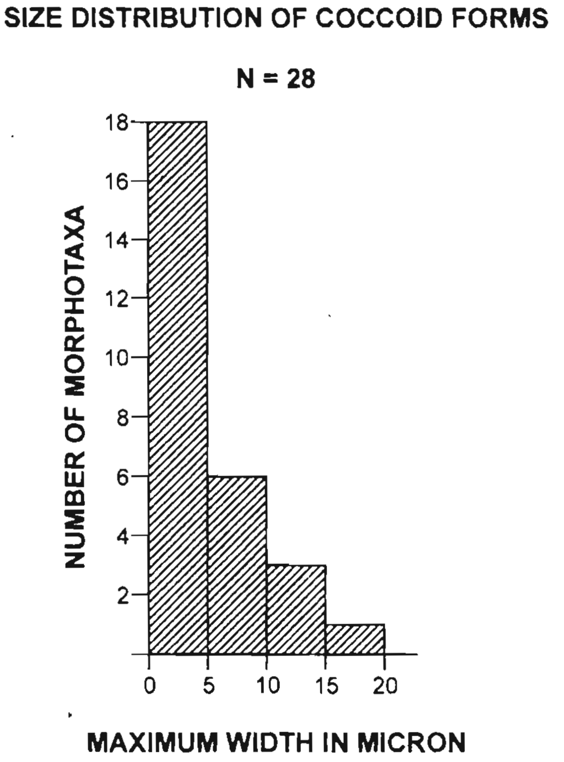


Fig. 8—Histogram for minimum width of filamentous forms including those which have been described by Kumar and Srivastava (1992).

Discussion—Specimens are cf. *Scissilisphaera* sp. belonging to family Pleurocapsaceae Schopf and Fairchild (1973) reported unnamed forms with few similar morphological features and are comparable to extant cyanobacterial form *Myxosacrcina*. Size of cells is smaller in comparison to specimens reported by Schopf and Fairchild (1973). Typical mode of occurrence in rosette or radially arranged cells is the diagnostic feature of this form and assignable to genus *Scissilisphaera*. Since present forms differ specifically from the established species of this genus, it is described as *Scissilisphaera* sp.

Order—CHROOCOCCALES

Family—CHROOCOCCACEAE

Genus—CONIUNCTIOPHYCUS Zhang, 1981

Type species—CONIUNCTIOPHYCUS GAOYUZHUANGENSE Zhang, 1981

Species—CONIUNCTIOPHYCUS GAOYUZHUANGENSE Zhang, 1981

(Pl. 3·3, 4)

Description—Cells small, spherical to ellipsoidal in shape. 1·5-4·5 µm across, averaging 3·6 µm (80 cells measured), solitary or in cluster. Some times occur in pair with loosely dispersed aggregates. Few cells with dark inclusions are present.

Discussion—The genus was first described by Zhang (1981) from the Gaoyuzhuang Formation of China and compared it with living cyanobacteria *Microcystis*. Subsequently Golovenok and Belova (1984, 1986) described a genus *Eomicrocystis* as a fossil form of this extant counter part. Sergeev *et al.* (1995) considered the *Eomicrocystis* as a junior synonymn of *Coniunctiophycus*. In general morphology and appearance, the Deoban forms show close resemblance to the fossil forms *Coniunctiophycus gaoyuzhuangense* reported by Zhang (1981) from China.

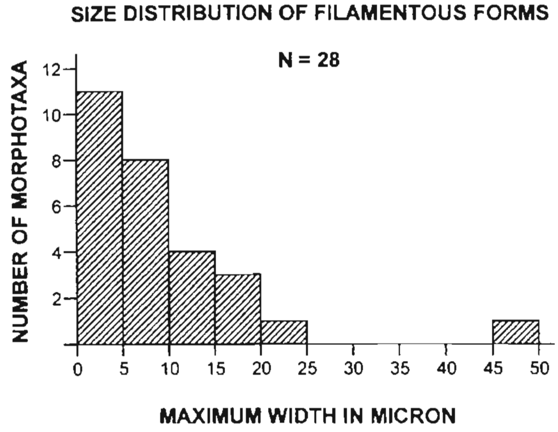
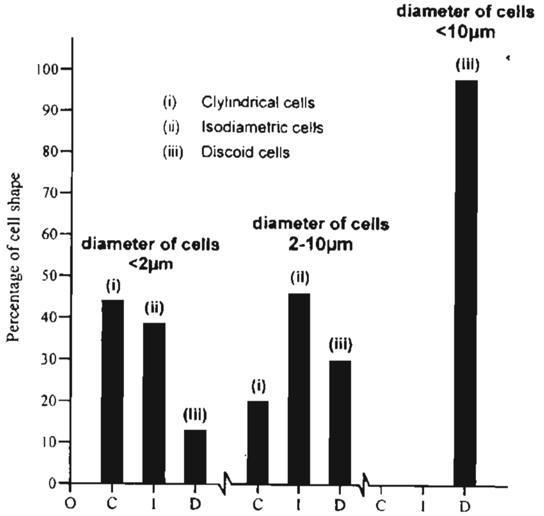


Fig. 9—Histogram for maximum width of filamentous forms including those, which have been described by Kumar and Srivastava (1992).



Percentage of cell shape (C= Cylindrical, I= Isodiametric &D= Discoid) for the filaments

Fig. 10—Relationship between cell size and shape.

Genus—ARCHAEOPHYCUS Fuxing *et al.*, 1983

Type species—ARCHAEOPHYCUS VENUSTUS Fuxing *et al.*, 1983

Species—ARCHAEOPHYCUS sp. Fuxing *et al.*, 1983

(Pl. 1·7)

Description—Spheroidal to hemispheroidal or polyhedral, angular to irregular cell like units, range in diameter between 5-9 µm, 7·5 µm average. Occur in colonies composed of a few to tens of cells. Enclosing sheath is absent. Cell margins are sharp. Intracellular mass may or may not be present (15 units measured).

Discussion—Cell dimensions and absence of enclosing sheath and angularity in cells differentiate this genus from *Sphaerophycus* Schopf (1968). Morphologically the Deoban specimens are comparable to Jinning Yunnan's specimens (Fuxing *et al.*, 1983) except a comparatively narrow diameter range.

Genus—GLOEODINIOPSIS LAMELLOSA Schopf, emend. Knoll & Golubic, 1979

Type species—GLOEODINIOPSIS LAMELLOSA Schopf, emend. Knoll & Golubic, 1979

Species—GLOEODINIOPSIS LAMELLOSA

(Pl. 1·8, 9, 10, 12; Pl. 2·1; Pl. 3·9; Pl. 4·4)

Description—Spheroidal to hemispheroidal cell-like units, occurring in pairs, encompassed by a common organic sheath. Mesh of well arranged spheroids some times acquire hexagonal shape, in a net-like structure or some times arranged in a row. Very distinct and large intracellular mass and very faint cell walls are observed in cluster of spheroids with variable diameters. Vesicles with 2 to 3 intracellular spheroids are also present. Diameter of cells ranges from 8-18 µm, 14 µm average (50 cells measured). Diameter of intracellular mass ranges between 4-7 µm, 5 µm average (20 units measured).

Discussion—Two equal sized cell like units exhibited in Pl. 1.9, 10 are encompassed within a common sheath and are comparable to the specimens described by Schopf and Blacic (1971) as *Eozigion grande,* from the Bitter Springs Formation. They also have suggested chroococcalean (prokaryotic) affinity to this form, which was comparable with the two celled extant form *Chroococcus turgidus* or *Anacystis dimidiata.* Genus *Eozigion grande* is now merged with *Gloeodiniopsis lamellosa.* Cells distorted by mutual compressions are considered to be the result of cell division, producing two equal daughter cells. Cell walls acquired hexagonal to polyhedral shape due to mutual compression resulted in an entirely different look (Pl. 1.8, 12). Since specimens described here, deviate from the conventional appearance of the *G. lamellosa* and exhibit different morphological characters than the previously described specimens in 1992 paper, this form has been redescribed here.

Genus—MYXOCOCCOIDES Schopf, 1968

Type species—MYXOCOCCOIDES MINOR Schopf, 1968

Species—MYXOCOCCOIDES CHLORELLOIDEA Knoll *et al.*, 1991

(Pl. 2·3, 4, 5; Pl. 6·11)

Description—Thin, single walled, unicells comprising large spheroids in form of diads, tetrads and octads. Internal cell like units are well rounded to hemispherical and mostly attached to each other. Diameter of outer cell wall ranges between 15-35 µm, (22 µm average) and internal vesicle ranges between 6-12 µm, 10 µm average (20 specimens measured). Intracellular mass may or may not be present.

Discussion—Organisation of internal vesicles in diads, tetrads, octads within an encompassing sheath or outer vesicle like structure differentiate this species from the other species of *Myxococcoides* and lack of multiple lamellae differentiate it from *Gloeodiniopsis* species. In all respect it is identical to the Spitsbergen's specimens described by Knoll *et al.* (1991). It has been compared with the living green alga *Chlorella* (Knoll *et al.,* 1991).

Species—MYXOCOCCOIDES STRAGULESCENS Green *et al.*, 1989

(Pl. 6·9)

Description—Spheroidal cell like units have robust single walls, displaying functional tears lacking colonial mucilage and forming dense monospecific layers. Diameter of coccoids ranges between 10-17 µm, average 12 µm (27 cells measured).

Discussion—Functional tearing in cell walls has been taken as characteristic feature of *Myxococcoides stragulescense*, which favours its affinity towards protists. According to Green *et al.* (1989) it has been interpreted as an eukaryotic cyst. Among the comparable extant forms found today in physically similar tidal flat environments, cysts are made by *Dunaliella*, a green alga and *Paratetramitus*, an amoebo-flagellate protozoa (Green *et al.*, 1989). Deoban forms show almost similar morphology with Spitsbergen forms except narrow diameter range. Though forms exhibiting tearing are categorised as an individual species of *Myxococcoides*, but authors suggest that it should be merged with *Myxococcoides inornata* as it occurs in association with them and tearing may be a preservational feature, rather than a phylogenetic character.

Genus—PALAEOMERISMOPEDIA gen. nov.

Type species—PALAEOMERISMOPEDIA MISRAI gen. & sp. nov.

Etymology—Because of its similarity with modern form *Merismopedia.*

Diagnosis—Small spheroidal to ellipsoidal cell like units arranged bilineary or trilineary in a flat rectangular colonies.

Discussion—Schopf and Fairchild (1973) described from the Skillogalee Dolomite, South Australia an unnamed form, which was compared with the living cyanobacterial form *Merismopedia.* In dimensions, the Deoban microfossils fall in range of *Sphaerophycus parvum* (Schopf, 1968) but typical arrangement of cells in the form of rectangular colony is the differentiating feature of this genus. It is comparable to the living cyanobacterial form *Merismopedia tenneyssima* (Desikachary, 1959) in the size of the cell as well as in the rectangular arrangement. The Deoban form exhibits smaller aggregates in comparison to the Skillogalee specimens described by Schopf and Fairchild (1973).

Species—PALAEOMERISMOPEDIA MISRAI gen. & sp. nov.

(Pl. 3·5)

Type Locality—Deoban Limestone, Chakrata area, Dehradun District, Uttaranchal.

Type Specimen—Slide no. Db$_3$-6, Coordinates 55.0/10.6 (Nikon).

Etymology—In honour of late Prof. R.C. Misra.

Diagnosis—Monospecific genus.

Description—Small colonies of 4-64 cell like units, spheroidal to ellipsoidal in shape where cells arranged in rectangular colonies, loosely packed and 2-3 µm (2.5 µm average) in diameter. Sharp margins with or without mucilagenous matrix are present (50 cells measured).

Class—HORMOGONAE

Order—NOSTOCALES Geitler, 1925

Family—NOSTOCACEAE

Genus—ARCHAEOELLIPSOIDES Horodyski & Donaldson, 1980 emend. Sergeev & Knoll, 1995

Type species—ARCHAEOELLIPSOIDES GRANDIS Horodyski & Donaldson, 1980

PLATE 1 →

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all photomicrographs except for 1, 2, 3 and 4 where it is equal to 2 mm. Name of the microscope used for photography is also given in the bracket)

1. *Tawuia dalensis*, Deoban Limestone, Chakrata area, Uttaranchal.
2. *Tawuia dalensis*, Deoban Limestone, Chakrata area, Uttaranchal.
3. *Chuaria circularis*, Deoban Limestone, Chakrata area, Uttaranchal.
4. *Chuaria circularis*, Deoban Limestone, Chakrata area, Uttaranchal.
5. *Archaeoellipsoides major*, Slide No. II/D/89-11, 50.2/22.6 (Nikon).
6. *Archaeoellipsoides minor*, Slide No. Db$_1$- 16, 76.8/5.9 (Leica).
7. *Archaeophycus* sp., Slide No. Db$_2$- 5, 139.1/19.4 (Olympus).
8. *Gloeodiniopsis lamellosa*, Slide No. Db$_3$- 6F, 48.5/15.5 (Nikon).
9. *Gloeodiniopsis lamellosa,* Slide No. Db$_3$- 6F, 57.9/12.9 (Nikon).
10. *Gloeodiniopsis lamellosa* Slide No. Db$_3$- 6F, 56.9/12.4 (Nikon).
11. Filament with akinite like structure, Slide No. Db$_1$- 11, 51.3/5.5 (Nikon).
12. *Gloeodiniopsis lamellosa*, Slide No. II/D/89, 60.7/0.4 (Leica).

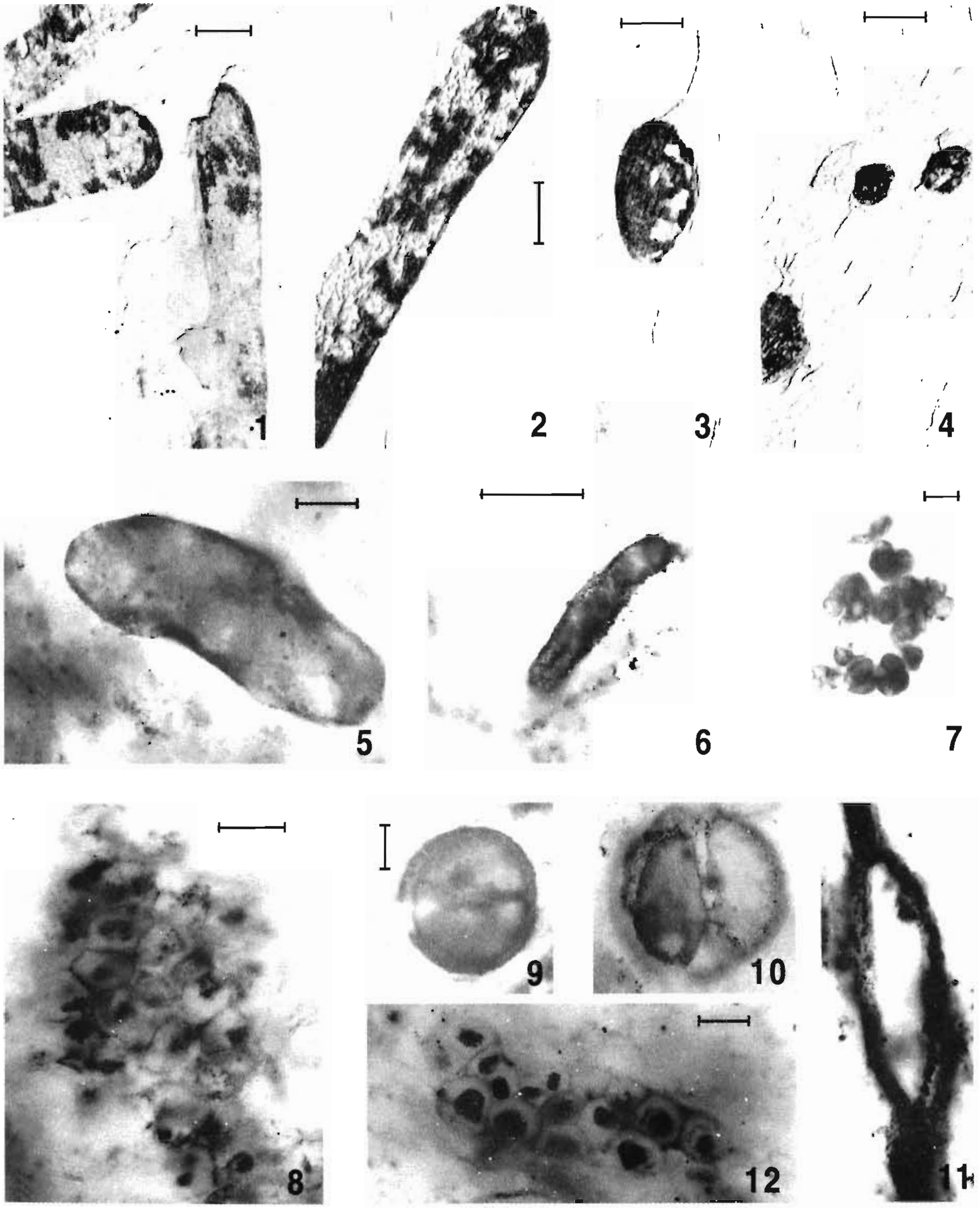


PLATE 1

Species—ARCHAEOELLIPSOIDES MINOR Sergeev & Knoll, 1995

(Pl. 1·6)

Description—Ellipsoidal cell-like units, solitary, with or without intracellular mass. Organic matrix may or may not be present. Ellipsoids show more or less smooth margins. Long axis ranges between 18-26 µm, average 20 µm. Short axis ranges between 6-9 µm, average 7 µm (5 specimens measured).

Discussion—Horodyski and Donaldson (1980) erected this genus for solitary occurring ellipsoidal structures. Zhang Yun (1985) also reported this form from the Wumishan Formation. This form has also been reported from the Fawn Limestone Member of the Kheinjua Formation, Lower Vindhyans, India by Kumar and Srivastava (1995). *Archaeoellipsoides* are considered as the akinites of nostocalean cyanobacteria. In Neoproterozoic microbial assemblages, these saussage like microfossils have been described as *Brevitrichoides* (see Jankauskas *et al.,* 1989), which occur rarely. Since Mesoproterozoic assemblages usually dominated by akinites or *Archaeoellipsoides*, Knoll and Sergeev (1995) considered them as evolutionary as well as environmental changes among microorganisms during Meso-Neoproterozoic periods. On comparing exceptionally well preserved microfossil assemblages from the Billyakh Group (Golovenok & Belova, 1984; Yakschin, 1991; Sergeev *et al.*, 1995), Kutungda and Debengda Formation of Northern Siberia (Yakschin, 1990; Sergeev *et al.*, 1994), the Jixian Group, Northern China (Zhang, 1981, 1985), Bangemall Group, Australia (Buick & Knoll, 1999), Dismal Lakes Group, Arctic Canada (Horodyski & Donaldson, 1980) and Kheinjua Formation, India (Kumar & Srivastava, 1995), it has been observed that marked decline in occurrence of akinite like structures or *Archaeoellipsoides* across the Meso-Neoproterozoic transition has taken place which is interpreted as a consequence of eukaryotic radiation during this period (Knoll & Sergeev, 1995).

Species—ARCHAEOELLIPSOIDES MAJOR Golovenok & Belova, 1984; Sergeev & Knoll, 1995

(Pl. 1·5)

Description—Single layered, solitary, straight or slightly curved sac like bodies, with rounded ends. Surface psilate to granular, obliterating the wall. Length varies between 20-65 µm, average 40 µm, width ranges between 6-12 µm, average 10 µm, (3 specimens measured).

Discussion—*Archaeoellipsoides minor* was originally described as *Eosynechoccus major* by Golovenok and Belova (1984). Dimensions of Deoban specimens are more in comparison to forms described by Amard and Sarfati (1997) from the Franceville Group, Gabon.

Genus—NOSTOCOMORPHA Xing & Liu, 1978; Hofmann & Jackson, 1994

Species—NOSTOCOMORPHA sp.

(Pl. 7·1, 3)

Description—Chain-like aggregates of spheroidal to polyhedral opaque grains of iron minerals arranged linearly within an unbranched sheath or without sheath, maximum length of entire structure measured is up to 220 µm. Width of filament is 1.5-8 µm, 5.5 µm average, unbranched. Sheath may or may not be present. Diameter of filaments varies from chain to chain (4 specimens measured).

Discussion—Morphology of these specimens is comparable to a number of Proterozoic microfossils. Hofmann and Jackson (1994) reported microfossils of identical morphologies as *Nostocomorpha* (excluding wider diameter range). Hofmann (1984) merged all taxa exhibiting opaque mineral replacement within a tubular sheath as *Siphonophycus* or *Eomycetopsis*. This form is a rare form of the Deoban Assemblage. These filaments inclining towards Oscillatoriacean affinity, but replacement by any mineral could give rise to such morphology.

Family—SCYTONEMATACEAE Rabenhorst, 1865

Genus—CIRCUMVAGINALIS Sergeev, 1993 emend. Sergeev & Knoll, 1995

Type species—CIRCUMVAGINALIS ELONGATUS Sergeev, 1993 emend. Sergeev & Knoll, 1995

Species—cf. CIRCUMVAGINALIS sp.

(Pl. 8·3)

Description—Tube-like structure composed of successively superimposed funnel-shaped units, which appear to be partly inserted into each other as cone in cone structure. Width of the individual unit ranges between 10-11 µm, 10·5 µm

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PLATE 2 ⟶

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1 *Gloeodiniopsis lamellosa*, Slide No. I/D/89-3, 59.4/15.2 (Nikon).
2. *Scissilisphaera* sp., Slide No. Db_2- 6, 87.8/14.5 (Leica).
3 *Myxococcoides chlorelloidea*, I/D/89, 55.6/13.4 (Nikon).
4. *Myxococcoides chlorelloidea*, II/D/89, 59.7/11.9 (Nikon).
5. *Myxococcoides chlorelloidea*, Slide No. Db_1-9, 53.3/14.3 (Nikon).
6. *Scissilisphaera gradata*, I/D/89, 52.0/12.8 (Nikon).
7. *Scissilisphaera gradata*, Slide No. Db_3-6, 69.0/16.7(Nikon).

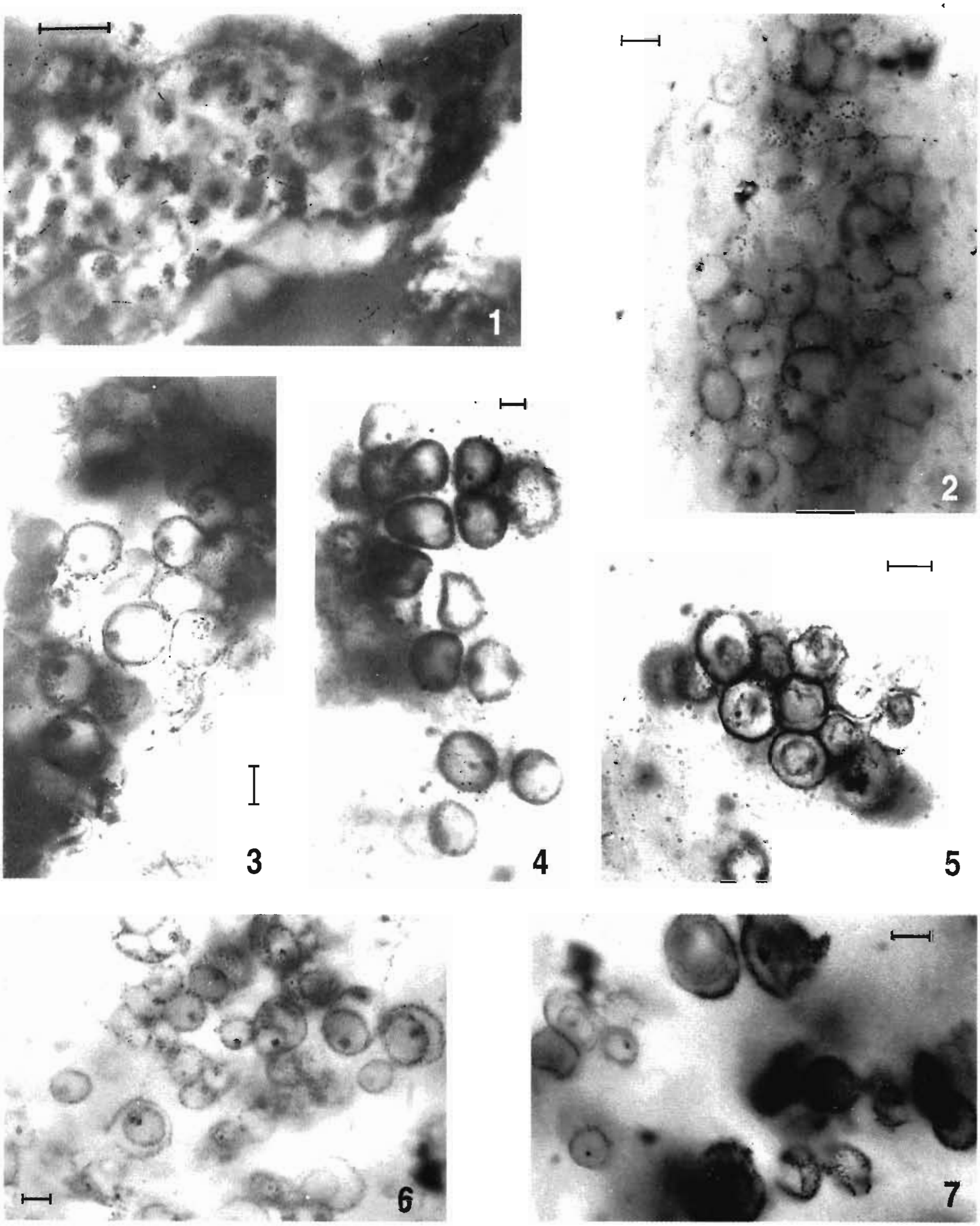

PLATE 2

average, which is almost uniform throughout the length. Length varies from 5-7 µm. Length of the entire structure is 105 µm. Granular organic matter is seen at the margins of funnel-shaped units (Single specimen).

Discussion—Different degradational stages of *Scytonema* particularly the last stage shown by Golubic and Barghoorn (1977) exhibited more or less the same features as seen in the present form. Therefore the Deoban microfossils may be interpreted as a degradational stage of *Scytonema*-like form. Width of Deoban's specimen is less than the forms described by Sergeev *et al.* (1995), but the morphology is comparable.

Order—OSCILLATORIALES

Family—OSCILLATORIACEAE

Genus—SIPHONOPHYCUS Schopf, 1968

Type species—SIPHONOPHYCUS KESTRON Schopf, 1968

Species—SIPHONOPHYCUS SEPTATUM Schopf, 1968; Butterfield in Butterfield *et al.*, 1994

(Pl. 10·9)

Description—Thin tubular filaments, which are unbranched, septate, straight or sinuous with granular texture. Diameter of tubes varies between 1-1·5 µm. Maximum length measured for these filaments exceeded up to 200 µm (15 filaments measured).

Discussion—Morphological features except the dimensions are almost same for forms assigned to *Archaeotrichion, Eomycetopsis* and *Siphonophycus*. Knoll *et al.* (1991) merged *Eomycetopsis* into *Siphonophycus*. Very thin tubular sheaths ranging in diameter from 1-1.5 µm have been assigned to *Archaeotrichion* and tubular sheaths with diameter of more than 2 µm to genus *Siphonophycus*. But Butterfield *et al.* (1994) described *A. contortum* as junior synonymy of *Siphonophycus septatum*. Here authors follow taxonomy recommended by Butterfield *et al.* (1994).

Species—SIPHONOPHYCUS ROBUSTUM Schopf, 1968 emend. Knoll & Golubic, 1979 comb. Knoll *et al.*, 1991

(Pl. 7·2; Pl. 10·10)

Description—Thin, tubular, nonseptate filaments which may be straight or sinuous. Walls smooth and cross sections are mostly circular. Diameter of filaments varies between 3-12 µm. Normally filaments acquire quite long length, up to 220 microns.

Discussion—This is one of the very common species of Proterozoic microfossils. As far as affinity of these forms is concerned they are considered as the empty sheaths of cyanobacterial trichomes. Deoban forms also exhibit normal basic features of this abundantly occurring taxa. This partricular species has already been reported in paper on Deoban Microfossil assemblage by Kumar and Srivastava, (1992), but then it was described as *Eomycetopsis robustum*.

Species—SIPHONOPHYCUS SOLIDUM Golub, 1979 emend. Butterfield in Butterfield *et al.*, 1994

(Pl. 7·6; Pl. 9·6)

Description—Unbranched, nonseptate filamentous sheaths acquiring ring-shaped morphology, occur solitary. Surface texture is psilate to granular. Width of filament ranges between 19-25 µm, (22 µm average). Septae-like structures are also present at a few places. Maximum length measured 180 µm. Filament is ruptured at few places. Thickness of wall ranges from 1·5-2 µm (2 specimens measured).

Discussion—Butterfield in Butterfield *et al.* (1994) emended the thick sheath acquiring ring-shape as *Siphonophycus solidum*. Width of the Deoban specimens is comparable to the forms reported from SW China by Fuxing *et al.* (1983) where filament acquired a ring-shaped structure and septae-like structures present. It was previously named as *Circulinema muirae*. Apparently there is no difference between *C. muirae* and *Siphonophycus solidum*. Pl. 7·6 shows comparatively smaller diameter (14-15 µm), but almost similar morphology except, sheath does not acquire ring-shape, it is sinuous structure. Hence categorised under *S. solidum*.

Species—SIPHONOPHYCUS TYPICUM Hermann, 1974 emend. Butterfield in Butterfield *et al.*, 1994

(Pl. 5·4; Pl. 9·8)

Description—Filamentous tubes of variable diameters are occurring together in different orientations. Tubes are straight to sinuous, without inclusions. Diameter varies from

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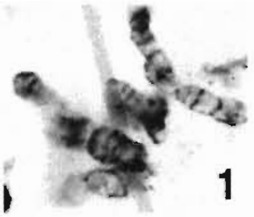
PLATE 3

⟶

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1. *Palaeopleurocapsa* sp., Slide No. Db_2-12, 139.0/16.2 (Olympus).
2. *Palaeopleurocapsa* sp., Slide No. Db_1-15, 144.8/12.3 (Olympus).
3. *Nannococcus vulgaris*, Slide No. Db_1-15, 46.9/10.2 (Nikon).
4. *Nannococcus vulgaris*, Slide No. Db_1-7, 55.3/17.1 (Nikon).
5. *Palaeomerismopedia misrai*, Slide No. Db_3- 6, 55.0/10.6 (Nikon).
6. *Palaeococcus indicus*, Slide No. Db_2-12, 49.8/20.5 (Nikon).
7. *Palaeococcus indicus*, Slide No. Db_2-12, 49.4/15.5 (Nikon).
8. *Palaeosphaeridium zonale*, Slide No. Db_1-6, 53.7/13.3 (Nikon).
9. *Gloeodiniopsis lamellosa*, Slide No. 11/D/89, 58.8/10.2 (Nikon).
10. Ascogenous hyphae like structure of Ascomycetes, Slide No. Db_1-12, 137.8/5.1(Olympus).
11. *Maithea indica* gen. and sp. nov., Slide No. Db_2-12, 50.6/20.8 (Nikon).
12. *Maithea indica*, Slide No. Db_2-12, 50.2/20.8 (Nikon).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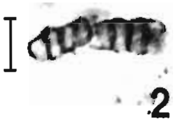
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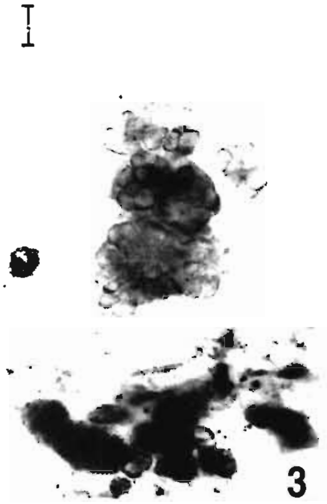
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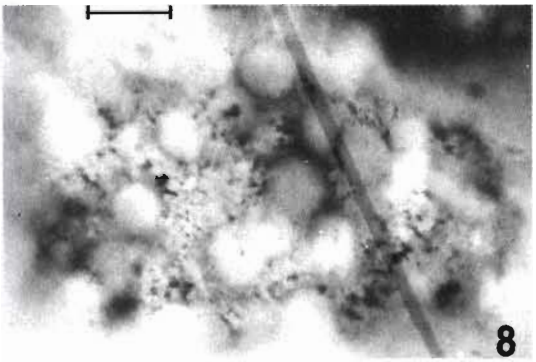
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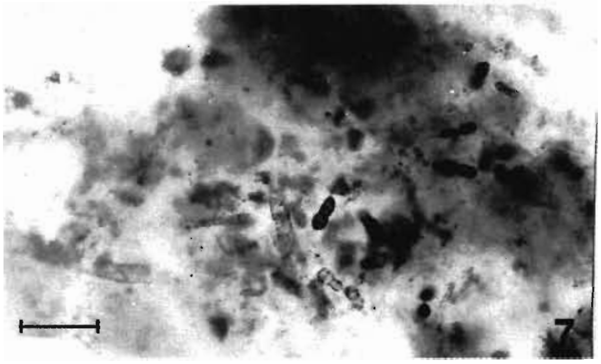
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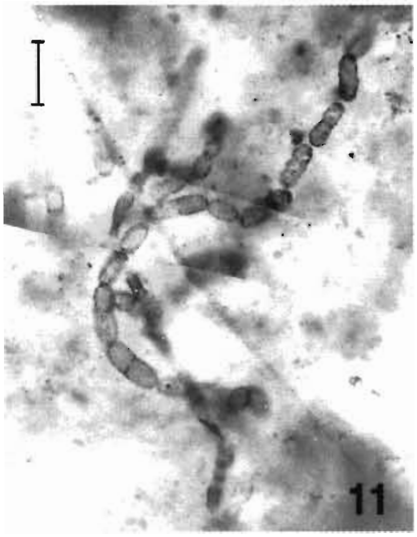
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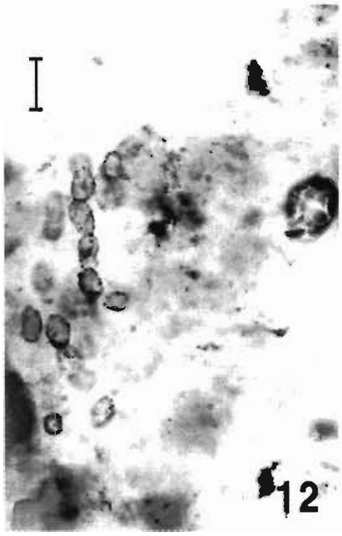
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PLATE 3

3 to 10 µm, 4·5 µm average (15 tubes measured). Length of sheath ranges between 20-26 microns.

Discussion—According to revision suggested by Butterfield in Butterfield *et al.* (1994), the present forms are assignable to *S. typicum*.

Genus—POLYTRICHOIDES Hermann (1974) emend. Hermann, 1976 (in Timofeev & Hermann, 1976)

Type species—POLYTRICHOIDES LINEATUS Hermann (1974) emend. Hermann, 1976

Species—POLYTRICHOIDES LINEATUS Hermann (1974), emend. Hermann, 1976

(Pl. 8·7)

Description—Filamentous septate tubes arranged parallel and closed to each other within a common enclosing sheath. Filaments psilate to finely granular 5-6 tubes in a bundle (5 specimens measured). Each tube ranges in diameter from 2·5 to 4 µm (3 µm average). Diameter of a bundle ranges between 20-24 µm, 22 µm average (3 specimens measured).

Discussion—General morphology of *Polytrichoides* and *Microcoleus* is almost same except the presence of enclosing sheath in case of *Polytrichoides* and filaments exhibit presence of septae. The Deoban forms are comparable to the Chinese forms described by Zang and Walter (1992).

Genus—OSCILLATORIOPSIS Schopf, 1968

Type species—OSCILLATORIOPSIS OBTUSA Schopf, 1968

Species—OSCILLLATORIOPSIS AMADEUS Schopf, 1968 comb. Butterfield in Butterfield *et al.*, 1994

(Pl. 7·8)

Description—Multicellular, uniseriate, unbranched, trichomed filaments, 10-18 µm in width, 13·5 µm average (5 specimens measured). Transverse walls of cells are distinct, compressed cells contain numerous inclusions. Tapering in one end is well marked.

Discussion—Width range is comparable to *O.amadeus* reported by Butterfield *et al.* (1994) from the Svanbergjellet Formation of Spitsbergen.

Species—OSCILLATORIOPSIS OBTUSA Schopf, 1968 emend. Butterfield in Butterfield *et al.*, 1994

(Pl. 9·4)

Description—Multicellular, uniseriate, unbranched trichome, cross walls very faint, sheath absent. Filaments are solitary, straight up to 92 µm long. Diameter of the filament ranges from 4-5 µm (single specimen traced).

Discussion—Morphologically it is comparable to many species of extant oscillatoriacean filament. Deoban's specimen is comparable to the *O. obtusa* reported from the Bitter Springs Formation by Schopf and Blacic (1971).

Species—OSCILLATORIOPSIS BREVICONVEXA Schopf & Blacic, 1971

(Pl. 7·4, 10)

Description—Trichome multicellular, unbranched, uniseriate, slightly constricted at cross walls. Since both filaments assignable to *O. breviconvexa* are incomplete, nature of filaments towards ends is not known i.e., whether it is attenuated or dialated. Remnants of sheath are seen in one of the specimens. Filaments range in diameter from 6-8 µm. Maximum length measured is 102 µm.

Discussion—The Deoban specimens exhibit comparable morphology and size range as mentioned for the Bitter Springs' specimens.

Genus—RHICNONEMA Hofmann, 1976

Type species—RHICNONEMA ANTIQUUM Hofmann, 1976

Species—RHICNONEMA ANTIQUUM Hofmann, 1976

(Pl. 7·9; Pl. 8·6; Pl. 9·2)

Description—Unbranched multicellular uniseriate trichome surrounded by tubular sheath. Filament is straight or curved, septation in inner thin filament is apparently seen at few places. Width of inner filament ranges between 1·5-3 µm, 2 µm average, width of outer sheath ranges between 6-9 µm, 7·2 µm average (7 specimens measured).

Discussion—General morphology of forms assigned *to Rhicnonema antiquum* is similar to that described by Hofmann (1976) from the Belcher Islands except the helicoid nature of

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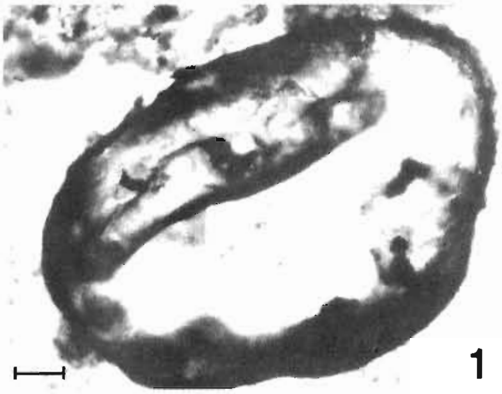
PLATE 4 ⟶

(Photomicrographs of coccoid forms in thin sections of black bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs except for 'a', 'e' and 'j' where it is equal to 50 microns Name of the microscope used for photography is also given in bracket)

1. *Trachysphaeridium* sp., Slide No. I/D/89—8, 50.7/18.6 (Nikon).
2. *Trachysphaeridium* sp., Slide No. II/D/ 89—11, 49.2/20.5 (Nikon).
3 *Leiosphaeridia crassa*, (Spirally grooved), Slide No. Db-2 A, 56.1/12.8 (Nikon).
4. *Gloeodiniopsis lamellosa*, Slide No. Db$_1$-7, 56.8/2.0 (Leica).
5. *Trachysphaeridium* sp., Slide No. I/D/ 89—8, 57.1/12.3 (Nikon).
6. *Leiosphaeridia crassa*. Slide No. I/D/89-1, 55.4/8.4 (Nikon).
7 *Micrhystridium* sp., Slide No. Db$_1$-15, 46.7/9.3 (Nikon)
8, 11. *Favosphaeridium favosum*, Slide No. Db$_2$-1, 133.1/9.5 (Olympus).
9. *Leiosphaeridia crassa*, Slide No. 1/D/89- 1, 55.4 /10.4 ((Nikon).
10. *Trachysphaeridium* sp., Slide No. Db$_1$-17, 50.9/17.8 (Nikon).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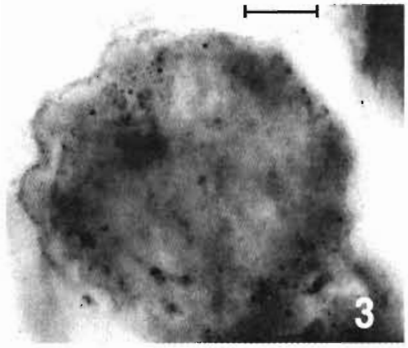
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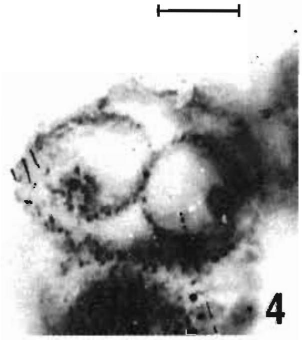
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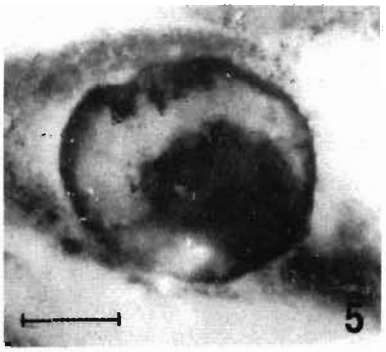
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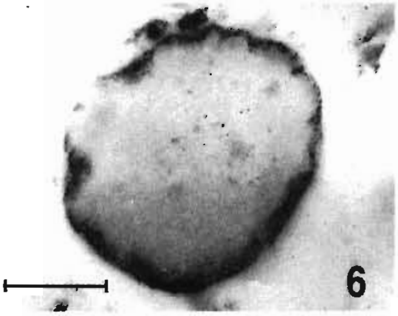
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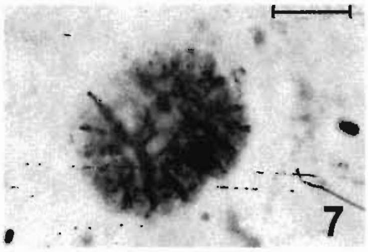
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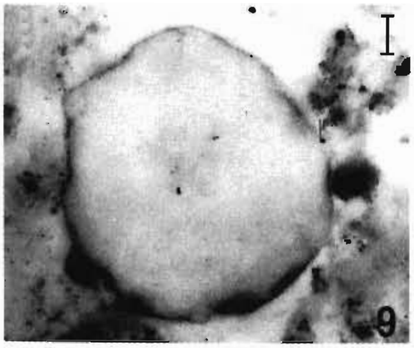
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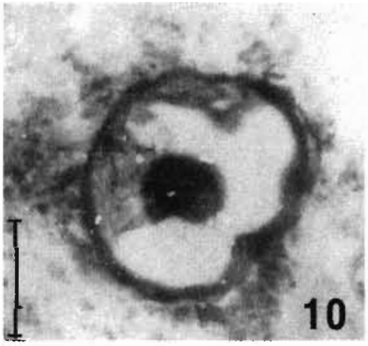
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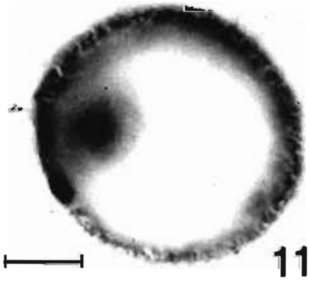
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PLATE 4

the median filament as mentioned by him. Diameter range of median filament is almost same where as outer sheath like structure shows wide diameter range in comparison to the Belcher specimens. Fuxing *et al.* (1983) also reported specimens with similar morphology (including the helical structures of trichome) from China. Width of the median filaments in the Deoban assemblage is more than the forms reported by Zhang Yun (1985) from China, while outer sheath shows same diameter range. The taxa also show some resemblance with *Siphonophycus typicum.*

Genus—EOMICROCOLEUS Horodyski & Donaldson, 1980

Type species—EOMICROCOLEUS CRASSUS Horodyski & Donaldson, 1980

Species—EOMICROCOLEUS CRASSUS Horodyski & Donaldson, 1980

(Pl. 8·9; Pl. 9·9)

Description—Unbranched, thin filaments, laterally enclosed within a common cylindrical sheath up to 40 µm in width. Each sheath encompasses a bundle of closely arranged filamentous tubes with diameter 1·5-3 µm (2 µm average). Number of tubes vary in each sheath. Texture of filaments is granular, numerous inclusions present in these ensheathed filaments (4 specimens measured).

Discussion—Width of the Deoban specimens is little larger than the Dismal Lake's specimens described by Horodyski and Donaldson (1980), but overall morphology is same. The width is also larger in comparison to *Eomicrocoleus* sp. reported by Hofmann and Jackson (1994) and by Buick and Knoll (1999). It has a smaller dimension in comparison to cf. *E. crassus* reported from the Newari locality, Fawn Limestone Member of the Kheinjua Formation, India by Kumar and Srivastava (1995). This form is a rare component of Deoban Assemblage. Preservation of the filaments is rather poor and details of morphology are not clearly visible. In morphology, the Deoban form resembles with extant *Microcoleus lacustris* Desikachary (1959).

Genus—CYANONEMA Schopf, 1968

Type species—CYNONEMA ATTENUATUM Schopf, 1968

Species—CYANONEMA sp.

(Pl. 7·5, 7, 11; Pl. 9·3)

Description—Multicellular, uniseriate, unbranched, occasionally slightly constricted at septa, solitary filamentous forms without enclosing sheath. Cells elongate, slightly curved and occasionally break into segments from the septa. Length of cells 3-6 µm and width ranges between 2-5 µm (12 cells measured, 3 specimens found).

Discussion—Tendency of filaments to break into segments from the septa is identical to the species reported from Jinning Yunnan of SW China by Fuxing *et al.* (1983). Oehler (1977) also reported filaments with well-marked septa. The Deoban forms show close resemblance with *C. inflatum* but its internal feature is not well preserved. Thus, the form is identified up to generic level only. Dimensions and some features are comparable to *C. ligamen* reported by Zhang Yun (1981) from the Gaoyuzhuang Formation of China; the difference is the presence of cross walls only. *Cyanonema minor* is the species from Mc Arthur Group described by Oehler (1977), differentiable by its small dimensions. In Pl. 7·7 morphology resembles to some extent with extant cyanobacterial form *Gloeotrichia.*

Genus—PALAEOLYNGBYA Schopf, 1968

Type species—PALAEOLYNGBYA BARGHOORNIANA Schopf, 1968

Species—PALAEOLYNGBYA CATENATA Hermann, 1974 emend. Butterfield in Butterfield *et al.*, 1994

(Pl. 9·5, 7)

Description—Multicellular, uniseriate, filaments with enclosing sheaths. Trichomes solitary, straight to slightly curved, granular surface, prominent cross walls may or may not be present. Width of filaments ranges between 12-20 µm (14 µm average, inclusive of encompassing sheath), cells are disc-shaped with length 5-7 µm, 5·5 µm average and width of 8-16 µm, 13 µm average (23 cells measured). Maximum length is 180 µm (4 specimens measured).

Discussion—According to Schopf (1968), septation is simply due to cell division, resulting in asexual reproduction. This genus is a rare member of the Deoban Assemblage. Width

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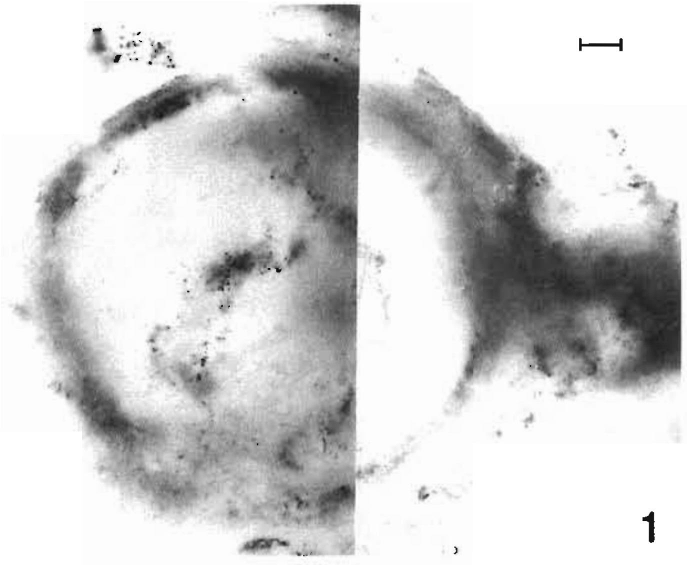
PLATE 5 ⟶

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1. cf. *Cymatiosphaera* sp., Slide No. I/D/89-9, 62.0/10.6 (Nikon).
2. Septate filament with akinite like structures, Slide No. Db$_2$-12, 52.8/9.58 (Nikon).
3. *Leiosphaeridia jacutica*, Slide No. I/D/89-4, 54.1 /12.9 ((Nikon).
4. *Siphonophycus robustum*, Slide No. Db$_1$-15, 50.7/18.8 (Olympus).
5. *Caudosphaera* sp., Slide No. Db$_2$-7, 49.9/15.8 (Olympus).
6. cf *Ovulum saccatum*, Slide No. Db$_1$-2, 80.2/14.2 (Leitz).
7. Unusual form with aestrix mark seen within a vesicle, Slide No. Db$_2$-F, 142.2/3.6 (Olympus).
8. V-shaped engrovement in spheroid with prominent intracellular mass, Slide No. Db2-12, 49.8/ 9.9 (Nikon).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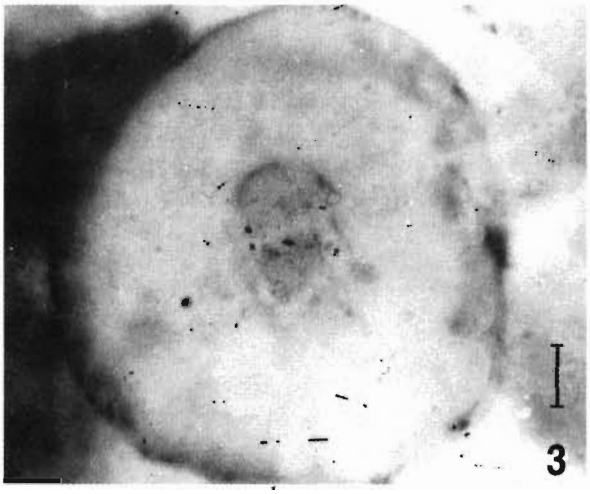
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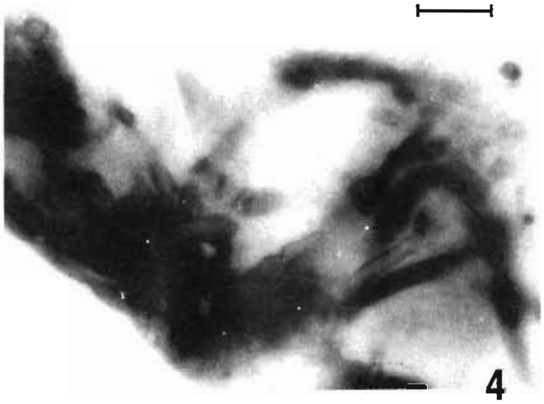
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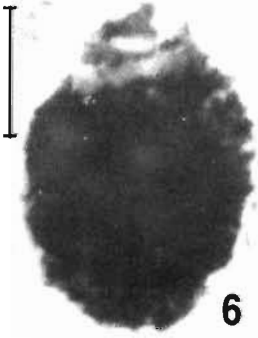
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PLATE 5

of filaments is comparable to the *Palaeolyngbya maxima* described by Zhang Yunl (1981) from China, which was subsequently synonymised by Butterfield in Butterfield *et al.* (1994) to *Palaeolyngbya catenata.*

Genus—OBRUCHEVELLA Reitlinger, 1948, emend. Yakschin & Luchinina, 1981

Type species—OBRUCHEVELLA DELICATA Reitlinger, 1948

Species—OBRUCHEVELLA AFF. PARVA Reitlinger, 1959

(Pl. 10·3)

Description—Tightly to loosely coiled nonseptate tubular filaments are showing different modes of coiling. Sometimes they are single whirled and most of the times there are 4-6 whorls. Diameter of tubular filaments ranges from 5 to 6 µm (5 specimens measured). Diameter of helix ranges from 45 to 60 µm, 55 µm average.

Discussion—Filaments acquiring helically coiled morphology are observed in Deoban Assemblage, which are much thinner than the other reported forms. Range of the diameter of the Deoban specimens are comparatively less than the Chinese forms described by Song (1984) from the Jinning Yunnan.

Species—OBRUCHEVELLA VALDAICA Jankauskas in Jankauskas *et al.*, 1989

(Pl. 10·7)

Description—Tightly coiled, nonseptate, tubular filament with 4 to 5 whorls. Diameter of tube is uniform throughout, which is 6 µm (single specimen).

Discussion—Tight coiling with a round, empty central space is the feature exhibited by a single specimen in Deoban Assemblage. Morphology shows close resemblance with *O. valdaica* reported from the Thule Supergroup, Northwest Greenland by Samuelsson *et al.* (1999). Dimensions are also comparable to the Thule specimens.

Species—OBRUCHEVELLA MINOR Zhang Zhong Ying, 1984.

(Pl. 10·5, 6)

Description—Tubular, spring like, spirally coiled filaments of 2·5 to 3 µm diameter, helically coiled around an open centre. Helixes straight to slightly curved along its length. External diameter of helix is from 12 to 22 µm. Coiling is loose and adjacent coils do not touch each other. Transverse markings are not seen.

Discussion—*Obruchevella minor* is differentiable from the other species of the genus by its mode of coiling and diameter range of tubes. This species is supposed to be the smallest spirally coiled fossil filaments.

Genus—GLOMOVERTELLA Reitlinger, 1959

Type species—GLOMOVERTELLA GLOMERATA Reitlinger, 1959

Species—GLOMOVERTELLA GLOMERATA Reitlinger, 1959

(Pl. 10·8)

Description—Tightly to loosely coiled nonseptate tubular filaments are exhibiting different modes of coiling. Sometimes they are single whorled and most of the times there are 4 to 6 whorls. Diameter of tubes ranges between 1·5 to 4·5 µm (5 specimens measured). Diameter of helix ranges from 15 to 35 µm, 24 µm average.

Discussion—Haphazardly oriented loosely coiled filaments are easily differentiable from the helically coiled filamentous form *Obruchevella.*

INCERTAE SEDIS

Coccoid forms

Genus—PALEOSPHAERIDIUM Yin Chongyu, 1985

Type species—PALEOSPHAERIDIUM ZONALE Yin Chongyu (1985) emended Zang & Walter, 1992

Species—PALEOSPHAERIDIUM ZONALE Zang & Walter, 1992

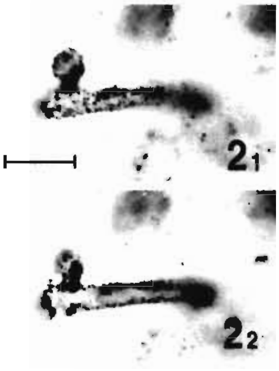
(Pl. 3·8)

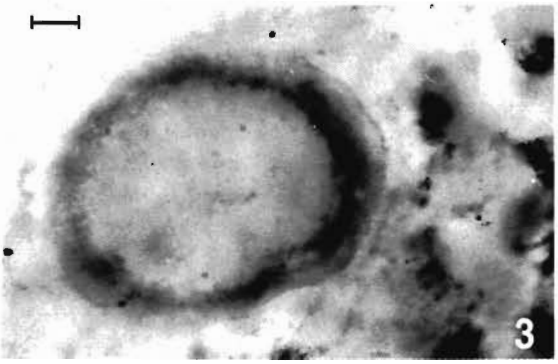
PLATE 6

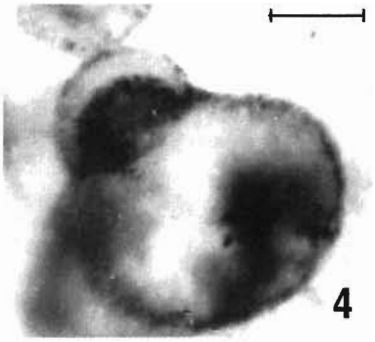
⟶

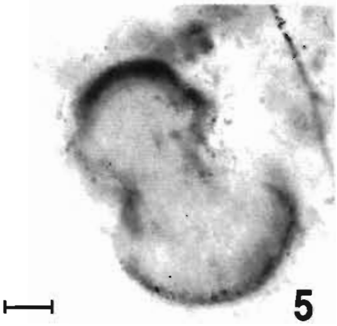
(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

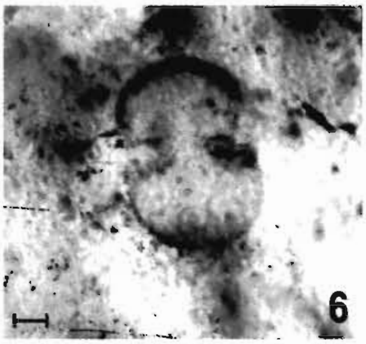
1. *Germinosphaera* sp., Slide No. Db$_1$-15, 51.6/17.7 (Nikon).
2-$_1$, 2-$_2$. Budding-like structure in a filamentous form, Slide No. Db$_2$-F, 142.5/2.6 (Olympus).
3 *Leiosphaeridia crassa*, Slide No. Db$_3$-9, 46.8/10.2 (Nikon).
4. Budding-like structure in coccoid form, Slide No. Db$_2$-G, 53.8/6.0 (Leica).
5. *Dumbellina deobanensis*, gen. and sp. nov. Slide No. II/D/89-6, 57.8/16.5 (Nikon).
6. *Dumbellina deobanensis*, gen. and sp. nov, holotype, Slide No. II/D/89-6, 42.0/24.2 (Nikon).
7. *Scissilisphaera gradata*, Slide No. Db$_3$-6, 69.5/17.3 (Leica).
8. *Trachysphaeridium* sp., Slide No. Db2-7.57.8/ 12.0 (Nikon).
9. *Myxococcoides stragulescense*, Slide No. Db$_3$-9, 74.6/14.2 (Nikon).
10. *Scissilisphaera gradata*, Slide No. Db$_3$-6, 69.6/17.3 (Leica).
11 *Myxococcoides chlorelloides*, Slide No. Db$_3$-6, 80.0/12.7 (Nikon).

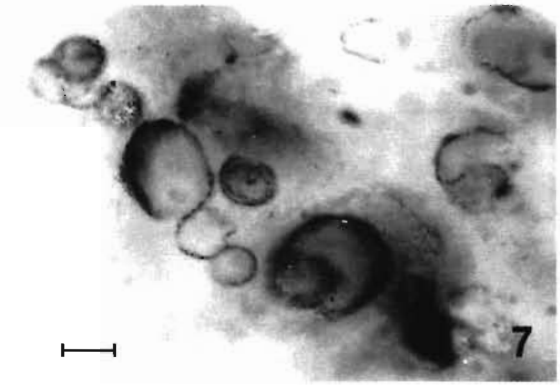


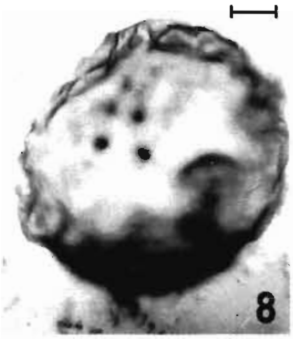












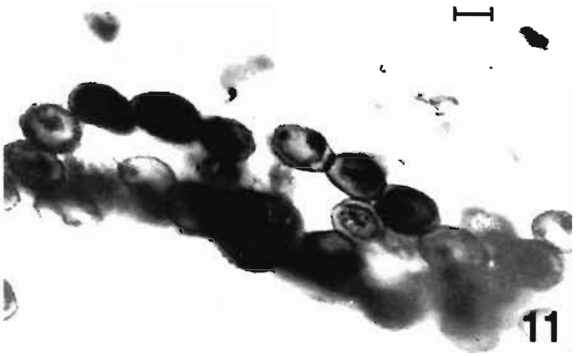


PLATE 6

Description—Colonies of group of spheroidal vesicles, joined together by a sheath like structure. Vesicles are psilate to granular in texture. Cell walls form a thickened ring like structure around each vesicle. Vesicle diameter ranges between 8-10 µm, (8·5 µm average) (22 specimens measured).

Discussion—Solitary vesicles of *Palaeosphaeridium* resemble with *Leiosphaeridia asperata,* except the thick walls, size and granular texture. Diameter of vesicle is smaller in comparison to Anhui and Jiangsu specimens from China described by Zang and Walter (1992).

Genus—GERMINOSPHAERA Mikhailova, 1986

Type species—GERMINOSPHAERA UNISPINOSA
Mikhailova 1986; Amard & Sarfati, 1997

Species—GERMINOSPHAERA sp.

(Pl. 6·1)

Description—Spheroidal to ellipsoidal psilate vesicle with a tube extending outward from the vesicle. Diameter of the vesicle ranges from 8-15 µm, 12·5 µm average, tube 9-22 µm long and 3-5 µm wide (4 specimens measured). In one of the specimen, extant end of the tube is opened whereas in rest of the specimens extending tube is closed.

Discussion—This form is comparable to *Germinosphaera* sp. described by Amard and Sarfati (1997) from the Franceville Group of Gabon. Dimensions of the Deoban forms are comparatively larger than the Franceville forms and smaller than the type specimens described from the Upper Riphean Dashkin Formation, Siberia by Mikhailova (1986). Affinity of this form is not clearly established. It has been compared with the germinating zoospores of modern Xanthophycean algae, *Vaucheria* (Butterfield *et al.*, 1988, 1994).

Genus—PALAEOCOCCUS gen. nov.

Type species—PALAEOCOCCUS INDICUS gen. & sp. nov.

Diagnosis—Spheroidal to ellipsoidal and some times sickle-shaped cell like units, mostly less than one micron in dimensions.

Discussion—Small size and shape of these forms differentiate them from *Eosynechoccus amadeus* described by Knoll and Golubic (1979). Shape and mode of occurrence of some of these forms are comparable to *Sphaerophycus parvum* and *Eosynechococcus* but, size of these tiny spheroids is differentiable from any other cyanobacterial form and support their bacterial affinity. Yuan and Hofmann (1998) described bacterial form among problematica and reported them as Rod-bacteria like type 'B' from the Neoproterozoic Doushantou Formation of China.

Species—PALAEOCOCCUS INDICUS gen. & sp. nov.

(Pl. 3·6, 7)

Type Locality—Deoban Limestone, Chakrata area, Dehradun District, Uttaranchal.

Type Specimen—Slide no. Db$_2$-12, Coordinates 49·8/20·5 (Nikon).

Etymology—With reference to its occurrence in India.

Diagnosis—Monospecific genus.

Description—Very small micron sized spheroids, ellipsoids or sickle-shaped structures occur isolated, diads or in small clusters, granular texture, margins smooth or granular. Diameter 0·5-1 µm (50 specimens measured). Intracellular mass may or may not be present.

Discussion—Exceptionally small size of this form is characteristic feature and differentiate it from any other cyanobacterial form. Mode of occurrence and dimensions are comparable to extant bacterial forms. When it occurs as solitary individuals then it can be comparable to *Micrococcus* and when it occurs as diads then it is comparable to *Diplococcus.* And when it occurs in chains, it is called *Streptococcus* as seen in Pl. 3·7. Elliptical forms can be compared with *Bacillus* and *Diplobacillus*. Though the morphology is also comparable to *Eosynechococcus* and *Sphaerophycus* but its small dimensions disfavour the *Eosynechococcus* affinity. Some of these specimens are comparable to Chinese Rod-bacteria like type reported from the Neoproterozoic Doushantou Formation by Yuan and Hofmann (1998). Deoban Forms cannot be considered as the degraded cyanobacterial cells because preservation of these forms is very good.

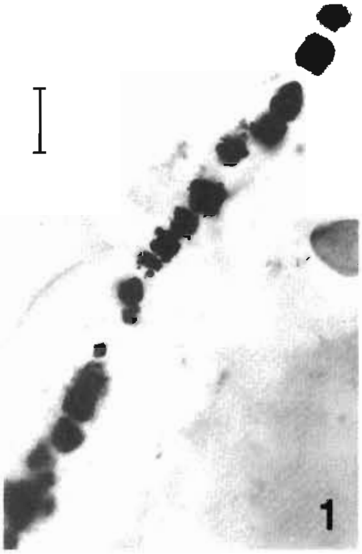
Genus—DUMBELLINA gen. nov.

Type species—DUMBELLINA DEOBANENSIS

PLATE 7 →

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1. *Nostocomorpha* sp., Slide No. Db$_2$-D-9, 50.3/21.5 (Nikon).
2. *Siphonophycus robustum,* Slide No. Db$_3$-6, 49.1/19.6 (Nikon).
3. *Nostocomorpha* sp., Slide No. Db$_3$-9, 79.2/18.7 (Leica).
4. *Oscillatoriopsis breviconvexa*, Db2-9, 50.3/ 21.5 (Nikon).
5. *Cynonema* sp., Slide No. Db$_3$-9, 70.8/10.4 (Leica).
6. *Siphonophycus solidum,* Slide No. II/D/89, 54.6/1.4 (Leitz).
7. *Cyanonema,* morphology comparable also to extant Cyanobacterial taxa *Gloeotrichia,* Slide No. Db1-19. 52.7/ 7.8 (Nikon).
8. *Oscillatoriopsis amadeus*, Slide No. Db$_2$-16, 63.9/13.54.6/1.4 (Nikon).
9. *Rhicnonema antiquum*, Slide No. Db$_2$-6, 51.1/11.9 (Nikon).
10. *Oscillatoriopsis breviconvexa*, Slide No. Db$_1$-26, 139.7/14.2 (Olympus).
11. *Cynonema* sp., Slide No. Db$_3$-6, 53.9/10.8 (Nikon).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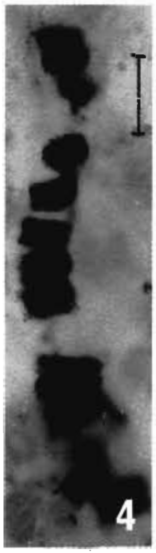
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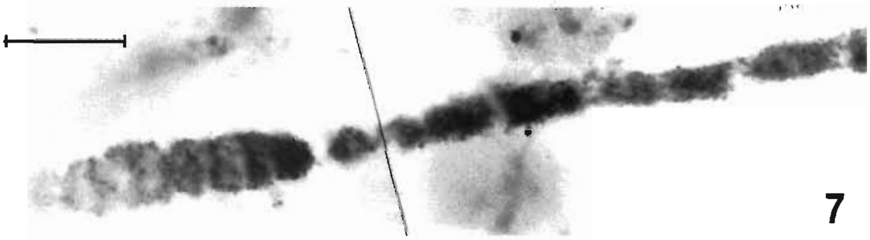
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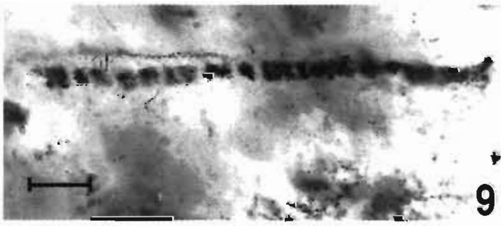
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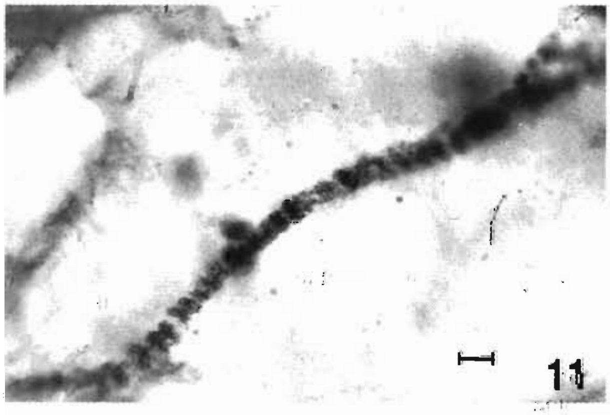
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PLATE 7

Etymology—Because of its dumbbell-shaped morphology.

Diagnosis—A dumbbell-shaped body with marked constriction in median part.

Discussion—The form is differentiable from the chroococcacean cyanobacteria by typical dumbbell-shaped morphology, which is comparable to extant chlorophycean form. The form shows a possible division stage of a Chlorophycean aggregate or may be an individual entity. Tewari (1992, 1996) reported a form of comparable morphology without any description and taxonomic affinity. He simply mentioned it as a division stage. Zang and Walter (1992) described an acritarchean form *Leiosphaeridia timofeevi* as a paired cell exhibiting vegetative cell division. Dimensions and shape of Deoban specimens are easily differentiable from the other acritarchean forms from China.

Species—DUMBELLINA DEOBANENSIS gen. & sp. nov.

(Pl. 6·5, 6)

Type Locality—Deoban Limestone, Chakrata area, Dehradun District, Uttaranchal.

Type Specimen—Slide no. II/D/89-6, Coordinate 42·0/24·2 (Nikon).

Etymology—Because of its occurrence in the Deoban Limestone.

Diagnosis—Monospecific genus.

Description—Dumbbell-shaped cellular body is markedly constricted centrally, resulting into two perfectly symmetrical halves. Diameter of constricted part is 10-20 µm. Maximum diameter measured is 42 µm, length of entire structure is 60-85 µm, 72 µm average (3 specimens measured).

Discussion—Consistency in morphological features in three different specimens supports their original entity in place of degradational variant of any other genera or species. Internal structures are absent.

Genus—MAITHEA gen. nov.

Type species—MAITHEA INDICA new gen. & sp. nov.

Etymology—In honour of Dr PK Maithy.

Diagnosis—In association with elongated or rod-shaped cell like units arranged in chains, presence of segmented or broken filaments, where segments (as reported in Cyanonema) arranged linearly.

Discussion—Small size of these forms differentiate them from the other known Proterozoic microfossils occurring as akinites in chains like *Archaeoellipsoides conjunctivus*, Zhang (1981). In extant chlorophycean form *Hormidium*, plant body tends to break into many fragments and each fragment subsequently forms an individual plant. Specific mode of occurrence (small rod-shaped cells arranged in chains) and in association with these chains or diads, presence of fragmented/segmented filamentous or tubular structures of almost same diameter range, favour the assignment of present forms with *Hormidium*, an extant chlorophycean form. There is also a possibility that these forms represent the variables of *Eosynechococcus* like structures. Smaller size and horizontal division line is the feature differentiating it from the *Archaeo ellipsoides*.

Species—MAITHEA INDICA new gen. & sp. nov.

(Pl. 3·11, 12)

Type Locality—Deoban Limestone, Chakrata area, Dehradun District, Uttaranchal.

Type Specimen—Db_2-12, coordinates 50·6/20·8 (Nikon).

Etymology—Because of its occurrence in India.

Diagnosis—Monospecific genus.

Description—Small rod-shaped cell like units with marked constriction in the middle part across the length. Margins very sharp and at places cells arranged in pairs or in chains, which are straight or highly sinuous. The ellipsoidal units attached each other from the short axis. Cell diameter or long axis ranges between 9-13 µm, 11 µm average, while short axis ranges between 3-5 µm, 4 µm average (15 cells measured).

Discussion—Chain of elongated cells as in *Eosynechococcus mooreii* (McMenamin *et al*., 1983) and in association with these cells, presence of thin filaments (nonseptate) broken into segments, arranged in linear manner and spheroids with intracellular mass and ruptured or cracked surface, to some extent support chlorophycean affinity as seen in extant chlorophycean form *Hormidium*.

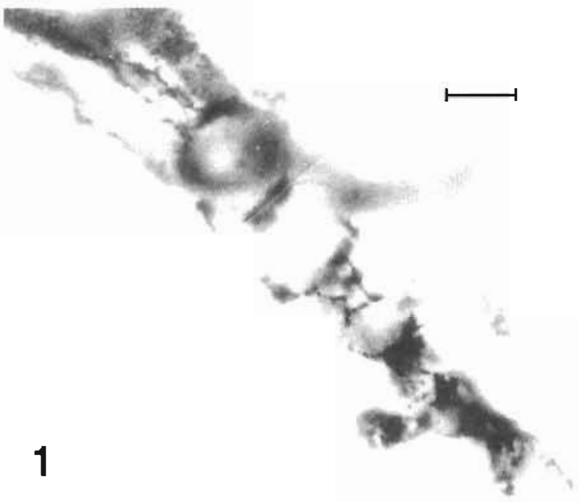
Form 'A'

(Pl. 8·4, 5)

PLATE 8 →

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1. *Bulgenia septata*, gen. & sp. nov., Slide No. Db_1-26, 59.3/6.2 (Nikon). A bud-like structure is seen in the lower part of the photomicrograph.
2. *Leiosphaeridia jacutica*, Slide No. Db_3-9, 53.7/14.5 (Nikon).
3. *Circumvaginalis*, Slide No. I/D/89, 55.3/9.3 (Nikon).
4. Form *'A'*, Slide No. Db_3-9, 73.6/16.9 (Leica).
5. Form 'A'. Slide No. Db_3- 9, 80.2/15.1 (Leica).
6. *Rhicnonema antiquum*, Slide No. Db_1-15, 53.0/11.5 (Nikon).
7. *Siphonophycus typicum*, Slide No. II/D/89-G, 79.1/ 36.9 (Leitz).
8. *Bulgenia septata*, gen. & sp. nov., Slide No. Db_1-26, 59.3/6.2 (Nikon).
9. *Eomicrocoleus crassus*, Slide No. Db_2-12, 49.4/20.8 (Nikon).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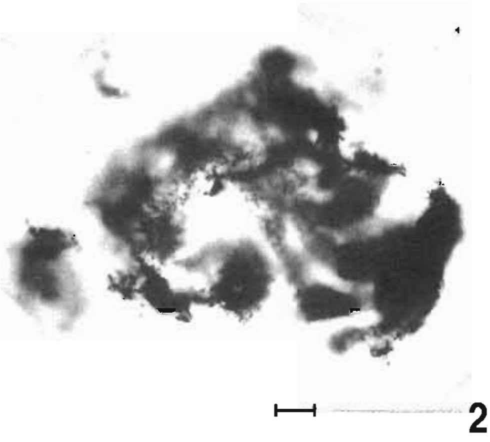
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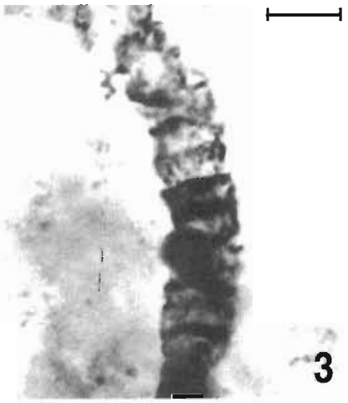
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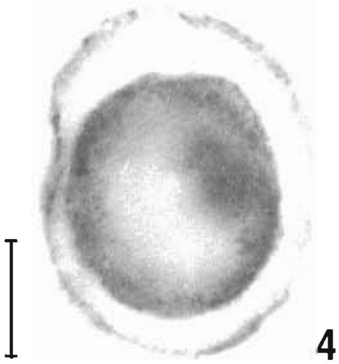
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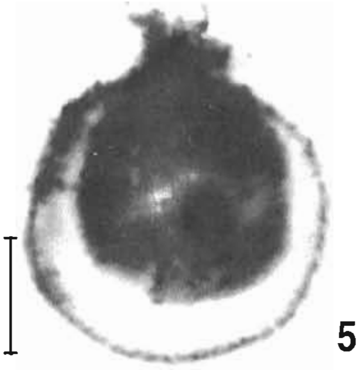
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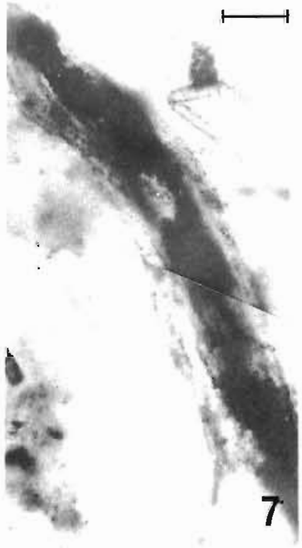
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PLATE 8

Description—Two spheroids slightly of different size, one encapsulating the other, outer spheroid light coloured, thick walled ranging in diameter from 22-26 µm, inner spheroid darker and thicker walled ranging in diameter from 16-18 µm. Inner spheroid both detached as well as contiguous. In one specimen intracellular mass appears to be coming out from the inner spheroid (2 specimens traced).

Discussion—The Deoban specimens show some resemblance with *Globophycus rugosum* described from the Bitter Springs Formation by Schopf (1968). However in Deoban forms the wall is very thick, the inner spheroid is also contiguous and in one specimen the intracellular mass is oozing out. It is also not clear whether the inner spheroid is a separate spheroid or is the condensed intracellular mass.

FILAMENTOUS FORMS

Genus—BULGINIA gen. nov.

Type Species—BULGINIA SEPTATA gen. & sp. nov.

Type Specimen—Sample No. Db-1-26, Coordinates 59·3/ 6·2 (Nikon).

Etymology—With reference to repetitive bulging in cells.

Diagnosis—Tubular septate filaments with sac-like bulging at regular intervals and with lateral branching forming a bud-like structure.

Discussion—Branching among Proterozoic filaments is already recorded in forms like *Ulophyton* and *Proterocladus,* but repeated bulging in tubular septate filament resulted in sac-like structure and a bud-like feature differentiate it from the rest of the Proterozoic branched filamentous forms. Consistency and repetitive occurrence of bulging rule out the possibility of secondary origin of these structures

Species—BULGENIA SEPTATA gen. & sp. nov.

(Pl. 8·1, 8)

Type Locality—Black Bedded chert, Deoban Limestone, Chakrata area, Dehradun District, Uttaranchal.

Type Specimen—Db-1-26, Coordinates- 59.3/6.2 (Nikon).

Diagnosis—monospecific genus.

Etymology—with reference to its septate filamentous structure.

Description—Thick walled, granular, septate filaments with uneven margins and variable width. Sudden bulging resulted in an empty sac-like structures without much internal details. Bulging is repeated and at a few places in between two bulged structures a common neck-like joining is seen. Diameter of the connecting tube varies between 3-4.5 µm (3.5 µm average). Maximum diameter of these bulged structures is 15 µm. Maximum length measured 160 µm (4 specimens measured). An outgrowth or a bud-like structure is seen in (Pl. 8.1) where diameter of bud is 3 µm, length is measured as 9 µm.

Discussion—Sudden bulging and septation in filamentous part, and bud-like structure are the characteristic features of this form. Edhorn (1973) reported terminal and intercalated heterocysts like features in forms of the *Animikia* from the Thunder Bay, Ontario, however her illustrations are not convincing. Amard and Sarfati (1997) reported specimens of almost similar morphologies and described them as budding bacteria, however dimensions of Deoban specimens are comparatively much larger. Barghoorn and Tyler (1965) also described *Animikea septata* with identical morphology. For similar structures phylogenetic affinities with green algae Voucheriaceae were earlier suggested by Barghoorn and Tyler (1965). Awramik and Barghoorn (1977) interpreted almost similar morphologies as budding bacteria. Amard and Sarfati (1997) suggested it rather yeast type budding. A living green algal genus *Oedogonia* represents morphological similarity with Deoban forms. Akinite like structures or bulged portions of septate filaments can also be interpreted as Oogonium, in which formation of oospores occur. Budding structure may be a dwarf male plant called *Nannandrea* as in *Oedogonium concatenatum* (see Vashistha, 1977). There is one more possibility that these bulged portions of septate filaments can be akinites produced by nostocalean cyanobacteria.

Genus—EOPHYCOMYCES Allison and Awramik, 1989

Type species—EOPHYCOMYCES HERKOIDES Allison and Awramik, 1989

Species—cf. EOPHYCOMYCES HERKOIDES

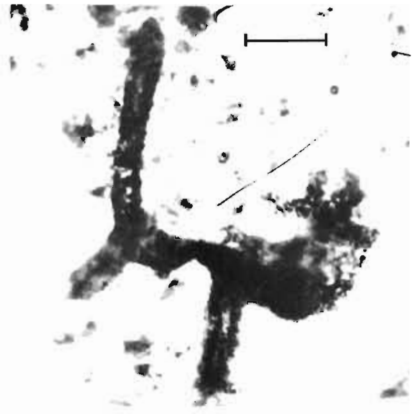
(Pl. 9·1; Pl. 10·4)

Description—Tubular cylindrical filaments of variable diameter, exhibiting branching are present. These are gently to strongly curved structures. Filaments have prominent walls, at places compressed or collapsed, granular to psilate texture. Bulbous and thumb-like protrusions are the characteristic features of this form. Diameter of filament ranges between 12-48 µm (2 specimens measured).

PLATE 9 ⟶

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1 *Eophycomyces herkoides*, Slide No. Db$_2$-E, 51.3/ 21.5 (Nikon).
2. *Rhicnonema antiquum*, Slide No. Db$_1$-15, 53.0/ 11.5 (Nikon).
3. *Cyanonema antiquum*, Slide No. Db2-1, 57.4/ 6.6 (Nikon).
4. *Oscillatoriopsis obtusa*, Slide No. Db$_1$-26, 57.6/ 21.6 (Nikon).
5 *Palaeolyngbya catenata*, Slide No. Db$_1$-7, 53.8/ 18.6 (Nikon).
6. *Siphonophycus solidum*, Slide No. Db$_1$-15, 52.4/ 24.5 (Nikon).
7 *Paleolyngbya catenata*, Slide No. Db$_1$-11, 51.3/ 5.5 (Nikon).
8. *Siphonophycus typicum*, Slide No. Db$_2$-12, 54.0/ 14.3 (Nikon).
9. *Eomicrocoleus crassus*, Slide No. II/D/89-6, 82.5/ 29.4 (Leica).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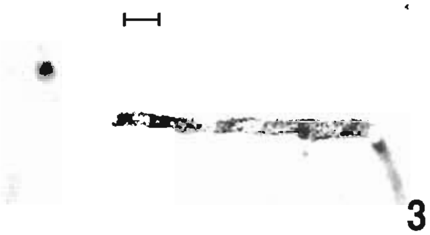
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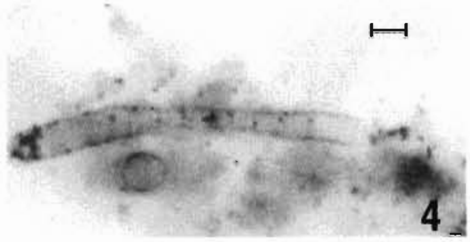
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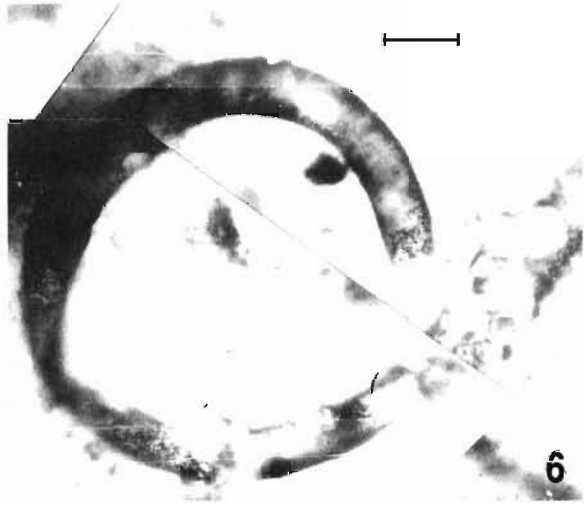
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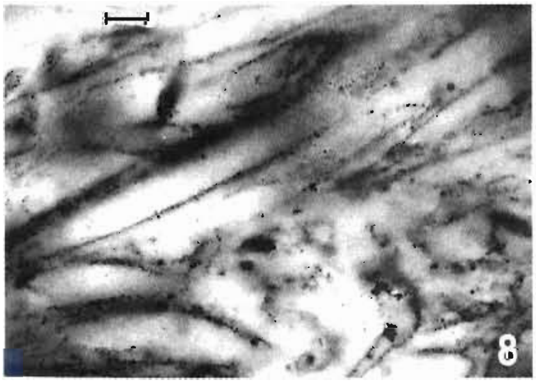
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PLATE 9

Discussion—Bulbous protrusions, branching and thumb-like structures favour fungal affinity (more closely towards *Allomyces;* Allison & Awramik, 1989). Barghoorn and Tyler (1965) and Awramik and Barghoorn (1977) also described, a nonseptate, branched, tubular filaments as *Archaeorestis*, and Licari (1978) described branched tubular structures as *Palaeosiphonella.* Branching can also be false in nature. General morphology of the Deoban form is comparable to the *Eophycomyces* described by Allison and Awramik (1989) from the Tindir Group, Canada.

Group—ACRITARCHA

Domain—EUCARYA

Genus—CYMATIOSPHAEROIDES Knoll, 1984

Type species—CYMATIOSPHAEROIDES KULINGII Knoll, 1984 emend. Knoll *et al.,* 1991

Species—cf. CYMATIOSPHAEROIDES sp.

(Pl. 5·1)

Description—Large, spheroidal to subspheroidal vesicle-like structure with prominent enclosing sheath. Diameter of the vesicle ranges from 100-250 µm, diameter of the outer sheath ranges between 105-265 µm (3 specimens measured). Process like structures are invisible.

Discussion—Presence of outer sheath encompassing the spheroidal vesicle-like structures is the distinguishing feature of this genus. Deoban specimens exhibit all mentioned features except hairy processes, therefore the form has only been reported as cf. *Cymatiosphaeroides.*

Genus—MICRHYSTRIDIUM Deflandre (1955) emend. Downie and Sarjeant, 1963

Type species—MICRHYSTRIDIUM DISSIMILARE Volkova, 1969

Species—MICRHYSTRIDIUM sp.

(Pl. 4·7)

Description—Spheroidal vesicle-like structure with a number of thin or slender, almost equally placed processes around it. Vesicle diameter 23 µm. Length of process like structures varies between 5-7 µm, diameter of processes up to 1.5 µm. At the surface, pentagonal and hexagonal chambers or a reticulate pattern acquiring honey- comb like feature is visible. Single specimen is traced.

Discussion—Diameter of Deoban form is more than the range given by Knoll and Swett (1987) from Spitsbergen. Generally, species of genus *Micrhystridium* are less than 20 µm in diameter. Details of thin processes whether they widened or tapered at the base or tapered at distal parts, are not clear. However, the general appearance of Deoban specimen is comparable to *Micrhystridium*, reported by Knoll and Swett (1987) from Spitsbergen.

Genus—FAVOSPHAERIDIUM (Timofeev) Timofeev, 1966

Type species—FAVOSPHAERIDIUM SCANDICUM Timofeev, 1966

Species—FAVOSPHAERIDIUM FAVOSUM Vidal, 1976

(Pl. 4·8, 11)

Description—Spheroidal to ellipsoidal solitary vesicles with honey-comb like surface ornamentation. Walls moderately thick. Diameter ranges between 26-36 µm, 30 µm average. Intracellular mass may or may not be present (6 specimens measured).

Discussion—The Deoban specimens described here are similar to the forms described by Vidal (1976). Zang and Walter (1992) described a form comparable to *Favosphaeridium* sp. from China in which presence of an opening has also been mentioned. This particular feature is not visible in the Deoban forms.

Genus—TRACHYSPHAERIDIUM Timofeev (1959), 1969

Type species—TRACHYSPHAERIDIUM ATTENUATUM Timofeev 1959 emend. Knoll & Calder, 1983

Species—TRACHYSPHAERIDIUM sp.

(Pl. 4·1, 2, 5, 10)

Description—Spheroidal vesicles are thick walled, robust, psilate to finely granular or reticulate surface texture. Inside each vesicle there is large and prominent intracellular mass, which is dense and almost round in shape and eccentric in position. Diameter ranges from 60-105 µm (75 µm average). Diameter of intracellular mass ranges between 12-23 µm (4 specimens measured).

PLATE 10 →

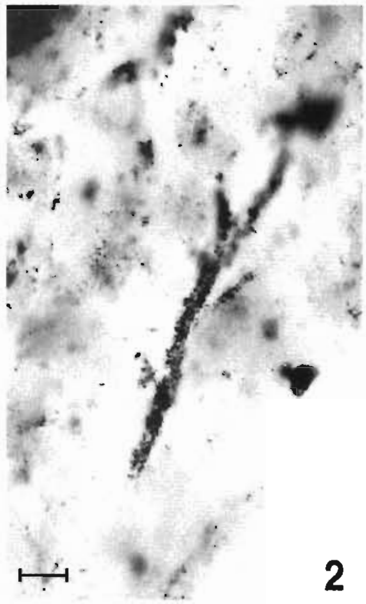
(Photomicrographs of filamentous forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1. Branching in filamentous form, Slide No. Db2-16, 83.7/17.8 (Leica).
2. Branching in filamentous form, Slide No. Db2-16, 69.8/14.4 (Leica).
3. *Obruchevella parva*, Slide No. Db1-26, 56.0/17.9 (Leica).
4. *Eophycomyces herkoides*, Slide No. Db2-19, 78.3/16.3 (Leica).

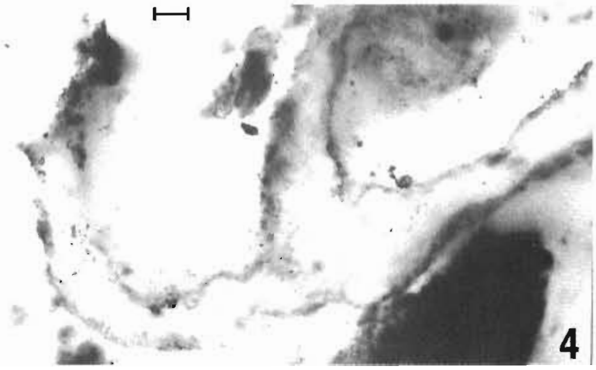
5, 6. *Obruchevella minor*, Slide No. Db2-12, 54.9/12.5 (Nikon).

7. *Obruchevella valdaica*, Slide No. Db2-12, 47.8/18.2 (Nikon).
8. *Glomovertella glomerata*, Slide No. Db2-12, 47.8/18.2 (Nikon).
9. *Siphonophycus septatum*, Slide No. Db2-1, 55.2/6.8 (Nikon).
10. *Siphonophycus robustum*, Slide No. Db2-12, 49.4/20.8 (Nikon).


1


2


3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6


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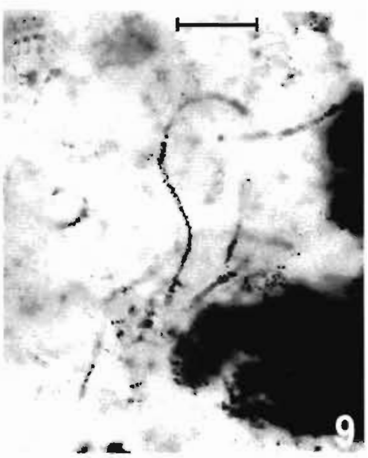
9

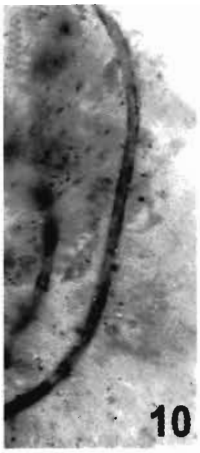
10

PLATE 10

Discussion—Unusual large size and thick, robust wall with prominence of intracellular mass, are the characters of *Trachysphaeridium*. However, numerous hollow processes, mentioned by Knoll and Calder (1983) on the inner walls of vesicle are not observed in present form. Diameter range is more in comparison to specimens from the Spitsbergen by Knoll and Swett (1987). Dimensions and general morphology is comparable to Kheinjua specimens described from Newari locality of the Vindhyan Supergroup, India (Kumar & Srivastava, 1995).

Genus—LEIOSPHAERIDIA Eisenack, 1958 emend. Downie & Sarjeant, 1963

Type species—LEIOSPHAERIDIA BALTICA Eisenack, 1958

Species—LEIOSPHAERIDIA CRASSA (Naumova, 1949) comb. Jankauskas *et al.*, 1989

(Pl. 4·3, 6, 9; Pl. 6·3, 8)

Description—Unornamented sphaeromorph ranging in diameter from 30 to 70 µm (40 µm average), occur sporadically as isolated aggregates, trapped within algal mats. Walls are thin and generally smooth (8 specimens measured). Cell wall 1·5 to 2 µm thick and shows crenulation or folding in a few specimens.

Discussion—Morphologically there is no difference between sphaeromorphs assignable to *Leiosphaeridia crassa* and *Leiosphaeridia jacutica* except the diameter. Considering the recent revision of Leiosphaerids proposed by Jankauskas and Mikhailova in Jankauskas *et al.* (1989) forms ranging in diameter from 70 µm up to 800 µm are assigned to *L. jacutica*, where as forms with diameter less than 70 µm are assigned to *L. crassa*. Deoban forms show resemblance with the Spitsbergen specimens described as *L.crassa* by Knoll *et al.* (1991).

Species—LEIOSPHAERIDIA JACUTICA Timofeev (1966) emend. Mikhailova, 1986; Jankauskas; in Jankauskas *et al.* 1989

(Pl. 5·3; Pl. 8·2)

Description—Large, thin and smooth walled unornamented sphaeromorphs exhibiting wall thickness between 2-4 µm and diameter 75-240 µm (98 µm average), occur solitary or colonial aggregates (9 specimens measured).

Discussion—Morphology is comparable to the forms described from the Spitsbergen by Knoll and Swett (1987).

Genus—CAUDOSPHAERA Hermann & Timofeev in Jankauskas *et al.*, 1989

Type species—CAUDOSPHAERA EXPANSA Hermann & Timofeev 1989 in Jankauskas *et al.*, 1989

Species—CAUDOSPHAERA sp.

(Pl. 5·5)

Description—A globular or balloon-shaped structure truncated longitudinally in a thin tail like extension. Maximum diameter of cellular unit is 18 µm, with psilate to granular texture. Length of entire unit is 26 µm (Single specimen traced).

Discussion—*Caudosphaera expansa* described by Hermann and Timofeev in Jankauskas *et al.* (1989) is comparatively much larger in size than the Deoban specimen. Russian specimen has diameter up to 440 µm. Thus, except dimensions, other morphological features are comparable, suggesting only generic assignment to the present specimen.

Genus—OVULUM ACRITARCHA Jankauskas, 1975

Type species—OVULUM ACRITARCHA Jankauskas 1975 Zang & Walter, 1992

Species—cf. OVULUM SACCATUM (?)

(Pl. 5·6)

Description—Vesicle is unornamented with granular surface texture, wall apparently folded. Vesicle rounded at one end and seems opened and tapered at the other end. Opening, at places seems to be double walled. Long axis 24 µm, short axis 8·5 µm, opening like structure is present on long axis (single specimen).

Discussion—Jankauskas (1975) has first erected this genus, but described in detail by Volkova *et al.* (1979). Genus is differentiable from the Chitinozoan forms in lacking the neck like feature and smaller dimensions. This particular specimen can also represent an oogonium like structure during oospore formation specially reminds a stage in the life cycle of *Oedogonium* (Chlorophycean affinity) where oogonium acquires identical morphology. Since present specimen is fairly degraded, it is not clear whether the opening mentioned in Deoban form is of primary origin or not.

DISCUSSION AND CONCLUSIONS

1. The over all Deoban microfossil assemblage is comprised of 75 forms and now represents as one of the most diversified microbial assemblages of the world. Twentyfive taxa among coccoid forms vary from less than one micron to 265 microns in diameter. Relative abundance, affinity, general morphology and size distribution of coccoid forms is given in (Fig. 4) and for filamentous forms, diameter ranges from less than one micron to 48 microns in width, their general morphology, relative abundance, affinity and size distribution is given in (Fig. 5). Size distribution, for both shorter and longer diameter for coccoids are unimodal (Figs 6 & 7). Only 6% coccoids exhibit diameter more than 60 microns. Thus, very small sized coccoid are the most dominating

community. Size distribution for the filamentous forms (Figs 8 & 9) exhibit minimum width with mode at 2.5 microns (Fig. 8) and 64 % filamentous forms are having less (minimum) width than 5 microns and only 4% filaments are having width of more than 15 microns. The most dominant forms are very small sized coccoids and filaments of less than 5 microns.

2. Fairchild (1985) has used size of the microfossils as one of the most important criterion for distinguishing probable eukaryotic unicell in silicified Precambrian microfloras. He has suggested that, coccoids with more than 55 µm diameter tends to be of eukaryotic affinity. In contrast, Sun (1987), Sergeev (1994) and Steiner (1996) represented that empty colonies of prokaryotes may go up to a few millimeters. In Deoban assemblage, many forms with less than 55 microns in diameter have been assigned eukaryotic affinity. Therefore in addition to size, we mainly related microfossil morphology as distinguishing feature for identification of eukaryotes. For instance, forms displaying budding structure illustrated in Pl. 6.2-$_1$, 2-$_2$ 4, where the dimensions are generally typical of prokaryotes, have been considered showing possible chlorophycean, acritarchean and fungal affinities. Hence, it is very difficult to draw any demarcating line for distinction between prokaryotes and eukaryotes considering the size of the microfossils as the only parameter. Complete morphology should be considered in assigning the taxonomic position of any specimen.

3. Demoulin and Janssen (1981) observed that filamentous blue green algae of average size tend to have isodiametric cells. Very thin filamentous forms often have cylindrical cells and forms with larger width (> 10 µm) have only discoidal cells. This change in cell dimensions appears to be due to difficulties faced by the cell in building and regulating cytoplasmic structures for the synthesis of heavy hydrophobic proteins, because of the distance from the nucleoplasm. This problem among large sized cells could be solved by flattenning the cells and decreasing the distance between the nucleoplasm and the cell periphery. In Deoban assemblage, the cyanobacterial population of average size of about 5 µm in diameter have tendency to have isodiameteric cells, while very narrow filamentous forms have mostly cylindrical cells. Discoid cells are common among broad filaments of > 10 µm in diameter (Fig. 10) as also described by Demoulin and Janssen (1981).

4. Extensive diversity represented by different morphologies assignable to a wide range of taxonomic affinities is an important aspect of the Deoban assemblage. Affinity varies from simple cyanophycean filaments and coccoids to forms exhibiting some resemblance with chlorophycean, xanthophycean (?), chlorococcalean, fungal, bacterial and forms of uncertain affinity placed among acritarchean forms. There are still few forms, which could not be identified and have not been assigned any taxonomic position, hence are placed among incertae sedis. One of these forms has informally been described as Form 'A'.

5. In modern peritidal environments, where microbial mats occur, community composition and diversity vary strongly as a function of environments (Logan *et al.*, 1974; Golubic,1976, 1985). It has been noticed that the diversity is lowest in harshest environments, such as hypersaline pools (Bauld, 1984; Golubic, 1985). The diversity in the Deoban assemblage represents an environmental setting which was very conducive for the growth of life, where a complex ecosystem flourished probably in a tidal zone.

6. The assemblage represents an ecosystem, which was comprised of plant life dominated by cyanobacterial population. However, the presence of forms inclined possibly towards animal affinities described by Srivastava and Kumar (1997) needs additional support.

7. Considering the spatial distribution, microfossils can be categorized as mat builders, mat dwellers and allocthonous forms. They occur in clusters as well as in isolation. *Siphonophycus* among the filaments and *Eoentophysalis* among coccoids (both of cyanobacterial affinity) are the most dominating communities of this assemblage and both occur as mat builders. A number of forms especially large population of *Myxococcoides* and isolated filaments of *Siphonophycus* or Oscillatoriacean filaments occur in between algal clasts. Acritarchs occur as allocthonous aggregates representing planktic mode of occurrence. In recent/modern microbial mats domination of *Entophysalis, Microcoleus* and *Phormidium* is well recorded in Andros Islands, Shark Bay and Bahamas Islands (Monty, 1965) and abundance of similar looking benthic community of the Deoban Assemblage suggests extreme conservatism in algal mat building community. In all these modern analogous cases, the *Entophysalis, Phormidium* and *Microcoleus* population dominates in the warm, shallow, hypersaline bodies of quite water in the intertidal zones or in coastal ponds that have very limited access to the open ocean (Knoll & Golubic, 1979). It supports the observations of Schopf and Klein (1992) that the microbial communities in modern coastal environments such as the Bahamas, Persian Gulf, Shark Bay of Australia and parts of lagoon in Baja- California, represent the fossilised communities, documenting the persistance of specific microbial taxa and groups of taxa in particular/specific environments.

8. Several types of division patterns are marked which help in assigning taxonomic position. These are as follows:

a. Budding like features in a few spheroids may represent a stage of vegetative reproduction and may have given rise to a new individual (Pl. 6.4). There is also a possibility that it can be a result of degradation.

b. Specimens exhibiting a dumbbell-shaped body (*Dumbellina deobanensis,* gen. nov. & sp. nov.) are distinctly constricted in the centre (Pl. 6.5, 6). It can be a desmid-like structure (of Conjugalean affinity) or it can also be a division stage of a large chroococcacean cyanobacterial coccoid representing the intracellular mass, where envelope was destroyed or detached from the central mass. It represents a single unit, which has lost any other details due to degradation (Pl. 6.5, 6).

c. The branching in filaments is recorded in a few specimens but it is not clear whether it is true or false branching (Pl. 10.1, 2, 4).

d. A bud-like structure is recorded in *Bulgenia septata,* which is comparable to recent Chlorophycean form *Oedogonium* and mode of occurrence comparable with *Anabaena,* represents a vegetative mode of reproduction (Pl. 8.1).

e. Hexagonal cell like structures are of quite small size with plasmolysed inner wall and prominent intracellular mass. Typical arrangement of cells and morphology of this form is incomparable to any known fossil form. However, it shows some resemblance with extant chlorococcalean form *Scenedesmus platydiscus* as well as with chroococcacean form *Aphanocapsa.* Present morphology can also be a result of mutual compression of cells, where muitilamellate cell like units of *Gloeodiniopsis lamellosa* exhibit such morphology (Pl. 1.12; Pl. 3.9). However, uniformity in cell structure acquiring hexagonal shape suggested to be their original morphological character. It can also represent a typical division pattern or a mode of occurrence comparable to extant Chlorophycean form belonging to *Chetophorales* (?) or *Coleochaete* affinity (Pl. 1.12; Pl. 3.9).

f. Budding as occurs in extant Xanthophycean algae (Yellow-Green algae) *Vaucheria* has also been marked in one specimen (Pl. 6.2-$_1$, 2-$_2$). By changing the focus attachment point of bud-like structure with adjacent elongated unit is clearly visible which rules out the possibility of superimposition of two units.

9. The Deoban microfossil assemblage is marked by a number of forms, which can be grouped as eukaryotes, represented by forms comparable to some extent to chlorophycean, xanthophycean and fungal forms. A few forms have been assigned to acritarchs, which are considered as microfossils of uncertain affinity. Presence of forms of animal-affinity, however could not be conclusively proved (Srivastava & Kumar, 1997).

10. Since Mesoproterozoic assemblages are mostly devoid of cellularly preserved green algae or vase-shaped protists, *Ovulum* like microfossils (Pl. 5.6) and acanthomorphic (process bearing) acritarchs (Pl. 4.7) in the Deoban Assemblage support Neoproterozoic age for the fossil bearing horizon.

11. Presence of helically coiled filamentous form assignable to *Obruchevella* can also be considered as an age marker. Its occurrence has been recorded from the Neoproterozoic and younger sequences (Pl. 10.3, 5, 6, 7, 8).

12. Spinose acritarchs are rare before the latest Proterozoic. Volkova (1969) and Lo (1980) reported rare occurrence of *Micrhystridium* in the late Proterozoic of Russian Platform and Yudoma Group. However, abundance of acanthomorphs in the Vendian assemblages is well recorded. It sharply diversified further in Lower Cambrian assemblages. Rare presence of *Micrhystridium* (Pl. 4.7) and a form, which is spirally engrooved (may be an initiation of spines, Pl. 4.3) in the Deoban assemblage supports the Neoproterozoic or a pre-Vendian age for the Deoban Formation.

13. Abundance of *Leiosphaerids* is a characteristic feature of the Vendian assemblages, particularly in shallow marine environments. Since Deoban assemblage shows rare occurrence of these acritarchs, which also suggests a pre-Vendian age or it can also be a function of environments as well.

14. Presence of akinite like bodies in the filamentous forms confirm the ability of cyanobacterial forms to fix nitrogen (Pl. 1·11; Pl. 5·2; Pl. 8·1, 8). It should be mentioned here that true heterocysts in Proterozoic cyanobacteria have not yet been recorded (Willmotte & Golubic, 1991; Golubic *et al.,* 1995). Most enlarged cells on fossilised filaments of cyanobacteria are interpreted as a result of degradation (Golubic & Barghoorn, 1977; Gerasimenko & Krylov, 1983).

15. Because of very small size, recognition of bacteria is very difficult in thin section studies. Its presence in Deoban assemblage (Pl. 3.6, 7) suggests an ideal condition for preservation of biota and also its role in algal mat building activity during Precambrian.

16. There is a single specimen, which shows a prominent aestrix mark within an ellipsoidal vesicle with granular surface texture (Pl. 5.7). Long axis is 26 μm and short axis measured is 16 μm. The asetrix mark may be an original feature or it may be due to degradation. The morphology could not be interpreted.

17. There are specimens in which discoid cell like units arranged linearly and give appearance of a diffused septation (Pl. 3·10). Diameter ranges between 7-9 μm, length varies from 28-32 μm. There are five specimens. The form shows close resemblance with *Ascogenous* hyphae or ascospores belonging to higher fungi

Ascomycetes. There is a remote possibility that present morphology is a result of degradation.

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REFERENCES

Allison CW & Awramik SM 1989. Organic walled microfossils from earliest Cambrian or latest Proterozoic Tindir Group Rocks, Northwest Canada. Precambrian Research 43 : 253-294.

Amard B & Bertrand Sarfati J 1997. Microfossils in 2000 Ma. Old cherty stromatolites of the France-Ville Group, Gabon. Precambrian Research 81 : 197-221.

Awramik SM & Barghoorn ES 1977. The Gunflint microbiota. Precambrian Research 5 : 121-142.

Barghoorn ES & Tyler SA 1965. Microorganisms from the Gunflint Chert. Science 147 : 563-577.

Bauld J 1984. Microbial mats in marginal marine environments: Shark Bay Western Australia and Spencer Gulf, South Australia. *In* : Cohen Y, Castenholtz RW & Halvorson HO (Editors)—Microbial Mats : Stromatolites : 39-58. Alan R Liss, New York.

Buick R & Knoll AH 1999. Acritarchs and microfossils from the Mesoproterozoic Bangemall Group, Northwestern Australia. Journal of Palaeontology 73 : 744-764.

Butterfield NJ, Knoll AH & Swett K 1988. Exceptional preservation of fossils in an Upper Proterozoic Shale. Nature 334 : 424-427.

Butterfield NJ, Knoll AH & Swett K 1994. Palaeobiology of the Neoproterozoic Svanbergfjellet Formation, Spitsbergen. Fossil and Strata 34 : 1-84.

Defandre G 1955. Sur l'existance, des le Precambrian d'acritarches type Acanthomorphitae: Eomicrhystridium nov. gen. typification du genre Palaeocryptidium C. r. Acad. Sci. D. Vol. 266. P. 2385-2389.

Demoulin V & Janssen MP 1981. Relationship between diameter of the filament and cell shape in blue-green algae. Bryophytes and Phycology Journal 16 : 55-58.

Desikachary TV 1959. Cyanophyta, New Delhi, ICAR. 688 p.

Downie C, Evitt WR & Sarjeant WAS 1963. Dinoflagellates hystrichospheres and the classification of acritarchs, Stanford University Published in Geological Sciences 7 : 3-16.

Edhorn ES 1973. Further investigations of fossils from the Animikie, Thunder Bay, Ontario. Geological Association Canada Proceedings 25 · 37-66.

Eisenack A 1958. Mikroplankton aus dem nord-deutschen'Apt/nebst Bemerkungen über fossile Dinoflagellaten Neur Jahrbuch Geologie und Paläontologie Abhandlungen 106 : 383-422.

Fairchild TR 1985. Size as criterion for distinguishing probable eukaryotic unicells in silicified Precambrian microfloras. VIII Congress Brazil. Palaeontology. MME- DNPM. Seriia Geologian, Palontologia Estratigraphica 27 : 15-20.

Fuxing V, Xuanyang Z & Ruihuan G 1983. Sinian microfossils from Jinning, Yunnan, SW China. Precambrian Research 23 : 133-175.

Gansser A 1964. Geology of the Himalayas. Inter Science Publishers, London 261 pp.

Geitler L 1925. Cyanophyceae. A Pascher's Die Susswasserflora Deutschlands, Osterreichs und der Schweiz. Gustav Fischer, Jena Germany 12 : 450.

Gerasimenko LM & Krylov IN 1983. Post mortem alteration of cyanobacteria in the algal- bacterial films from the thermal springs of Kamchatka. Doklady Akademiya Nauka. SSSR 272 : 201-203.

Golovenok VK & Belova MYu 1984. Riphean microflora in cherts of Billyakh Group on the Anabar Uplift (English translation). Paleontological Journal 1984 : 20-30.

Golovenok VK & Belova MYu 1986. The Riphean microflora in the cherts from the Malgin Formation in the Yudoma-Maya Basin (English translation). Paleontological Journal 1986 : 85-90.

Golub IN 1979. A new group of problematic microforms in the Vendian Deposits of the Orsha Depression (Russian Platform). *In* : Sokolov BS (Editor)—Palaeontology of the Precambrian and early Cambrian (in Russian) Nauka Leningrad : 147-155.

Golubic S 1976. Organisms that build stromatolites. *In* : Walter MR (Editor)—Elsevier Amsterdam: 113-126.

Golubic S 1985. Microbial mats and modern stromatolites in Shark Bay, Western Australia. *In* : Caldwell DE, Brierley J & Brierley CL (Editors)—Planetary Ecology : 3-16. Van Nostrand Reinhold: New York.

Golubic S & Barghoorn ES 1977. Interpretation of microbial fossils with special reference to the Precambrian. *In* : Flügel E (Editor)—Fossil Algae, Recent results and Developments (Springer Verlag, Berlin) : 1-14.

Golubic S, Sergeev VN & Knoll AH 1995. Mesoproterozoic *Archaeoellipsoides:* akinites of heterocystous cyanobacteria. Lethaia 28 : 285-298.

Green JW, Knoll AH & Swett K 1988. Microfossils from the oolites and pisolites of the Upper Proterozoic Eleonore Bay Group, Central East Greenland. Journal of Palaeontology 62 : 835-852.

Green JW, Knoll AH & Swett K 1989. Microfossils from silicified stromatolitic carbonates of the Upper Proterozoic Limestone-Dolomite Series Central East Greenland. Geological Magazine 126 : 567-585.

Hermann TN 1974. Findings of mass accumulations of trichomes in the Riphean. *In* : Timofeev BV (Editor)—Proterozoic microfossils of USSR : 6-10 (In Russian), Nauka. Moscow.

Hofmann HJ 1976. Precambrian microflora, Belcher Islands, Canada : Significance and Systematics. Journal of Palaeontology 50 : 1040-1073.

Hofmann HJ 1984. Organic walled microfossils from the Latest Proterozoic and earliest Cambrian of the Wernecke Mountains, Yukon. Geological Survey of Canada 84-1B : 285-297.

Hofmann HJ & Jackson GD 1994. Shale Facies microfossils from the Proterozoic Bylot Supergroup, Baffin Island, Canada. The Paleontological Soceity Memoir 37 : 1-35.

Horodyski RJ & Donaldson JA 1980. Microfossils from the Middle Proterozoic Dismal Lakes Group, Arctic Canada. Precambrian Research 11 : 125-159.

Jankauskas TV 1975. New Lower Cambrian Acritarchs of the Baltic Region. Paleontological Journal 1 : 94-104.

Jankauskas TV (Editor-in-Chief), Mikhailova NS & TN German 1989. Precambrian microfossils of the USSR, Nauka Leningrad : 191.

Knoll AH 1984. Microbiotas of the Late Precambrian Hunnberg Formation, Nordaustlandet, Svalbrad. Journal of Palaeontology 58 : 131-162.

Knoll AH, Barghoorn ES & Golubic S 1975. *Palaeopleurocapsa wopfernii* gen. et sp. nov. A Late Precambrian algae and its modern counterpart. Proceedings National Academy of Sciences US 72 : 2488-2492.

Knoll AH & Calder S 1983. Microbiotas of the Late Precambrian Ryssö Formation, Nordaustlandet, Svalbard. Palaeontology 26 : 467-496.

Knoll AH & Golubic S 1979. Anatomy and taphonomy of a Precambrian Algal Stromatolite. Precambrian Research 10 : 115-151.

Knoll AH & Sergeev VN 1995. Taphonomic and Evolutionary changes across the Mesoproterozoic-Neoproterozoic transition. Neur Jahrbuch Paläontologie Abhandlungen Stuttgart 195 : 289-302.

Knoll AH & Swett K 1987. Micropalaeontology across the Precambrian-Cambrian boundary in Spitsbergen. Journal of Palaeontology 61 : 898-926.

Knoll AH, Swett K & Burkhardt E 1989. Palaeoenvironmental distribution of microfossils and stromatolites in the Upper Proterozoic Backlundtoppen Formation, Spitsbergen. Journal of Paleontology 63 : 129-145.

Knoll AH, Swett K & Mark J 1991. Palaeobiology of a Neoproterozoic Tidal Flat/lagoonal complex: the Draken Conglomerate Formation, Spitsbergen. Journal of Palaeontology 65 : 531-570.

Kumar S & Singh S 1979. Discovery of microorganisms from the bedded cherts of the Deoban Limestone (Late Precambrian), Lesser Himalaya, Uttar Pradesh. Current Science 48 : 209-211.

Kumar S & Srivastava P 1992. Middle to Late Proterozoic microbiota from the Deoban Limestone, Garhwal Lesser Himalaya, India. Precambrian Research 56 : 291-318.

Kumar S & Srivastava P 1995. Microfossils from the Kheinjua Formation, Middle Proterozoic Semri Group (Lower Vindhyan) Newari area, Central India. Precambrian Research 74 : 91-117.

Licari GR 1978. Biogeology of the late Prephanerozoic Beck- Spring Dolomite of eastern California. Journal of Paleontology 52 : 767-792.

Lo SC 1980. Microbial fossils from the Lower Yudoma Suite. Earliest Phanerozoic, Eastern Siberia. Precambrian Research 13 : 109-166.

Logan BW, Hofmann P & Gebelein CD 1974. Algal mats, cryptalgal fabrics and structures. Hamelin Pool, Western Australia. American Society of Petroleum Geologists Memoir 22 : 140-194.

Mc Menamin DS, Kumar S & Awramik SM 1983. Microbial fossils from the Kheinjua Formation, Middle Proterozoic Semri Group (Lower Vindhyan), Son Valley area, Central India. Precambrian Research 21 : 247-271.

Mikhailova NS 1986. New occurrence of microphytofossils from the upper Riphean of the Krasnoyarsk region. *In* : Sokolov BS (Editor)—Current questions in contemporary palaeoalgology : 31-37. Naukova Dumka: Kiev.

Monty CLV 1965. Recent algal stromatolites in the Windward Lagoon, Andros Island, Bahamas. Annales de la Societe Geologique de Belgique 88 : 269-276.

Naumova SN 1949. Spory nizhnego kembriya (Spores from the Lower Cambrian). Izvestiya Akademiy Nauka 1949, 4 : 49-56.

Oehler DZ 1977 Microflora of the HYC Pyritic Shale Member of the Barney Creek Formation (McArthur Group), middle Proterozoic of the northern Australia. Alcheringa 1 : 315-349.

Raaben ME, Sinha AK & Sharma M 2001. Precambrian stromatolites of India and Russia (A catalogue of Type-Form Genera). Birbal Sahni Institute of Palaeobotany : 125.

Rabenhorst L 1865. Flora Europaea Algarum, Eduard Kummer. Leipzig 2 : 319.

Reitlinger EA 1948. Kembrijskie foraminifery Yakutii (Cambrian foraminifers of Yakutsk) Maskovskogo Obschestva. Isptalej. Prirody, Otdelenic Geologii 23 : 77-81.

Reitlinger EA 1959. Atlas of microscopic organic remains and problematica of ancient deposits of Siberia. Trudy geologischeskii institute Akademiya Nauka. SSSR 25 : 1-62 (Translated by associated technical Services, New Jersey).

Samuelsson Joakim, Daws R & Vidal G 1999. Organic walled microfossils from the Proterozoic Thule Supergroup, Northwest Greenland. Precambrian Research 96 : 1-23.

Schopf JW 1968. Microflora of the Bitter Springs Formation Late Precambrian Central Australia. Journal of Paleontology 42 : 651-688.

Schopf JW & Blacic JM 1971. New microorganisms from the Bitter Springs Formation (Late Precambrian) of the North Central Amadeus Basin, Australia. Journal of Paleontology 45 : 925-960.

Schopf JW & Fairchild TR 1973. Late Precambrian microfossils : A new stromatolitic biota from Boorthana, South Australia. Nature 242 : 537-538.

Schopf JW & Klein C 1992. The Proterozoic Biosphere: a multidisciplinary study. Cambridge University Press : 1348.

Sergeev VN 1993. Silicified Riphean microfossils of the Anabar Uplift. Stratigraphy and Geological Correlation 1 : 264-278 (1993).

Sergeev VN 1994. Microfossils in cherts from the Middle Riphean (Mesoproterozoic) Avzyan Formation, Southern Ural Mountains, Russian Federation. Precambrian Research 65 : 231-254.

Sergeev VN & Knoll AH 1995. Taphonomic and evolutionary changes across the Meso-Neoproterozoic transition. Neur Jahrbuch Palaeontologische Abhandlungen Stuttgart 195 : 289- 302.

Sergeev VN, Knoll AH & Grotzinger JP 1995. Palaeobiology of the Mesoproterozoic Billyakh Group, Anabar Uplift, Northeastern Siberia. Palaeontological Society Memoir 39 : 1-37.

Sergeev VN, Knoll AH, Kolosova SP & Kolosov PN 1994. Microfossils in cherts from the Mesoproterozoic (Middle Riphean Debengda Formation, the Olenek Uplift, Northern Siberia. Stratigraphy and Geological correlation 2 : 19-33 (English Translation).

Shukla M, Tewari VC & Yadav VK 1987. Late Precambrian microfossils from the Deoban Limestone Formation, Lesser Himalaya, India. Palaeobotanist 35 : 347-356.

Sinha AK & Raaben ME 1981. Lower Cambrian Stromatolites from the Deoban Limestone of Lesser Himalaya. Himalayan Geology 9 : 317-323.

Song Xueliang 1984. *Obruchevella* from the early Cambrian Meischucun Stage of the Meischucun Section, Jinning Yunnan, China. Geological Magazine 121 : 179-183.

Srivastava P & Kumar S 1995. Significance of *Obruchevella* sp. Reitlinger in the Deoban Limestone, Garhwal Lesser Himalaya, Uttar Pradesh. Group meeting on Seismotectonics and Geodynamics of the Himalaya. Roorkee University, Roorkee (Abstract).

Srivastava P & Kumar S 1997. Possible evidences of animal life in Neoproterozoic Deoban microfossil assemblage, Garhwal Lesser Himalaya, Uttar Pradesh. Current Science 72 : 145-149.

Steiner M 1996. Die Neoproterozoischen mega algen Sudenina. Berliner Geowissen Schäftliche Abhandlungen. Reihe. E : 15.

Sun WG 1987. Paleontology and Biostratigraphy of Late Precambrian Macroscopic colonial algae, *Chuaria* and *Tawuia* Hofmann. Palaeontographica B 203 : 109-134.

Tewari VC 1992. Global decline of Pre-Ediacara (Riphean) stromatolites and the emergence of Ediacaran Biota: Palaeobiological and stable isotope evidence from the Lesser Himalaya. Geological Society of India 39 : 260-261.

Tewari VC 1996. Discovery of pre Ediacaran acritarch *Chuaria circularis*, (Walcott 1899, Vidal & Ford, 1985) from the Deoban Mountain, Lesser Himalaya, India. Geoscience Journal 17.

Tewari VC 1998. Regional correlation of the Lesser Himalayan Basin sediments of Kali Valley, Indo-Nepal area, Nepal. Journal Geological Society 18 : 37-57.

Timofeev BV 1959. The most ancient Baltic Flora and its significance. Trudy Institute for the All Union Scientific Investigation and Prospecting of Petroleum (in Russian) 129 : 1-20.

Timofeev BV 1966. Microphytological investigations of ancient formations. Academy of Science, USSR. Lab for Precambrian Geology and Geochronology, Nauka, Leningrad : 145 (in Russian).

Timofeev BV 1969. Proterozoic sphaeromorph. Academy of Sciences, USSR, Institute for Precambrian Geology and Geochronology, Nauka, Leningrad : 146 (in Russian).

Timofeev BV & Herman TN 1976. Microphytofossils of the Precambrian- Cambrian and Ordovician. Nauka Leningrad : 137-147.

Vashistha BR 1977. Algae. Part I. S. Chand & Company Ltd., New Delhi, 545 pp.

Vidal G 1976. Late Precambrian acritarchs from the Eleonore Bay Group and Tillite Group in East Greenland. Grönlands Geologiske Undersogeise Rapport 78 : 1-19.

Volkova NA 1969. Acritarchs of the north-west Russian Platform. *In* : Rozanov AYu. *et al.* (Editors)—Tommotian stage and the Cambrian Lower Boundary Problem. Transactions Academy of Sciences USSR, 206, Nauka Moscow : 86-88, 259-273.

Volkova NA, Kiryanov VV, Piskun LV, Pashkyavichene LT & Yankauskas TV 1979. Upper Precambrian and Cambrian Palaeontology of the East European Platform. Nauka Moscow : 4-38.

Willmotte A & Golubic S 1991. Morphological and Genetic criteria in the Taxonomy of Cyanophyta/ Cyanobacteria. Algological Studies 64 : 1-24.

Xing Y & Liu H 1978. Sinian Microplant and algal fossils. *In* : Stratigraphy and Palaeontology, Sinian to Permian East Gorge area. Shanshia stratigraphic Division, Hubei : 109-126 (Geological Survey in Chinese).

Yakschin MS 1990. On the problem of the microfabric origin in the Early Riphean stratified stromatolites. Iskopaemye Problematiki SSSR, Moscow: Nauka : 5-13.

Yakschin MS 1991. Algal microbiota from the Lower Riphean deposits of Anabar Uplift of the USSR. Nauka Sibirskoe Otdelenie Novosibirsk : 61.

Yakschin MS & Luchinina VA 1981. New data on fossil algae of the family Oscillatoriaceae. Academiya Nauka. SSSR 475 : 28-34.

Yin Chongyu 1985. New data of microfossils from the Shuijingtuo Formation (Lower Cambrian) in Hefeng, Hubei Province. Acta Micropalaeontologica Sinica, 12 (3).

Yuan X & Hofmann HJ 1998. New microfossils from the Neoproterozoic (Sinian) Doushantuo Formation, Wengan, Guizhou Province, South Western China. Alcheringa 22 : 189-222.

Zang Wenlong & Walter MR 1992. Late Proterozoic and Early Cambrian microfossils and biostratigraphy, northern Anhui and Jiangsu, Central Eastern China. Precambrian Research 57 : 243-323.

Zhang Yun 1981. Proterozoic stromatolite microfloras of the Gaoyuzhuang Formation (Early Sinian-Riphean Hebei China. Journal of Palaeontology 55 : 485-506.

Zhang Yun 1985. Stromatolitic microbiota from the middle Proterozoic Wumishan Formation (Jixian Group) of the Ming Tombs. Beijing, China. Precambrian Research 30 : 277-302.

Zhang Zong Ying 1984. On the occurrence of *Obruchevella* from the Doushantou Formation (Late Sinian) of Western Hubei and its significance. Acta Palaeotologica Sinica 23 : 447-451.

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A Triassic palynoflora from Pali Formation, South Rewa Gondwana Basin, Madhya Pradesh, India

RAM-AWATAR

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.
E-mail: rawatar_2003@yahoo.com

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ABSTRACT

Ram-Awatar 2003. A Triassic palynoflora from Pali Formation, South Rewa Gondwana Basin, Madhya Pradesh, India. Palaeobotanist 52(1-3) : 49-54.

The palynofloral assemblage, comprising 33 genera with 45 species, is recorded from the Upper Member of Pali Formation, exposed along Son-Chundi River Section in Shahdol District, M.P. The significant palynotaxa identified are—*Densoisporites playfordii, Brachysaccus ovalis, Falcisporites stabilis, Krempipollenites vistitus, Tikisporites balmei, Lundbladispora brevicula, Chordasporites* sp., *Staurosaccites marginalis, Satsangisaccites nidpurensis, Samaropollenites speciosus* and *Goubinispora morondavensis*. In comparison with known Triassic palynoassemblages of Peninsular India, the Son-Chundi palynoassemblage is assigned an Early to Middle Triassic. Stratigraphic relationships between the Pali and Tiki formations are also discussed.

Key-words—Palynology, Triassic, Pali Formation, South Rewa Basin, Madhya Pradesh.

भारत के मध्य प्रदेश प्रान्त के दक्षिणी-रीवॉं गोण्डवाना द्रोणी के पाली शैलसमूह से प्राप्त एक ट्रायसिक परागाणु वनस्पतिजात

राम अवतार

सारांश

मध्य प्रदेश के शहडोल जिले के सोन-चण्डी नदी परिच्छेद के आस-पास अनावरित पाली शैलसमूह के उपरि सदस्य से *एक्रोस्टिकम* 35 वंशों तथा 45 प्रजातियों से युक्त परागाणु समुच्चय अंकित किया गया है। अभिनिर्धारित किए गए प्रमुख परागाणु वर्गक हैं, - *डेन्सोइस्पोराइटीज़ प्लेफोर्डाइ, ब्रैकीसैक्कस ओवेलिस, फाल्सिस्पोराइटीज़ स्टेबिलिस, क्रेम्पीपोलेनाइटीज़, विस्टाइटस, टीकीस्पोराइटीज़ बाल्मेइ, लुण्डब्लेडिस्पोरा ब्रीविक्यूला, कॉर्डेस्पोराइटीज़* प्रजाति, *स्टाउरोसैक्काइटीज़ मार्जिनेलिस, सत्संगीसैक्काइटीज़ निदपुरेन्सिस, समारोपोलेनाइटीज़ स्पीशियोसस* तथा *गेबिनीस्पोरा मोरोनडेवेन्सिस।* प्रायद्वीपीय भारत के ज्ञात ट्रायसिक परागाणु समुच्चयों से तुलना करने पर सोन-चण्डी परागाणु समुच्चय को प्रारंभिक से मध्य ट्रायसिक में सन्दर्भित किया गया है। इसके अतिरिक्त प्रस्तुत शोध पत्र में पाली तथा टीकी शैलसमूहों के मध्य स्तरिकीय सम्बन्धन की भी चर्चा की गयी है।

संकेत शब्द—परागाणु विज्ञान, पाली शैलसमूह, दक्षिणी रीवॉं द्रोणी, मध्य प्रदेश, भारत.

INTRODUCTION

HUGHES (1881, 1884) mapped the South Rewa Basin and used a comprehensive term, "Supra-Barakar", to accommodate all the unclassified sedimentary units lying above the Barakar Formation. Hughes (1881) designated the "Pali Bed" for the sequence of brick red shale and sandstone exposed along the Johilla River Section about 3 km West of Pali Village (23° 21'40" : 80° 3'15"), on Pali-Umaria Road, Shahdol District, M.P. Fox (1931) used the term "Tiki Bed", and Lele (1964), "Daigaon Stage", for the similar rock sequences, exposed around the villages of Tiki (23°55'0": 81°22'12") and Chota Daigaon (23°23'32" : 81°0'10") respectively. Dutta and Ghosh (1993) united Pali and Tiki formations into a single lithostratigraphic unit due to lithological similarities of those formations and proposed a new term "Pali-Tiki Formation" in the basin.

The plant megafossils—*Schizoneura gondwanensis, Glossopteris indica, G. communis, Vertebraria indica* and *Dictyopteridium* have been reported from the Pali Formation by Feistmantel (1882), Lele (1962, 1964) and Saksena (1961). The palynofloral assemblages recorded by Tiwari & Ram-Awatar (1986) and Ram-Awatar (1988, 1996, 1997) from the Pali Formation are dominated by striate disaccate and monosaccate pollen (*Faunipollenites, Striatopodocarpites, Crescentipollenites* and *Densipollenites*). A Late Permian/Early-Middle Triassic age has been assigned to the Pali sediments on the basis of plant mega/microfossils. In this paper, a new palynofloral assemblage is recorded from Son River Section, Sohagpur Coalfield, M.P.

STRATIGRAPHIC SUCCESSION

The generalised lithological succession of the post-Barakar sequence, in the western part of the South Rewa Basin is given below (after Raja Rao, 1983; Mitra 1993; Tarafdar *et al.*, 1993; Bandhopadhyay, 1999) (Fig. 1).

MATERIALS

Nineteen outcrop samples were collected along the Son-River Section, near the confluence of Chundi River, about 2.8 km West of Nigal Village (Fig. 2). Sample details are given below (Fig. 3). Productive samples are asterisked *.

Age	Formation	Lithology
Late Cretaceous to Eocene	Deccan Trap	Basalt flow and dolerite dyke.
Late Cretaceous	Lameta Bed	White impure marl, pinkish to White sandstone.
Early to Middle Jurassic	Parsora	Coarse ferruginous sandstone, shale and lilac-coloured mudstone.
	---Unconformity---	
Rhaetic Late Norian-Early Norian	Tiki	Coarse grained sandstone, green sandstone, calcareous sandstone, grey feldspathic sandstone and lime pellet conglomerate.
Middle Triassic Early Triassic	Upper Pali Member	Coarse to medium grained sandstone, green to yellow micaceous sandstone; grey siltstone to red-green mottled sandstone and carbonaceous shale.
Late Permian	Middle Pali Member	Greenish sandstone, grey shale, feldspathic sandstone, carbonaceous to coaly shale.
Middle Permian	Lower Pali Member	Medium grained ferruginous sandstone and red claystone.
Early Permian	Barakar	Feldspathic sandstone, shale and coal seams.

Fig. 1—Lithological succession of the Post-Barakar Sequence in western part of the South Rewa Basin (after Raja Rao, 1983; Mitra, 1993; Tarafdar *et al.*, 1993; Bandhopadhyay, 1999).

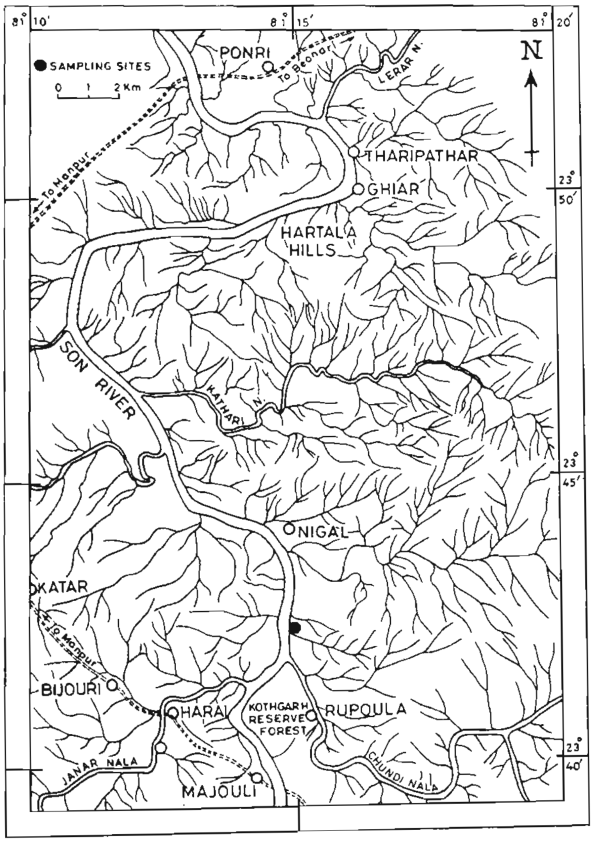

Fig. 2—Map of a part of Umaria Subdivision, Shahdol District, Madhya Pradesh, showing the sample site.

PALYNOLOGICAL COMPOSITION

Out of the 19 samples five samples yielded spore and pollen grains. The palynotaxa identified from the productive samples are given in Fig. 4.

Recovery of spore and pollen grains in all the productive samples is fair except in two samples (SCC-5 & 15). The percentage frequency of the productive samples is plotted in Fig. 5. All of the productive samples show a more or less similar pattern of spore/pollen frequencies; therefore, all are representing a single palynofloral assemblage (Assemblage-1). The assemblage is dominated by non-striate disaccate pollen—*Alisporites* (10.5%); *Falcisporites* (6.5%), *Krempipollenites* (6.5%)- in association with taeniate and striate bisaccate pollen taxa, viz., *Arcuatipollenites* (2.5%), *Striatopodocarpites* (1.5%) and *Faunipollenites* (1.5%). The other genera are : *Lundbladispora, Tikisporites, Densoisporites, Callumispora, Densipollenites, Hamiapollenites, Minutosaccus, Samaropollenites, Reticulatisporites, Chordasporites, Pretricolpipollenites, Convolutispora, Brachysaccus, Lycopodiumsporites, Satsangisaccites, Nidipollenites* and *Goubinispora*; these comprise 0.5- 1% of the assemblage.

DISCUSSION AND CONCLUSIONS

The paucity of striate disaccates, taeniate and monosaccates (*Faunipollenites, Striatopodocarpites, Arcuatipollenites* and *Goubinispora*) and of cavate/ cingulate trilete spore (*Densoisporites* and *Lundbladispora*) in Assemblage-I indicates that it belongs to the Panchet palynoflora of the Indian Peninsula.The Son-Chundi Confluence (SCC) palynoassemblage compares well with the Lower Triassic palynoflora described from the Sukri River Section, Auranga Coalfield (Maheshwari & Banerjee, 1975), with prominent *Falcisporites,* rare trilete spore and striate disaccate pollen grains. The Nidpur palynoflora (Bharadwaj & Srivastava, 1969; Tiwari & Ram-Awatar, 1990) is dominated by non-striate disaccate pollen (*Satsangisaccites, Falcisporites, Nidipollenites* and *Krempipollenites*) with sporadic occurrence of striate disaccate pollen viz., *Faunipollenites, Striatopodocarpites* and *Crescentipollenites.* It is comparable with SCC palynoassemblage to some extent; however, the occurrence of *Staurosaccites, Tikisporites, Brachysaccus, Samaropollenites* and *Minutosaccus* indicates that later assemblage is younger than the Nidpur palynoflora. The Late Triassic palynoassemblages recorded from the Denwa Formation, Satpura Basin (Nandi, 1996) and Tiki Formation (Tharipather and Ghiar and Janar Nala sections) South Rewa Basin (Maheshwari & Kumaran, 1979; Kumaran & Maheshwari,

Sample No.	Lithology	Thickness (m)
SCC-1	Fine grained sandstone	0·50
SCC-2*	Micaceous fine grained sandstone	0·50
SCC-3	Shale (grey)	0·25
SCC-4	Micaceous siltstone	0·50
SCC-5*	Micaceous siltstone	0·50
SCC-6*	Carbonaceous shale	0·50
SCC-7	Carbonaceous shale	0·50
SCC-8	Mudstone (grey)	0·75
SCC-9*	Mudstone (grey)	0·75
SCC-10	Mudstone (grey)	0·50
SCC-11	Shale	1·00
SCC-12	Mudstone	0·50
SCC-13*	Mudstone (grey)	1·00
SCC-14	Mudstone (chocolate colour)	1·00
SCC-15	Mudstone (chocolate colour)	1·50
SCC-16	Mudstone (chocolate colour)	0·50
SCC-17	Fine grained siltstone	1·00
SCC-18	Siltstone (green)	0·50
SCC-19	Siltstone (green)	1·50 section base

Fig. 3—List of samples.

Alisporites Daugherty emend. Jansonius, 1971**
Arcuatipollenites (partim *Lunatisporites*) Tiwari & Vijaya, 1995
Brachysaccus Madler, 1964*
Callumispora Bharadwaj & Srivastava emend. Tiwari *et al.*, 1989
Chordasporites Klaus, 1960*
Convolutispora Hoffmeister *et al.*, 1955
Cyclogranisporites Potonie & Kremp, 1954*
Crescentipollenites Bharadwaj *et al.*, 1974
Densipollenites Bharadwaj, 1962
Densoisporites (Weyland & Krisege) Dettmann, 1963*
Distriatites Bharadwaj, 1962*
Falcisporites Leschik emend. Klaus, 1963*
Faunipollenites Bharadwaj emend. Tiwari *et al.*, 1989
Goubinispora Tiwari & Rana, 1980*
Hamiapollenites Wilson emend. Tschudy & Kosanke, 1966
Horriditriletes Bharadwaj & Salujha, 1964
Krempipollenites Jansonius emend. Tiwari & Vijaya, 1994
Lundbladispora (Blame) Playford, 1965*
Lycopodiacidites Couper emend. Potonié, 1956*
Minutosaccus Mädler, 1964
Nidipollenites Bharadwaj & Srivastava, 1969*
Osmundacidites Couper, 1953
Playfordiaspora Maheshwari & Banerji emend. Vijaya, 1995
Pretricolpipollenites Bharadwaj, 1962
Reticulatisporites Ibrahim emend. Potonié & Kremp, 1954
Rhizomaspora Wilson, 1962
Samaropollenites Goubin, 1965*
Satsangisaccites Bharadwaj & Srivastava, 1969*
Staurosaccites Dolby in Dolby & Balme, 1976*
Striatopodocarpites Bharadwaj & Salujha, 1964**
Tikisporites Kumaran in Kumaran & Maheshwari, 1980*
Todisporites Couper, 1958
Weylandites Bharadwaj & Srivastava, 1969*

(* Are those Genera and Species which are given in Plate 1)

Fig. 4—Checklist of palynotaxa.

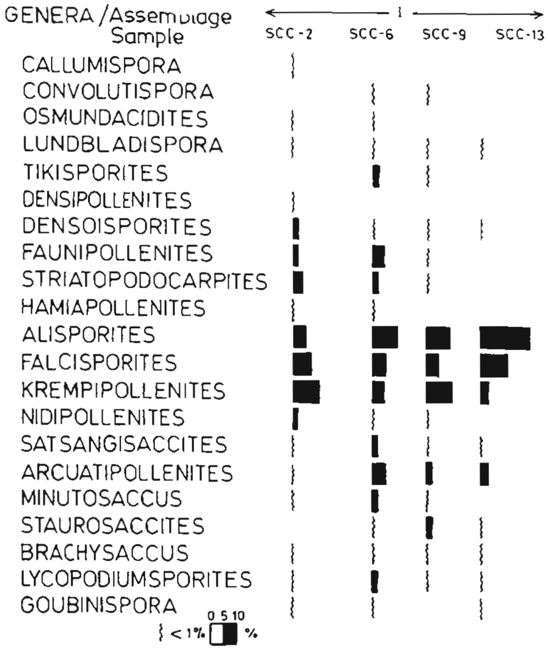

Fig. 5—Percentage frequency of significant spore-pollen taxa recovered from the Son River Section, district Shahdol, M.P.

1980) contained non-striate disaccates in association with *Brachysaccus, Staurosaccites, Densoisporites, Tikisporites,* and *Samaropollenites;* it is therefore, broadly comparable with the present assemblage. However, the former assemblages contain taxa—*Camarzonosporites, Dictyophyllidites, Ringospora, Enzonalasporites* and *Aratrisporites*; these are indicative of a younger age than SCC palynoassemblage. The Rajmahal palynoassemblage (Tiwari *et al.*, 1984; Assemblage Zone-A) and Krishna-Godavari palynozones (Prasad, 1997; Zone-IV) are partially comparable with the present assemblage, in view of being dominated by non-striate disaccate pollen and in their sporadic occurrence of *Brachysaccus, Densoisporites, Lundbladispora* and *Straurosaccites.* However, the presence of *Dubrajisporites, Rajmahalispora, Voltaziacesporites* and *Enzonalasporites* makes the former assemblages younger than the Son-Chundi palynoassemblage.

There are differences of opinion regarding the age and order of super-position of the Pali and Tiki formations in the South Rewa Basin. Dutta and Ghosh (1993) considered that rock exposed around villages Pali, Bara Daigaon and Salaia in the south and between Kelhari and Tiki have similar lithological characteristics and association. Therefore, both

PLATE 1

(Photomicrographs are taken on Olympus Microscope, BH-2 Model, all the figures are enlarged ca x 500)

1. *Alisporites asansolensis* Maheshwari & Banerjee, 1975
2. *Falcisporites minutosaccus* Kumaran & Maheshwari, 1980
3. *Satsangisaccites nidpurensis* Bharadwaj & Srivastava, 1969
4. *Cyclogranisporites distinctus* Kumaran & Maheshwari, 1980
5. *Distriatites insculptus* Bharadwaj & Srivastava, 1969
6. *Alisporites indicus* Bharadwaj & Srivastava, 1969
7. *Goubinispora morondavensis* (Goubin) Tiwari & Rana, 1980
8. *Staurosaccites marginalisin* Maheshwari & Kumaran, 1979
9. *Brachysaccus ovalis* Mädler, 1964
10. *Falcisporites* sp. Klaus, 1963
11. *Densoisporites* cf. *D. playfordii* (Balme) Dettmann, 1963
12. *Nidipollenites monoletus* Bharadwaj & Srivastava, 1969
13. cf. *Lycopodiumsporites* sp. in Kumaran & Maheshwari, 1980
14. *Tikisporites balmei* Kumaran in Kumaran & Maheshwari, 1980
15. *Lundbladispora brevicula* Balme, 1963
16. *Chordasporites* sp. Klaus, 1960
17. *Striatopodocarpites ovatus* (Maheshwari) Tiwari & Rana, 1980
18. *Striatopodocarpites magnificus* Bose & Maheshwari, 1968
19. *Samaropollenites speciosus* Goubin, 1965


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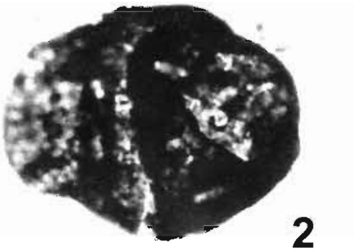
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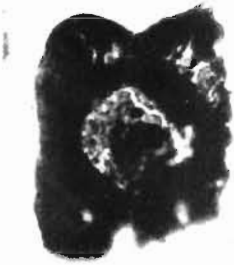
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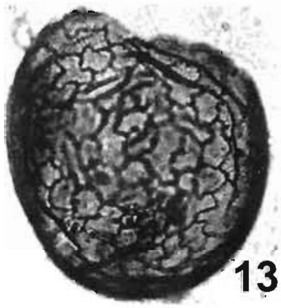
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PLATE 1

formations may be coeval, spanning the latest Permian to Early-Middle Triassic. Bandhopadhyay (1999) did not favour grouping the Pali and Tiki formations, due to the presence of feldspathic sandstone and coal/carbonaceous shale in the former formation but not in the latter unit.

The palynoflora described from Tharipathar and Ghiar (Kumaran & Maheshwari, 1980) and the Janar Nala Section (Maheshwari & Kumaran, 1979) and vertebrate remains (*Metaposaurus malariensis*, *Paradapedon huxleyi*, *Phytosaurus malariensis* : Chatterjee & Roychowdhury, 1974) reveal the Carnian-Norian age of the Tiki Formation. Moreover, palynotaxa recorded from the Chundi River Section and the tract between Kelhari and Tiki areas (Ram-Awatar, 1997) have been dated as Late Permian/Early-Middle Triassic, showing these sediments to be equivalent to the Upper Member of the Pali Formation. The present palynological data from the Upper Pali Member (Son-Chundi confluence), also suggest similarities between the Pali and Tiki formations. However, it is premature to predict that the Pali and Tiki formations are age equivalents, as more palynological and other evidences are required. Therefore, it is concluded that the strata hosting the SCC palynoflora were deposited during Early to Middle Triassic and may represent the lower part of the Tiki Formation, as recognised from the western part of the South Rewa Basin, M.P.

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REFERENCES

Bandhopadhyay SK 1999. Supra–Barakar rocks of the South Rewa Basin and its stratigraphic status. Geological Survev of India, Special Publication 20 : 24-31.

Bharadwaj DC & Srivastava Shyam C 1969. A Triassic mioflora from India. Palaeontographica B 125 : 119-149.

Chatterjee S & Roychowdhury T 1974. Triassic Gondwana vertebrate from India. Indian Journal of Earth Science 1 96-112.

Dutta PK & Ghosh SK 1993. The century- old problem of the Pali-Parsora-Tiki stratigraphy and its bearing on the Gondwana classification in peninsular India. Journal of Geological Society of India 42 . 17-31

Feistmantel O 1882. The fossil flora of the Gondwana System 4. 1. The fossil flora of the South Rewa Gondwana Basin. Memoir of the Geological Survey of India 14 : 1-52.

Fox CS 1931. Gondwana System and related formations. Memoir of the Geological Survey of India 58 : 1-241

Hughes TWH 1881. Notes on the South Rewa Basin. Record Geological Survey of India 14 : 126-138.

Hughes TWH 1884. The Southern coalfields of the South Rewa Gondwana Basin · Umaria, Korar, Johilla, Sohagpur, Kurasia, Koreagarh, Jhilmili. Record Geological Survey of India 21 · 1-68.

Kumaran KPN & Maheshwari HK 1980. Upper Triassic *Sporae dispersae* from the Tiki Formation 2 Miospores from the Janar Nala Section, South Rewa Gondwana Basin, India. Palaeontographica B173 . 26-84.

Lele KM 1962. Studies in the Indian Middle Gondwana Flora 2. Plant fossils from the South Rewa Gondwana Basin. Palaeobotanist 10 : 69-83.

Lele KM 1964. The problem of Middle Gondwana in India. *In*: Proceeding of Symposium 22nd International Geological Congess. New Delhi, 1964, Part, IX : 181-200.

Maheshwari HK & Banerjee J 1975. Palynomorphs from the Panchet Group exposed in Sukri River, Auranga Coalfield, Bihar. Palaeobotanist 22 158-170.

Maheshwari HK & Kumaran KPN 1979. Upper Triassic *Sporae-dispersae* from the Tiki Formation 1 : Miospores from the Son River Section between Tharipathar and Ghiar, South Rewa Gondwana Basin. Palaeontographica B171 : 137-164.

Mitra ND 1993. Stratigraphy of Pali-Parsora-Tiki Formation of South Rewa Basin and Permo-Triassic boundary problem. *In* Dutta KK *et al.* (Editors)—Gondwana Geological Magazine, Special Volume (1993) : 41-48.

Nandi A 1996. Palynodating of carbonaceous shales from Denwa Formation, Satpura Basin, M.P., India. *In* Mitra ND *et al.* (Editors)—9th International Gondwana Symposium, Hyderabad, India I : 79-87. Oxford & IBH Publ. Co. Pvt. Ltd.

Prasad B 1997. Palynology of the subsurface Triassic sediments of Krishana-Godavari Basin India. Palaeontographica B242 91-125.

Raja Rao CS 1983. Coalfields of India · Coal resources of Madhya Pradesh, Jammu and Kashmir. Bulletin Geological Survey of India. Volume III, Series A, no. 45 : 119-129.

Ram-Awatar 1988. Palynological dating of Supra-Barakar formations in Son Valley Graben. Palaeobotanist 36 133-137.

Ram-Awatar 1996. Palynostratigraphy of Supra-Barakar sediments (Pali, Tiki & Parsora formations) and their stratigraphic positions in South Rewa Basin, Madhya Pradesh. *In* · Mitra ND *et al.* (Editors)—9th International Gondwana Symposium, Hyderabad, India I : 439-454.

Ram-Awatar 1997. Palynological evidence for the Permian-Triassic boundary in Sohagpur Coalfield, India. Palaeobotanist 46 · 101-106.

Saksena SD 1961. On some fossils plants from Karkati, Kamtadand and Parsora in the South Rewa Gondwana Basin, Central India. Palaeobotanist 10 : 91-96.

Tarafdar P, Sinha PK, Das DP, Kundu DR, Rajaya V, Parui PK, Patel MC, Thanavelu MR, Asoka Kumar, Pillai KR, Agasty A & Dutta NK 1993. Recent advances in post-Barakar stratigraphy in parts of Rewa Gondwana Basin. *In* : Dutta KK *et al.* (Editors)—Gondwana Geological Magazine, Special Volume (1993) : 60-69.

Tiwari RS & Ram-Awatar 1986. Late Permian palynofossils from the Pali Formation, South Rewa Basin, Madhya Pradesh. Bulletin Geological Mineral Metrological Society of India 54 : 250-255.

Tiwari RS & Ram-Awatar 1990. Palyno-dating of Nidpur beds, Son Graben, Madhya Pradesh. Palaeobotanist 38 : 105-121.

Tiwari RS, Kumar P & Tripathi A 1984. Palynodating of Dubrajpur and intertrappean beds in subsurface strata of North-Eastern Rajmahal Basin. *In* : Tiwari RS *et al.* (Editors)—Vth Indian Geophytological Conference, Lucknow (1983), Special Publication · 207-225.

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Petrified araucarian remains from Sonajori, Rajmahal Basin, India

JAYASRI BANERJI AND B.N. JANA

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.

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ABSTRACT

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Permineralized araucarian ovulate and pollen cones are described here for the first time in close association from Early Cretaceous intertrappean rocks of the Sonajori Locality in the Rajmahal Basin, Jharkhand. These cones were found associated with woods and leafy shoots bearing spirally arranged falcate to oblanceolate leaves. The leaf, in longitudinal section shows epidermis followed by parenchymatous mesophyll and transfusion tissue. Ovulate cones, elliptical-spherical in shape, with spirally attached bracts and ovuliferous scales bearing mostly one and rarely two ovules/seeds per cone scale complex. Cone scale complex is characterised by the presence of "circa" (ligular sulcus). In one specimen, cross-section shows close association of numerous pollen grains with the cone scale complex of the cone indicating the preservation of cone at pollination stage. In another specimen, cross-section shows cone scale with oblong inverted ovule/seed, ovule integument/seed testa with three distinct layers, nucellus free except at chalazal end, shrunken at micropylar region and the presence of an embryonic tissue shows a post fertilisation stage of cone preservation. Anatomical features of these cones indicate various stages of cone maturity. The microsporangiate cone elongated in shape, in tangential view shows microsporophylls as well as circular-oval sporangia in cross-section. Transverse-sections of cone shows a central axis surrounded by numerous elongated narrow sporangia in longitudinal section and rhomboidal tip of the microsporophyll. The microsporophyll shows only parenchymatous tissue in sectional view of distal part; dispersed circular alete pollen grains are found associated with ovulate/seed cone and sterile shoots. Morphological and anatomical features of all the Indian species of araucarian cone described earlier are also critically assessed.

Key-words—Araucarian remains, Sonajori, Rajmahal Formation (Intertrappeans), Early Cretaceous, India.

भारत की राजमहल द्रोणी के सोनाजोरी से प्राप्त अश्मीभूत अराउकेरियन अवशेष

जयश्री बनर्जी एवं बृजेन्द्र नाथ जाना

सारांश

झारखण्ड की राजमहल द्रोणी की सोनाजोरी संस्थिति के प्रारंभिक क्रिटेशस अन्तर्ट्रेपीय शैल प्रस्तरों से निकटस्थ साहचर्य में प्रथम बार प्राप्त पर खनिजीय अराउकेरियन बीजाण्डी तथा परागाणु शंकुओं का वर्णन यहाँ अभिप्रेत है। ये शंकु सर्पिलतः व्यवस्थित हँसियाकार से प्रतिकुन्ताकार पत्तियों से युक्त काष्ठ एवं पर्ण प्ररोह से साहचर्य में पाए गए। अनुदैर्ध्य परिच्छेद में पर्ण बाह्यत्वचा प्रदर्शित करती है, तत्पश्चात् क्रमशः मृदूतकी पर्णमध्योतक तथा संचरण ऊतक आते है। बीजाण्डी शंकु जो दीर्घवृतीय-गोलाकार है तथा सर्पिलतः सयुग्मित सहपत्रों तथा बीजाण्डीय मापन से युक्त है, में प्रायः अधिकतम एक अथवा विरलतः दो बीजाण्ड/बीज प्रति शंकु मापक संकुल पाए गए हैं। शंकु मापक संकुल को "सिरका" (जीभिकाकार सल्कस) की उपस्थिति द्वारा अभिलक्षणित किया गया है। एक प्रादर्श में, क्रॉस परिच्छेद अनेक परागकणों की परागण अवस्था के दौरान शंकु के संरक्षण को इंगित करने वाले शंकु के शंकु मापक संकुल के साथ निकटस्थ साहचर्य

प्रदर्शित करता है। एक अन्य प्रादर्श में क्रॉस परिच्छेद बीजाण्डद्वारीय क्षेत्र संकुचित, विभाग; कैलाजा छोर अतिरिक्त बीजाण्डकाय युक्त, तीन सुस्पष्ट परतों से युक्त बीजाण्ड अध्यावरण/बीज चोल, दीर्घयत प्रतिलोमित बीजाण्ड/बीज से युक्त शंकु मापक प्रदर्शित करता है तथा एक भ्रूणीय ऊतक की उपस्थिति शंकु संरक्षण की एक उत्तर निषेचन अवस्था प्रदर्शित करती है। इन शंकुओं के शारीरीय अभिलक्षण शंकु परिपक्वता की विभिन्न दशाएँ इंगित करते हैं। स्पर्श रेखीय दृष्टिकोण से दीर्घित सूक्ष्म बीजाणुधरू शंकु क्रॉस परिच्छेद में सूक्ष्म बीजाणुपर्ण तथा वृत्ताकार अण्डाकृतिक बीजाणुधानी प्रदर्शित करता है। शंकु का अनुप्रस्थ परिच्छेद एक मध्य अक्ष प्रदर्शित करता है, जो अनुप्रस्थ परिच्छेद में अनेक दीर्घित संकुचित बीजाणुधानियों तथा सूक्ष्म बीजाणुपर्ण के चतुष्कोणी टिप द्वारा घिरी हुई है। ससूक्ष्म बीजाणुपर्ण दूरस्थ भाग के परिच्छेदीय प्रदर्शन में मात्र मृद्तक ही प्रदर्शित करता है। परिक्षिप्त वृताकार अरहीन परागकण बीजाण्डी/बीज शंकु तथा बन्ध्य प्ररोह के साथ साहचर्य में पाए गए है। पूर्व वर्णित अराउकेरियन शंकु की सभी भारतीय प्रजातियों के आकारवर्गिकीय तथा शारीरीय अभिलक्षणों का भी इस शोध पत्र में समीक्षात्मक मूल्यांकन किया गया है।

संकेत शब्द—अराउकेरियन अवशेष, सोनाजोरी, राजमहल शैल समूह (अन्तर्ट्रेपीय), प्रारंभिक क्रिटेशस, भारत ।

INTRODUCTION

THE family Araucariaceae appeared during Permian, diversified in Jurassic-Early Cretaceous in Northern and Southern Hemispheres and declined during Upper Cretaceous Period. At present this family is confined only in the Southern Hemisphere with a restricted distribution. Evidence of *Araucarites* (detached cone scale complexes) is well known from the Rajmahal Basin but the ovulate/seed cones are recorded so far only from Bindrabun, Amarjola and Sonajori localities of Rajmahal Basin. Vishnu-Mittre (1954) described well preserved cones from the Bindrabun Locality as *Araucarites bindrabunensis* showing resemblance with the living species of *Araucaria bidwillii* Hook. of the section—*Bunya* (Wilde & Eames, 1952). Miller (1977) suggested that the *Araucarites bindrabunensis* Vishnu Mittre perhaps represents an extinct species of the section- Bunya of *Araucaria*. Bohra and Sharma (1980b) described *Araucarites mittrii* from Sonajori locality near Pakur in the Rajmahal Basin.

MATERIAL AND METHODS

The present cones and cone fragments are recovered as permineralised specimens from the Sonajori Locality of Rajmahal Basin. This locality is about 4 km west of Pakur Railway Station near an abandoned quarry at Sonajori. The petrified cherts are found scattered in the field near the quarry. Four cones with ovules/seeds and a few pieces of seed cone fragments have been recovered from this locality. Out of which, two are broken parts of probably elongated-spherical mature cone in transverse section with well preserved cone scales and another two cones are young elliptical in shape. The rest specimens appear to be shattered pieces of mature cones. While sectioning the cherts, in one chert slice an oblique tangential section of a pollen cone and a transverse section of another specimen have also been recovered. Besides these fossils, conifer shoots with spirally arranged falcate leaves, stem with secondary wood and numerous araucarian root sections have been recognised which shows the dominance of conifers (Araucariaceae) in this assemblage. Slides were prepared by usual method of cutting, grinding, polishing process and mounted in Canada Balsam.

DESCRIPTION

Root—Numerous sections of petrified diarch-triarch roots preserved as silicified condition (Pl. 1·1), and identified as *Arauamyelon pakurensis* Bohra and Sharma (1980a). Cross-section of roots usually 7-9 mm in diameter. Periderm is generally about 0·5 mm wide, comprised of rectangular cells. The inner cortex in young roots is about 0·2-0·3 mm wide and is parenchymatous. Primary xylem not preserved in older roots. Secondary xylem is equally or unequally developed showing growth rings.

Remarks—Bohra and Sharma (1980a) and Sharma (1989) show a similar type of equal and unequal lobing of excentric secondary growth in extinct coniferous roots.

PLATE 1

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1 *Arauamyelon pakurense* Bohra & Sharma, showing diarch condition, Slide No. BSIP 12628. x 8.
2. Cross-section of decorticated secondary wood of *Araucarioxylon* sp., Slide No. BSIP 12629. x 1.
3. Transverse section showing growth rings, Slide No. BSIP 12630. x 60.
4. Tangential longitudinal section showing radial pits, Slide No. BSIP 12631 x 120.
5. Radial longitudinal section showing tracheidial pits (Rp.) and cross field pits (Cfp.), Slide No. BSIP 12632. x 160.
6. Leafy shoot. Slide No. BSIP 123633. x 6.
7. Male cone in oblique longitudinal section, Specimen No. BSIP 38882. x 4
8. T.S. of female cone showing bract-scale complex associated with pollen bearing hyphae-like pollen tube (Pt.), Slide No. BSIP 12634. x 8.
9. Doubtful pollen, Slide No. BSIP 12633. x 28.
10. Leafy shoot found associated with pollen, Slide No. BSIP 12633. x 8.


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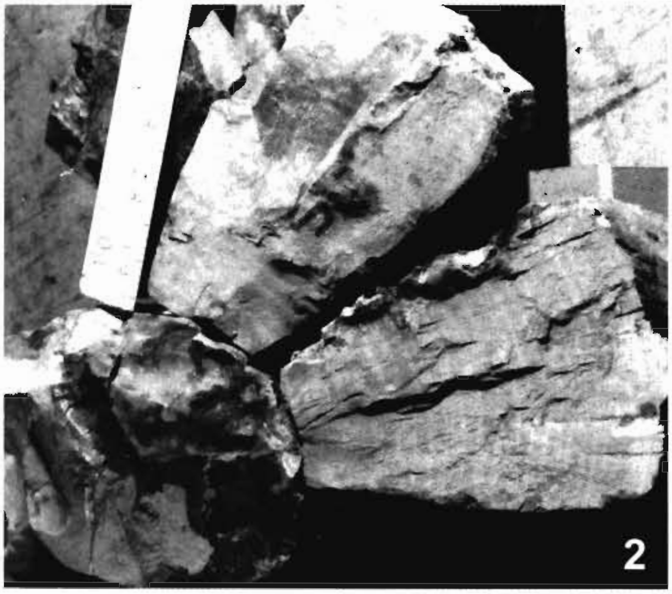
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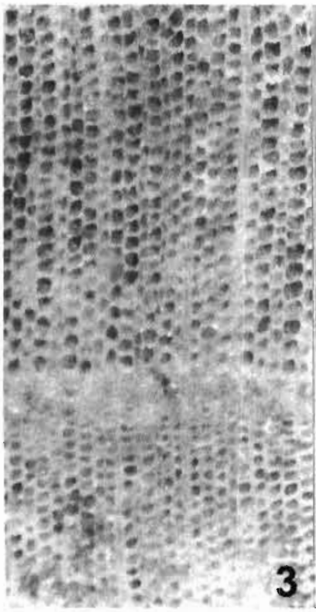
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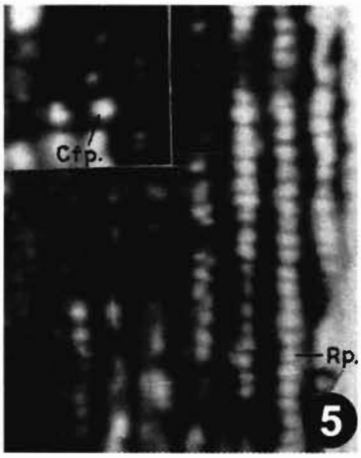

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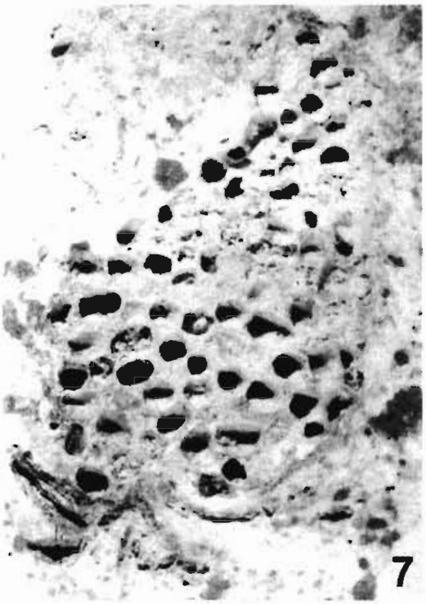
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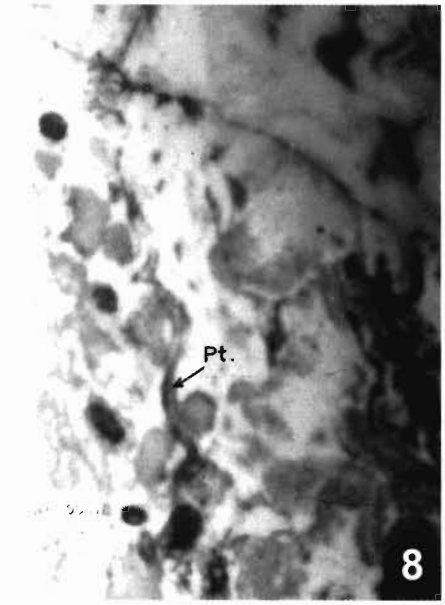

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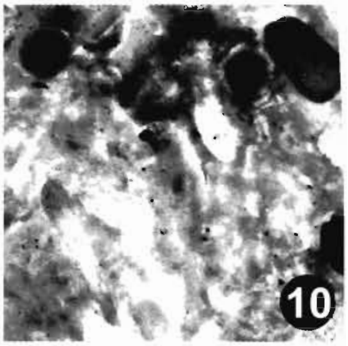
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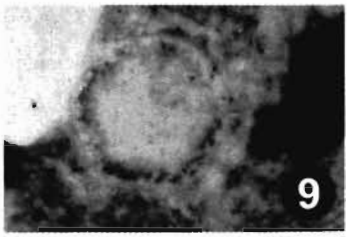
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Stem—Large block of decorticated stem (Pl. 1·2) perhaps preserved in *in-situ* was vertically deposited in the rock matrix. The block is about 14 cm in diameter, with distinct growth rings (Pl. 1·3).The pith is well defined consisting of parenchymatous tissue, 0·9 cm wide. Protoxylem at places is faintly visible and appears endarch . Radial walls of the tracheids usually have one row of hexagonal, contiguous, bordered pits with a circular aperture (Pl. 1·5), rarely biseriate. Alternate crossfield pits are mostly not preserved except in few places where they appear circular. Tangential sections of wood show (Pl. 1·4) medullary rays, uniseriate, 2-12 cells high. Xylem parenchyma is absent.

Comparison—On the basis of the presence of araucaroid hexagonal, contiguous bordered pits on the tracheid wall of the present wood, it is assigned to the taxon-*Araucarioxylon* sp. In anatomical features this wood differ from all the known species of the Rajmahal Basin except *A. santalense* (Sah & Jain) Bose and Maheshwari (1974). It can be distinguished from *A. santalense* in possessing a single circular pit in the cross-field instead of 2-6 circular bordered pits in the crossfield as in *A. santalense*.

Shoot—Twigs with spirally attached leaves are present at this locality (Pl. 1·6, 10). Leaves 2 x 0·5 mm in size, attached at an angle of 45°-50°, lanceolate-falcate in shape with acute-subacute apex. Leaf bases are rhomboidal. In sectional view leaves show a single midvein accompanied by transfusion tissue. The mesophyll is loose, poorly preserved and cannot be differentiated into palisade and spongy parenchyma. The epidermis is distinct.

Comparison—In general appearance these twigs show resemblance to *Pagiophyllum araucaroides* Vishnu-Mittre (1957, pl. 12, fig. 92).

Pollen Cone—Two incomplete pollen cones are recognised in the chert. One is cut in tangential (oblique) longitudinal section (Pl. 1.7) showing a cone in terminal end, 1.3 x 0.7 cm in size. The axis bearing spirally attached microsporophylls with circular-oval depressions that may be sporangia and at places microsporophylls also partly visible . In another slide, a cone in cross sectional view (Pl. 2.1) is faintly visible. The distal end of microsporophyll in sectional view (Pl. 2.1M) shows parenchymatous cells. No anatomical details of the central axis is discernable except elongated sporangia could be seen (Pl. 2.1sp.) in longitudinal sectional view.

Remarks—Pollen is not preserved in the pollen sac but large no. of pollen grains are found associated with the pollen cone as well as the seed cone (Pl. 2.1, 6). The pollen (Pl. 1.8-10) are alete, circular, and the exine is probably granulose, although the exinal pattern is not very distinct. However, in size, exinal features and alete nature these pollen are similar to *Araucariacites*-type pollen confirming the affinity of these dispersed pollen with Araucariaceae. Moreover, the close-association of these pollen cones, seed cones and pollen conclusively prove their affinity with Araucariaceae.

Ovulate or Seed Cone—Four well preserved young and mature cones were recovered that show the cone scale complex with typical features of araucarian cones, i.e., spirally attached large hairy bracts, overlain by thin ovuliferous scale, distal part of ovuliferous scale is free forming a "ligular sulcus". The depth of the sulcus varies, depending upon the maturity of cone as stated by the study of ovule and seed of *Araucaria bidwilli* (Wilde & Eames, 1948) and is also observed by Stockey (1978) in *Araucaria mirabilis* (Segazzini) Windhausen. Two elliptical cones are found embedded in the rock matrix. The weathered specimens have exposed ovules/seeds in places (Pl. 2.2, 3) and 5.5 x 3.0 cm in size. Other two specimens recovered show half portion (Pl. 2.6; 9) of a spherical cone in transverse section. Besides these, cone fragment that is the best preserved is about 5.5 cm in diameter. These fragments may be shattered portion of a mature cone showing well preserved anatomical features.

Cone Axis—In cross section of the cone axis (Pl. 2.5) is 5.5 x 3.5 mm in diameter. It consists of a parenchymatous pith with sclerotic cells at places in the central region, that is surrounded by secondary vascular tissue 2 mm thick, cortex is not preserved. The vascular traces seem to be originated separately for bract scale and ovuliferous scale as shown in Pl. 2.8. Separate origins of ovuliferous scale and bract scale traces from cone axis is represented by extant species *Araucaria bidwillii* (Wilde & Eames 1948, text-fig. 10A) of the section- *bunya-bunya* of Araucariaceae.

PLATE 2

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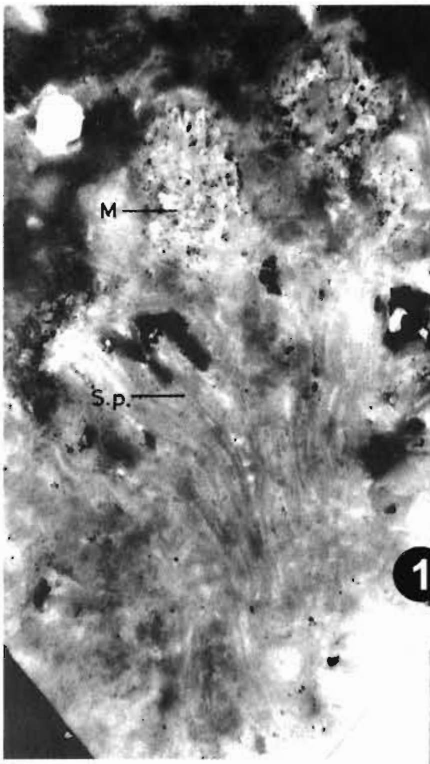
1. Male cone in transverse section showing elongated sporangia (Sp.) and distal part of microsporophyll (M), Slide No. BSIP 12635. x 15.
2. Half portion of mature cone preserved in the rock matrix, Specimen No. BSIP 38883. x ca 1.
3. Elleptical young cone showing seeds, Specimen No. BSIP 38884. x 1.
4. Sterile bract scale with hairs, Slide No. BSIP 12636. x 8 .
5. Cross section of cone axis showing central pith and secondary tissue, Slide No. BSIP 12636. x 7.
6. Cross section of cone showing spirally attached seed scale complex, Slide No. BSIP 12634. x 1.
7. Cross section of cone-scale at distal region showing bract scale (B.S.) with loose parenchymatous cells and ovuliferous scale (O.S.) with vascular tissue, Slide No. BSIP 12637. x 6.
8. Cross section of cone scale complex showing separate vascular traces of bract scale (shown by upward arrows) and ovuliferous scales (shown by downward arrows) and resin ducts. Slide No. BSIP 12638. x 8.
9. Cross section of cone showing seed scale complex, Slide No. BSIP 12639. x 1.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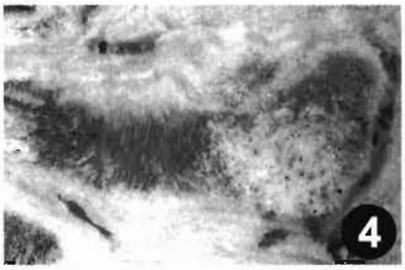
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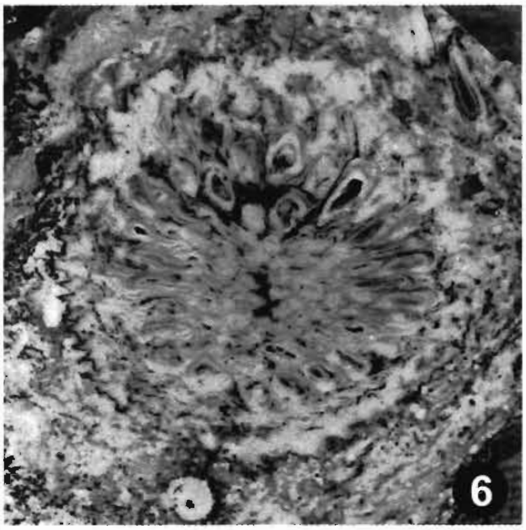
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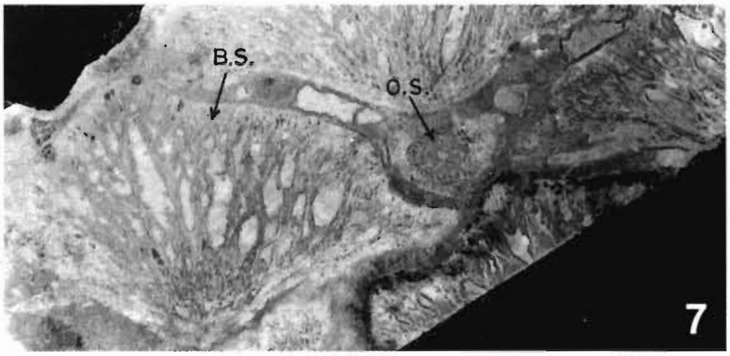
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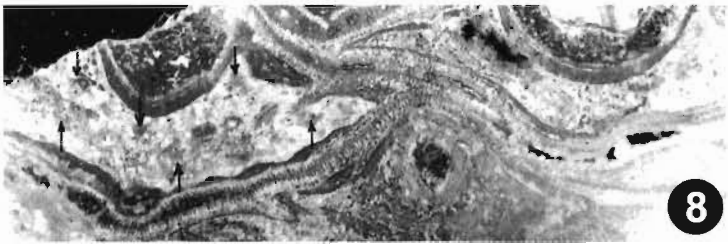
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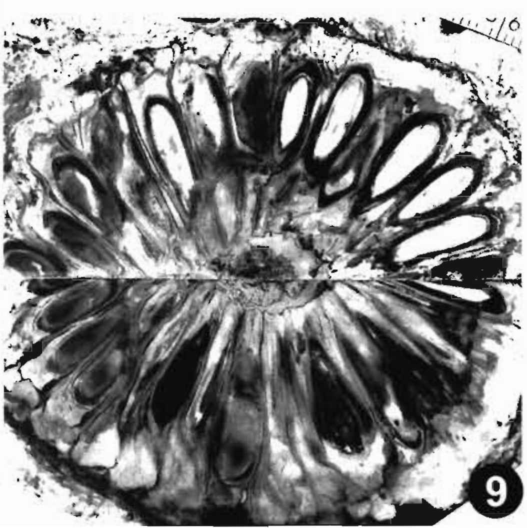
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PLATE 2

Cone-Scale Complex—Cone scale complex typically consists of a bract and ovuliferous scale with free distal tip the so-called "ligule". The space between the ovuliferous scale and the bract scale —"ligular sulcus" (shown in Pl. 3.2) varies in different specimen probably depending upon the maturity of the cone. Ovuliferous scale tip is vascularised (Pl. 2.7) as in *A. mirabilis* (Stockey, 1978) and in *A. bidwillii* (Wilde & Eames, 1948). Each cone scale complex shows two rows of vascular traces, one row of vascular trace for bract scale and other for ovuliferous scale as shown in Pl. 2.8. Bract scales are spirally attached to the cone axis. Proximally a few bract scales are sterile without any ovules and they are densely hairy as shown in Pl. 2.4. The bracts with lateral wings, wings measure 2.0-2.1 x 0.6-0.7 cm. In cross section the bract (Pl. 2.8) shows outer epidermal cells with trichomes followed by 1-2 layers of thick hypodermal cells. Ground tissue consists of parenchymatous thin wall cells. Vascular tissue could be differentiated at places in a row. Resin canals are also present in a series but their position are not exactly marked whether they are alternate with the vascular trace or below the vascular trace.

The ovuliferous scale can easily be differentiated (in cross-section) upon the bract scale and partially adhered with the bract scale. This feature is visible in radial longitudinal and cross-sections of the cone scale complex (Pl. 3.1, 2, 6). Ovuliferous scale also has epidermal trichomes, a hypodermis and parenchymatous cells. Vascular traces could be seen at places in a row with resin ducts. Epidermis in surface view consists of elongated cells with hairy appendages as shown in Pl. 2.8; Pl. 3.1, 3.

Each cone scale complex has an ovuliferous scale and a ovule or seed embedded in its upper surface. Seed is cylindrical in shape, 4-8 mm long and 1.4-1.5 mm broad, inverted, micropyle facing towards cone axis. The ovule/seed integument usually consists of three layers (Pl. 3.1) i.e., an outer layer- sarcotesta (thin, 0.1 mm thick and mostly fused with the ovuliferous tissue), middle layer -sclerotesta (0.5 mm thick and consists of branched and simple sclerotic cells forming zig-zag pattern) and the inner layer—endotesta (thin and about 0.2 mm thick). Ovule/Seed integument differentiation is seen well in the chalazal end of the mature seed (Pl. 3.2). Ovule/Seed integument differentiation is a feature which developed after pollination (Wilde & Eames, 1948) and presence of marking of pollen tube penetration in nucellus (Pl. 3.5P.t.) indicates that this cone is preserved or buried after pollination stage. The nucellus is quite distinct and free except at the chalazal end of the ovule (Pl. 3.6, 8). Mature ovule/seed also shows megagametophyte and embryo with coiled suspensor (Pl. 3.4, 6, 7) indicating post-fertilisation stage. The nucellus tissue, as in extant *Araucaria* (Eames, 1913) has a wavy or undulating appearance (Pl. 3.8) at micropylar end which also confirms that this cone was buried after pollination.and fertilisation stages. Embryo perhaps with two laminar cotyledons and with coiled suspensor.

DISCUSSION AND CONCLUSIONS

Petrified cones, recently recovered from Sonajori Locality of Rajmahal Basin, are best preserved Indian silicified cones of *Araucaria* belonging to the section—*Bunya* of the family Araucariaceae. Cones with helically arranged cone scale complexes, winged bracts adhered with ovuliferous scales except at distal ends and a single inverted ovule are the characteristic features of the family Araucariaceae. The presence of a distinct ligular sulcus and wingless seeds embedded in the ovuliferous scale tissue suggest affinity with the extant genus *Araucaria*. Winged nature of cone scale complex with a large seed, distinct ligular tip with vascularisation, the presence of double vascular supply to the cone scale complex i.e., the separate vascular supply for bract scale and ovuliferous scale are the significant features (Wilde & Eames, 1948, p. 316) of the section *Bunya* are clearly visible in the present cone anatomy (Pl. 2.8). In other morphological and anatomical features, these present specimens of cones come closer to *Araucaria mirabilis* (Spegazzini) Windhausen described by Calder (1953) and Stockey (1975, 1978) from Jurassic-Cretaceous bed of Cerro Cuadrado, Patagonia. Besides the present study of petrified cones from Sonajori, morphological and anatomical features of earlier described Indian species—*Araucarites bindrabunensis* Vishnu-Mittre (1954) from Bindrabun and *A. mittrii* Bohra and Sharma (1980b) from Sonajori have also been reassessed. *A. bindrabunensis*, according to the author, "resembles the cones of *Araucaria mirabilis*. However, it differs from *A. mirabilis* in the longer scales and seeds, in the absence of sclereids and the presence of mucilage duct in the

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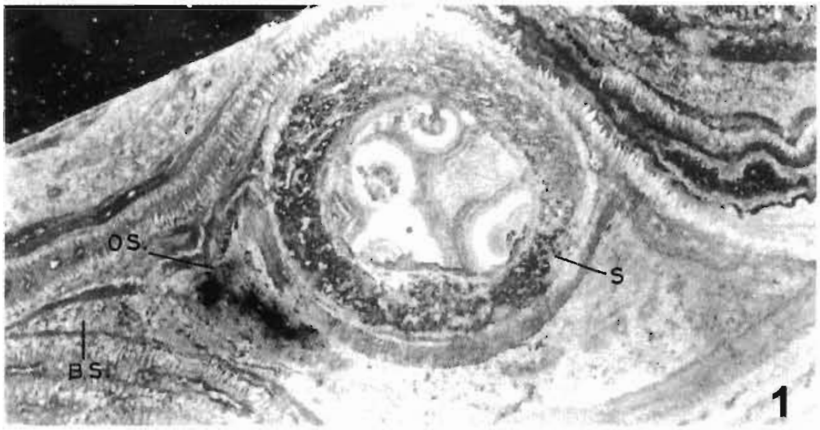
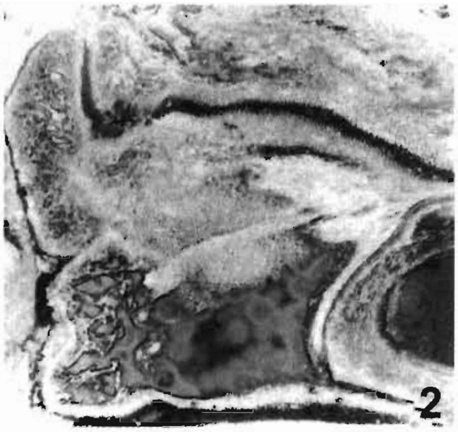
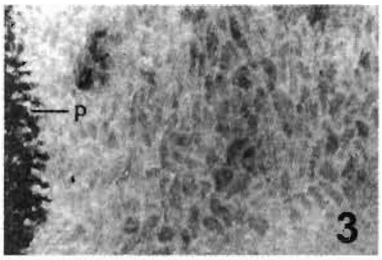
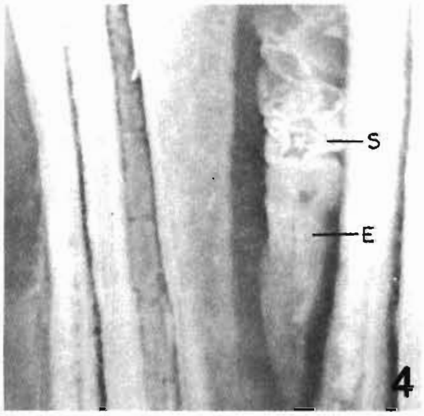
PLATE 3 ⟶

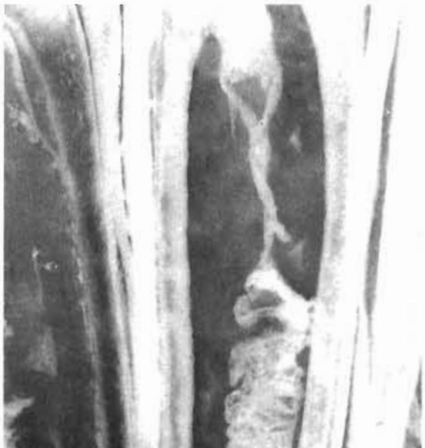
1. Cross section of seed scale complex showing bract scale (B.S.) and ovuliferous scale (O.S.) with a seed (S) showing well defined three layers of seed integument, Slide No. BSIP 12638. x 16.
2. Longitudinal section of cone showing distal tip of cone scale complex, Slide No. BSIP 12640. x 6.
3. Surface of ovuliferous scale showing papillate (p) epidermal cells, Slide No. BSIP 12640. x 12.
4. L.S. of seed scale complex showing seed with embryo (E) and coiled suspensor (S), Slide No. BSIP 12639. x 8.
5. L.S. of seed showing shrunken nucellus and marking of pollen tube (Pt.) penetration, Slide No. BSIP 12641 x 12.
6. L.S. of seed scale complex showing shrunken nucellus and embryonal tissue at the chalazal end of seed, Slide No. BSIP 12641. x 6.
7. L.S. of seed, Slide No. BSIP 12639. x 6.
8. L.S. of cone scale complex showing shrunken nucellus (S.N.) at the micropylar region, Slide No. BSIP 12639. x 8.











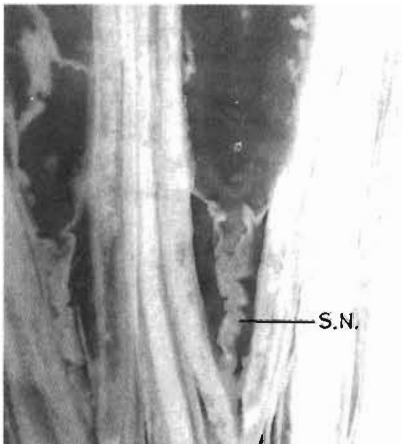


PLATE 3

pith and the absence of the resin cells from below the vascular bundles of the scales and the ligules". Moreover, Bohra and Sharma (1980b) suggested that *A. mittrii* can be compared with *A. bindrabunensis*, but differs in the absence of long distal end of bract scales, absence of mucilage ducts in the pith, differentiation of integument layers, shrunken nucellus in the micropylar region of the seed, nucellus is free from integument and sometimes two ovules are seen on a single scale. After critical assessment of the above variable characters of Indian species and their comparison with *A. mirabilis* and ontogenetic features of extant species of *A. bidwillii*, it has been observed that most of the features of differentiation are developmental (ontogenetic) features and those characters should not be used for taxonomic delimitation unless we know at what stage of maturity those cones had been preserved. Absence or presence of sclereids and mucilage duct or resin cells which are obliterated on the maturity of the cone, differentiation of seed integument layer and shrinkage of nucellus are also developed in the mature stage after pollination. Bohra and Sharma (1980b) used these feature for comparison, on p. 7 stated that the nucellus is free from the integument in the new species where as nothing is known about this structure in *A. bindrabunensis*. According to Eames (1913, figs 33, 35) araucarian nucellus is 'stipitate' i.e., it is free from the enclosing integuments except at the chalazal region. This character is a feature of the genus—*Araucaria* and should not be used further for specific differentiation. So, the only difference left between *A. mittrii,* and the present specimens is the presence of 1-2 ovule per scale which seems to be a normal feature often present in the extant *Araucaria* also (Biswas & Johri, 1997, p. 259). Thus, the creation of a new species on the basis of this generic character only is not justified. Bohra and Sharma (1980b, p. 4) in their description mentioned that in cross-section of some of the scales two ovules are also seen, the two nucellar cavities enclosed by a common integument and the two nucellar cavities are produced either due to false partitioning of nucellus or as a result of fusion of two ovules. In comparison, Bohra and Sharma suggested that the *A. mittrii* differs from *A. bindrabunensis* in the absence of long distal end of bract scale. But, the specimen figured by Bohra and Sharma (1980b) in Pl. 1 fig. F, the distal end of bract scale is somewhat similar in length as shown in Pl. 1 fig. 7 by Vishnu-Mittre (1954). So at present, the Indian species *Araucarites bindrabunensis* Vishnu-Mittre, *A. mittrii* Bohra & Sharma and the present cones are placed under *Araucaria mirabilis* (Spegazzini) Windhausen.

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REFERENCES

Biswas Chhaya & Johri BM 1997. *The Gymnosperms. Narosa Publishing House*, Delhi : 494p.

Bohra DR & Sharma BD 1980a. *Arauamyelon pakurense* gen. et sp. nov. from the Jurassic of Rajmahal Hills, India. Bulletin of National Science Museum Series-Geology, Tokyo 6 93-96.

Bohra DR & Sharma BD 1980b. *Araucarites mittrii* sp. nov. a petrified megastrobilus from the Rajmahal Hills, India. Ameghiniana 17 : 3-8.

Bose MN & Maheshwari HK 1974. Mesozoic conifers. *In* : Surange KR *et al.* (Editors)—Aspects & Appraisal of Indian Palaeobotany : 212-223. Birbal Sahni Institute of Palaeobotany, Lucknow.

Calder MG 1953 A coniferous petrified forest in Patagonia. Bulletin of British Museum (Natural History) Geology, London 2 : 99-138.

Eames AJ 1913. The morphology of *Agathis australis*. Annals of Botany 27: 191-204.

Miller Jr CN 1977. Mesozoic conifers. Botanical Review 43 : 217-280.

Sharma BD 1989. Petrified conifers with anamolous secondary growth from the Rajmahal Hills, India. Geophytology 19 : 49-51.

Stockey RA 1975. Seed and embryos of *Araucaria mirabilis*. American Journal of Botany 62 : 856-868.

Stockey RA 1978. Reproductive biology of Cerro Cuadrado fossil conifers : ontogeny and reproductive strategies in *Araucaria mirabilis* (Segazzini) Windhausen. Palaeontographica 166 : 1-15.

Vishnu Mittre 1954. *Araucarites bindrabunensis* sp. nov. a petrified megastrobilus from the Jurassic of Rajmahal Hills, Bihar. Palaeobotanist 3 : 103-106.

Vishnu Mittre 1957. Studies on the fossil flora of Nipania, Rajmahal Hills- Coniferales. Palaeobotanist 6 : 82-112.

Wilde MH & Eames AJ 1948. The ovule and "seed" of *Araucaria bidwillii* with discussion of the taxonomy of the genus I Morphology. Annals of Botany 12 : 311-326.

Wilde MH & Eames AJ 1952. The ovule and " seed" of *Araucaria bidwillii* with discussion of the taxonomy of the genus. II-Taxonomy. Annals of Botany 16 : 27-47.

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Fossil flora of the Chui Hill, Jabalpur Formation, Satpura Basin, Madhya Pradesh, India

NEERU PRAKASH

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.

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ABSTRACT

Prakash N 2003. Fossil flora of the Chui Hill, Jabalpur Formation, Satpura Basin, Madhya Pradesh, India. Palaeobotanist 52(1-3) 63-71.

Diversed types of fossil leaf impressions have been collected in abundance on reddish-pinkish clay from the Chui Hill, Jabalpur Formation of Satpura Basin. The flora has dominance of conifers followed by bennettitales and pteridophytes, e.g., *Elatocladus jabalpurensis, Elatocladus* sp., *Brachyphyllum jabalpurensis* sp. nov., *Pagiophyllum chawadensis, Araucarites minutes, Satpuria sehoraensis, Taeniopteris spatulata, Ptilophyllum cutchense* and *Anomozamites* sp. These taxa are commonly found in Early Cretaceous floral assemblages of India. The floral assemblage is compared with other contemporaneous deposits of Satpura and South Rewa basins.

Key-words—Clay impressions, Megaflora, Dominance conifers, Early Cretaceous.

भारत के मध्य प्रदेश प्रान्त की सतपुड़ा द्रोणी के जबलपुर शैल समूह की चुई पर्वत श्रेणी का अश्मित वनस्पतिजात

नीरू प्रकाश

सारांश

सतपुड़ा द्रोणी के जबलपुर शैल समूह की चुई पर्वत श्रेणी से प्राप्त लाल गुलाबी मृतिका की प्रचुरता में अश्मित पर्ण मुद्राश्यों के विभिन्न प्ररूप संग्रहीत किए गए है । वनस्पतिजात में शंक्वाकारों की प्रचुरता है, तत्पश्चात् क्रमशः बेनीटाइटेलीज तथा टेरिडोफाइट, जैसे—*इलेटोक्लेडस जबलपुरेन्सिस, इलेटोक्लेडस* प्रजाति, *ब्रैकीफिल्लम जबलपुरेन्सिस* नव प्रजाति, *पेजियोफिल्लम चावाडेन्सिस, अराउकेराइटीज माइन्यूटीज, सतपुड़िया सिहोरेन्सिस, टीनियॉप्टेरिस स्पाच्यूलाटा, स्पाच्यूलाटा, टिलोफिल्लम कचेन्स* तथा *एनोमोजेमाइटीज* प्रजाति आते हैं। ये वर्गक भारत के प्रारंभिक क्रिटेशस वनस्पतिजात समुच्चय सतपुड़ा तथा दक्षिणी रीवॉ द्रोणियों के अन्य समकालिक निक्षेपों से तुलनीय है।

संकेत शब्द—मृत्तिका मुद्राश्म, गुरूवनस्पतिजात, प्रभावी शंक्वाकार, प्रारंभिक क्रिटेशस।

INTRODUCTION

THE Upper Gondwana strata of Jabalpur Formation is exposed around Mahadeo Hills and is recognised by its carbonaceous or coaly content or reddish brown and whitish-grey clays. Earlier it was referred as 'Damuda Series' by Oldham (1893) but later he placed these sequences under Jabalpur Group. Several sedimentary outliers occur near Narsinghpur (Sehora), Jabalpur in Satpura Basin and in Bansa and Chandia of South Rewa Gondwana Basin. Feistmantel (1877) recorded fragmentary plant megafossils from various localities of Jabalpur Formation. Few sporadic reports were made by Deb (1917) and a note is published by Agarwal (1963). In this paper morphotaxonomic study of plant megafossils has been carried for the first time to augment the flora of Chui Hill. Their interrelationship with South Rewa and Rajmahal basins also attempted and observed that these floras were dominant in the same period.

GEOLOGY AND AGE

The sedimentary rocks of Jabalpur Formation, Satpura Basin unconformably overlies Precambrian basement which are further overlain by Lameta or Deccan Intertrappean beds (Fig. 1). The rocks of Jabalpur Formation consist of massive sandstone, soft white clays, jaspar bearing sandy conglomerate, earthy nodules of haematite, thin strips of carbonaceous and red clays associated with cherts. The Jabalpur sediments attain its maximum thickness about 150 m near the vicinity of Hard and Sukkur River towards east of Chhindwara-Narsinghpur Road. At the vicinity of Sher River these sediments attained maximum thickness of about 75 m and appear to be quite massive.

Crookshank (1936) and Pascoe (1959) biostratigraphically subdivided 'Jabalpur Series' into Lower (Chaugan) and Upper (Jabalpur) Formation. They suggested that the Umia plant bed should be associated with Jabalpur Group on the basis of occurrence of conifers and absence of cycades. Whereas,

Formation	**Beds with Lithological characters**	**Age**
	Laterite, old and recent Alluvium soil caps	Recent
DeccanTrap/	Lava flows	Late Cretaceous-Palaeocene
Lameta	Coarse, calcareous, conglomerate, limestone, purple grits/sills, green sandstone	Late Cretaceous
	UNCONFORMITY	
Jabalpur	Sandstone alternating with clays, conglomerate, earthy haematite, coal, carbonaceous shale, red clay and bed of chert	Jurassic-Early Cretaceous
	UNCONFORMITY	
Denwa	Alternating bed of sandstone and variegated clays (red green and buff coloured clays)	Triassic
Bagra	Conglomerates, limestone and variegated red clays	
	UNCONFORMITY	
Lower Gondwana		Permian
	Archaean basement	Azoic

(Partially modified after Kumar, 1994)

Fig. 1—Showing sedimentary sequences around the area.

PLATE 1

⟶

1. *Ptilophyllum cutchense* Morris. Specimen No. BSIP 38010. x 1
2. *Cladophlebis medlicottiana* (Oldham) Pascoe. Specimen No. BSIP 38005. x 2.
3. *Pachypteris indica* (Oldham & Morris). Bose and Roy. Specimen No. BSIP 38006. x 1.
4. *Elatocladus jabalpurensis* (Feistmantel) Sahni, Specimen No. BSIP 38881 x 1.
5. *Araucarites minutes* Bose and Maheshwari. Specimen No. BSIP 38015. x 1
6. *Pagiophyllum chawadensis* Bose and Banerji. Specimen No. BSIP 38013. x 1.
7. *Taeniopteris spatulata* McClelland. Specimen No. BSIP 38007. x 1
8. *Elatocladus jabalpurensis* (Feistmantel) Sahni. Specimen No. BSIP 380011 x 3.
9. *Anomozamites* sp., Specimen No. BSIP 38008. x 1
10. *Elatocladus jabalpurensis* (Feistmantel) Sahni, Specimen No. BSIP 38011 x 1
11. *Elatocladus jabalpurensis* (Feistmantel) Sahni. Specimen No. BSIP 38017 x 1
12. *Satpuria sehoraensis* Sukh-Dev and Zeba-Bano. Specimen No BSIP 38016. x 1
13. *Anomozamites* sp., Specimen No. BSIP 38018. x 1.
14. *Elatocladus* sp., Specimen No. BSIP 38012. x 1
15. *Satpuria sehoraensis* Sukh-Dev and Zeba-Bano. Specimen No. BSIP 38016. x 2.
16. *Araucarites minutes* Bose and Maheshwari. Specimen No. BSIP 38015. x 1
17. *Araucarites minutes* Bose and Maheshwari, Specimen No. BSIP 38880. x 1.
18. *Anomozamites* sp., Specimen No. BSIP 38008. x 2.
19. *Brachyphyllum jabalpurensis* sp. nov., Specimen No. BSIP 38014. x 1 (Holotype).
20. *Elatocladus jabalpurensis* (Feistmantel) Sahni. Specimen No. BSIP 38019. x 1
21. *Ptilophyllum cutchense* Morris. Specimen No. BSIP 38010. x 4.

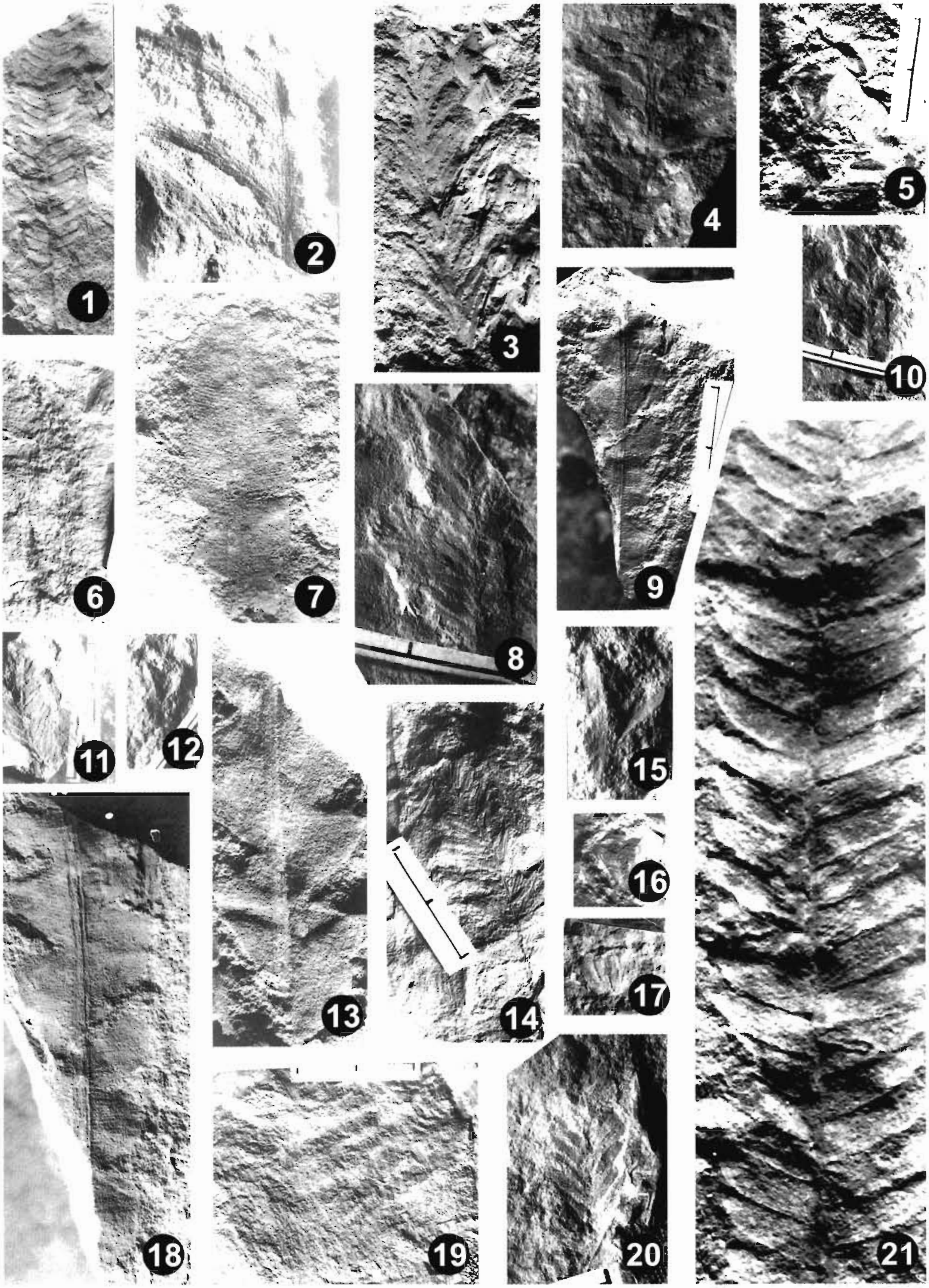

PLATE 1

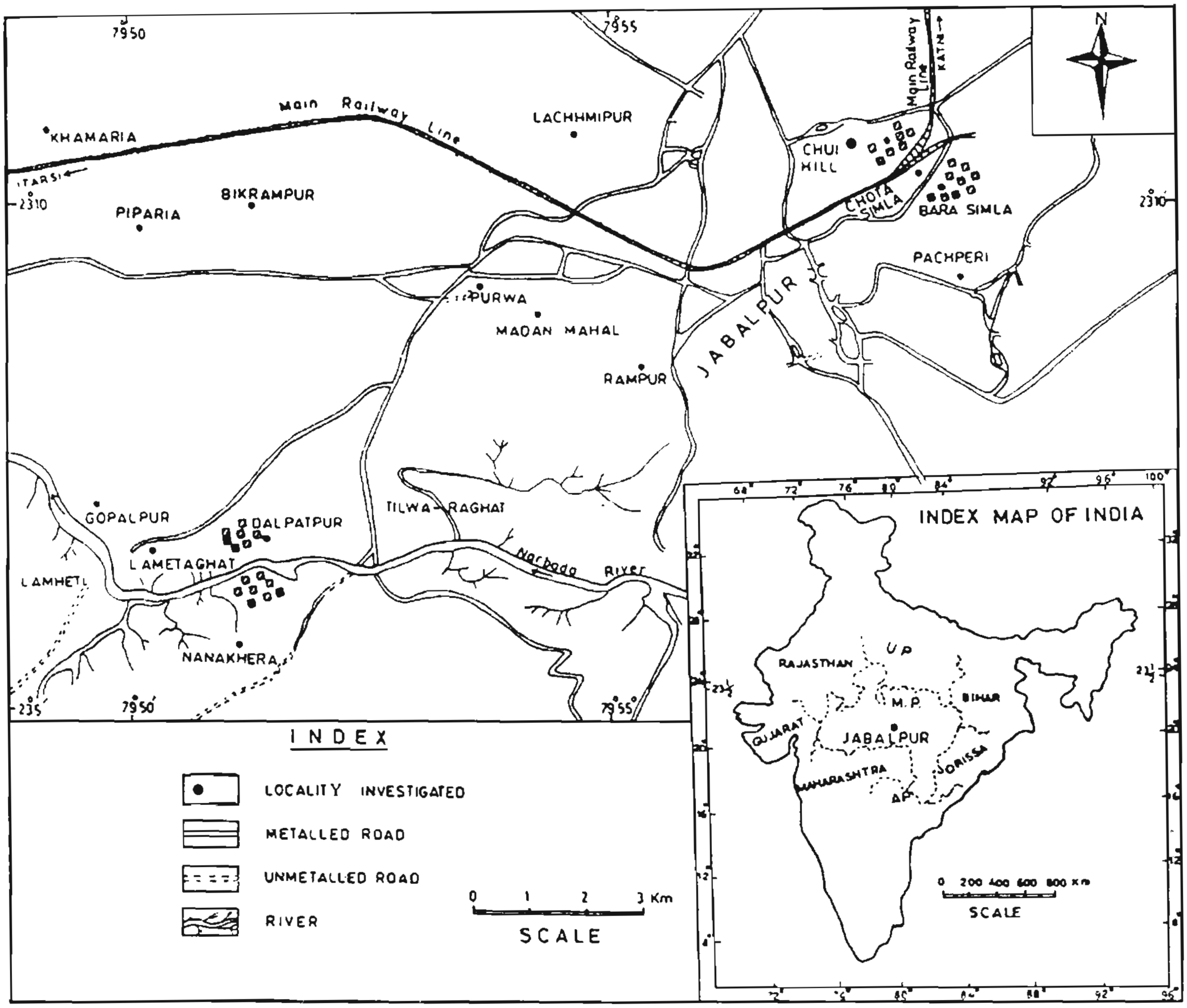

Fig. 2—Locality map of the area (after Dogra *et al.*, 1994)

Singh (1966, 1970) palynologically assigned Lower Cretaceous age to Jabalpur Formation. However, Bharadwaj (1970) and Bharadwaj *et al.* (1972) concluded Upper Jurassic age on the basis of high frequencies of *Cycadopites* and *Classopollis*. But Singh and Venkatachala (1988) while reassessing the palynoflora dated an Early Cretaceous age for Jabalpur Formation.

MATERIAL AND METHODS

Plant megafossils dealt in present study have been collected from exposed sequence at Chui Hill (24°41' : 78°38') near Jabalpur Town (Fig. 2). All these megafossils are preserved as impression on reddish brown or white grey clays. The specimens of the present study are housed in the repository of the Birbal Sahni Institute of Palaeobotany, Lucknow.

UNCLASSIFIED FERN

Genus—CLADOPHLEBIS Brongniart 1849

CLADOPHLEBIS MEDLICOTTIANA (Oldham) Pascoe 1959

Pl. 1·2

Synonym—Alethopteris medlicottiana (Oldham) Feistmantel, 1877, p. 87, pl. 1, figs 2-6.

Description (Emended)—(Based on Feistmantel's and present specimens) Frond bipinnate, pinnae alternate broad at base, narrowing towards distal end, measuring 1·9-3 cm in length and 1·7-2·2 cm in width, making an angle of about 60° to main rachis. Main rachis 3 mm wide. Pinnules linear, straight or slightly falcate, rarely bent backward, broader at base, gradually narrowing towards apex, 2-2·4 cm long and 0·2-0·4 cm wide, arising at an angle of about 40°-60°, angle of divergence less towards apical region. Pinnules attached to rachis by entire base. Acroscopic basal margin extending upward and sometimes joined togather by a narrow web. Apex acute or obtuse. Midrib prominent, originating closer to basiscopic edge of pinnule, persisting up to apex. Secondary veins numerous, catadromic, arising at an angle of about 20°-30°, forking once.

Comparison—The specimens of *Cladophlebis medlicottiana* (Oldham) Pascoe (1959) described by Sukh-Dev (1970) and Zeba-Bano (1980) from various localities (Bansa, Sehora, Hard River, Jatamao and Patparha) of Jabalpur Formation resembles in shape, size and venation pattern. This specimen shows apparent resemblance with *Cladophlebis* sp. described by Bose and Sah (1968) from Lower Cretaceous of Rajmahal Hills, where secondary veins are forked more than once but in *C. medlicottiana* secondary veins are only once forked.

Collection—Specimen no. BSIP 38005.

GYMNOSPERMS

Family—CORYSTOSPERMACEAE

Genus—PACHYPTERIS Brongniart 1828

PACHYPTERIS INDICA (Bose & Roy) Bose & Banerji 1984

(Pl. 1·3)

Remarks—*Pachypteris indica* is reported for the first time from Chui Hill, Jabalpur Formation. The specimen matches exactly with the *Pachypteris indica* (Bose & Roy) Bose & Banerji (1984) in shape, size and venation pattern. The only difference is that the present specimen lack cuticle. Apparently it also resembles with *P. lanceolata* Harris (1964) from Jurassic of Yorkshire, England. However, latter differs in having broad and lanceolate pinnules.

Collection—Specimen no. BSIP 38006.

CYCADALES

Family—CYCADACEAE

Genus—TAENIOPTERIS Brongniart 1832

TAENIOPTERIS SPATULATA McClelland 1850

(Pl. 1·7)

Remarks—The specimen described here resembles *Taeniopteris spatulata* McClelland (1850) described by Bose & Banerji (1981) from the Rajmahal Hills showed presence of loops in secondary veins, which are not observed in the present specimen.

Collection—Specimen no. BSIP 38007.

BENNETTITALES

Family—WILLIAMSONIACEAE

Genus—PTILOPHYLLUM Morris, 1840

PTILOPHYLLUM CUTCHENSE Morris 1840

(Pl. 1·1, 21)

Remarks—*Ptilophyllum cutchense* occurs frequently in Jabalpur Formation but not so common in Chui Hill.

Collection—Specimen no. BSIP 38010.

Genus—ANOMOZAMITES Schimper 1870

ANOMOZAMITES sp.

(Pl. 1·9, 13, 18)

Description—Leaves 1·7-8·5 cm in length and 1·4-1·8 cm in width, incomplete. Rachis prominent, about 2 mm wide, longitudinally striated. Lamina-segments sub-opposite to opposite, broader than their length, attached to rachis at about right angle by entire base, 6-8 mm long and 7-14 mm broad. Lateral margins entire, distal margin broad with rounded or pointed corners; occasionally distal margin notched. Veins arising at right angle, simple, parallel, sometimes forked.

Comparison—*Anomozamites* sp. is comparable to *A. amarjolense* Sharma *et al.* (1971), *A. fissus* Feistmantel (1879) and *A. hasnapurensis* described by Bose & Banerji (1981). But all these species differ from *Anomozamites* sp. by squarish segments or twice in length than breadth. *A. thomsi* Harris (1960) described from Yorkshire do resembles in shape and size with present specimen but mostly they are longer than broad.

Collection—Specimen nos BSIP 38008, 38009 and 38018.

CONIFERALES

Family—PODOCARPACEAE

Genus—ELATOCLADUS Halle, 1913

ELATOCLADUS JABALPURENSIS (Feistmantel) Sahni, 1928

(Pl. 1·4, 8, 10, 11, 20)

Synonyms—*Palyssa jabalpurensis* Feistmantel (1877), p. 96, pl. 9, figs 1-6, pl. 10, fig. 1.

Lectotype—*Elatocladus jabalpurensis* (Feistmantel), Sahni (1928), p. 14, pl. 5, fig. 73. pl. 10, fig. 1 (Feistmantel, 1877).

Diagnosis (Emended)—Branched leafy twigs, 2·1-9·0 cm long and 0·8-7·5 cm wide. Branches stiff and spreading, arising at an angle of 30°-70°. Leaves spirally borne but lying in one plane, narrow linear-lanceolate, straight, measuring 3-10 mm in length and about 1 mm in width, attached at an angle of 20°-

Name	Sehora	Jabalpur	Bansa
Pteridophytes			
Todites indicus	+	-	-
Cladophlebis indica	-	-	+
C. medlicottiana	+	+	+
Cladophlebis sp. cf. *C.longipennis*	+	-	-
Cladophlebis sp.	+	-	-
Gleichenia rewahensis	-	-	+
G. nordenskioldii	-	-	+
Hausmannia pachyderma	-	-	+
Phlebopteris polypodiodes	-	-	+
Onychiopsis psilotoides	-	-	+
O. paradoxus	-	-	+
Weicheselia reticulata	-	-	+
Sphenopteris sp. cf. *sarguta*	+	+	-
Sphenopteris cf. *C. otagoensis*	-	+	-
Sphenopteris sp.	+	-	-
Pteridospermales			
Pachypteris indica	+	+	-
Cycadopteris pulcherrima	-	-	+
C. brauniana	-	-	+
C. auriculata	-	-	+
C. indica	-	-	+
C. majus	-	-	+
Cycadales			
Pterophyllum princeps	-	+	-
Taeniopteris spatulata	-	+	-
Doratophyllum senii	+	-	-
Anomozamites sp.	-	+	-
Bennettitales			
Ptilophyllum acutifolium	+	-	-
P. cutchense	+	+	-
P. distans	+	-	+
P. horridum	+	-	+
P. jabalpurense	+	-	-
P. gladiatum	-	-	+
Ptilophyllum sp.cf. *P. horridum*	-	-	+
P. rewahensis	-	-	+
Ptilophyllum sp.	-	-	+
Williamsonia seniana	+	-	-
Cycadolepis	+	-	-
Ginkgoales			
Ginkgoites lobata	+	-	-
Pentoxylae			
?*Nipaniophyllum hirsuatum*	-	-	+
Coniferales			
Elatocladus confertus	-	+	+
E. tennerrima	-	-	+
E. pseudotenerrima	+	-	-
E. plana	+	-	-
E. jabalpurensis	-	+	-
E. sehoraensis	+	-	-
E. bosei	+	-	-
Elatocladus sp.	-	+	-
Araucaria indica	+	-	+
Araucarites cutchensis	+	+	-
A. macropterus	-	-	+

Name	Sehora	Jabalpur	Bansa
A. minimus	+	+	-
A. sehoraensis	+	-	-
A. fibrosa	-	-	+
Araucaria pantiana	-	-	+
Pagiophyllum sherensis	+	-	-
P. satpuraensis	+	-	-
P. marwarensis	-	-	+
P. bansaensis	-	-	+
P. rewahensis	-	-	+
Pagiophyllum sp.	-	+	-
Pagiophyllum sp. cf. *P. peregrinum*	-	-	+
Brachyphyllum jabalpurensis sp. nov.	-	+	-
B. ekaiostomum	+	-	+
B. feistmantellii	-	-	+
B. bansaensis	-	-	+
B. rhombicum	-	+	+
B. sehoraensis	+	-	-
Allocladus bansaensis	+	-	+
A. sehoraensis	+	-	-
Strobilites anceps	-	-	+
Satpuria sehoraensis	+	+	-
Satpuria sp.	+	-	-
Coniferocaulon rajmahalense	+	-	-
Strobilites sewardi	+	+	-
Czekanowskia sp.	-	+	-

Fig. 3—Comparative chart of the Jabalpur flora.

60°, and never swept back. Base constricted and decurrent, margin entire, apex acute or bluntly acute and unicostate.

Remarks—The morphological observations of *Elatocladus jabalpurensis* is based on impressions which is characterised by stiff branches and the leaves are linear, straight and narrow, never swept back and attached to rachis by constricted and decurrent leaf bases. Bose & Banerji (1984) from Kutch, Ganesan & Bose (1982) from Bhutan and Halle (1913) reported similar specimens from Grahamland.

Collection—Specimen nos. BSIP 38011, 38017, 38019 and 38881.

ELATOCLADUS sp.

(Pl. 1·14)

Description—Leafy twig 4·1 cm in length and 0·9 cm in width. Rachis thick, stout about 1 mm wide. Leaves spirally arranged but in one plane; narrow linear, up to 8 mm long and about 1 mm wide, attached to rachis by broad base, margin entire. Midrib distinct up to apex.

Comparison—*Elatocladus* sp. is characterised by long, narrow leaves which are mostly attached by entire bases. *E. plana* (Feistmantel) described by Sahni (1928) are similar in appearance, leaves attached at right angle and are reflexed back. Comparison is also made with *E. longifolia* Borkar and Chiplonkar (1973) from Tarnetar (Saurashtra), leaves of *Elatocladus* sp. are stiff and scale leaves are absent.

Collection—Specimen no. BSIP 38012.

Family—ARAUCARIACEAE

Genus—PAGIOPHYLLUM Heer 1881

PAGIOPHYLLUM CHAWADENSIS Bose & Banerji 1984

(Pl. 1·6)

Description—Leafy-twig 4·8 cm in length and about 0·3 cm in width. Leaves closely appressed on stem, forwardly directed, small, triangular, 1-2 mm long and 1-1·5 mm wide; arising from a rhomboidal leaf base-cushions. Margin entire, apex obtuse or acute.

Remarks—The present specimen resembles morphologically with *Pagiophyllum chawadensis* Bose & Banerji (1984) described from Early Cretaceous of Kutch. Cuticle is unknown in the present material.

Collection—Specimen no. BSIP 38013.

Genus—BRACHYPHYLLUM Brongniart 1828

BRACHYPHYLLUM JABALPURENSIS sp. nov.

(Pl. 1·19)

Diagnosis—Twig leafy, branches cylindrical; leaves rhomboidal, broad, closely appressed on the stem, few leaves elongated, triangular and spirally arranged on distant branches. Leaf cushions rhomboidal, leaf margin straight, apex acute.

Description—Branched leafy-twig 4·4 cm long and 4·5 cm wide. Branches cylindrical arising at an angle of 50°-70° (mostly 60°) up to 3·2 cm long and 0·3 cm wide. Leaves rhomboidal, about 2 mm long and 2 mm broad, closely appressed on stem, a few leaves towards distant end of branch are elongated, triangular and spirally arranged; arising from a rhomboidal leaf base cushion, margin straight, apex acute.

Comparison—Brachyphyllum jabalpurensis is characterised by dimorphism of leaves. Mostly they are rhomboidal, closely appressed on the stem as in *B. rhombhicum* Feistmantel, described by Sahni (1928) but few leaves towards distal end of branch are elongate and triangular. Cuticle is not preserved in *B. jabalpurensis*. It is also comparable with *B. feistmantelii* (Halle) Sahni (1928) in dimorphism of leaves but in the later species larger leaves occur on main branches and smaller ones on short branches.

Holotype—Specimen no. BSIP 38014.

Genus—ARAUCARITES Presl 1838

ARAUCARITES MINUTES Bose & Maheshwari 1973

(Pl. 1·5, 6, 17)

Description—Detached seed scales, 0·8-1·6 cm long and 0·5-0·8 cm wide; cuneate, shoulder convex or straight, in some slightly raised with sloping sides to a narrow base. Tip short, 1-2 mm long, acute. Seed obovate, 4-6 mm long and 2-4 mm wide.

Remarks—Araucarites minutes described here resembles *A. minutes* Bose & Maheshwari (1973), Bose and Banerji (1984) recorded from Early Cretaceous of Sehora and Kutch.

Collection—Specimen nos BSIP 38015 and 38880.

Genus—SATPURIA Sukh-Dev & Zeba-Bano 1978

SATPURIA SEHORAENSIS Sukh-Dev & Zeba-Bano 1978

(Pl. 1·12-15)

Description—Leaves strap shaped, lanceolate, 0·7-1·8 cm long, 0·1-0·2 cm wide, abruptly narrowing towards base and apex; apex acute, bases with a short curved stalk, margin entire. Veins few, faint, parallel and dichotomising.

Remarks—The specimens described here are preserved as impressions. The *Satpuria sehoraensis* (Sukh-Dev & Zeba-Bano, 1978) resembles in gross morphology with the specimens reported from Early Cretaceous of Sehora, but cuticle is unknown in the present specimens.

Collection—Specimen no. BSIP 38016.

FLORAL COMPOSITION AND ITS COMPARISON

The fossil flora of Jabalpur Formation (Satpura Basin) is characterised by dominance of conifers followed by bennettitalian remains. The pteridophytic remains are meagre whereas, Ginkgophytes are rare in occurrence. Pentoxylae have so far not been recorded from Jabalpur Formation.

It is evident from the comparative chart (Fig. 3) the Jabalpur flora (Chui Hill) is closely comparable to Sehora (in both the assemblage conifers are dominant over cycadophytes) but differ due to the occurrence of *Onychiopsis* along with some other cycadophytes e.g., *Anomozamites, Ptilophyllum* and *Taeniopteris*. Although Sukh-Dev (1988) in spite of some difference had placed them together with in the assemblage zone 9.

Bansa flora is characterised by the occurrence of index fossil *Weicheselia* and genus *Cycadopteris* along with pteridophytes viz., *Gleichenia, Hausmannia, Onychiopsis* and *Phlebopteris* with few species of *Ptilophyllum* and cycads are totally absent; is placed in assemblage zone 10 (Sukh-Dev, 1988) (the basic difference is that in Jabalpur cycadophytes occur in good number).

The Rajmahal flora is recognised by the dominance of broad leaved cycadophytes and conifers while in Jabalpur flora conifers are the main constituent as compare to the broad leaved cycadophytes.

On the basis of above discussed floral elements Jabalpur flora is younger than Rajmahal and older than Bansa flora, therefore assigned to an Early Cretaceous age.

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REFERENCES

Agarwal AP 1963. A note on the Palaeontology and Stratigraphy of the Jabalpur Series. Current Science 32 : 411.

Bharadwaj DC 1970. Palynological succession through the Mesozoic Era in India. Journal of Palynology 5 : 85-94.

Bharadwaj DC, Kumar P & Singh H 1972. Palynostratigraphy of coal deposits of Jabalpur stage, Upper Gondwana, India. Palaeobotanist 19 : 225-247.

Borkar VD & Chiplonkar GW 1973. New plant fossil from the Umias of Saurashtra. Palaeobotanist 20 : 269-279.

Bose MN & Banerji J 1981. Cycadophytic leaves from Jurassic – Lower Cretaceous rocks of India. Palaeobotanist 28 & 29 : 218-300.

Bose MN & Banerji J 1984. The fossil flora of Kachchh 1. Mesozoic megafossils. Palaeobotanist 34 : 1-189.

Bose MN & Maheshwari HK 1973. Detached seed scales belonging to Araucariaceae from the Mesozoic rocks of India. Geophytology 3 : 205-214.

Bose MN & Sah SCD 1968. Some pteridophytic remains from the Rajmahal Hills, Bihar. Palaeobotanist 16 : 12-28.

Brongniart A 1828. Prodrome d'une histoire des vegetaux fossiles. Dictionuaire. Sci. Nat. 57 : 61-212.

Brongniart A 1832. Histoire des vegetaux fossiles ou recher botanique et geologiques sur les vegetaux renefermes dans les diverses couches du globe Paris. G, Dufourand Ea Ocagene 1 : 268-288.

Brongniart A 1849. Tableu des generes de ve'getaux fossiles consideres sous le point de vue de leur classification botanique et de leur distribution geologique. L. Martinct, Paris : 1-127.

Crookshank H 1936. Geology of the northern slopes of the Satpuras between the Morand and Sher rivers. Memoir Geological Survey of India 66 : 173-381.

Deb S 1917. A short note on some fossil plants from Jabalpur, C.P. Quarterly Journal of Geological Mining and Metallurgical Society of India 4 : 103-105.

Dogra NN, Singh RY & Kulshrestha SK 1994. Palynostratigraphy of infratrappean and Lameta formations (Lower and Upper Cretaceous) in Madhya Pradesh, India. Cretaceous Research 15 : 205 -215

Feistmantel O 1877. Flora of the Jabalpur Group (Upper Gondwanas), in the Son-Narmada region. Memoir Geological Survey of India, Palaeontologica Indica Series -II · 81-105.

Feistmantel O 1879. Outliers on the Madras Coast in 'Fossil flora of the Upper Gondwanas'. Memoir Geological Survey of India, Palaeontologica Indica Series I 1-34.

Ganeshan TM & Bose MN 1982. Plant remains of Mesozoic age from Lingshi Basin, Bhutan. Geophytology 12 : 279-286.

Halle TG 1913. The Mesozoic flora of Grahamland. Wissenschafliche Ergebnisse Schwedischen Sudpolar Expedition 1901-1903, 3 . 1-122.

Harris TM 1960. The Yorkshire Jurassic flora 1. Thallophyta – Pteridophyta. Bulletin of British Museum of Natural History, London : 1-205

Harris TM 1964. The Yorkshire Jurassic flora 2. Caytoniales, Cycadales & Pteridosperms. Bulletin of British Museum of Natural History, London : 1-184.

Heer O 1881. Contributions a la flore fossile du Portugal. Comm. Trab. Geol Portugal : 1-51.

Kumar P 1994. The Jabalpur Formation of Satpura Basin -Palynology and Palaeoclimate. Gondwana 9 : 364-385.

McClelland J 1850. Report of the Geological Survey of India for the season of 1848-49. I. General remarks; II. Geognosy; III. Description of Plates and collection. Geological Survey of India 51-57.

Morris 1840. See appendix in Capt. Grants, C.W. Memoire to illustrate the geological map of Cutch. Translation of Geological Society Series II 5 : 289-329.

Oldham T 1893. The Gondwana System. Manual of Geological Survey of India II · 149-156.

Pascoe EH 1959. A manual of Geology of India and Burma, II 909-1064.

Presl 1838. In Stenburg, C. ver such einer geognostish-botanischen Darstellung der Flora der vorwelt Fasc: 1-8 (1820-38), Leipzig.

Sahni B 1928. Revisions of Indian fossil plant, Part I- Coniferales (Impressions and Incrustations). Memoir Geological Survey of India, Palaeontologia Indica (n. ser.) 11 : 1-45.

Schimper WPh 1870-72. Traite de palaeontologie vegetale du la flore du monde permitit dans es rapports avee les formations geologic et al. actual. Paris 2.

Sharma BD, Surana AC & Singh AP 1971. Jurassic plants from Amarjola in the Rajmahal Hills. Journal of the Palaeontological Society of India 16 : 27-34.

Singh HP 1966. Reappraisal of the mioflora from the Jabalpur Series of India with remarks on the age of the beds. Palaeobotanist 15 : 85-92.

Singh HP 1970. On some species of *Rouseisporites* Pocock, occurring in the Jabalpur Series (Lower Cretaceous) of India. Palaeobotanist 18 : 8-11.

Singh HP & Venkatachala BS 1988. Upper Jurassic-Lower Cretaceous spore pollen assemblages in the peninsular India. Palaeobotanist 36 : 168-176.

Sukh-Dev 1970. Some ferns from the Lower Cretaceous of Madhya Pradesh 1. Palaeobotanist 18 : 197-207.

Sukh-Dev 1988. Floristic zones in the Mesozoic formations and their relative age. Palaeobotanist 36 : 161-167

Sukh-Dev & Zeba-Bano 1978. *Araucaria indica* and two other conifers from the Jurassic –Cretaceous rocks of Madhya Pradesh, India. Palaeobotanist 25 : 495-508.

Zeba-Bano 1980. Some pteridophytes from Jabalpur Formation. Palaeobotanist 26 : 237-247.

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Unisexual flowers from the Deccan Intertrappean Bed of Madhya Pradesh, India

R.K. KAR[1], K. AMBWANI[1], A. SAHNI[2] AND P. SHARMA[1]

[1]*Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.*
[2]*Centre of Advanced Study in Geology, Panjab University, Chandigarh 160 014, India.*

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ABSTRACT

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Unisexual flowers are described for the first time from the Deccan Intertrappean Bed of Mohgaon-Kalan, Chhindwara District, Madhya Pradesh, India. The female flower viz., *Flosfemina intertrappea* is sessile with perianth and unilocular, superior ovary with many ovules. The male flower viz., *Flosvirulis deccanensis* has six perianth parts and six pairs of anther lobes reflecting six stamens. The anthers contain tricolporate, anguloaperturate, laevigate pollen.

Key-words—Unisexual flowers, Deccan Intertrappean, Maastrichtian, India, Angiosperm.

भारत के मध्य प्रदेश प्रान्त के दक्खिनी अन्तर्ट्रेपीय संस्तर से प्राप्त एकलिंगी पुष्पों का अध्ययन

रंजीत कुमार कर, कृष्ण अम्बवानी, अशोक साहनी एवं पूनम शर्मा

सारांश

भारत के मध्य प्रदेश प्रान्त के छिंदवाड़ा जिले के मोहगाँव कलाँ के दक्खिनी अन्तर्ट्रेपीय संस्तर से प्रथम बार एकलिंगी पुष्प अभिवर्णित किए गए हैं। मादा पुष्प, जैसे—*फ्लॉसफेमिना इण्टरट्रेपिया* परिदलपुंज तथा एकको ठकी, अनेक बीजाण्डों युक्त ऊर्ध्ववर्ती अण्डाशय से युक्त अवृन्त है। नर पुष्प, जैसे—*फ्लॉसवाइरुलिस डेक्केनेन्सिस* मे छह परिदलपुंज भाग तथा परागकोशकों के छह जोड़े हैं, जो छह पुंकेसर प्रदर्शित करता है। परागकोशकों में त्रिकॉल्पसी, कोण. द्वारकी, चिकने परागकण विद्यमान हैं।

संकेत शब्द—एकलिंगी पुष्प, दक्खिनी अन्तर्ट्रेपीय, मास्ट्रिशियन, भारत, आवृतबीजी।

INTRODUCTION

THE Deccan Trap in the opinion of Deshmukh (1990) is one of the most extensive and largest flood basalt provinces in the world. It covers roughly an area of 5,00,000 sq km, in central, western and southern India. The lava mass consists of compound and simple flows with a particular pattern of spatial and temporal distribution. The lower 1,200 m thick lava mass of the Western Ghats are made up of compound flows with slow rate of effusion whereas the overlying sequence of flows are of simple nature and were deposited in a quick succession.

The Deccan volcanism is thought to have been a major Cretaceous-Tertiary Boundary event by Courtillot *et al.* (1986, 1988, 1990), Baksi (1987), Duncan & Pyle (1988), Hallam 1988), Sahni & Bajpai (1988), Sahni *et al.* (1996). Sahni (1990) remarked that on the basis of Ar ^{40}/Ar ^{39} dates, it is now presumed that Deccan volcanism was an event of unprecedented magnitude

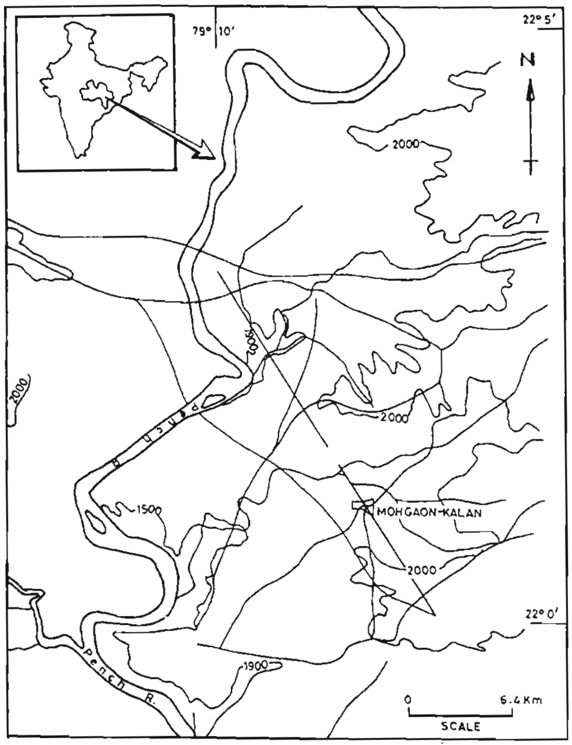

Fig. 1—Showing the village of Mohgaon-Kalan from where the material was collected.

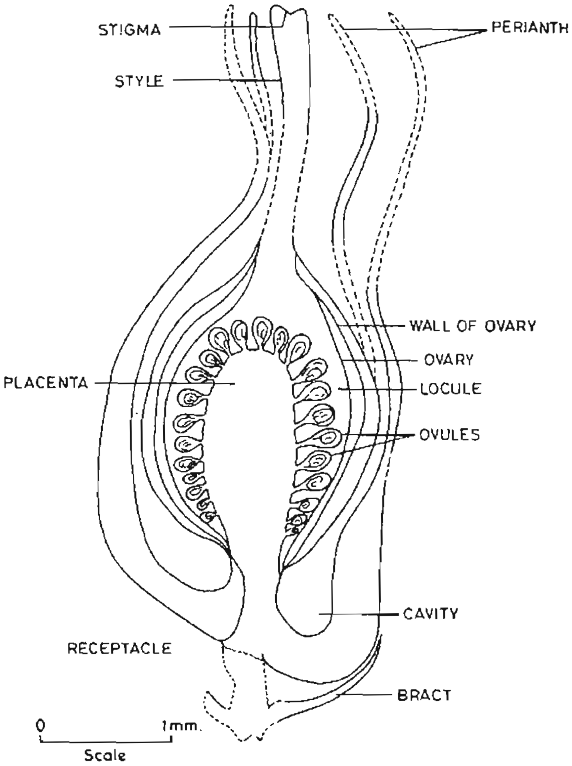

Fig. 2—Showing the various parts in longitudinal section of *Flosfemina intertrappea* sp. nov.

bordering the Cretaceous-Tertiary boundary. The ejection of several thousand tonnes of CO_2, NO_2 and SO_2 should have had a major effect on the biosphere.

According to Sahni (1990), the initial flows of the Deccan exposures, spreading from the west coast marginal basins of Kutch through the central Indian exposures of Madhya Pradesh to those occurring at Krishna-Godavari Basin around Rajahmundhry and marginal offshore deposits of Narsapur, were supposed to be of the quieter, intermittent type with a regional hiatus in which drainage was dammed and lakes developed leading to the abundance of flora and fauna.

Outside India, many fossil angiospermic flowers from Cretaceous are also known. Dilcher & Crane (1984) recovered *Archaeanthus*—an early angiospermic flower from the Cenomanian of the western interior of North America. Takahashi *et al.* (1999a, b) described angiospermic flowers, fruits, seeds, leaf fragments and woods from Ashizawa Formation (Upper Cretaceous) of Japan. The assemblage shows strong similarity to the northern hemisphere flora. Mohr and Friis (2000) noted early angiosperms from the Aptian of Brazil. Friis *et al.* (2001) reported the Nymphaeales from the Early Cretaceous of Portugal. Sun *et al.* (2002) reported Archaefructaceae, a new basal angiosperm family from the Upper Jurassic-Lower Cretaceous of China. They advocate it as an aquatic plant, their reproductive axes lack petals and sepals, the stamens are in pairs below the conduplicate carpels.

GEOLOGICAL SETTING

The volcano-sedimentary exposures of the Deccan Trap are either found below the trap (infratrappean) or in between the two traps (intertrappean). The number of intertrappean/ infratrapppean beds vary from locality to locality. At Mohgaon-Kalan only one Intertrappean Bed is observed, whereas at

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PLATE 1

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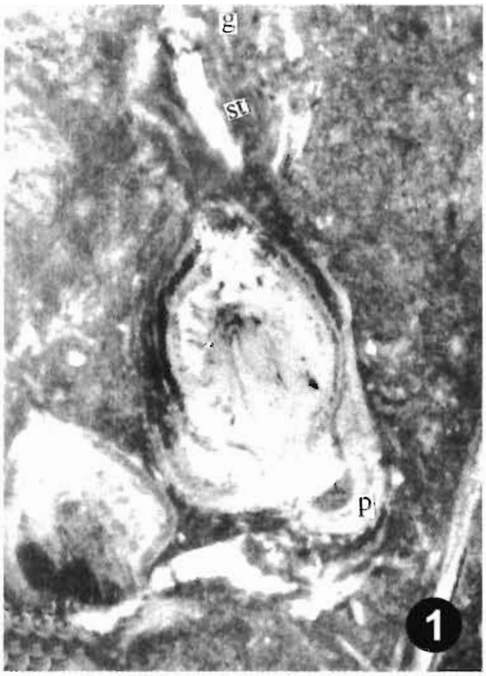
1-2. *Flosfemina intertrappea* sp. nov. in longitudinal sections showing perianth (p), style (st), stigma (g), ovary wall (ow), ovule (o) and the locule (lc). *ca.* x 10.

3. *Flosvirulis deccanensis* sp. nov. showing perianth lobe (p) and anther (ar). *ca.* X 12.

4. Tricolporate pollen in the anther. *ca.* X 300.

5,7 Showing the anther sacs in transverse section (SEM).

6. Showing the basal vascular supply of the flower (SEM).



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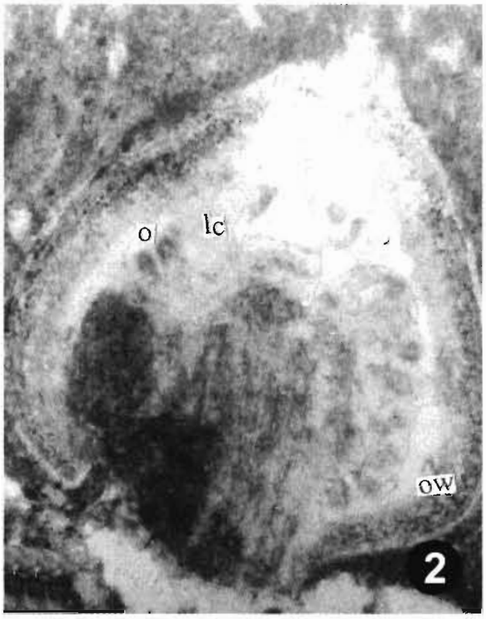

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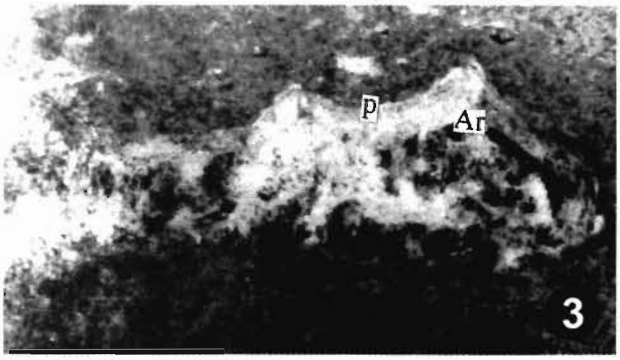

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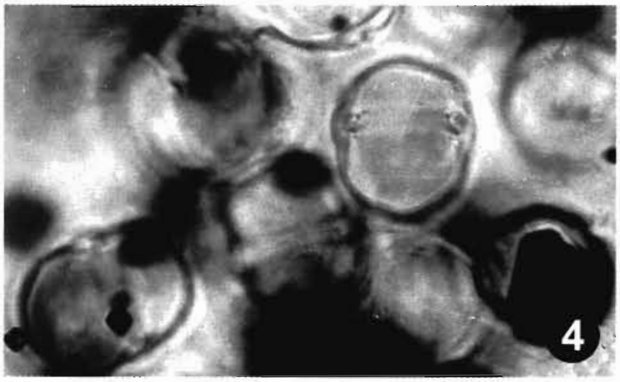

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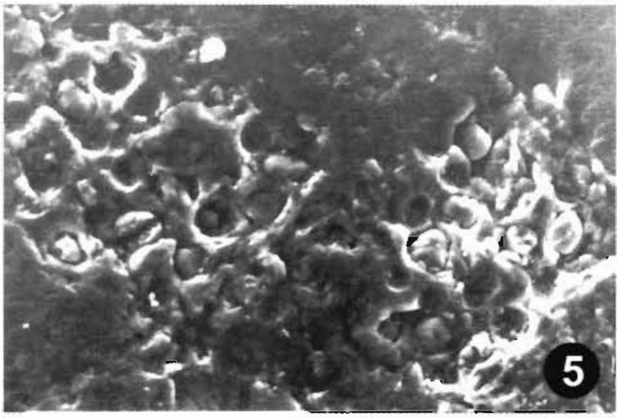

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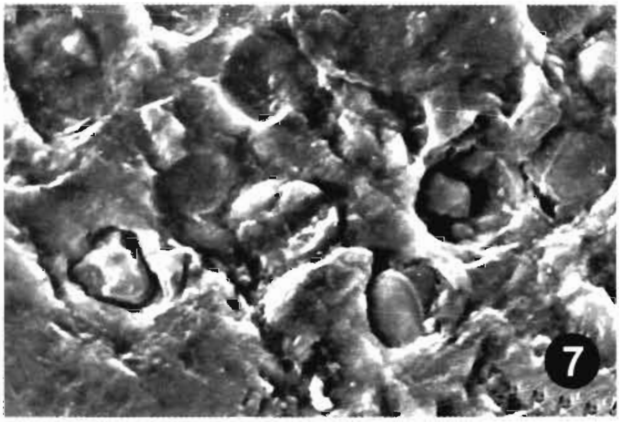

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PLATE 1

Padwar and Ranipur in Jabalpur District at least two intertrappean beds are detected. At Anjar in Kutch District, several intertrappean beds were reported by Ghevariya (1988) and Ghevariya & Srikarni (1990).

The overlying trap flow covers the intertrappean sediments with a sharp contact without evidence of lava having flowed into a water body or even over a wet ground. Deshmukh (1990) remarked that in many intertrappean sediments number of palm fossils were preserved, but no where a mould of fossil palm was observed. He presumed that this provides a suggestion that the intertrappean sediments prior to the deposition of overlying lava flows were completely desiccated with total extinction of biota caused due to extremely hot volcanic effusion.

MATERIAL AND METHODS

A number of chert samples were collected from the village Mohgaon-Kalan (79°11'E : 22°1'N) (Fig. 1). The cherts are well exposed around this village and also at Paladon, Paratwara and Rajalwari covering approximately 10 km. The cherts are hard, compact, cryptocrystalline and consist predominantly of quartz less than 30 µm in size. They are tough, splintery and variously coloured. The chert is found only at the basal part of the intertrappean bed. The thickness of the intertrappean bed is roughly 1 m and this could be ascertained in a number of unlined water wells around the village. The basalmost sediment consists of variegated hard chert of 0·25 m thick containing fresh water pelecypod shells. The topmost unit is carbonaceous and is roughly 0·30 m thick. This has a variety of dinosaur/avian egg shell fragments, ostracodes, molluscs, fishes and wood fragments. The intertrappean sediments are sandwiched between the two basaltic flows.

The chert collected from Mohgaon-Kalan was cut into pieces and fixed on to glass slides by means of Canada Balsam. When dry, the slides were polished using Carborundum powder to the required thinness. The slides were finally mounted with cover glass in Canada Balsam. All the slides are deposited at the repository of the Birbal Sahni Institute of Palaeobotany, Lucknow.

EARLIER RECORD OF FOSSIL FLOWER

Shukla (1944) described *Sahnianthus*—a bisexual angiosperm flower from the chert of Mohgaon-Kalan, Chhindwara District, Madhya Pradesh. Chitaley (1955), Dwivedi and Shukla (1958), Paradkar and Senad (1984) contributed further to the knowledge of *Sahnianthus*. Shukla (1950) instituted *Sahnipushpam*—another bisexual flower from the chert of Mohgaon-Kalan. Verma (1956) proposed *Sahnipushpam shuklai*—the type species for the genus followed by *S. glandulosum* by Prakash (1956) from the same locality. Prakash and Jain (1964) reinvestigated *Sahnipushpam* and made *S. glandulosum* a junior synonym of *S. shuklai*. Chitaley and Kate (1974) described *Deccanthus savitrii*—a bisexual flower from the same locality. Paradkar (1971) proposed *Chitaleypushpam mohgaoense* from Mohgaon-Kalan. Chitaley and Patel (1975) described a new bisexual flower and named it as *Raoanthus*. Lakhanpal *et al.* (1975, 1982), Bande (1993) investigated a monocotyledonous inflorescence. Bonde (1996) reported *Arecoideostrobus*—a palm rachilla from the intertrappean bed.

SYSTEMATICS

Genus—FLOSFEMINA gen. nov.

Type Species—FLOSFEMINA INTERTRAPPEA sp. nov.

Generic Diagnosis—Flowers bracteate, unisexual, 2-5 mm long, 1·8-2 mm broad, with two perianth whorls, perianths extend up to apex of the ovary, probably fused at base. Gynoecium 2-4 mm long, ovary superior, unilocular, ovules many, anatropous, placentation free central, placenta present up to half length of ovary, style long, stigma bifid.

Description—Two bracts observed in L.S. below the base of perianth extending for roughly one third length of flower. Perianth arising from basal part of ovary, lower part swollen, stalk free, some tissue made up of arenchymatous cells could be observed, same cellular structure was also seen as remnant parts of perianth at apical region. Vascular supply extends from basal part of ovary to perianth (Fig. 2).

Ovary unilocular, marginal cells composed of 3-4 layers of thick walled cells, seems to be lignified, stalked, oval with a broad base, ovules many, placenta slender, a central vascular supply within parenchymatous tissue of placenta seen, vascular strands with annular and spiral thickenings, style short, almost surrounded by perianth lobes, style slender, upper part well preserved in one specimen, cells parenchymatous, rectangular in shape, a fine vascular strand observed running longitudinally. Stigma seems to be bifid perhaps due to mechanical injury. Vascular supply occasionally observed reaching up to stigma.

Comparison—*Flosfemina* is readily separated from all the fossil flowers of Deccan Intertrappean by its unisexuality and unilocular ovary with free central placentation. *Sahnianthus* Shukla (1944) is a bisexual, trimerous flower with a tubular calyx, 6-8 locular ovary and axile placentation. *Sahnipushpam* Shukla (1950) is also a bisexual flower in which the receptacle forms a cup like hypanthium enclosing the pentalocular ovary with basal placentation. *Deccananthus* Chitaley and Kate (1974) is bisexual with six perianth parts found in two whorls around a syncarpous, tricarpellary ovary. *Chitaleypushpam* Paradkar (1971) and *Raoanthus* Chitaley and Patel (1975) are also bisexual.

FLOSFEMINA INTERTRAPPEA sp. nov.

(Pl. 1·1-2)

Holotype—Pl. 1·1 Slide No. BSIP 12004.

Type Locality—Mohgaon-Kalan, Deccan Intertrappean, Maastrichtian, Chhindwara District, Madhya Pradesh.

Specific Diagnosis—As for the genus.

Remarks—Flowers observed so far only in L.S. Among dicots, unisexual flowers are present in many families e.g., Casuarinaceae, Piperaceae, Chloranthaceae, Salicaceae, Garryaceae, Leitneriaceae, Betulaceae, Moraceae, etc. So it would be difficult to compare the female flower described here by this character alone. However, unilocular, superior ovary with free central placentation are found mostly in Balanophorales and Primulales (Lawrence, 1951; Cronquist, 1988). Of the Balanophorales, Aristolochiaceae has got bisexual flowers and Rafflesiaceae is either dioecious or monoecious. But the flowers in Rafflesiaceae are very big in size.

The Primulales are generally gamopetalous with pentamerous flowers and are divided into Theophrastaceae, Myrsinaceae and Primulaceae. In Theophrastaceae, the flowers are either bisexual or unisexual but the unilocular ovary is 5 carpelled whereas in the present specimen there is only one carpel. Myrsinaceae has also bisexual or unisexual flowers but the carpels bear 4-6 locules. Primulaceae has only bisexual flowers and the carpels are 5 in number. So the flower described here is not assignable to any known families of angiosperms.

Genus—FLOSVIRULIS gen. nov.

Type Species—FLOSVIRULIS DECCANENSIS sp. nov.

Generic Diagnosis—Perianth lobes six with imbricate aestivation, one lobe overlapped by adjacent two lobes. Six pairs of anther chambers observed within perianth lobes. Pollen grains surrounded by parenchymatous anther wall. Pollen grains subtriangular-subcircular, tricolporate, anguloaperturate, exine up to 2 µm thick, laevigate.

Description—Specimen studied only in T.S., represented by perianth lobes and anthers. Perianth lobes in T.S. distinct, unequal in size, six lobes could be traced; aestivation seems to be imbricate, six pairs of pollen chamber confined within perianth lobes indicate perhaps dithecal nature of anthers, filaments, however not observed in T.S. Each anther lobe contains numerous mature and immature pollen surrounded by anther wall made up of parenchymatous cells. Pollen grains generally subtriangular, sometimes subcircular in shape, some pollen also observed in dyad and tetrad condition, size range 18-25 µm, anguloaperturate, tricolporate, colpi long, narrow, slit-like, pore distinct, less than 2 µm in diameter, exine 1·5-2 µm thick, laevigate.

Comparison—The earlier flowers described from the Deccan Intertrappean beds of India viz., *Sahnianthus* Shukla (1944), *Sahnipushpam* Shukla (1950), *Chitaleypushpam* Paradkar (1971), *Deccananthus* Chitaley and Kate (1974), *Raoanthus* Chitaley and Patel (1975) are all bisexual and hence are readily distinguished from the present unisexual male flower.

FLOSVIRULIS DECCANENSIS sp. nov.

(Pl. 1·3)

Holotype—Pl. 1·3. Slide No. BSIP 12004.

Type Locality—Mohgaon-Kalan, Deccan Intertrappean, Maastrichtian, Chhindwara District, Madhya Pradesh.

Specific Diagnosis—As for the genus.

Remarks—Anguloaperturate, tricolporate pollen grains are found in Apocynacee, Barbeyaceae, Clethraceae, Cneoraceae, Nyssaceae, Strasburgeriaceae, Theaceae, Tiliaceae, Trochodendraceae, Ulmaceae, Verbenaceae, Vitaceae and Vochysiaceae (Erdtman, 1952). However, the pollen grains of these families are not closely comparable to the present genus except *Clethra* of Clethraceae. The pollen of *Clethra* are also anguloaperturate, 15-30 µm in size, tricolporate and the exine is more or less laevigate. But the flowers in Clethraceae are bisexual, the calyx are 5 lobed, imbricate, polypetalous, petals distinct. stamens generally 10 in two whorls (Lawrence, 1951). Hence, *Flosvirulis* proposed here is readily distinguished from Clethraceae in having unisexual flower.

None of the dispersed pollen recovered and illustrarted from the various intertrappean and equivalent beds by Chitaley (1951), Baksi and Deb (1981), Mathur and Sharma (1990), Prakash *et al.* (1990), Bonde and Kumaran (1993), Sahni *et al.* (1996) and Kar and Srinivasan (1998) is comparable to the pollen of this male flower.

Presence of tricolporate pollen in the Maastrichtian of India shows that this type of aperture was prevalent in India, U.S.A. and other countries in that time. Doyle (1969) suggested that the evolution of angiospermic aperture from monosulcates (*Clavatipollenites* type) during Barremian-Aptian to tricolpate and tricolporoidate in Albian. According to him tricolporate with triangular amb evolved in the Cenomanian. Friis *et al.* (1997) reported *Anacostia*—an angiosperm from Early Cretaceous of North America and Portugal with trichotomocolpate/monocolpate pollen. Nair (1968, 1970) on the other hand assumed that trichotomosulcate pollen rather than sulcate pollen represents the basal, primitive pollen type in the Ranales. Walker (1974) advocated that in the ranalean complex, anasulcate pollen gave rise to zonasulcate, trichotomosulcate, ulcerate, catasulcate and inaperturate forms. He postulated that it is from this inaperturate type that the colpate, colporate and porate types evolved.

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REFERENCES

Baksi AK 1987. Critical evaluation of the age of the Deccan Traps. India : Implications for flood-basalt volcanism and faunal extinctions. Geology 15 : 147-150.

Baksi SK & Deb U 1981. Palynology of the Upper Cretaceous of the Bengal Basin. India. Review of Palaeobotany and Palynology 31 : 335-365.

Bande MB 1993. Further observations on the structure and affinities of *Monocotylostrobus bracteatus* Lakhanpal, Prakash & Bande from the Deccan Intertrappean beds of India. Palaeobotanist 42 : 78-85.

Bonde SD 1996. *Arecoideostrobus moarei* nov. a palm rachilla from Deccan Intertrappean beds of India. Palaeobotanist 43 : 102-109.

Bonde SD & Kumaran KPN 1993. A liliaceous inflorescence from the Deccan Intertrappean beds of India. Current Science 65 : 776-778.

Chitaley SD 1951. Fossil microflora from the Mohgaon Kalan beds of Madhya Pradesh, India. Proceedings of the National Institute of Sciences, India 17 : 373-381.

Chitaley SD 1955. A further contribution to the knowledge of *Sahnianthus*. Journal of the Indian Botanical Society 34 121-129.

Chitaley SD & Kate UR 1974. *Deccananthus savitrii*, a new petrified flower from the Deccan Intertrappean beds of India. Palaeobotanist 21 317-320.

Chitaley SD & Patel MZ 1975. *Raoanthus intertrappea* a new petrified flower from India. Palaeontographica 153B 141-149.

Courtillot V, Besse J, Vandamme D, Montingny R, Gaeger JJ & Cappetta H 1986. Deccan flood basalts at the Cretaceous/Tertiary Boundary. Earth and Planetary Science Letters 80 : 361-374.

Courtillot V, Feraud G, Malluski H, Vandamme D, Morean MG & Besse J 1988. Deccan flood basalts and the Cretaceous/Tertiary Boundary. Nature 333 . 843-846.

Courtillot V, Feraud G, Malluski H, Vandamme DJJ & Javoy M 1990. Deccan volcanism at the Cretaceous/Tertiary Boundary : data and inferences. Geological Society of America, Special Paper 247 : 401-409.

Cronquist A 1988. *The evolution and classification of flowering plants*. The New York Botanical Garden, Bronx, New York, USA.

Deshmukh SS 1990. Some aspects of Deccan volcanism in relation to biotic extinctions and Cretaceous-Tertiary Boundary. *In* . Sahni A & Jolly A (Editors)—Cretaceous event stratigraphy and the correlation of the Indian nonmarine stratigraphy. Contributions from the Seminar-cum-Workshop IGCP 216 & 245, Chandigarh : 115-117.

Dilcher DL & Crane PR 1984. *Archaeanthus* : an early angiosperm from the Cenomanian of the western interior of North America. Annals Missouri Botanical Garden 71 : 351-383.

Doyle JA 1969. Cretaceous angiosperm pollen of the Atlantic Coastal plain and its evolutionary significance. Journal of the Arnold Arboretum Harvard University 50 : 1-35.

Duncan RA & Pyle DG 1988. Rapid eruption of the Deccan flood basalts at the Cretaceous-Tertiary Boundary. Nature 333 : 841-843.

Dwivedi JN & Shukla RK 1958. On the pollen grains and pollination of *Sahnianthus parijai* Shukla from the Intertrappean beds of the Deccan. Journal of the Palaeontological Society of India 3 · 105-108.

Erdtman G 1952. Pollen morphology and plant taxonomy Angiosperms (An introduction to Palynology 1). Almqvist & Wiksell, Stockholm.

Friis EM, Crane PR & Pedersen KR 1997. *Anacostia*, a new basal angiosperm from the Early Cretaceous of North America and Portugal with trichotomocolpate/monocolpate pollen. Grana 36 225-244.

Friis EM, Pedersen KR & Crane PR 2001. Fossil evidences of water lilies (Nymphaeales) in the Early Cretaceous. Nature 410 357-360.

Ghevariya ZG 1988. Intertrappean dinosaurian fossils from Anjar area, Kutch District, Gujarat. Current Science 57 . 248-251

Ghevariya ZG & Srikarni C 1990. Anjar Formation, its fossils from Anjar area, Kachchh District, Gujarat. Current Science 57 : 248-251.

Hallam A 1988. A compound scenario for the end-Cretaceous mass extinction. Revista Espanola de Paleontologia no. Extraordinario 7-20.

Kar RK & Srinivasan S 1998. Late Cretaceous palynofossils from the Deccan Intertrappean beds of Mohgaon-Kalan, Chhindwara District, Madhya Pradesh. Geophytology 27 . 17-22.

Lakhanpal RN, Prakash U & Bande MB 1975. An angiospermous inflorescence from the Deccan Intertrappean Series of India. Geophytology 5 · 229-230.

Lakhanpal RN, Prakash U & Bande MB 1982. A monocotyledonous inflorescence from the Deccan Intertrappean beds of India. Palaeobotanist 30 · 316-324.

Lawrence GHM 1951 *Taxonomy of Vascular Plants*. The Macmillan Company, New York.

Mathur YK & Sharma KD 1990. Palynofossils and age of the Ranipur Intertrappean Bed, Gaur River, Jabalpur, M.P. *In* · Sahni A & Jolly A (Editors)—Cretaceous event stratigraphy and the correlation of the Indian nonmarine stratigraphy. Contributions from the Seminar-cum-Workshop, IGCP 216 & 245, Chandigarh : 115-117.

Mohr B & Friis EM 2000. Early angiosperms from the Aptian Crato Formation (Brazil), a preliminary report. International Journal of Plant Sciences Supplement 6 : 155-167.

Nair PKK 1968. A concept on pollen evolution in the "Primitive" angiosperms. Journal of Palynology 4 : 15-20.

Nair PKK 1970. Pollen morphology of angiosperms - a historical and phylogenetical study. Lucknow Publishing House, Lucknow.

Paradkar SA 1971. *Chitaleypushpam mohgaonense*, gen. et sp. nov. from the Deccan Intertrappean beds of India. Silver Jubilee Volume of the Birbal Sahni Institute of Palaeobotany, Lucknow : 77 (Abstract).

Paradkar SA & Senad VA 1984. *Sahnianthus parijai* Shukla - reinvestigated. Fifth Indian Geophytological Conference

Proceedings Symposium and Technical Sessions. The Palaeobotanical Society, Lucknow : 138-146.

Prakash U 1956. On the structure and affinities of *Sahnipushpam glandulosum* sp. nov. from the Deccan Intertrappean Series. Palaeobotanist 4 : 91-100.

Prakash U & Jain RK 1964. Further observations on *Sahnipushpam* Shukla. Palaeobotanist 12 : 128-139.

Prakash T, Singh RY & Sahni A 1990. Palynofloral assemblage from the Padwar Deccan Intertrappeans (Jabalpur), M.P. *In* : Sahni A & Jolly A (Editors)—Cretaceous event stratigraphy and correlation of the Indian nonmarine strata. Contributions from the Seminar-cum-Workshop IGCP 216 & 245, Chandigarh : 68-69.

Sahni A 1990. Recent advances and short-comings in understanding nonmarine Cretaceous basins of India. Proceedings of IGCP 216 & 245 Seminar-cum-Workshop (Chandigarh) : 18-21.

Sahni A & Bajpai S 1988. Cretaceous-Tertiary Boundary events; the fossil vertebrate, palaeomagnetic and radiometric evidences from peninsular India. Journal of the Geological Society of India 32 . 382-396.

Sahni A, Venkatachala BS, Kar RK, Rajanikanth A, Prakash T, Prasad GVR & Singh RY 1996. New palynological data from the Deccan intertrappean beds: implications for the latest record of dinosaurs and synchronous initiation of volcanic activity in India. *In* : Sahni A (Editor)—Cretaceous Stratigraphy and Palaeoenvironments. Memoir Geological Society of India 37 : 267-283.

Shukla VB 1944. On *Sahnianthus*, a new genus of petrified flowers from the Intertrappean beds at Mohgaon Kalan in the Deccan and its relation with the fruit *Enigmocarpon parijai* Sahni from the same locality. Proceedings of the National Academy of Sciences, India 14 : 1-39.

Shukla VB 1950. *Sahnipushpam* gen. nov. and other plant remains from the Deccan Intertrappeans. Palaeobotany in India. Journal of the Indian Botanical Society of India 29 : 29.

Sun G, Ji Q, Dilcher DL, Zheng S, Nixon KC & Wang X 2002. Archaefructaceae, a new basal angiosperm family. Science 296 : 899-904.

Takahashi M, Crane PR & Ando H 1999a. Fossil flower and associated plant fossil from Kamikitaba Locality (Ashizawa Formation, Futaba Group, Lower Coniacian, Upper Cretaceous) of northeast Japan. Journal of Plant Research 112 : 187-206.

Takahashi M, Crane PR & Ando H 1999b. *Esgueiria futabensis* sp. nov., a new angiosperm flower from the Upper Cretaceous (Lower Coniacian) of northeastern Honshu, Japan. Paleontological Research 3 : 81-87.

Verma JK 1956. On a new petrified flower, *Sahnipushpam shuklai* sp. nov. from the Intertrappean beds of Mohgaon-Kalan in the Deccan. Journal of the Palaeontological Society of India 1 131-141.

Walker JW 1974. Aperture evolution in the pollen of primitive angiosperms. American Journal of Botany 61 : 1112-1136.

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First occurrence of fossil paraphyses resembling *Acrostichum* Linn. from the Lalitpur Intertrappean sediments (Palaeocene), Uttar Pradesh, India

RATAN KAR AND R.S. SINGH

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.

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ABSTRACT

Kar Ratan & Singh RS 2003. First occurrence of fossil paraphyses resembling *Acrostichum* Linn. from the Lalitpur Intertrappean sediments (Palaeocene), Uttar Pradesh, India. Palaeobotanist 52(1-3) : 81-85.

A new microfossil of paraphyses viz., *Lithoparaphysis paproensis* gen. et sp. nov. recovered from the Lalitpur Intertrappean bed (Palaeocene) is described here. This fossil species closely resembles the paraphyses of *Acrostichum aureum* Linn., a mangrove fern, and is found in association with the Palaeocene marker spore-pollen taxa.

Key-words—Paraphyses, *Acrostichum*, Deccan Intertrappean, Palaeocene, Lalitpur and Uttar Pradesh.

भारत के उत्तर प्रदेश प्रान्त के ललितपुर अन्तर्ट्रेपीय अवसादों (पेलियोसीन) से प्राप्त *एक्रोस्टिकम* लिन के सदृश अश्मित सहसूत्रों की प्रथम प्राप्ति

रतन कर एवं रमाशंकर सिंह

सारांश

प्रस्तुत शोध पत्र में ललितपुर अन्तर्ट्रेपीय संस्तर से खोजे गए सहसूत्रों के एक नवीनतम सूक्ष्म पादपाश्म *लिथोपैराफाइसिस पापरोएन्सिस* वंश नव प्रजाति का वर्णन अभिप्रेत है। यह अश्मित प्रजाति *एक्रोस्टिकम ऑरियम* लिन नामक मैंग्रोव फ़र्न के सहसूत्रों के निकटस्थ सदृश है तथा यह पेलियोसीन सूचक बीजाणु परागकण वर्गकों के साथ साहचर्य में पाई गई है।

संकेत शब्द—सहसूत्र, *एक्रोस्टिकम,* दक्खिनी अन्तर्ट्रेप, पेलियोसीन, ललितपुर तथा उत्तर प्रदेश।

INTRODUCTION

PARAPHYSES are sterile hairs growing mostly around the reproductive structures in some algae, fungi, bryophytes and pteridophytes often of very characteristic forms (Usher, 1966; Brown, 1966). In *Funaria* (Bryales, Bryophyta) they are very conspicuous and comprises row of cells tapering at the base and swollen at the apex (Campbell, 1918). *Cibotium chamiss* of Cyatheaceae exhibits numerous long hair like paraphyses in the sporangium (Bower, 1963). In Ascomycetes (Fungi), vegetative hyphae grow among the ascogonium as slender paraphyses during the development of asci (Cook,

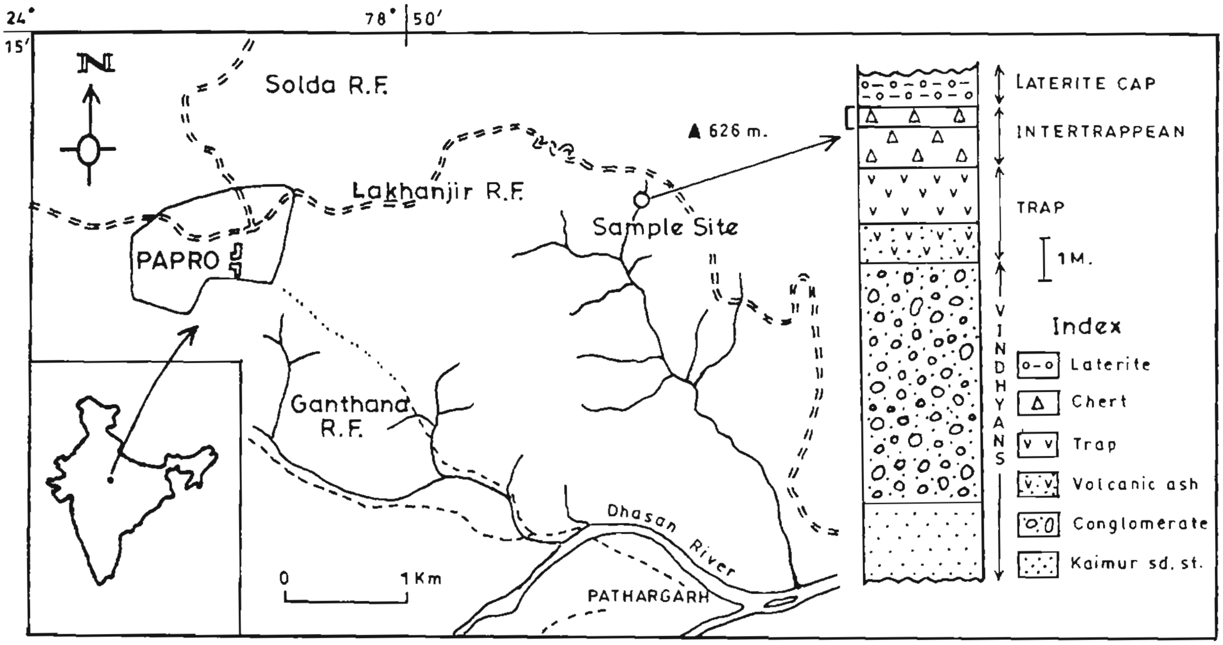

Fig. 1—Map showing the locality and lithology of the Intertrappean exposures near the village Papro, Lalitpur District, U.P.

1966). *Acrostichum aureum* Linn. has somewhat globose, irregularly lobed paraphyses while *Acrostichum danaeifolium* Long. & Fisch. possesses less lobed ones-these characters of paraphyses are considered as one of the distinguishing parameters of the above two species (Tryon & Tryon,1982).

GEOLOGY OF THE AREA

The Lalitpur Intertrappean beds are exposed on two *nalas* 3 km north-east of Papro Village (Long. 78°48'20": Lat. 24°14'; Toposheet No. 54L/16; Fig. 1). The basal most part of the section consists of Kaimur Sandstone of Vindhyan age, which is overlain by approximately six meters of loosely cemented conglomerates with volcanic ash. It is overlain by about one meter of white, loose, volcanic ash. One to one and half meters of Deccan Trap lies on the ash bed and is overlain by one meter of grey and half meter of black chert respectively, containing organic detritus, ostracodes and gastropods. The sequence is capped by a laterite cover. Kumar *et al.* (1980) recorded *Lymnaea, Physa* and different species of *Chara* from the black chert and advocated an Eocene age for this bed. Recently, Singh and Kar (2002) recovered a spore-pollen assemblage from these Intertrappean beds and assigned it a Palaeocene age on the basis of marker species.

MATERIAL AND METHODS

The black and grey chert along with embedded organic detritus were macerated in hydrofluoric acid (40%) and then washed in potassium hydroxide solution (5%). The slides were made by smearing a drop of maceral and polyvinyl alcohol on a cover-slip and mounted in Canada balsam. The slides are

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PLATE 1

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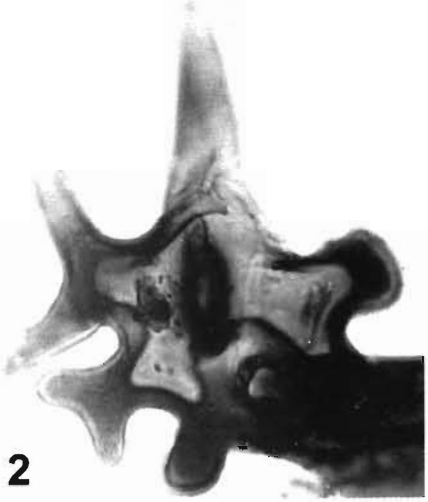
1. *Lithoparaphysis paproensis* gen. *et* sp. nov. (Holotype) recovered from the Lalitpur Intertrappean bed, *ca.* x 500. Slide No. BSIP 12594, E.F no. G-37/3.
2. Isotype, *ca* x 500, Slide No. BSIP 12594, E.F. No. F-18/3.
3. Showing morphological variation *ca* x 500, Slide No. BSIP 12594 E.F. No. D-12/2.
4. A part of the holotype *ca* x 1000, showing the nature and ornamentation of lobes.
5. Specimen showing weak striation in the lobes, *ca* x 500. Slide No. BSIP 12596 , E.F. No. N-20.
6. A part of the above, *ca* x 1000. Note the grana in the lobes.

7, 8. Comparatively smaller sized specimens, *ca* x 500. Slide Nos BSIP 12595 E.F. No. L-17/2 and BSIP 12596, E.F. No. X-38 respectively.

9-12. Extant paraphyses of *Acrostichum aureum* Linn. *ca.* x 500, observed in the pollen preparations from specimen growing in Sunderban delta, West Bengal, India.


1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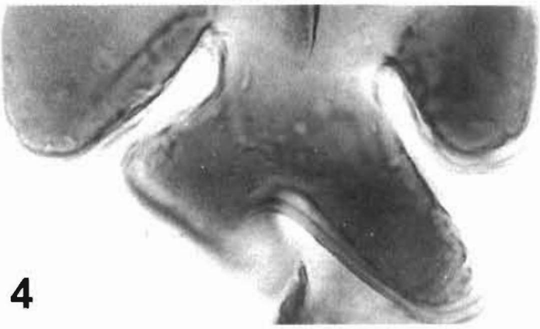
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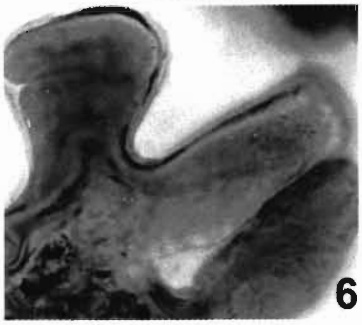
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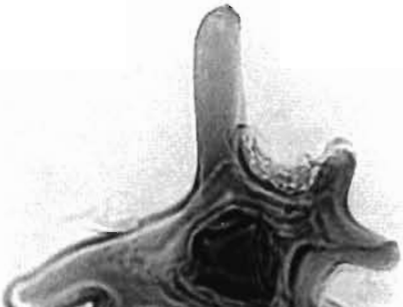
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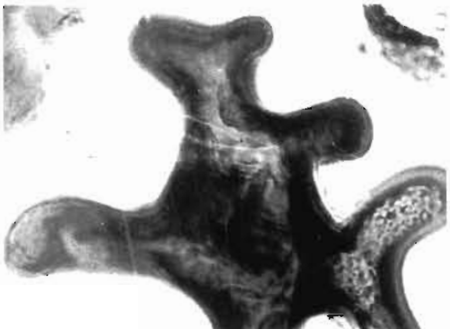
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PLATE 1

deposited at the repository of Birbal Sahni Institute of Palaeobotany, Lucknow, India.

PALYNOLOGICAL ASSEMBLAGE

An assemblage comprising *Phragmothyrites eocenica, Inapertusporites kedvesii, Cyathidites minor, Todisporites major, Dandotiaspora dilata, Dandotiaspora pseudoauriculata, Spinizonocolpites echinatus* and *Lakiapollis ovatus* was recorded. A Palaeocene age was ascribed to this assemblage by Singh and Kar (2002) due to the presence of *Dandotiaspora dilata, D. pseudoauriculata, Spinizonocolpites echinatus* and *Lakiapollis ovatus*. Besides, numerous paraphyses were also observed in the slides along with these taxa, which is the subject matter of this paper .

SYSTEMATICS

Genus—LITHOPARAPHYSIS gen. nov.

(Pl. 1·1-8)

Generic Diagnosis—Paraphyses unicellular, 60-120 µm in size; possessing 5-8 robustly built, finger-like, sometimes bifurcating projections, 20-60 µm in size. Surface of the paraphyses mostly smooth but sometimes weakly ornamented, with a few grana or weakly striated.

Remarks—The new genus instituted here closely resembles the paraphyses of the genus *Acrostichum* Linn. in its gross morphology and more particularly to those of *Acrostichum aureum* Linn.

Type Locality, Horizon & Age—Papro Village, Lalitpur District, U.P., Deccan Intertrappean, Palaeocene.

Genotype—Lithoparaphysis paproensis sp. nov. Pl. 1·1, 4; Slide no. BSIP 12594, E.F. no. G-37/3.

Derivation of name—The generic name is derived from the terms 'litho' and 'paraphyses'. Litho indicates rock whereas paraphyses refers to the sterile body associated with the reproductive structure.

LITHOPARAPHYSIS PAPROENSIS sp. nov.

(Pl. 1·1-8)

Specific Diagnosis—Paraphyses 60-120 µm, strongly built, star-shaped due to 5-8 finger-like projections radiating from all sides, projections robust, not of same size, one particularly bigger than rest, broad at base, tapering at tip, mostly smooth, sometimes a few grana or striations present.

Comparison—Lithoparaphysis paproensis sp. nov. was compared with the fossil and living forms of various plant groups. It was observed that these are remarkably similar to the paraphyses of extant *Acrostichum aureum* Linn. (Pl. 1·9-12) in its morphology, in size range (60-120 µm), number (5-8) and length of projections (20-60 µm). In addition, the bifurcating habit of projections is also similar in both the population. These observations led to the assumption that the fossil paraphyses reported here belong to *Acrostichum aureum* Linn.

Type Locality, Horizon & Age—Papro Village, Lalitpur District, U.P., Deccan Intertrappean, Palaeocene.

Holotype—Pl. 1·1, 4; Slide no. BSIP 12594, E.F. no. G-37/3.

Derivation of name—The species is named after the village Papro, Lalitpur District, Uttar Pradesh, India, from where the fossils were collected.

DISCUSSION

Acrostichum aureum Linn. is placed in the family Pteridaceae and has the unique distinction of being the only pteridophyte which has pan tropical distribution in mangrove swamps (Blasco, 1975; Chapman, 1975). It is a rhizomatous, erect, pinnate plant growing up to the height of two meters. The upper pinnae of this plant are fertile and smaller in size than the lower, sterile pinnae. This plant is known to grow luxuriantly in the tidal brackish water of India and Bangladesh (Rao & Sastry, 1974; Rao *et al*., 1973). The fossil spores resembling the modern *Acrostichum* are described as *Acrostichumsporites* Kar and are known from the Early Palaeocene sediments of India and Late Palaeocene of Senegal, West Africa (Kar, 1992; Caratini *et al.*, 1991).

The Intertrappean beds were deposited during the quiescence phase of successive Deccan volcanic eruptions (Late Cretaceous-Early Palaeocene) under lacustrine conditions. The occurrence of paraphyses resembling those of *Acrostichum aureum* in the Lalitpur Intertrappean bed indicates that there was some sort of salinity associated with the lake around which this plant was growing. Megafossil and microfossil remains of *Nypa*, (a mangrove palm) and marine algae are also known from the other intertrappean localities in Madhya Pradesh (Sahni & Rode, 1937; Bande *et al*., 1981; Kar *et al.*, 1998) strengthening the supposition that brackish water conditions were prevalent in at least some lakes of the Deccan Trappean province. Recently Bonde & Kumaran (2002) described a megafossil, bearing stem, petioles and roots from the Deccan Intertrappean beds of Nawargaon, Wardha District, Maharashtra, as *Acrostichum intertrappeum*. Occurrence of this *Acrostichum* corroborates our study indicating existence of back water conditions during Intertrappean depositional times.

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REFERENCES

Bande MB, Prakash U & Bonde SD 1981. Occurrence of *Peyssonnela* and *Distichoplax* in the Deccan Intertrappean, with remarks on the age of Chhindwara Traps and Palaeogeography. Geophytology 11 : 182-188.

Blasco F 1975. The mangroves of India. Institute Francais de Pondicherry. Travaux de la Section Scientifique et Technique 14 : 1-175.

Bonde SD & Kumaran KPN 2002. A permineralized species of mangrove fern *Acrostichum* L. from Deccan Intertrappean beds of India. Review of Palaeobotany and Palynology 120 : 285-299.

Bower FO 1963. The Ferns (Filicales) Vol. I. Today & Tomorrow's Book Agency, New Delhi 238-239.

Brown WH 1966. The Plant Kingdom. Vakils, Feffer and Simmons Pvt. Ltd., Bombay : 543.

Campbell DH 1918. The structure and development of Mosses and Ferns. Macmillan Company, New York : 11.

Caratini C, Kar RK, Sarr R, Tissot C & Venkatachala BS 1991. Palaeocene palynoflora from Walalane boreholes, Senegal. Palaeoecology Africa 22 : 123-133.

Chapman V 1975. Mangrove biogeography, Proceeding International Symposium Biology of Mangrove (Walsh G *et al.* editors). Institute of Food and Agricultural Science University of Florida 1 : 3-22.

Cook CDK 1966. Aquatic and wetland plants of India. Oxford University Press, Oxford : 27.

Kar RK 1992. Occurrence of *Acrostichum* spores from the Langpar Formation, Early Palaeocene of Meghalaya. Geophytology 21 : 33-35.

Kar RK, Sahni A, Ambwani K & Singh RS 1998. Palynology of Indian onshore-offshore Maestrichtian sequences in India: implication for correlation and palaeogeography. Indian Journal of Petroleum Geology 7 : 39-49.

Kumar S, Singh MP & Singh SN 1980. Lithostratigraphy, age and palaeogeography of the newly discovered Intertrappeans, Lalitpur District, Uttar Pradesh. Geophytology 10 : 72-80.

Rao TA, Mukherjee AK & Banerjee LK 1973. Is *Acrostichum aureum* L., truly a mangrove fern. Current Science 42 : 456-457.

Rao TA & Sastry ARK 1974. An ecological approach towards classification of coastal vegetation of India II. Estuarine border vegetation. Indian Forestry 100 : 438-452.

Sahni B & Rode K 1937. Fossil plants from the Intertrappean beds of Mohgaon Kalan, in the Deccan, with a sketch of the Chhindwara District. Proceeding of National Academy of Sciences, India 7 : 165-174.

Singh RS & Kar RK 2002. Paleocene palynofossils from the Lalitpur Intertrappean beds, Uttar Pradesh, India. Journal of the Geological Society of India 60 : 213-216.

Tryon RM & Tryon AF 1982. Fern and allied Plants. Springer-Verlag, New York : 348-354.

Usher G 1966. A Dictionary of Botany. Constable & Company Ltd., London : 265.

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Palynological investigation and environmental interpretation on Akli Formation (Late Palaeocene) from Barmer Basin, western Rajasthan, India

S.K.M. TRIPATHI[1], U.K. SINGH[2] AND M.S. SISODIA[2]

[1]*Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.*
[2]*Department of Geology, J.N.V. University, Jodhpur 342 005, India.*

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ABSTRACT

Tripathi SKM, Singh UK & Sisodia MS 2003. Palynological investigation and environmental interpretation on Akli Formation (Late Palaeocene) from Barmer Basin, western Rajasthan, India. Palaeobotanist 52(1-3) : 87-95.

Akli Formation of Barmer Basin, mainly a claystone, shale and lignite sequence, is divided into two members viz., Thumbli Member and Kapurdi Fuller's earth Member. Palynological studies on samples from the Thumbli Member exposed near Barmer, western Rajasthan were carried out and a rich palynological assemblage constituted by dinoflagellate cysts, fungal remains, pteridophytic spores and angiospermic pollen was recorded from shale and lignite samples. The assemblage is dominated by angiospermic pollen which are assigned to the families Arecaceae, Liliaceae, Oleaceae, Caesalpiniaceae, Rubiaceae, Meliaceae, Myricaceae, Onagraceae and Lamiaceae. Palynotaxa having affinity with Arecaceae are abundant indicating deposition of sediments in coastal environment. Many pteridophytic spores and abundant fungal remains in the assemblage indicate warm and humid climate with high precipitation. Presence of dinoflagellate cysts indicates marine influence.

Most of the families represented in the assemblage are presently confined to tropical to subtropical areas. Considering the high frequency of *Nypa/Nypa*-like pollen in the assemblage it is inferred that sediments were deposited in an area which was fringed by thick vegetation of mangrove chiefly constituted by *Nypa*.

Key-words—Palynology, Palaeoenvironment, Akli Formation, Late Palaeocene, Western Rajasthan (India).

भारत के पश्चिमी राजस्थान की बाड़मेर द्रोणी के अकली शैलसमूह (अन्तिम पेलियोसीन) का परागाणविक अन्वेषण तथा पर्यावरणीय निर्वचन

सूर्यकान्तमणि त्रिपाठी, यू.के. सिंह एवं एम.एस. सिसोदिया

सारांश

बाड़मेर द्रोणी का अकली शैलसमूह, मूलतः मृत्तिका प्रस्तर, शेल तथा लगुडांगार अनुक्रम है, को दो सदस्यों, थुम्बली सदस्य तथा कापुर्डी फुलर के मृदा सदस्य में विभाजित किया गया है। पश्चिमी राजस्थान के बाड़मेर के समीप अनावरित थुम्बली सदस्य से प्राप्त नमूनों का परागाणविक अध्ययन किया गया तथा शेल एवं लगुडांगार नमूनों से घूर्णीकशाभ पुटियों,

कवकीय अवशेषों, टेरिडोफाइटी बीजाणुओं तथा आवृतबीजी परागकणों द्वारा निर्मित एक सम्पन्न परागाणविक समुच्चय अंकित किया गया। इस समुच्चय में आवृतबीजी परागकणों की प्रधानता है, जो एरीकेसी, लिलिएसी, ओलिएसी, सीज़ेलपिनेसी, रूबिएसी, मीलिएसी, माइरिकेसी, ओनाग्रेसी तथा लेमिएसी कुलों से संदर्भित हैं। एरीकेसी से सन्दर्भनीय परागाणु वर्गक प्रचुरता में हैं, जो तटीय पर्यावरण में अवसादों का निक्षेपण इंगित करते हैं। समुच्चय में अनेक टेरिडोफाइटी बीजाणु तथा प्रचुर कवकीय अवशेष उच्च वर्षण के साथ उष्ण तथा आर्द्र जलवायु इंगित करते हैं। घूर्णीकशाभ पुटियों की उपस्थिति समुद्री प्रभाव का संकेत करती है।

समुच्चय में निरूपित अधिकांश कुल वर्तमान में उष्णकटिबन्धीय से उपोष्ण कटिबन्धीय क्षेत्र में संवितरित हैं। समुच्चय में *नाइपा/नाइपा* की भाँति के परागकणों की उच्च आवृत्ति के आधार पर यह अनुमानित किया जाता है कि अवसाद एक ऐसे क्षेत्र में निक्षेपित थे, जो मुख्यतः *नाइपा* द्वारा निर्मित मोटी मैंग्रोव वनस्पतियों द्वारा किनारों पर अवस्थित था।

संकेत शब्द—परागाणुविज्ञान, पुरापर्यावरण, अकली शैलसमूह, अन्तिम पेलियोसीन पश्चिमी राजस्थान ;भारतद्ध.

INTRODUCTION

THE sedimentary sequences in north-western Rajasthan are predominantly intracratonic type and cover an area of about 1,20,000 sq km. These sediments are part of the western Rajasthan Shelf and are subdivided into several basins viz., Jaisalmer Basin, Barmer Basin, Bikaner-Nagaur Basin and Sanchore Basin. The Barmer Basin, mainly constituted by Middle Jurassic to Early Eocene sediments, are mostly covered under extensive desert sand. Exposed in central part of the Barmer Basin, the Akli Formation is made up of sand-poor bentonitic claystone, grey bituminous claystone, shale and lignite. This formation is divided into two members viz., Thumbli Member and Kapurdi Fuller's earth Member. Altogether 17 samples from Thumbli Member representing claystone, shale and lignite were analysed for the palynological studies. Out of these, two shale samples and one lignite sample yielded palynofossils. The recovered assemblage has been described and an attempt has been made to determine the palaeovegetation and depositional environment.

GEOLOGY OF THE BARMER BASIN

The Barmer Basin is a narrow N-S trending graben and is a north extension of Cambay rift (Sisodia, 1996; Sisodia & Singh, 2000). Peripheries of the Barmer Basin are constituted by the faults exposed at Fatehgarh on Barmer Hills near Barmer and at Sarnu. These faults are the result of the break up of the Indian craton during Late Cretaceous-Early Palaeocene time. Considering this rifting as a major event in the history of Barmer Basin, sediments of this basin are classified into pre-rift, syn-rift and post-rift sediments (Fig. 2). These sediments were deposited on Late Proterozoic Malani Igneous Suit.

The pre-rift sediments are represented by : 1. siliceous facies comprising shale, sandstone and orthoquartzite (Randha Formation), 2. calcareous facies comprising limestone, phosphorites and dolomudstone (Birmaria Formation), 3. the thinning and fining upward sand bodies with intervening red siltstone (Sarnu Formation) and 4. the medium to coarse grained, fining up ward fluvial sands with fossil logs (Lathi Formation).

The syn-rift sediments are exposed at Barmer and Fatehgarh (Fig. 1) representing Barmer-Hill and Fatehgarh formations. The Barmer-Hill Formation, exposed along the western boundary of basin at N25° 45' : E71° 24', rests unconformably on the basement. The Barmer Hill Formation is comprised of sandstone and clast-supported conglomerate representing rapid deposition in an alluvial fan environment with source from Malani Rhyolite. The Fatehgarh Formation, exposed at the northern boundary of the basin at N26° 26' : E71° 12', shows a mixed sand and mud tidal-flat environment

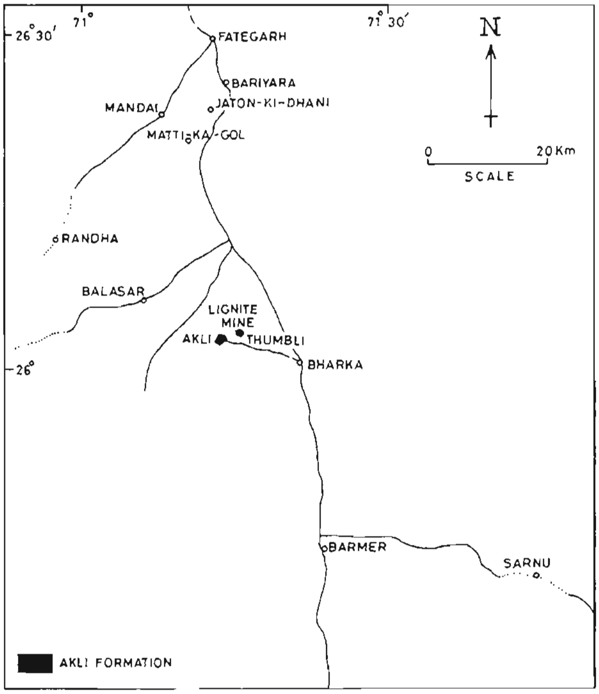

Fig. 1—Location map of the Barmer Basin (after Sisodia & Singh, 2000).

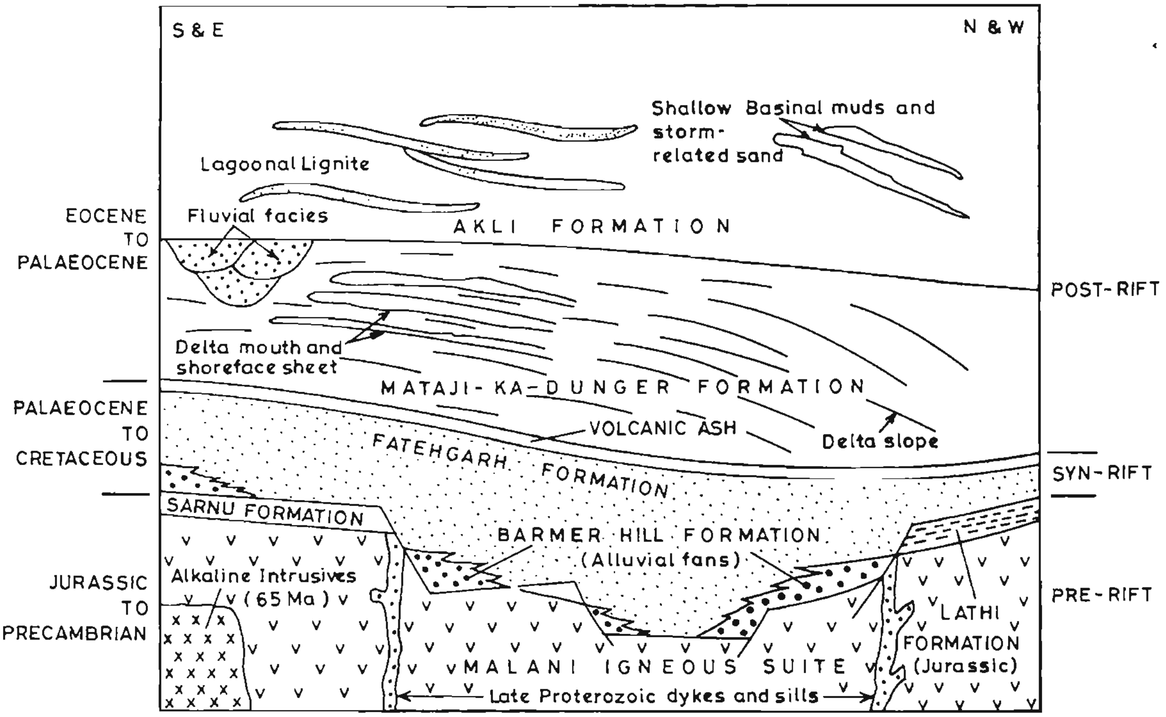

Fig. 2—Lithostratigraphy of Barmer Basin (after Sisodia & Singh, 2000).

and is comprised of conglomerate at base which is overlain by sandstone. The Fatehgarh Formation is overlain by Siliceous Earth of Bariyara Member (base of Mataji-ka-Dungar Formation).

The post-rift sediments representing Mataji-ka-Dungar and Akli formations largely fill the Barmer Basin. Mataji-ka-Dungar Formation is exposed at the northern end and margins of the basin at N26°06' : E71°12'; N26°24' : E71°12' and N26°13' : E71°15'. The Akli Formation overlies the Mataji-ka-Dungar Formation and is made up of sand-poor bentonitic claystone, grey bituminous claystone, light yellow claystone and lignites. It is exposed at the central part of the basin. The Akli Formation is divisible into two members: Thumbli-shale Member and Kapurdi Fuller's earth Member. The measured thickness of Akli Formation is about 35 m in Thumbli lignite mine. At Thumbli (N26°03' : E71°15') these beds are arranged in 2-3 m thick cycles commencing with bentonite followed with bituminous claystone and ending up with lignite. The top of the Akli Formation is covered by dune sand and gravel.

The base of Akli Formation in Thumbli mine is represented by shale which has burrows and nodules. The soft greyish shale often contains leaf impressions and fossil woods. The upper horizons of shale are mixed with bentonite which also contains fossil woods. The lignite is grey-black in colour, friable and occurs as lenses. The bentonite is 10-12 m thick, poorly bedded and pale blueish-grey in colour. It is provided with ferruginous nodules, chert and phosphate cores. The bentonite beds dip 35°-40° to SW. Montmorillonite is major component mineral in bentonite and silt content is generally 1-2%. Lithostratigraphy of the Barmer Basin is given in Fig. 2.

Previous palynological works in Rajasthan Basin

Palynological reports from Rajasthan Basin are meagre and are chiefly confined to the description of recorded palynotaxa only. These studies have been taken up in Barmer (Bose, 1952; Jain *et al.*, 1973; Naskar & Baksi, 1978; Tripathi, 1994, 1995, 1997), Bikaner (Singh & Dogra, 1988; Kar, 1995, 1996a; Ambwani & Singh, 1996; Kar & Sharma, 2001) and Palana beds (Rao & Vimal, 1950, 1952; Sah & Kar, 1974). Due to non-availability of palynostratigraphical information from these sediments interrelationship of these sediments is less understood. However, Singh and Dogra (1988), considering the distribution of palynotaxa vis-a-vis marine fauna, attempted to correlate Palaeocene sequences of Rajasthan Basin with other strata of the same age in India. Palynological assemblage from five bore-holes drilled near Kapurdi and Jalipa in Barmer District were described by Tripathi (1994, 1995). Continuing these studies Tripathi (1997) established two informal palynozones in two of these bore-hole sequences and

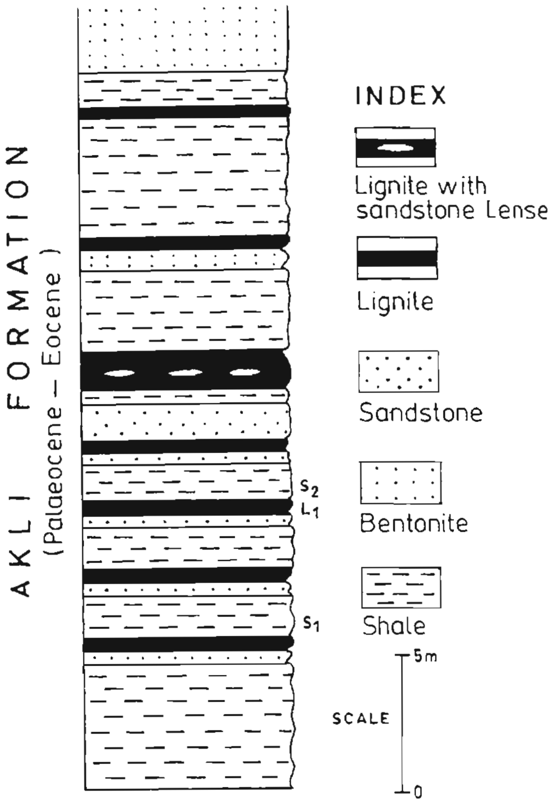

Fig. 3—Stratigraphical Section of Akli Formation at Thumbli Lignite Mine and sample position.

demarcated Palaeocene and Eocene sediments. Kar and Sharma (2001) carried out palynostratigraphical studies on subsurface Late Palaeocene and Early Eocene sediments of Bikaner-Nagaur Basin, Rajasthan.

PRESENT STUDY

Rock samples for the present study were collected from the Akli Formation which is mainly made up of bentonite, shale and lignite sequences. In all 17 samples were collected and processed for the recovery of palynofossils, of which, two shale samples S-1 and S-2 and one lignite samples L-1 (Fig. 3) proved productive. Good suits of palynofossils represented by algal cysts, fungal remains, pteridophytic spores and angiospermic pollen were recovered from the two shale samples. Angiospermic pollen are dominant in the assemblage and are followed by pteridophytic spores. Dinoflagellate cysts are few in number and have not been included in the present communication. The assemblage from lignite sample is not rich and is mainly constituted by monosulcate palm pollen. In the assemblage 5 genera and 6 species belong to fungi, 5 genera and 7 species belong to pteridophytic spores and 16 genera and 29 species belong to angiospermic pollen.

PALYNOLOGICAL ASSEMBLAGE

The assemblage is noticeably dominated by monosulcate pollen appearing to be related to the family Arecaceae. Of these, four species have been assigned to *Spinizonocolpites*. These forms are related to modern brackish water Palm *Nypa*. The pollen grains of *Nypa* are characteristic in possessing an extended sulcus parallel to the polar axis (meridionosulcate) and a spinose exine. Shape and size of spines are quite variable. Inter-spinal area is smooth to microreticulate. Besides these, the assemblage is also richly represented by two species of *Kapurdipollenites* viz., *K. gemmatus* and *K. baculatus* and one species of *Retiverrumonosulcites* viz., *R. barmerensis*. These two genera had earlier been reported from Late Palaeocene subsurface samples of Barmer, Rajasthan (Tripathi, 1994). Other pollen genera in the assemblage which also show affinity with Arecaceae are *Proxapertites, Palmidites* and *Palmaepollenites*.

Species attributed to *Spinizonocolpites* are spheroidal to ovoidal in shape, possess an extended sulcus and are provided with a spinose exine. Size of pollen ranges between 50-70 µm. Shape and size of spines (5-15 µm) are variable being straight to slightly curved at the tip and may exhibit a bulbous base. Inter-spinal area is smooth to reticulate. The two species of *Kapurdipollenites* are also spherical to ovoidal in shape, possess an extended sulcus and range in size between 65-70 µm. Exine in these forms is provided with variety of sculptural elements like verrucae, gemmae, clavae and baculae. Both of these species possess an extended sulcus like that in *Spinizonocolpites* and appear to be related to *Nypa*. Studies suggest that fossil *Nypa* plants either produced pollen with more variable exine ornamentation or more species/varieties constituted this genus which probably produced pollen described under *Kapurdipollenites*.

The genus *Retiverrumonosulcites* is spherical to oval in shape, 45-58 µm in size and possesses single sulcus which is not extended. The sulcal margins are thickened. Exine is microreticulate and is provided with clavae or verrucae of varying size. Verrucae are 2-5 µm in diameter whereas the clavae are 7-20 µm long and 5-10 µm in diameter at the distal part. Morphological features of this genus strongly suggest that these pollen may also belong to plants of the family Arecaceae.

The list of recorded palynotaxa is given below.

Fungal remains :
Dicellaesporites popovii Elsik, 1986
D. minutus Kar & Saxena, 1976
Diporicellaesporites pluricellus Kar & Saxena, 1976
Diporisporites elongatus van der Hammen, 1954
Pluricellaesporites planus Trivedi & Verma, 1973
Inapertisporites kedvesii Elsik, 1968
Pteridophytic spores :
Lygodiumsporites eocenicus Dutta & Sah, 1970
L. lakiensis Sah & Kar, 1969

TAXA	SAMPLE NUMBER		
	S-1	S-2	L-1
Lygodiumsporites eocenicus	o	o	
L. lakiensis	o	o	
Todisporites kutchensis	+		
Dandotiaspora dilata	x	o	
D. telonata		o	
Foveotriletes pachyexinous	o		
Arecipites bellus		o	
Palmidites plicatus		o	o
P. naviculus	o	o	
P. ovatus	o		o
P. kutchensis	o	+	
Spinizonocolpites echinatus	o	+	
S. baculatus		o	o
S. prominatus	o	o	
S. adamanteus		o	
Retimonosulcites ovatus		o	
Matanomadhiasulcites maximus	o	o	
M. microreticulatus	o	+	
Proxapertites assamicus	o		
P. microreticulatus	+	x	
Kapurdipollenites baculatus	o	x	
K. gemmatus	o	+	
Retiverrumonosulcites barmerensis	+	+	
Clavadiporopollenites raneriensis	o	o	
Acanthotricolpites bulbospinosus	o	o	o
A. kutchensis	o	o	
A. complexus	o		
Tricolpites baculatus	o		
Grevilloidaepites eocenicus	o		
Fungal remains	+	+	
Dinoflagellate cysts	o	o	

o < 10%, + 11-20%, x 21-30%

Fig. 4—Frequency of palynotaxa.

Todisporites kutchensis Sah & Kar, 1969
Dandotiaspora dilata (Mathur) Sah *et al.*, 1971
D. telonata Sah *et al.*, 1971
Lycopodiumsporites palaeocenicus Dutta & Sah, 1970
Foveotriletes pachyexinous Dutta & Sah, 1970

Angiospermic pollen :

Arecipites bellus Sah & Kar, 1970
Palmidites plicatus Singh in Sah & Singh, 1974
P. naviculus Kar & Saxena, 1981
Palmaepollenites eocenicus (Biswas) Sah & Dutta, 1966
P. kutchensis Venkatachala & Kar, 1969
P. nadhamunii Venkatachala & Kar, 1969
P. ovatus Venkatachala & Kar, 1969
Spinizonocolpites echinatus Muller, 1968
S. baculatus Muller, 1968
S. prominatus (McIntyre) Stover & Evans, 1972
S. adamanteus Fredriksen, 1994
Retimonosulcites ovatus (Sah & Kar) Kar, 1985
Matanomadhiasulcites maximus (Saxena) Kar, 1985
M. microreticulatus (Dutta & Sah) Kar & Kumar, 1986
Incrotonipollis burdwanensis (Baksi *et al.*) Jansonius & Hills, 1981
Proxapertites assamicus (Sah & Dutta) Singh, 1975
P. cursus Hoeken-Klinkenberg, 1966
P. microreticulatus Jain *et al.*, 1973
Kapurdipollenites baculatus Tripathi, 1994
K. gemmatus Tripathi, 1994
Retiverrumonosulcites barmerensis Tripathi, 1994
Clavadiporopollenites raneriensis Ambwani & Singh, 1996
Acanthotricolpites bulbospinosus Singh & Misra, 1991
A. kutchensis (Venkatachala & Kar) Singh & Misra, 1991
A. complexus Singh & Misra, 1991
Tricolpites baculatus Kar & Jain, 1981
Grevilloideaepites eocenica Biswas emend. Singh & Misra, 1991
Ocimumpollenites indicus Kar, 1996
Kielmeyerapollenites eocenicus Sah & Kar, 1974

Quantitative analysis of palynoflora

In two shale samples S-1 and S-2 two hundred specimens were counted to determine the frequency of spores and pollen whereas, in lignite sample L-1 due to less productivity only one hundred specimens were counted. Angiospermic pollen share 48% of the total assemblage whereas pteridophytic spores are represented by 30%. Frequency of dinoflagellate cysts (6%) and fungal remains (16%) was counted as groups only (Fig. 4).

Most dominant taxa in sample S-1 are: *Lygodiumsporites eocenicus, Todisporites kutchensis* and *Dandotiaspora dilata*. Other abundant forms in this sample are *Proxapertites cursus* and *Retiverrumonosulcites barmerensis*. In the sample S-2 the palynotaxa present in high frequency are: *Spinizonocolpites echinatus, Matanomadhiasulcites microreticulatus, Proxapertites cursus, P. microreticulatus, Kapurdipollenites gemmatus* and *Retiverrumonosulcites barmerensis*. Palynological assemblage from the lignite sample L-1 is very poor and is constituted by only few pollen having affinity with the family Palmae.

PALYNOFLORAL COMPARISON

Present assemblage is closely comparable with those recorded from Palaeocene-Eocene sediments of Rajasthan (Tripathi, 1994, 1995, 1997; Kar & Sharma, 2001), Kutch (Kar, 1978, 1985; Saxena, 1981) and Indus Coal Region, Pakistan (Frederiksen, 1994).

Comparison with known Rajasthan palynological assemblages

The palynological assemblages described from samples of bore-holes drilled near Jalipa and Kapurdi in Barmer District, Rajasthan (Tripathi, 1994, 1995) are very similar to the present assemblage as in both of these occurrence of different species of *Kapurdipollenites, Retiverrumonosulcites, Acanthotricolpites* and *Spinizonocolpites* has been noticed in high frequency.

Palynoassemblages of Assemblage Zone-A from subsurface Late Palaeocene sediments of two bore-holes MK 327 and MK 332 drilled near Kapurdi in Barmer District, Rajasthan, (Tripathi, 1997) resemble closely with the present assemblage. Palynotaxa common between the two assemblages are: *Dandotiaspora dilata, D. telonata, Proxapertites assamicus, P. microreticulatus, Palmidites plicatus, P. naviculus, Spinizonocolpites echinatus, Retimonosulcites ovatus* and *Matanomadhiasulcites maximus*.

Present palynological assemblage is also comparable with that recorded by Kar and Sharma (2001) from Late Palaeocene part of the bore-hole BH-125 drilled near Bithnok, Bikaner, Rajasthan as both the assemblages show presence of *Dandotiaspora dilata, Proxapertites cursus, Spinizonocolpites baculatus* and *Ocimumpollenites indicus*. However, many arecaceous pollen such as *Kapurdipollenites baculatus, K. gemmatus* and *Retiverrumonosulcites barmerensis* occurring in high frequency in the present assemblage are missing in the Bithnok bore-hole assemblage.

Comparison with Kutch palynoflora

Resemblance between the present assemblage and that from Matanomadh Formation of Kutch is striking. Forms common between *Dandotiaspora dilata* Cenozone (Saxena, 1981) and *Neocouperipollis brevispinosus* Cenozone (Saxena, 1981) of Matanomadh Formation of Kutch and the present assemblage are: *Dandotiaspora dilata, D. telonata, Lygodiumsporites eocenicus, L. lakiensis, Palmaepollenites eocenicus, P. kutchensis* and *P. nadhamunii*. Forms recorded from the above mentioned two cenozones of Matanomadh Formation but absent in the present assemblage are: *Tricolpites minutus, Trilatiporites, Sonneratiopollis* and *Lakiapollis*. The present assemblage exhibits high frequency of *Spinizonocolpites*, a pollen which is absent in the Matanomadh Formation assemblage. Two species of *Acanthotricolpites* viz., *A. bulbospinosus* and *A. kutchensis* (= *Couperipollis kutchensis*) described from subsurface Tertiary sediments of Kutch (Venkatachala & Kar, 1969) are abundant in the present assemblage.

Comparison with Pakistan palynoflora

Late Palaeocene assemblage from core-hole samples of the Lower Indus coal region, Pakistan (Frederiksen, 1994) resembles with the present assemblage in exhibiting common occurrence of different species of *Spinizonocolpites, Proxapertites cursus* and *Matanomadhiasulcites maximus*.

AGE CONSIDERATIONS

Indian Palaeocene sequences are marked with the presence of *Dandotiaspora dilata, Lycopodiumsporites* spp., *Neocouperipollis* spp., *Proxapertites* spp., *Spinizonocolpites* spp., *Palmidites* spp. and *Kielmeyerapollenites* in high frequency (Singh, 1977; Saxena, 1980,1988; Tripathi & Singh, 1984; Kar, 1985; Kar & Kumar, 1986; Tripathi, 1995, 1997; Kar & Sharma, 2001). In Eocene these forms either dwindle or disappear and the sequences are marked with other dominant palynofossils (Kar, 1992). Age determination and recognition of Palaeocene and Eocene sediments based on ranges of palynotaxa alone is therefore rather difficult. However a few attempts have been made to define these sequences in the Rajasthan Basin also (Singh & Dogra, 1988; Tripathi, 1997).

Based on palynological studies Singh and Dogra (1988) identified five zones in Palaeocene to Early Eocene sequences

Families	Palynotaxa	Present day distribution
Osmundaceae	*Todisporites kutchensis*	cosmopolitan
Matoniaceae	*Dandotiaspora dilata, D. telonata*	cosmopolitan
Lycopodiaceae	*Lycopodiumsporites palaeocenicus, Foveotriletes pachyexinous*	cosmopolitan
Schizaeaceae	*Lygodiumsporites eocenicus, L. lakiensis*	tropical-subtropical
Arecaceae	*Palmidites plicatus, P. naviculus, Palmaepollenites eocenicus, P. kutchensis, P. nadhamunii, Proxapertites assamicus, P. cursus, P. microreticulatus, Spinizonocolpites baculatus, S. prominatus, S. adamenteus, S. echinatus, Kapurdipollenites baculatus, K. gemmatus, Arecipites bellus, Retiverrumonosulcites barmerensis*	tropical-subtropical
Liliaceae	*Retimonosulcites ovatus*	cosmopolitan
Oleaceae	*Tricolpites baculatus*	chiefly tropical
Guttiferae	*Kielmeyerapollenites eocenicus*	tropical
Lamiaceae	*Ocimumpollenites indicus*	tropical
Onagraceae	*Grevilloideaepites eocenica*	cosmopolitan

Fig. 5—Palynotaxa with present-day distribution of related families.

of Bikaner Basin, Rajasthan. Of these, the two lower zones viz., SP-1 and SP-2 represent Early Palaeocene, SP-3 and SP-4 zones represent Late Palaeocene and SP-5 zone represents Early Eocene. Many palynotaxa recorded in SP-3 and SP-4 zones have been recorded during the present study. These are: *Dandotiaspora* spp., *Lygodiumsporites lakiensis, Proxapertites* spp., *Kielmeyerapollenites eocenicus* and *Palmidites plicatus*. Palynological studies on bore-hole samples drilled near Kapurdi and Jalipa in Barmer District, Rajasthan also indicate presence of Palaeocene and Eocene sediments (Tripathi, 1995) and considering the palynotaxa distribution and frequency Late Palaeocene and Early Eocene sediments were demarcated in two bore-hole sequences (MK 327 and MK 332) of Kapurdi, Barmer (Tripathi, 1997). The lignite sequences in these bore-holes were dated as Late Palaeocene and have yielded *Dandotiaspora* spp., *Lycopodiumsporites* spp., *Matanomadhiasulcites* spp. *Proxapertites* spp. *Spinizonocolpites* spp. and *Palmidites* spp. Presence of these pollen in high frequency characterizes a Late Palaeocene age (Kar, 1996b, Tripathi, 1997). In the present assemblage different species of *Dandotiaspora, Proxapertites, Spinizonocolpites* and *Matanomadhiasulcites* are registered in high frequency. Considering the known ranges and frequencies of these palynotaxa in the assemblage the studied sequence is dated as Late Palaeocene in age.

PALAEOCLIMATE, PALAEOECOLOGY AND ENVIRONMENT OF DEPOSITION

Majority of angiospermic families represented in the assemblage (Schizaeaceae, Arecaceae, Oleaceae, Lamiaceae and Guttiferae) are tropical to subtropical in present day distribution. Other families (Osmundaceae, Matoniaceae, Lycopodiaceae, Liliaceae and Onagraceae) are cosmopolitan in distribution. Palynotaxa assigned to these families along with their present day distribution is summarised in Fig. 5. Temperate elements are completely missing in the assemblage. Abundance of pteridophytic spores and fungal elements indicate a tropical flora in the vicinity of deposition site. Dinoflagellate cysts in the assemblage indicate marine influence.

Characteristic elements of the present palynoflora are pollen having affinity with extant plants of *Nypa* suggesting that it was an important component of the vegetation. These are *Spinizonocolpites* spp., *Proxapertites* spp., *Kapurdipollenites* spp., *Retiverrumonosulcites barmerensis* and *Clavadiporopollenites raneriensis*. The genus *Nypa*, represented by one extant species *N. fruticans*, is a mangrove palm growing in tidal mud flats fringing the tidal reaches of large fresh water rivers. Presence of these pollen are very useful in interpreting the sedimentary environment as this genus has a low pollen productivity (Muller, 1964; Frederiksen, 1985) and its occurrence, even in low frequency, may indicate a good representation of this genus in the extant vegetation. Presence of these pollen further suggests monsoonal conditions. Considering the high frequency of *Nypa/Nypa*-like pollen in the assemblage it is inferred that deposition of sediments took place in an area which was fringed by thick vegetation of mangrove chiefly constituted by *Nypa*.

Chaloner (1968) suggested that large *Nypa* pollen are not transported to long distances towards the sea from the mangrove environment. Present assemblage is rich in large-sized *Nypa*-like pollen suggesting that the site of deposition, in all probability, was a mangrove swamp. These inferences are in conformity with the conclusions drawn by Pole and Macphail (1996) and Pole (1998), who on the basis of abundant pollen *Spinizonocolpites prominatus*, suggested existence of mangrove forest at the beginning of Eocene in some basins of Tasmania.

Proxapertites, based on the morphological features, has been interpreted to represent an extinct group of palms which were possibly related to *Nypa* (Muller, 1968). *Proxapertites* and *Nypa* pollen both had a pantropical distribution and have been recorded in high frequency in deltaic and shallow marine sediments (Muller, 1979; Mandal, 1986; Kar & Kumar, 1986; Tripathi, 1997; Kar & Sharma, 2001). The genus *Acanthotricolpites*, possibly related with *Nypa* (Venkatachala *et al.*, 1986), is also recorded in good number in the assemblage.

Different species of *Proxapertites, Palmaepollenites, Palmidites* and *Arecipites bellus* in the assemblage clearly indicate a coastal area close to the site of deposition. Pteridophytic spores and other angiospermic elements in the assemblage were driven to the site of deposition through the river channels. Marine influence at the time of deposition is evidenced by the presence of dinoflagellate cysts in the assemblage. Good representation of fungal remains suggests warm and humid conditions with high precipitation.

Sedimentological studies, supporting the palynological inferences, indicate that the sequence from which samples were collected was deposited in the flood plain with marine incursions (Sisodia & Singh, 2000). These conclusions were drawn on the basis of the inferred channel fill sedimentation and fining upward nature of each lignite cycle in the Akli Formation. The dominant bentonitic claystone facies of this formation represent low energy shallow basinal sedimentation. Occasional thin sandstone beds and siltstone within claystone show that the basin was periodically interrupted by flood events.

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REFERENCES

Ambwani AK & Singh RS 1996. *Clavadiporopollenites raneriensis* gen. et sp. nov. from the Tertiary sediments of Bikaner District, Rajasthan, India. Palaeobotanist 43 : 139-142.

Bose MN 1952. Plant remains from Barmer District, Rajasthan. Journal of Scientific and Industrial Research 11B : 85-190.

Chaloner WG 1968. The palaeoecology of fossil spores. *In* : Drake ET (Editor)—Evolution and Environment : 125-138.

Frederiksen NO 1985. Review of Early Tertiary sporomorph ecology. American Association of Stratigraphic Palynology Contribution Series Number 15 : 1-91.

Frederiksen NO 1994. Middle and late Palaeocene angiosperm pollen from Pakistan. Palynology 18 : 91-137.

Jain KP, Kar RK & Sah SCD 1973. A palynological assemblage from Barmer, Rajasthan. Geophytology 3 : 150-165.

Kar RK 1978. Palynostratigraphy from Naredi (Lower Eocene) and Harudi (Middle Eocene) formations in the district of Kutch, India. Palaeobotanist 25 : 161-178.

Kar RK 1985. Fossil floras of Kutch- IV. Tertiary palynostratigraphy. Palaeobotanist 34 : 1-280.

Kar RK 1992. Stratigraphical implications of Tertiary palynological succession in north-eastern and western India. Palaeobotanist 40 : 336-344.

Kar RK 1995. Diporocolpis: a new type of aperture from the Early Eocene sediments of Rajasthan, India. Palaeobotanist 42 : 380-386.

Kar RK 1996a. On the origin of *Ocimum* (Lamiaceae) : a palynological approach. Palaeobotanist 43 : 45-50.

Kar RK 1996b. Late Cretaceous and Tertiary palynological succession in India. Palaeobotanist 45 : 71-80.

Kar RK & Kumar M 1986. Palaeocene palynostratigraphy of Meghalaya. Pollen et Spores 28 : 177-217.

Kar RK & Sharma P 2001. Palynostratigraphy of Late Palaeocene and Early Eocene sediments of Rajasthan, India. Palaeontographica Abt. B 256 : 123-157.

Kedves M 1969. Palynological studies on Hungarian Early Tertiary Deposits. Akademiai Kiado, Budapest.

Lukose NG 1974. Palynology of subsurface sediments of Manhera-Tibba Structure, Jaisalmer, western Rajasthan, India. Palaeobotanist 21 : 285-297.

Mandal JP 1986. Palynological study of Sutunga coal seam, Jaintia Hills, Meghalaya. Palaeobotanist 35 : 196-199.

Muller J 1964. A palynological contribution to the history of mangrove vegetation in Borneo. *In* : Cranwell LM (Editor)—Ancient Pacific Floras, the Pollen story : 33-42, University of Hawaii Press, Honolulu.

Muller J 1968. Palynology of the Pedawan and Plateau Sandstone Formations (Cretaceous-Eocene) in Sarawak, Malaysia. Micropaleontology 14 : 1-37.

Mullar J 1979. Reflections on fossil palm pollen. *In* : Bharadwaj DC (Editor)—Proceedings of 4th International Palynological Conference 1 : 568-578. Birbal Sahni Institute of Palaeobotany, Lucknow.

Naskar P & Baksi SK 1978. Palynological investigation of Akli lignite, Rajasthan. Palaeobotanist 25: 314-319.

Pole MS. 1998. Early Eocene estuary of Strahan. Australian Journal of Earth Science 45 : 979-985.

Pole MS & Macphail MK 1996. Eocene *Nypa* from Regatta Point, Tasmania. Review of Palaeobotany and Palynology 92 : 55-67.

Rao AR & Vimal KP 1950. Plant microfossils from Palana lignite (Eocene), Bikaner. Current Science 19 : 82-84.

Rao AR & Vimal KP 1952. Tertiary pollen from lignites of Palana (Eocene), Bikaner. Proceedings of National Institute of Science, India 18 : 595-601.

Sah SCD & Kar RK 1974. Palynology of the Tertiary sediments of Palana, Rajasthan. Palaeobotanist 21 : 163-188.

Saxena RK 1980. Palynology of the Matanomadh Formation in type area, north-western Kutch, India (Part 3) - Discussion. Palaeobotanist 26 : 279-296.

Saxena RK 1981. Stratigraphy of the area around Matanomadh in North-western Kutch with special reference to the Matanomadh Formation. Palaeobotanist 27 . 300-313.

Saxena RK 1988. Significance of spores and pollen grains in Palaeocene biostratigraphy. *In* : Maheshwari HK (Editor)—Proceedings of the Symposium on Palaeocene of India: limits and subdivisions, Lucknow, 1986 : 68-82. Indian association of Palynostratigraphers, Lucknow.

Singh A & Misra BK 1991. A new spinose monosulcate genus *Spinomonosulcites* and an emendation of spinose porate *Acanthotricolpites*. Review of Palaeobotany and Palynology 67 : 217-227.

Singh RY 1977. Stratigraphy and palynology of the Tura Formation in the type area- Part II (Descriptive palynology). Palaeobotanist 23 : 189-205.

Singh RY & Dogra NN 1988. Palynological zonation of Palaeocene of India with special reference to western Rajasthan *In* : Maheshwari HK (Editor)—Palaeocene of India : Proceedings of the Symposium on Palaeocene of India: Limits and subdivisions 1986: 51-64. Indian Association of Palynostratigraphers, Lucknow.

Sisodia MS 1996. Lithostratigraphy of the Barmer Basin. Seminar on Geological evolution of western Rajasthan, Jodhpur, India. Abs. : 54-55.

Sisodia MS & Singh UK 2000. Depositional environment and hydrocarbon prospects of Barmer Basin, Rajasthan, India. North American Free Trade Association 9 : 309-326.

Tripathi SKM 1994. New angiosperm pollen from subsurface Early Palaeogene sediments of Barmer District, Rajasthan, India. Palaeobotanist 42 : 61-65.

Tripathi SKM 1995. Palynology of subsurface Palaeogene sediments near Kapurdi, Barmer District, Rajasthan, India. Palaeobotanist 43 : 45-53.

Tripathi SKM 1997. Palynological changes across subsurface Palaeocene-Eocene sediments near Barmer, Rajasthan, India. Palaeobotanist 46 :168-171.

Tripathi SKM & Singh HP 1984. Palynostratigraphical zonation and correlation of Jowai-Sonapur Road Section (Palaeocene-Eocene), Meghalaya, India. *In* : Tiwari RS, Awasthi N, Srivastava SC, Singh HP & Sharma BB (Editors)—Proceedings of the 5th Indian Geophytological Conference, Lucknow, 1983, Special Publication : 316-328. The Palaeobotanical Society, Lucknow.

Venkatachala BS & Kar RK 1969. Palynology of the Tertiary sediments of Kutch-1. Spores and pollen from bore hole no. 14. Palaeobotanist 17 : 157-178.

Venkatachala BS, Saxena RK, Singh HP, Kar RK, Tripathi SKM, Kumar M, Sarkar S, Singh RS, Mandaokar BD & Ambwani K 1986. Indian Tertiary angiosperm pollen : A critical assessment. Palaeobotanist 42 : 106-138.

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Palynology of the Baratang Formation, Andaman-Nicobar Islands and the significance of reworked palynomorphs

J. MANDAL, A. CHANDRA AND ANANTA P. BHATTACHARYYA

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.

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ABSTRACT

Mandal J, Chandra A & Bhattacharyya AP 2003. Palynology of the Baratang Formation, Andaman-Nicobar Islands and the significance of reworked palynomorphs. Palaeobotanist 52(1-3) : 97-112.

Spores-pollen and dinoflagellate cysts data from five sections of the Baratang Formation (Baratang Island) are analysed. The record of stratigraphic potential forms indicates an Early to Late Eocene age for the recovered assemblages. The palynoassemblages from this Formation are also associated with the reworked palynofossils belonging to Permian, Triassic and Jurassic-Cretaceous ages. The reworked taxa dominate over the poorly represented Eocene palynomorphs and have Gondwanic affinity. A comparison of Tertiary palynoflora of Baratang with Assam and Myanmar demonstrate the presence of some palynotaxa in all the areas but common occurrence of significant taxa such as *Retitrisyncolpites, Baculimonocolpites* and *Lanagiopollis (regularis)* shows more close relationship between Andaman and Myanmar flora than Assam. The recycled palynomorphs of Gondwanic affinity have provided valuable clue to locate the source and direction of sediments. Various views relating to provenance of reworked palynomorphs have been analysed on the basis of present data which suggest that Chindwin Basin of Myanmar mainly supplied reworked palynomorphs containing sediments. The palynological, palaeocurrent and lithological evidences do not support the origin of reworked elements from Wharton Basin, Assam Basin or autochthonous (Triassic) sediments.

Key-words—Palynology, Eocene, Baratang Formation, Reworked fossils.

अण्डमान-निकोबार द्वीप समूह के बारातांग शैलसमूह का परागाणु विज्ञान तथा पुनः करित परागाणु रूपों की प्रासंगिकता

जगन्नाथ प्रसाद मण्डल, अनिल चन्द्रा एवं अनन्त प्रसाद भट्टाचार्य

सारांश

बारातांग़ द्वीपसमूह के बारातांग शैलसमूह के पाँच अनावरित परिच्छेदों से प्राप्त स्तरिकीय बीजाणु-परागकण एवं घूर्णीकशाभ पुटीय आंकड़े प्रारंभिक से अन्तिम इओसीन आयु इंगित करते हैं। इस शैलसमूह का परागाणु समुच्चय परमियन, ट्रायसिक तथा जुरासिक क्रिटेशस आयु से सम्बन्धित सम्मिश्र वनस्पतिजात निरूपित करता है। पुनः चक्रित वर्गक में गोण्डवाना से निकटता पायी गयी हैं, जो इओसीन परागाणु रूपों में अधिक मात्रा में प्राप्त होते है। असम तथा मयनमार के टर्शियरी परागाणु वनस्पतिजात के साथ अण्डमान की वनस्पतिजातपरक तुलना करने पर प्रदर्शित होता है कि महत्त्वपूर्ण वर्गकों जैसे—*रेटिट्राइसिनकोलपाइटीज़, बाक्यूलीमानोकोलपाइटीज़, लैनेजियोपोलिस* (*रेगुलेरिस*) की प्रायः उपस्थिति असम की तुलना में अण्डमान तथा मयनमार वनस्पतिजात के मध्य अधिक निकटस्थ सम्बन्धन प्रदर्शित करती है। परागाणविक

आँकड़े इंगित करते हैं कि मयनमार की छिंदविन द्रोणी के आस-पास का क्षेत्र स्थलीय तथा समुद्री परागाणु पादपाश्मों का उद्गम स्थल था। आश्मिक, पुराधारापरक तथा पुराभौगोलिक प्रमाण इस निष्कर्ष की पुष्टि करते हैं।

संकेत शब्द—परागाणुविज्ञान, इओसीन, बारातांग शैलसमूह, पुनः चक्रित पादपाश्म.

INTRODUCTION

THE Andaman-Nicobar groups of islands are a part of Sunda Arc system that extends from Myanmar (Burma) to Sumatra. The sediments in these islands occur in two sets of exposures. The chain of north, middle and south Andamans including Baratang forms the primary island part and the other set is the small islands lying on east and west of the main chain. The primary chain of islands ranges in age from Late Cretaceous to Oligocene while the peripheral chain of islands is Neogene in age. The sediments of main Andaman islands are deep-sea flysch sediments, which were deposited through turbidity currents (Karunakaran *et al.*, 1964; Pandey, 1972; Pandey *et al.*, 1992). These flysch sediments are classified into two formations, namely the Baratang and the Port Blair formations (Chatterjee, 1967) with an unconformable junction. The Baratang sediments are mainly argillaceous and can be easily differentiated from the overlying arenaceous Port Blair Formation.

The marine fossils are meagre to absent in the flysch sequences of the main islands. Occasionally, the flysch sediments yield palynofossils as these sediments predominantly consist of land-derived clastics containing a variety of palynodebris. The palynological study is therefore, important for dating and correlation of these islands. The present work reports the result of palynological investigation of Baratang Island for deciphering the age of sediments, relationship of flora with neighbouring areas and to deduce the provenance of reworked palynomorphs.

PREVIOUS PALYNOLOGICAL WORK

The palynological data from the flysch–turbidites of Andaman-Nicobar Basin are few and are confined to the Middle Andaman and Baratang islands. Banerjee (1966) first recorded palynoflora of Port Blair Formation from Baratang Island. However, Jafar and Tripathi (2001) pointed out that this section actually belongs to Baratang Formation. A variety of angiosperm palynofossils were documented by Banerjee (1966) and he deduced a Palaeogene age by comparing this palynoassemblage with that of Assam. In subsequent publication, Banerjee, 1967 described an Upper Cretaceous palynoflora from the Middle Andaman and he compared this assemblage with the assemblages from Assam, Bengal and Krishna-Godavari basins. The palynoflora from the upper part of Baratang Formation, Middle Andaman (Mathur & Mathur, 1980) closely resembles with palynoassemblages of Laisong and Burdwan formations of Assam and Bengal basins respectively. Late Triassic terrestrial palynomorphs and dinoflagellate cysts were also documented from Middle Andaman (Sharma & Mehrotra, 1984; Sharma & Sarjeant, 1987). Mandal *et al.* (1994) recovered Early Eocene palynofossils from Middle Andaman and concluded that the assemblage compares grossly with those from Indian mainland and is closely similar to the Early Eocene flora of Myanmar. The mud of Mud volcano ooze from Baratang Island has yielded spores, pollen and dinoflagellate cysts and the rich assemblage consisted of palynomorphs belonging to Late Cretaceous to Oligocene (Mandal *et al.*, 1996). Recently Jafar and Tripathi (2001) reported Late Triassic mixed Late Cretaceous palynoassemblage from the Middle Andaman.

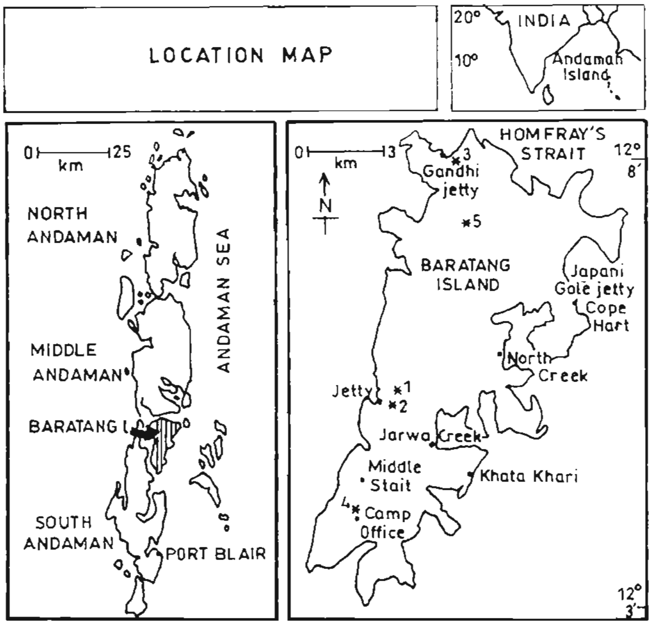

Fig. 1—Map of Baratang Island showing the locations of sections marked as * (Map adopted from Rajsekhar *et al.*, 1990).

It is therefore clear that palynofossils have been recorded only from the Baratang Formation of the main Andaman islands and the recorded assemblages do not resemble closely to each other. This dissimilarity may be due to difference of facie or interval time of deposition. However, the assemblages have one common feature in containing recycled palynomorphs of different ages.

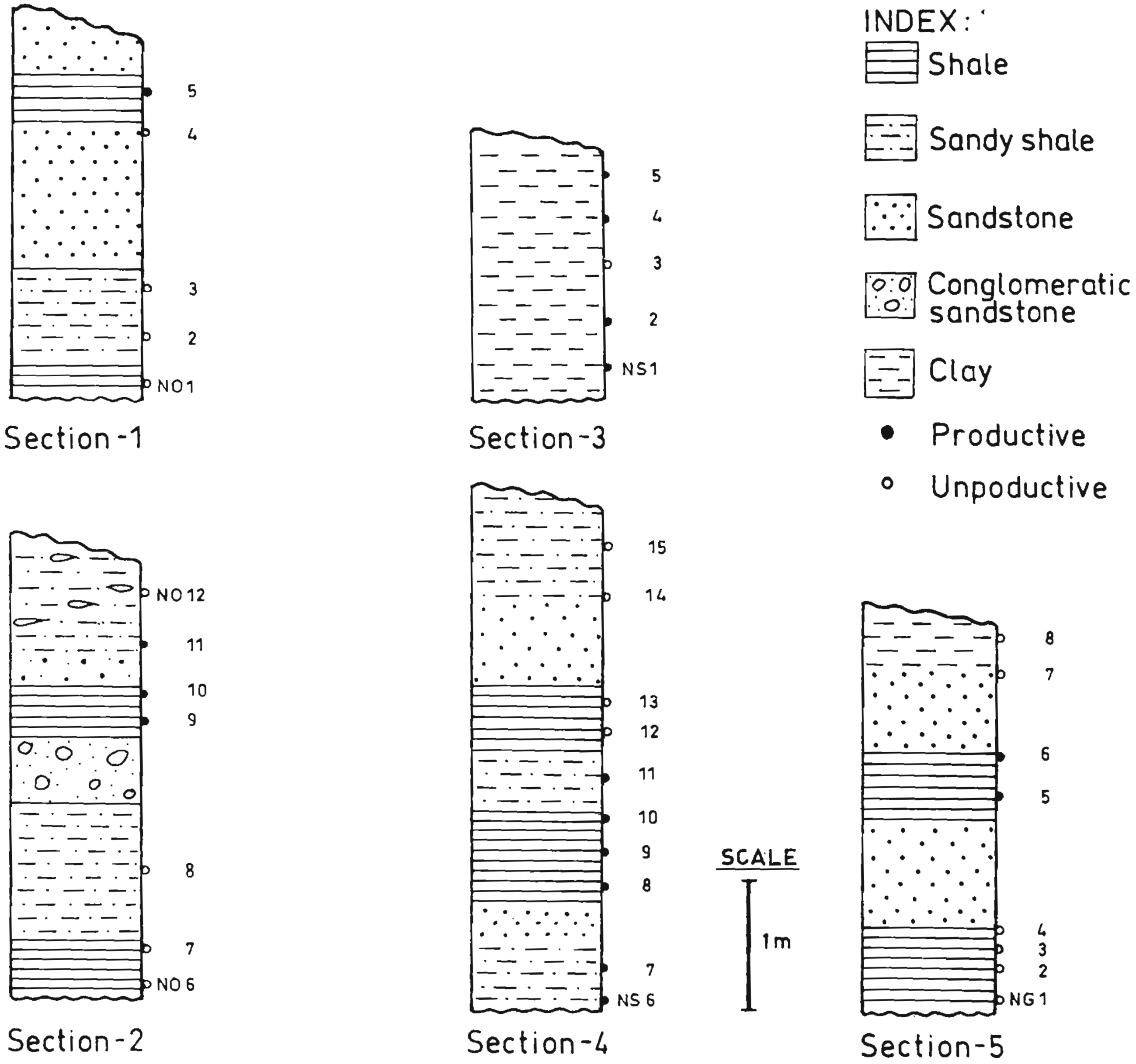

Fig. 2—Lithocolumns showing the position of samples.

MATERIAL AND METHODS

During the field session of 1984 two of us (AC & JM) collected samples from different locations of the Baratang Island. Thirty-five samples belonging to Baratang Formation collected from five sections have been studied. The locations of sections and lithocolumns indicating the position of samples have been shown in Figs. 1 & 2 respectively.

Samples

Section 1 (Nilambur–Oralkachcha Traverse)

The section is exposed in a nala behind the Oralkachcha School. The rocks are black and green splintery shale, sandy shale alternating with white, medium grained sandstone.

Section 2 (Nilambur Church premises)

The section contains black shale, grey sandy shale, black clay, nodular clay and conglomeratic sandstone. The samples were collected from a well pit within the church premises.

Section 3 (Nilambur–Shastri Nala Traverse)

This pit section lies 4 km before Gandhi Jetty on right side of Nilambur–Gandhi Jetty Road. The whole section consists of black clay.

Section 4 (Forest Camp Office Section)

The section consists of black splintery shale, grey sandy shale and white medium grained sandstone. The outcrop section lies in a nala on west side of the Forest Camp Office.

Section 5 (Nilambur–Gandhi Jetty Traverse)

The outcrop section is exposed on left side of Nilambur–Gandhi Jetty Road near 13 km post which consists of grey splintery shale, black clay and white sandstone.

Methods

The samples were chemically processed following the usual maceration procedure using HCl, HF, HNO_3 and 5% KOH solution. The polleniferous residue was mixed with polyvinyl alcohol and spread over the cover slip. After drying the cover slip, it was mounted in Canada Balsam. The slides and photonegatives have been deposited in the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow.

RESULTS

Out of thirty-five studied samples, only sixteen samples have yielded spore-pollen including dinoflagellate cysts in one section (Section 4). The yield of palynomorph is poor to moderate and majority of the specimens are badly preserved. Consequently, a number of specimens could not be identified. The location of productive samples is indicated in Fig. 2. Sections 3 and 4 are rich in palynomorph contents than other sections. Minimum number of palynofossils has been recovered from Section 5. However, all the sections produced reworked palynomorphs of older ages. These recycled palynotaxa belong to Permian, Triassic and Jurassic-Cretaceous ages and they out number the Tertiary palynomorphs. Simultaneously, Lower Cretaceous taxa are more common than Permian and Triassic forms. In contrast, Tertiary palynomorphs are meagre and require careful search to find them. Thus, no qualitative analysis is possible of these assemblages. In this context it is important to mention that sections 1 and 5 did not yield any palynofossil of Tertiary age.

The following is the list of palynomorphs recovered from each section. The taxa (reworked) with asterisk mark indicate restricted vertical range. Other taxa occasionally cross the time boundaries. Some of the important palynomorphs have been documented in plates 1–3.

Section 1

Permian—**Faunipollenites varius* Bharadwaj emend. Tiwari *et al.*, 1989; **Scheuringipollenites maximus* (Hart) Tiwari, 1973; **Aurangapollenites brevizonatus* (Tiwari) Bharadwaj & Dwivedi, 1981.

Triassic—**Klausipollenites schaubergeri* (Potonié & Klaus) Jansonius, 1962.

Jurassic–Cretaceous—*Araucariacites australis* Cookson, 1947; *Alisporites grandis* (Cookson) Dettmann, 1963.

Comment—Tertiary palynomorphs have not been found.

Section 2

Permian—**Faunipollenites varius* Bharadwaj emend. Tiwari *et al.*, 1989; **Corisaccites alutas* Venkatachala & Kar,

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PLATE 1 →

(Bars on the photographs represent 10 µm. England Finder numbers are given within bracket after slide number)

1. *Alangiopollis* sp., Slide No. BSIP 12651 (S30).
2. *Lakiapollis ovatus* Venkatachala & Kar, 1969, Slide No. BSIP 12649 (W48).
3. *Baculimonocolpites andamanensis* Mandal *et al.*, 1994, Slide No. BSIP 12658 (K33/1).
4. *Retitrisyncolpites thaungii* Mandal *et al.*, 1994, Slide No. BSIP 12653 (Q23).
5. *Striatriletes susannae* v.d. Hammen emend. Kar, 1979, Slide No. BSIP 12661 (Y36).
6. *Lanagiopollis regularis* Morley, 1982, Slide No. BSIP 12644 (S18).
7. *Palaeocystodinium australinum* (Cookson emend. Malley, 1972) Lentin & Williams, 1976, Slide No. BSIP 12653 (J15/1).
8. *Striatopollis* sp., Slide No. BSIP 12648 (N34).
9. *Spinizonocolpites baculatus* Muller, 1968, Slide No. BSIP 12650 (J21/4).
10. *Polypodiaceaesporites* sp., BSIP Slide No. 12666 (N10/4).
11 *Minutitricolporites minutus* Kar, 1985, Slide No. BSIP 12645 (Y39/2).
12. *Polypodiisporites impariter* (Potonié & Sah) Dutta & Sah, 1970, Slide No. BSIP 12659 (U17/3).
13. *Dandotiaspora telonata* Sah *et al.*, 1971, Slide No. BSIP 12642 (R40).
14. *Bacutriporites* sp., Slide No. BSIP 12659 (T 35/1).
15. *Dactylopollis magnificus* Muller, 1968, Slide No. BSIP 12659 (X 46).
16. *Proxapertites operculatus* v.d. Hammen, 1956, Slide No. BSIP 12662 (J30/4).
17. Palynomorph type 1, Slide No. BSIP 12654 (G 44).

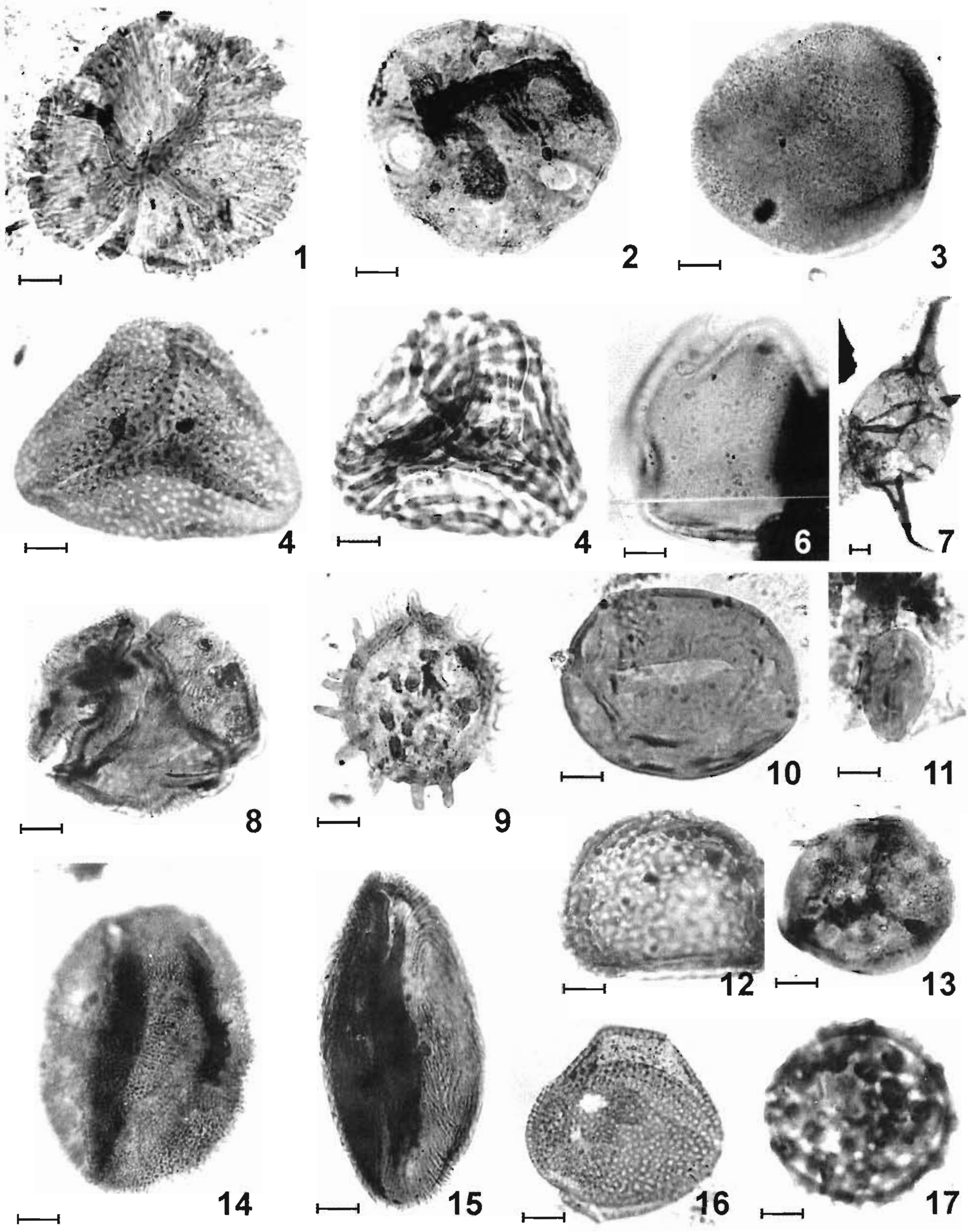

PLATE 1

1966; **Caheniasaccites indicus* Srivastava, 1970; **Chordasporites* sp.; **Scheuringipollenites maximus* (Hart) Tiwari, 1973; **Striatites varius* Kar, 1968; **Crescentipollenites fuscus* (Bharadwaj) Bharadwaj *et al.*, 1974; **Densipollenites invisus* Bharadwaj & Salujha, 1964; **Microbaculispora* sp.

Triassic—Verrucosisporites sp.; **Klausipollenites schaubergeri* (Potonié & Klaus) Jansonius, 1962; **Falcisporites stabilis* Balme, 1970; **Staurosaccites quadrifidus* Dolby in Dolby & Balme, 1976; **Ovalipollis* sp.; *Tikisporites complicatus* Kumaran, 1980.

Jurassic–Cretaceous—Araucariapollenites sp.; *Cicatricosisporites* sp.; **Aequitriradites dubius* Delcourt & Sprumont emend. Delcourt *et al.*, 1963; **Callialasporites dampieri* (Balme) Sukh-Dev, 1961; **C. lucidus* (Pocock) Maheshwari, 1974; *Alisporites grandis* (Cookson) Dettmann, 1963; *Cerebropollenites* sp.; *Osmundacidites* sp.; **Triporoletes reticulatus* (Pocock) Playford, 1971; *Dactylopollis magnificus* Muller, 1968; *Bacutriporites* sp.

Tertiary—Cyathidites australis Couper, 1953; *Dictyophyllidites* sp.; *Polypodiisporites impariter* (Potonié & Sah) Dutta & Sah, 1970; *Polypodiaceaesporites* sp.; *Striatriletes susannae* v.d. Hammen emend. Kar, 1979; *S. paucicostatus* Kar, 1985; *Retitrisyncolpites thaungii* Mandal *et al.*, 1994; *Striacolporites cephalus* Sah & Kar, 1970; *Minutitricolporites minutus* Kar, 1985; *Polyadopollenites miocenicus* Ramanujam, 1966; *Proxapertites operculatus* v.d. Hammen, 1956; *Baculimonocolpites andamanensis* Mandal *et al.*, 1994; *Striatopollis* sp.; *Neocouperipollis brevispinosus* (Biswas) Singh & Sarkar, 1988; *Phragmothyrites eocenicus* Edwards emend. Kar & Saxena, 1976.

Comment—Only 10% palynofossils belong to Eocene.

Section 3

*Permian—*Crescentipollenites fuscus* (Bharadwaj) Bharadwaj *et al.*, 1974; **Indotriradites korbaensis* Tiwari, 1964; * *Striatites varius* Kar, 1968; *Lundbladispora* sp.; *Densoisporites* sp.; **Scheuringipollenites maximus* (Hart) Tiwari, 1973; *Vesicaspora* sp.; * *Trochosporites tripus* Venkatachala & Kar, 1968; *Aurangapollenites brevizonatus* (Tiwari) Bharadwaj & Dwivedi, 1981.

*Triassic—*Klausipollenites schaubergeri* (Potonié & Klaus) Jansonius, 1962; **Falcisporites stabilis* Balme, 1970; *Chordasporites* sp., *Brachysaccus* sp.; **Staurosaccites quadrifidus* Dolby in Dolby & Balme, 1976; **Playfordiaspora cancellosa* (Playford & Dettmann) Maheshwari & Banerjee emend. Vijaya, 1995; **Goubinispora indica* Tiwari & Rana, 1981.

*Jurassic-Cretaceous—*Aequitriradites spinulosus* (Cookson & Dettmann) Cookson & Dettmann, 1961; *Alisporites grandis* (Cookson) Dettmann, 1963; *Podosporites* cf. *P. tripakshi* Rao emend. Kumar, 1981; *Cerebropollenites* sp.; *Podocarpidites khasiensis* Dutta & Sah, 1970; *Ginkgocycadophytus* sp.; *Araucariapollenites* sp.; *Cicatricosisporites* sp.; * *Callialasporites dampieri* (Balme) Sukh-Dev, 1961; **C. lucidus* (Pocock) Maheshwari, 1974; *Polycingulatisporites reduncus* (Bolkhovitina) Playford & Dettmann, 1964; **Contignisporites* sp.

Tertiary—Dandotiaspora telonata Sah *et al.*, 1971; *Lygodiumsporites eocenicus* Dutta & Sah, 1970; *Polypodiaceaesporites* sp.; *Minutitricolporites minutus* Kar, 1985; *Lanagiopollis regularis* Morley, 1982; *Tricolporopilites pseudoreticulatus* Kar, 1985.

Comment—Only 3% specimens belong to Eocene age.

Section 4

*Permian—*Crescentipollenites fuscus* (Bharadwaj) Bharadwaj *et al.*, 1974; *Lunbladispora* sp.; *Densoisporites* sp.; **Scheuringipollenites maximus* (Hart) Tiwari, 1973.

*Triassic—*Falcisporites stabilis* Balme, 1970; **Staurosaccites quadrifidus* Dolby in Dolby & Balme, 1976; **Klausipollenites schaubergeri* (Potonié & Klaus) Jansonius, 1962.

*Jurassic–Cretaceous—*Aequitriradites spinulosus* (Cookson & Dettmann) Cookson & Dettmann, 1961; *Alisporites* sp.; * *Callialasporites dampieri* (Balme) Sukh-Dev, 1961; *Cerebropollenites* sp.; *Podocarpidites khasiensis* Dutta & Sah, 1970; *Araucariapollenites* sp., *Bacutriporites* sp.

Tertiary—Cyathidites australis Couper, 1953; *Polypodiisporites impariter* (Potonié & Sah) Dutta & Sah, 1970; *Retitrisyncolpites thaungii* Mandal *et al.*, 1994; *R.*

PLATE 2 ⟶

(Bars on the photographs represent 10 μm. England Finder numbers are given within bracket after slide number)

1 *Caheniasaccites indicus* Srivastava, 1970, Slide No. BSIP 12654 (G44).
2. *Faunipollenites varius* Bharadwaj emend. Tiwari *et al.*, 1989, Slide No. BSIP 12655 (G30).
3. *Tikisporites complicatus* Kumaran, 1980, Slide No. BSIP 12660 (Q25).
4. *Callialasporites lucidus* (Pocock) Maheshwari, 1974, Slide No. BSIP 12664 (K46).
5. *Trochosporites tripus* Venkatachala & Kar, 1968, Slide No. BSIP 12646 (V23/4).
6. *Cuneatisporites exiguus* Salujha, 1965, Slide No. BSIP 12666 (P22/4).
7 *Callialasporites dampieri* (Balme) Sukh-Dev, 1961, Slide No. BSIP 12659 (T36/3).
8. *Polycingulatisporites reduncus* (Bolkhovitina) Playford & Dettmann, 1964, Slide No. BSIP 12642 (L14).
9. *Striatites varius* Kar, 1968, Slide No. BSIP 12661 (L46/1).
10. *Contignisporites* sp., Slide No. BSIP 12647 (O37/2).
11 *Staurosaccites quadrifidus* Dolby in Dolby & Balme, 1976, Slide No. BSIP 12659 (W31).
12. *Araucariapollenites* sp., Slide No. BSIP 12642 (L40).

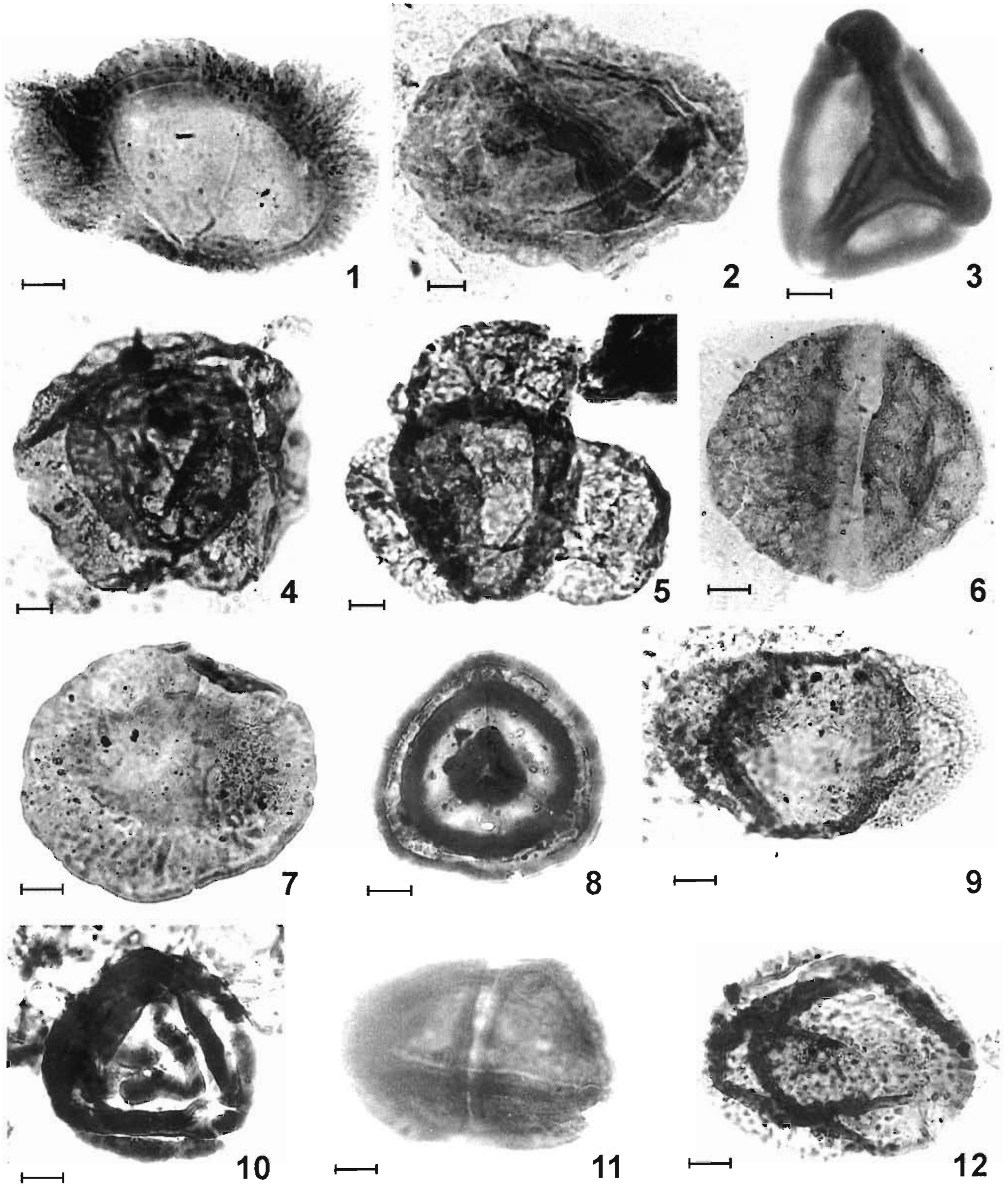

PLATE 2

reimannii Mandal *et al.*, 1994; *Monocolpites spinosus* Baksi, 1962; *Spinizonocolpites baculatus* Muller, 1968; *Lakiapollis ovatus* Venkatachala & Kar, 1969; *Proxapertites operculatus* v.d. Hammen, 1956; *Baculimonocolpites andamanensis* Mandal *et al.*, 1994; *Alangiopollis* sp.; *Acanthotricolpites kutchensis* (Kar & Kumar) Singh & Misra, 1991; *Neocouperipollis brevispinosus* (Biswas) Singh & Sarkar, 1988; *Pellicieroipollis* sp.; *Phragmothyrites eocenicus* Edwards emend. Kar & Saxena, 1976; *Notothyrites* sp.; *Operculodinium centrocarpum* (Deflandre & Cookson) Wall, 1967; *Achomosphaera* sp.; *Cleistosphaeridium brevispinosum* Jain & Millepeed, 1975; *Polysphaeridium subtile* (Davey & Williams) Bujak *et al.*, 1980; *Palaeocystodinium australinum* (Cookson emend. Malley, 1972) Lentin & Williams, 1976.

Comment—The reworked palynomorphs are about 50% at the base of the section which gradually decrease and become scare at the upper level.

Section 5

Permian—**Cuneatisporites exiguus* Salujha, 1965; **Striatites varius* Kar, 1968.

Triassic—**Falcisporites stabilis* Balme, 1970; **Playfordiaspora cancellosa* (Playford & Dettmann) Maheshwari & Banerjee emend. Vijaya, 1995.

Jurassic-Cretaceous—**Aequitriradites dubius* Delcourt & Sprumont emend. Delcourt *et al.*, 1963; *Callialasporites* sp.; *Araucariacites* sp.; *Alisporites grandis* (Cookson) Dettmann, 1963.

Comment—Tertiary palynofossils are absent in this section.

SYSTEMATICS

Descriptions of a few uncommon taxa and new to this area are given below.

Genus—DACTYLOPOLLIS Muller, 1968

DACTYLOPOLLIS MAGNIFICUS Muller, 1968

(Pl. 1·15)

Horizon—Baratang Formation, Late Cretaceous–Eocene.

Description—Pollen grain prolate, longitudinally folded, 93·5 µm in equatorial view. Tricolpate, colpi long and slit-like. Exine 2·5 µm, nexine thinner than sexine, 1 µm at equator, indistinct at poles. Surface striate at poles and colpus margins; striae fine, 1 µm wide, parallel to colpi, anastomose forming long narrow lumina, curve at margin and pass on to opposite surface. Surface foveo-reticulate in equatorial area, muri 1 µm, lumina circular to oval, irregular in arrangement which gradually change to striate pattern.

Comments—Single specimen has been found from Section 2. This specimen is very distinct and closely similar to *Dactylopollis magnificus* Muller, 1968. However, second ornamentation type below the reticulate-foveolate zone could not be recognised. Muller (1968) described this taxon from Senonian to Palaeocene sediments of Malaysia but is unknown from India and Myanmar.

Genus—LANAGIOPOLLIS Morley, 1982

LANAGIOPOLLIS REGULARIS Morley, 1982

(Pl. 1·6)

Horizon—Baratang Formation, Late Cretaceous–Eocene.

Description—Pollen grain subtriangular, oblate, amb convex, 60·5 µm in polar view. Tricolporate, colpus and pore characters indistinct due to oblique preservation, pores appear costate. Exine 3·5 µm at mesocolpia; sexine 1·5 µm, thinner than nexine (2 µm); both sexine and nexine gradually thin out towards aperture. Exine tectate, tectum ca. 1 µm, columellae distinct, closely placed, ca. 0·5 x 1 µm. Surface microreticulate on low focus; muri very low, simplicolumellate, lumina generally circular.

Comments—Single specimen has been recovered from Section 3. The thicker nexine and reticulate surface feature compare with *Lanagiopollis regularis* Morley, 1982. However, the present specimen has thinner exine and muri than the holotype. The character of aperture is masked due to oblique preservation.

PLATE 3 ⟶

(Bars on the photographs represent 10 µm. England Finder numbers are given within bracket after slide number)

1 *Vesicaspora* sp., Slide No. BSIP 12644 (E27).

2. *Aequitriradites dubius* Delcourt & Sprumont emend. Delcourt *et al.*, 1963, Slide No. BSIP 12663 (L49).

3. *Klausipollenites schaubergeri* (Potonié & Klaus) Jansonius, 1962, Slide No. BSIP 12657 (G10/1).

4. *Goubinispora indica* Tiwari & Rana, 1981, Slide No. BSIP 12645 (P42).

5 *Falcisporites stabilis* Balme, 1970, Slide No. BSIP 12658 (H22/3).

6. *Klukisporites* sp., Slide No. BSIP 12651(K17).

7 *Aurangapollenites brevizonatus* (Tiwari) Bharadwaj & Dwivedi, 1981, Slide No. BSIP 12647 (P37).

8. *Cerebropollenites* sp., Slide No. BSIP 12652 (U25/2).

9. *Crescentipollenites fuscus* (Bharadwaj) Bharadwaj *et al.*, 1974, Slide No. BSIP 12656 (F11/1).

10. *Scheuringipollenites maximus* (Hart) Tiwari, 1973, Slide No. BSIP 12655 (O25/2).

11. *Corisaccites alutas* Venkatachala & Kar, 1966, Slide No. BSIP 12655 (S15/4).

12. *Brachysaccus* sp., Slide No. BSIP 12642 (Q23).

13. *Ovalipollis* sp., Slide No. BSIP 12643 (P27/2).

14. *Playfordiaspora cancellosa* (Playford & Dettmann) Maheshwari & Banerjee emend. Vijaya, 1995, Slide No. BSIP 12665 (H26/2).

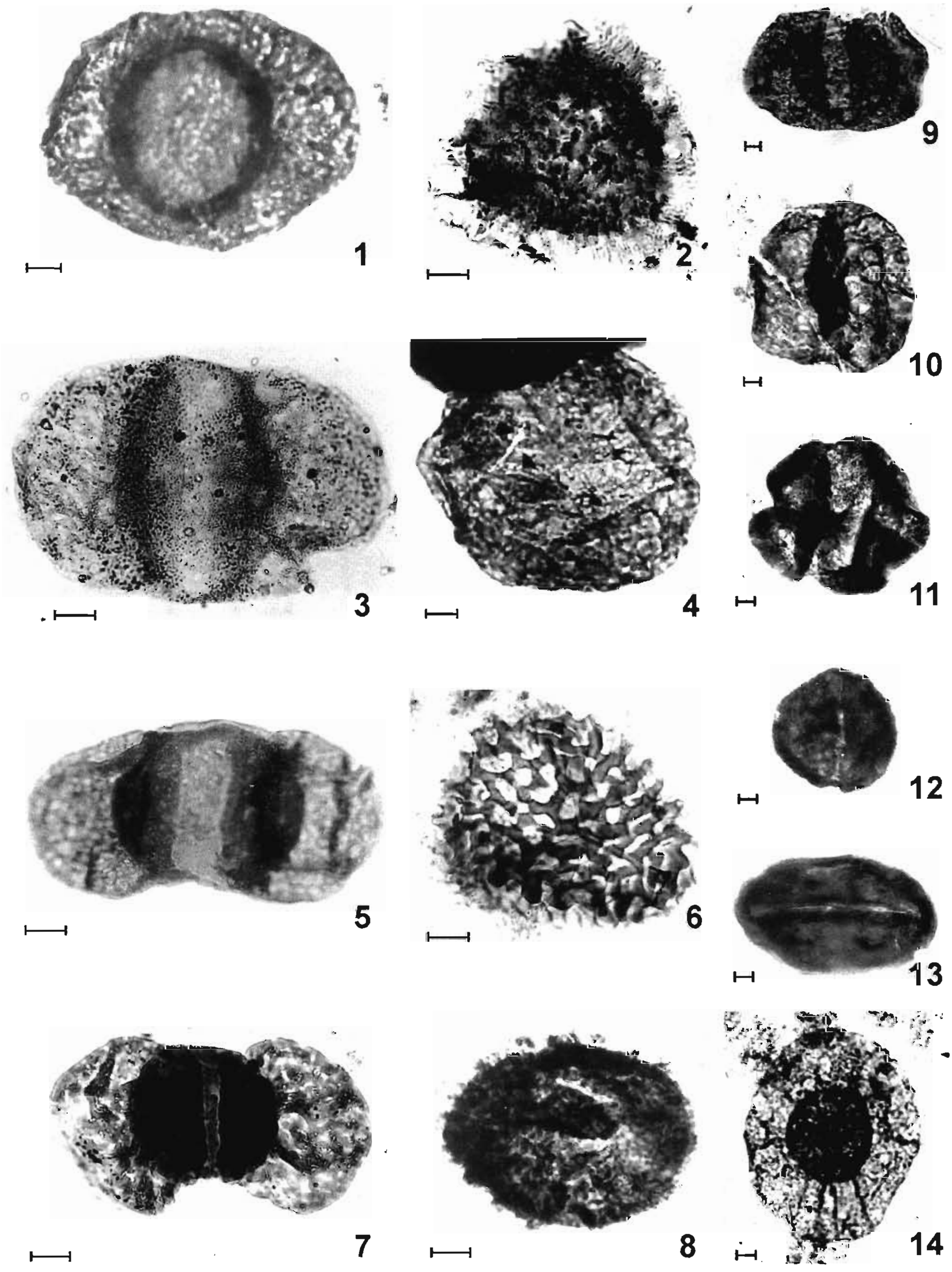

PLATE 3

Genus—ALANGIOPOLLIS Krutzsch, 1962

ALANGIOPOLLIS sp.

(Pl. 1·1)

Horizon—Baratang Formation, Late Cretaceous–Eocene.

Description—Pollen grains rounded triangular in polar view, 70 x 79 µm. Tricolporate, colpi long, 22 µm, tapering towards pole, margin granular; pore lalongate, 9 µm in diameter, thickening absent on colpus and pore margins. Exine 3·5-4 µm; sexine-nexine not separable and thickness near aperture not clear. Surface striate, striae parallel to colpi, varies in thickness of width, 1-2 µm, thicker at equator, anastomoses occasionally forming long narrow lumen, more common on polar area, lumen width always lesser than the striae. Only a single structural pattern (striate) present.

Comments—Two specimens have been recovered from Section 4. The character of exine is similar with the generic description of *Alangiopollis* by Morley (1982). The specimens are distinct having only one structural pattern and no comparable forms could be found.

Genus—STRIATOPOLLIS Krutzsch, 1959

STRIATOPOLLIS sp.

(Pl. 1·8)

Horizon—Baratang Formation, Late Cretaceous–Eocene.

Description—Pollen grain folded, oblate, 82 µm in equatorial view. Tricolpate, colpi long, slit-like, characters not distinct due to fold. Exine 4 µm at mesocolpium, 2 µm at apocolpium, nexine indistinct, 1 µm at mesocolpium. Surface intectate, columellae free, long, form pseudo-striate pattern on polar areas in low focus; 2 µm long, 1 µm wide, closely placed, closer and shorter at apocolpia and absent near colpi.

Comments—Section 2 has yielded single specimen. The specimen is grossly comparable to *Perfotricolpites neyvelii* (Navale & Misra) Mandal & Kumar, 2000 but differs in being smaller in size. Moreover in the present specimen, columellae are not digitate and surface is pseudo-striate but not perforate-reticulate.

Palynomorph Type—1

(Pl. 1·17)

Horizon—Baratang Formation, Late Cretaceous–Eocene.

Description–Single specimen, nearly circular, 37 x 39 µm, aperture not discernible. Surface beset with some raised structures, about 18 structure on one surface, intrastructural areas smooth; structures 2 µm high with little swollen base and flat tips. Each structure has 1 µm deep cavity at tips. Wall 2 µm thick, ca. 4 µm including the structure.

Comments—Single specimen has been recovered from Section 2. The specimen grossly compares to algal taxon *Intubidinium* Shanfu, 1999 in surface characters but the Chinese specimens have comparatively larger size, thinner wall and more surface structures (canals) than the present form.

COMPARISON OF ANDAMAN PALYNOFLORA

It is necessary to compare the Palaeogene palynoflora recorded till date from Andaman with Assam and Myanmar to examine their relationship. Few palynological data generated from Myanmar (Potonié, 1960; Reimann & Thaung, 1981) allow limited but significant comparison. Several taxa namely *Palmidites, Palmaepollenites, Dandotiaspora, Striatriletes, Disulcites, Neocouperipollis, Triporopollenites, Striacolporites, Triorites, Proxapertites, Meliapollis, Lakiapollis* and *Margocolporites* are present in all the three areas and a number of them are common at species level. In addition to the similarity, a few genera like *Retitrisyncolpites, Baculimonocolpites* and *Lanagiopollis (regularis)* are common between Andaman and Myanmar. On the other hand, few taxa, such as *Tricolpites phillipsii* and *Distaverrusporites margaritatus* of Malaysian affinity are present in Myanmar but are unknown from Andaman. Similarly, *Dactylopollis, Striatopollis* and *Meyeripollis* are present in Andaman while they are absent in Myanmar. A few genera known from Andaman like *Matanomadhiasulcites, Dermatobrevitricolporites, Sastripollenites, Minutitricolporites, Tricolporopilites, Meyeripollis* and *Striatopollis* are common in Assam and Andaman flora but many of them do not compare at species level.

The comparison thus indicates that though the Palaeogene palynoflora is grossly similar in Andaman, Assam and Myanmar but the common presence of few dominant and significant taxa like *Retitrisyncolpites, Lanagiopollis* and *Baculimonocolpites* point closeness of Andaman microflora with Myanmar rather than with Assam.

AGE OF THE SEDIMENTS

In the absence of marine nannoplankton and scarcity of marine fauna, palynology plays an important role in determination of age of the Andaman flysch sequences. The present assemblages contain palynomorphs of various ages and thus the palynofossils indicating youngest age is considered as the age of the sediments. Geologically the age of Baratang Formation ranges from Late Cretaceous to Eocene (Chatterjee, 1967). Though the palynomorphs (Tertiary) are poor in number, some of them are important marker and the range of vertical distribution is well defined. Thus age has been postulated from their known distribution range. The distribution of selected stratigraphically significant palynomorphs in the Baratang Formation has been presented in Fig. 3.

Taxa	Early Eocene	Middle Eocene	Late Eocene
Dandotiaspora telonata	———		
Baculimonocolpites andamanensis	———		
Lakiapollis ovatus	———		
Pellicieroipollis sp.	———		
Spinizonocolpites baculatus	———		
Retitrisyncolpites spp.	———	———	
Striatriletes susannae		———	———
Polyadopollenites miocenicus			———
Minutitricolporites minutus	———	———	———
Lanagiopollis regularis	———	———	———
Acanthotricolpites kutchensis	———	———	———

Fig. 3—Distribution of some stratigraphically important palynomorphs from Baratang Formation.

Section 2

The section yielded a variety of taxa that provide evidence on the age of assemblage. The first appearance of *Retitrisyncolpites* has been recorded in the Early Eocene of Myanmar (Reimann & Thaung, 1981) and Middle Andaman (Mandal *et al.*, 1994). The taxon abundantly occurs till Middle Eocene and is rare in Late Eocene in Myanmar (Reimann & Thaung, 1981). Similarly *Minutitricolporites* and *Striacolporites* also appear at the same time (Kar, 1985) and continued through Palaeogene. However, *Striatriletes* first appeared in the Middle Eocene in Indian main land (Kar, 1983) and is abundant in the overlying sequences. In Myanmar, the taxon appeared in Early-Middle Eocene as *Cicatricosisporites macrocostatus* (Reimann & Thaung, 1981). However, in other tropical areas the taxon was recorded later in the earliest Neogene (Germeraad *et al.*, 1968). The genus *Polyadopollenites* is commonly known from Oligocene in Assam but has also been recorded from the Late Eocene of Nagaland (Mandal, 1996). The above analysis indicates that the assemblage ranges from Middle to Late Eocene in age. In the absence of Oligocene marker taxa like *Crassoretitriletes, Trisyncolpites* and *Meyeripollis* the assemblage cannot be taken as younger than Late Eocene.

Section 3

The meagre Tertiary palynofossils recovered from this section do not help much in age assignment. The taxa *Minutitricolporites* and *Lanagiopollis regularis* appear in Early Eocene (Morley, 1982; Kar, 1985) and are restricted within the Eocene. *Dandotiaspora,* except *D. dilata* also rarely extends beyond the Early Eocene. Other taxa or their association in the assemblage do not reflect Middle Eocene or younger ages. Thus, at least an Early Eocene age may be postulated from the palynoassemblage.

Section 4

The dinoflagellate cysts, *Operculodinium centrocarpum, Cleistosphaeridium brevispinosum* and *Polysphaeridium subtile* recorded in this section are long ranging taxa (Eocene-Miocene) but dominantly occur within the Eocene (Williams *et al.*, 1993). However, *Palaeocystodinium australinum* is restricted within Early to Late Palaeocene. Considering the absence of other Palaeocene marker dinocysts and terrestrial palynofossils, the taxon *Palaeocystodinium* seems to be reworked.

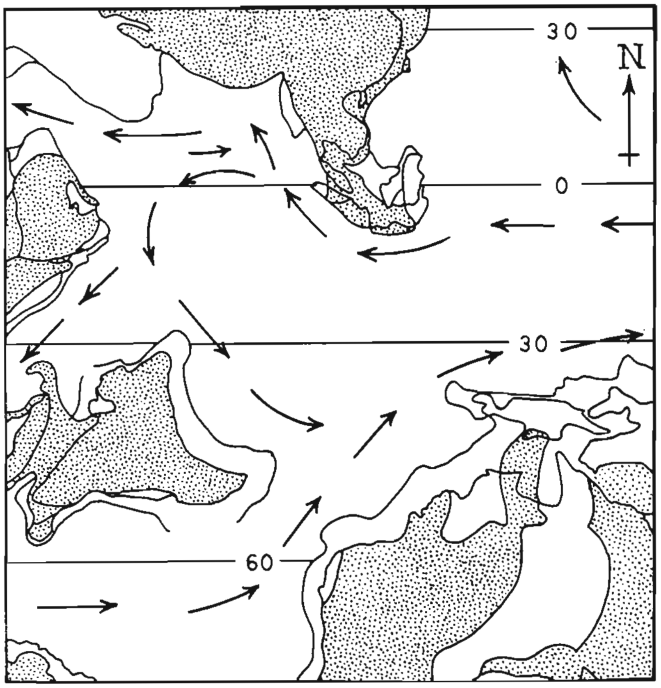

Fig. 4—Palaeogeography and ocean circulation during the middle Cretaceous (after Haq, 1985 in Kunihiro & Kunio, 1991).

The terrestrial taxa *Retitrisyncolpites, Baculimonocolpites, Lakiapollis ovatus, Pellicieroipollis, Proxapertites, Acanthotricolpites* and *Neocouperipollis* have limited vertical distribution. They present abundantly in the Late Palaeocene-Early Eocene sediments. *Lakiapollis ovatus* and *Pellicieroipollis* range within Late Palaeocene to Eocene (Thanikaimoni *et al.*, 1984; Venkatachala *et al.*, 1989) though *Lakiapollis* is known to extend rarely to the Early Miocene (Rao, 1996; Singh *et al.*, 1992). *Retitrisyncolpites* dominantly occurs in Early to Middle Eocene sediment of Myanmar. The last appearance of *Spinizonocolpites baculatus* is recorded in the Early Eocene (Muller, 1968). Moreover, *Proxapertites, Acanthotricolpites* and *Neocouperipollis* are rare to absent in overlying sequences of the Early Eocene. Thus, Early Eocene age can be assumed from the abundance of *Retitrisyncolpites* and *Baculimonocolpites* and in absence of any other marker taxa of Palaeocene or younger ages. Dinoflagellate cysts are long ranging and do not help in precise age determination.

Sections 1 & 5

Both the assemblages from sections 1 and 5 consist of Permian, Triassic and Jurassic-Cretaceous palynofossils without any Tertiary taxa. Obviously, Early Cretaceous age may be fixed for these two assemblages. However, it can be mentioned that reworked palynomorphs are similar to other sections containing Tertiary taxa. This indicates same source of the sediments containing these recycled palynofossils. Only one sample in Section 1 and two samples from Section 5 (Fig. 2) have poorly yielded palynomorphs. Had more samples been productive, it seems that palynomorphs of younger age would have yield. The assemblages do not contain *Aquilapollenites, Ariadnaesporites* and *Scordilla* to support Late Cretaceous age. However, Late Cretaceous taxa like *Dactylopollis* and *Bacutriporites* have been recorded here in the Eocene assemblage.

In Baratang Island, two horizons of fauna are known. The lower horizon has the indigenous *Globotruncana* assemblage of Late Cretaceous age and the upper horizon contains recycled Cretaceous fauna ranging in age from Palaeocene to Late Eocene (Pandey *et al.*, 1992). The Cretaceous–Palaeocene microfauna are known from Baratang Formation (Guha & Mohan, 1965; Pandey, 1972; Pandey & Rao, 1976; Kumar & Soodan, 1976). Cretaceous planktonic foraminifera and marine algae are also recorded from this Formation (Rajshekhar *et al.*, 1990; Badve & Kundal, 1986).

Though Cretaceous faunal assemblages have been recorded, palynoflora of Cretaceous or Palaeocene age is not known from Andaman Islands. The only Cretaceous palynoassemblage (Banerjee, 1967) reported from Middle Andaman, in fact contains Tertiary palynomorphs but abundance of Cretaceous forms led him to fix age as Cretaceous (Banerjee, 1967; p. 213). Similarly the Oligocene assemblage includes the reworked taxa (e.g., *Alisporites:* Mathur & Mathur, 1980; pl. 1, figs 8, 9). Recently Jafar and Tripathi (2001) claimed the recovery of Late Cretaceous palynoassemblage from Middle Andaman but did not mention the names of taxa or photo documented the specimens.

The above synthesis demonstrates that the Late Cretaceous palynoassemblage is still unknown from Andaman. Thus, from the palynoassemblages of sections 1 and 5, Cretaceous age connotation would be doubtful and age assignment remains unresolved.

SIGNIFICANCE OF REWORKED PALYNOFOSSILS

In the studied five sections from Baratang Island, recycled Permian, Triassic and Jurassic-Cretaceous pollen taxa of Gondwanic affinity are present. The previously recorded assemblages from Andaman Islands, except one, reveal similar admixture of pollen-spores of different ages. However, Permian palynotaxa have been recorded for the first time in the present assemblage. It is surprising that the Early Eocene assemblage recovered from lignitic sediments of Kadamtala, Middle Andaman (Mandal *et al.*, 1994) is completely free of reworked taxa. The sediments of Baratang Formation are flysch in nature and were deposited through turbidity currents. How this assemblage remained free from recycled palynomorphs within such terrain remains an unsolved issue.

The presence of Triassic palynomorphs and dinoflagellate cysts (Sharma & Mehrotra, 1984; Sharma & Sarjeant, 1987) has lead to conclusion that Triassic sediment present in Andaman Islands (Sharma & Mehrotra, 1984). This has aroused much debate. Several researchers (Pandey, 1986; Kumar, 1990; Jafar & Tripathi, 2001) ruled out the presence of Late Triassic sediment as inliner or exotic blocks in Middle Andaman. According to them Late Triassic palynomorphs are reworked. On the other hand Mehrotra and Sarjeant (1990) conformed the presence of Triassic sediments in the Andamans and strongly argued for the authocthonous nature of the Triassic elements. However, Jafar and Tripathi (2001) reported Late Triassic palynomorphs at several levels in the Late Cretaceous succession of Chainpur Section- the locality from where Sharma and Mehrotra (1984) reported Late Triassic sediments. Furthermore, microforaminifera of Cretaceous–Palaeogene age have been recovered from the same samples which Sharma & Mehrotra, 1984 had studied (Pandey, 1986). Mehrotra, however, in a written communication disagreed with the observation of Pandey (1986) and states "the samples containing Triassic spores-pollen and dinocysts do not contain any younger palynomorphs. Pandey (1986) while preparing the Cretaceous- Palaeogene microforaminifera from these has not given details of sample nos. and recorded species."

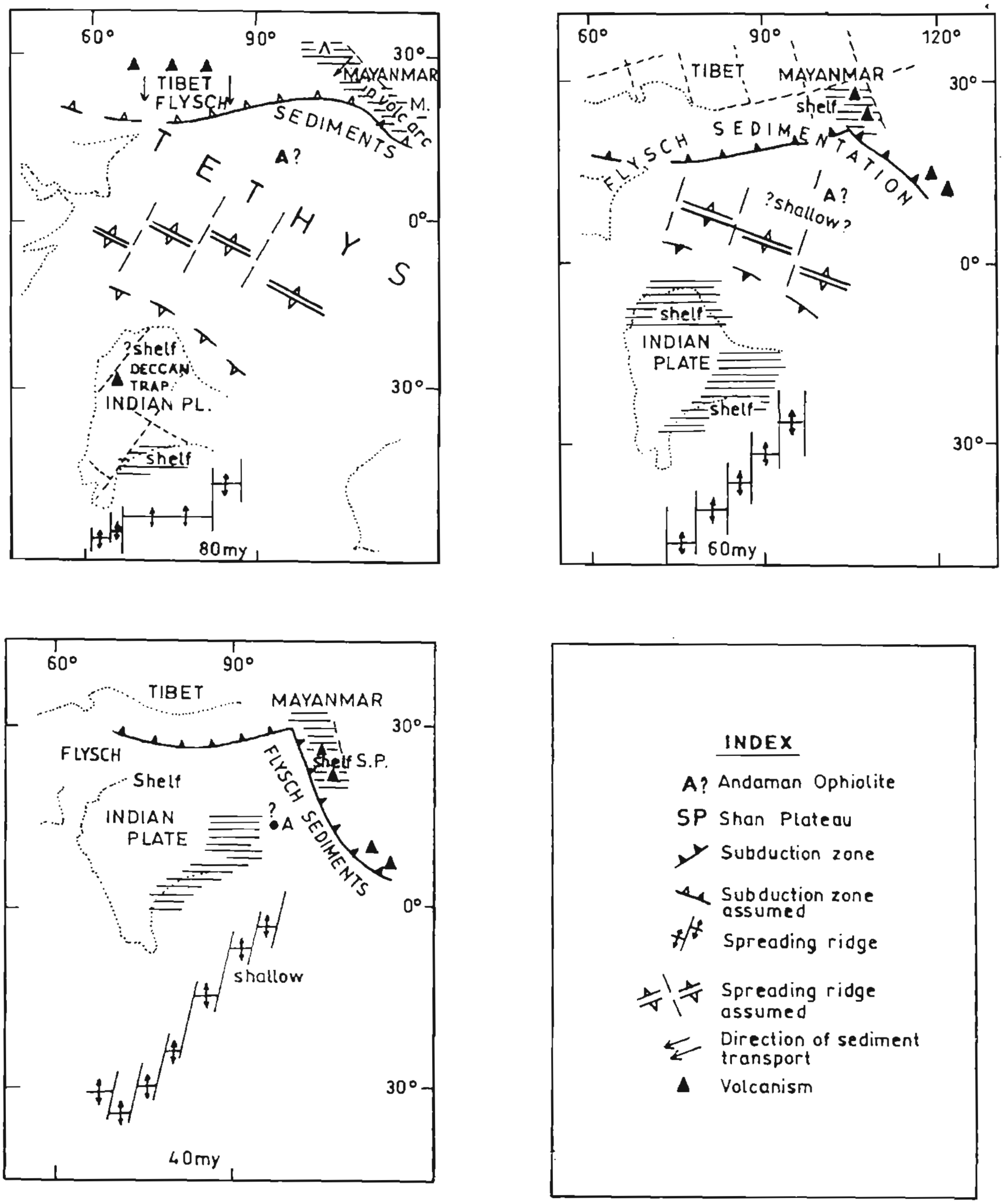

Fig. 5—Plate tectonic maps during 80 my, 60 my, 40 my of Myanmar-Andaman area (after Bender, 1983).

In the present work Triassic taxa recovered together with palynofossils of different ages from all the sections. Such recycling is expected in flysch turbidites of Middle Andaman. These Triassic specimens are reworked which were carried by the sediments with other Gondwanic elements and redeposited in Andaman. Though there is no significance of these recycled palynomorphs in age determination, they are very useful in palaeogeographical reconstructions.

Jafar and Tripathi (2001) remarked that Late Cretaceous sections of Andaman contain reworked Late Triassic palynomorphs while Late Cretaceous fossils occur in the Eocene assemblage. Although the present study shows that

Maastrichtian taxa like *Dactylopollis* and *Bacutriporites* present in Eocene assemblage and therefore, such conclusion needs verification. The taxa of Permian e.g., *Caheniasaccites, Faunipollenites, Corisaccites* and *Scheuringipollenites*: Triassic e.g., *Staurosaccites, Klausipollenites, Playfordiaspora, Brachysaccus* and *Goubinispora* in addition to Jurassic-Lower Cretaceous e.g., *Callialasporites, Cerebropollenites, Aequitriradites* and *Triporoletes* occur together in the Eocene assemblage of Baratang. Additionally, nearly same association of reworked taxa is also part of the assemblages of sections 1 & 5 which did not yield any Tertiary palynofossils. Moreover, as mentioned earlier, no Late Cretaceous and Palaeocene palynofloral assemblages have been documented from Andaman Islands. Hence the source of palynofossils must be the area around Andaman where both the terrestrial and marine sediments of these ages existed.

SOURCE OF THE REWORKED PALYNOMORPHS

Since the Cretaceous-Palaeogene sequences of Andaman Islands are turbiditic deposits, recycled fossils have Gondwanic affinity and Gondwana provinces were present around Andaman Basin, three schools of thoughts have emerged as to the provenance of the reworked taxa. Although three groups agree on the Gondwana land origin of the reworked fossils, they differ markedly on the provenance of sediments carrying these spores-pollen. According to Pandey (1986) long distance transportation of sediments including Permo-Triassic palynomorphs in Andaman was from "somewhere coalfield belt of Bihar". He postulated that long rivers draining through Bihar carried huge quantities of sediments and the mouth of the rivers opened in the Assam areas. As a result, Laisong (Barail Group) spore–pollen mixed with Gondwana palynomorphs were deposited in Upper Baratang through turbidity actions (Pandey, 1986; fig. 11). Similar composition of palynoassemblages with Gondwana palynofossils in Assam and Andaman during the Upper part of Palaeogene supports this hypothesis. Moreover, the genus *Meyeripollis,* an Oligocene marker taxon in Assam is also present in Andaman (Mathur & Mathur, 1980; Mandal *et al.*, 1996), which further strengthens the view. But the taxon *Meyeripollis* occurs in several parts of southeast Asia (Morley, 1991). Additionally, the above view cannot answer the occurrence of Late Triassic dinoflagellate cysts and Eocene terrestrial palynomorphs like *Retitrisyncolpites, Baculimonocolpites, Lanagiopollis regularis, Alangiopollis* sp., and *Dactylopollis* in Andaman. Marine Triassic sediment is not known from peninsular India, particularly from Bihar area. Moreover, the above-mentioned pollen taxa have not been recovered from any Indian section including Assam.

Jafar and Tripathi (2001) advocated that Triassic taxa including marine forms originated from Wharton Basin/ Exmouth Plateau which lies in the "Northeastern" sector of Andaman-Nicobar Basin. Late Triassic to Cretaceous marine strata is present in Wharton Basin (Rad *et al.*, 1992) but transportation of these sediments to Andaman Basin through the turbidity current during the Late Cretaceous remains unanswered. The palaeogeographical maps of this region during Cretaceous (Bender, 1983, fig. 66b; Acharyya, 1994, fig. 4; Rich & Vickers-Rich, 1999, fig. 5) show position of Andaman Islands at about 15°N latitude while Wharton Basin lies near to 30°S (Jafar & Tripathi, 2001). The palaeocurrent map of Cretaceous (Fig. 4) shows the flow of current from Andaman side towards northern margin of Australia. The authors also opined that the sedimentation provenance changed after Late Cretaceous from Australian direction to the north. In fact, change in directional pattern of sediments started in Andaman area with the uplift of Andaman geanticlines at the Early Miocene (Karunakaran *et al.*, 1964; Pandey, 1972), which stopped the pre-existing northerly turbidity channel. Palynological evidences also demonstrate identical recycled pollen-spore association in all the recorded assemblages. This indicates that source of sediment was same during deposition of Baratang Formation. Still, the validity of the hypothesis can be tested only after the recovery of Late Cretaceous palynoassemblage from Andaman.

The third view advocates that sediments in Andaman came from Myanmar (Kumar, 1990; Pandey *et al.*, 1992; Mandal *et al.*, 1994). The present palynological study substantiates the above contention. Most of the Eocene taxa like *Dandotiaspora, Striatriletes, Lakiapollis, Striatopollis, Neocouperipollis, Acanthotricolpites, Retitrisyncolpites, Spinizonocolpites, Proxapertites* and *Lanagiopollis* recorded from Andaman also occur in Myanmar. However, the genera *Retitrisyncolpites, Dactylopollis* and *Lanagiopollis regularis* recorded in Andaman are not known from mainland of India. The genus *Retitrisyncolpites* is a dominant element of Chindwin flora of Myanmar like Andaman.

In fact, Myanmar (western and southern part) was a part of Gondwanaland and was connected on the northern margin of Australia before fragmentation (Metcalfe, 1988; Acharyya, 1994; Hutchison, 1989). A nearly continuous Palaeozoic and Mesozoic sequences including marine strata are present in Myanmar (Krishnan, 1982; Bender, 1983; Kumar, 1990). Lithologically the turbiditic sediments of Andaman Islands (Baratang Formation) show gradual coarsening towards north (Pandey *et al.*, 1992). According to Ray (1982), Andaman flysch sequence comprises material from distant extrabasinal distributive source situated far beyond the limits of this mobile crustal belt and were brought within through turbiditic currents. Moreover, the evidences of palaeocurrents (Fig. 4) suggest that the current flow to Andaman Basin was from NNE or NE direction before the Oligocene. These currents carried the flysch sediments to fill the fast subsiding geosyncline and the provenance is the northern and northeastern frontiers of Myanmar or beyond it. The occurrence of palynomorph type 1 that has gross resemblance with Chinese algal taxon *Intubidinium* favours flow of sediments from northern province also. However, there is no evidence to establish flow from the continents situated on eastern and western sides of Andaman (Karunakaran *et al.*, 1964, 1968). The plate tectonic maps (Fig. 5) indicate that consolidation and uplift of the Sino-Myanmar Ranges which was caused by Kimmeridgean orogeny resulted continental erosion. The sediments were deposited subsequently in intermontane basins of Myanmar and in the Indo- Myanmar geosynclines. The flysch sediments also from Asian Plate including Myanmar stretched to the west and covered parts of oceanic Tethys sea floor reaching to Andaman Islands through turbidity during Cretaceous to Oligocene (Bender, 1983).

Thus the above evidences clearly demonstrate that the area around Chindwin Basin was the source of sediment of Andaman Islands (Baratang Formation) containing the recycled palynofossils.

CONCLUSION

The palynology of Baratang Island shows that the constituents of palynoassemblages are dissimilar in different sections and the sediments span Early to Late Eocene age. The assemblages contain mixed palynoflora belonging to Permian, Triassic, Jurassic-Cretaceous together with Eocene palynomorphs. The reworked taxa have Gondwanic affinity and are the major constituents of the assemblages. Moreover, dinoflagellate cysts of Tertiary Period and Permian recycled pollen have been recorded for the first time from Andaman islands. A number of Tertiary palynomorphs of Andaman are common with Assam and Myanmar but the assemblages compare closely with that of Myanmar due to common occurrence of some stratigraphically important taxa like *Retitrisyncolpites* and *Baculimonocolpites*. The evidences from palynology together with lithology, palaeocurrent and palaeogeography favour that the source of terrestrial as well as marine palynofossils in Andaman was Myanmar.

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REFERENCES

Acharyya SK 1994. Accretion of Indo-Australian Gondwanic Blocks along Peri-Indian collision margins. *In* : Proceedings of the IXth International Gondwana Symposium, Hyderabad, India . 1029-1049. Oxfrod IBH Publisher.

Badve RM & Kundal P 1986. Marine Cretaceous algae from the Baratang Formation, Andaman Islands, India. Bulletin of the Geological, Mining & Metallurgical Society of India 54 : 149-158.

Banerjee D 1966. A note on the Tertiary microflora from the Andaman Islands, India. Pollen et Spores 8 : 205-212.

Banerjee D 1967. Upper Cretaceous microflora from Middle Andaman Isles (India). Review of Palaeobotany and Palynology 5 : 211-216.

Bender F 1983. *Geology of Burma*. Gebrüder Borntraeger, Berlin : 293p.

Chatterjee PK 1967. Geology of the main Islands of the Andaman area. *In* : Proceedings of the Symposium Upper Mantle Project, Hyderabad, India : 348-362.

Germeraad JH, Hopping CA & Muller J 1968. Palynology of Tertiary sediments of tropical areas. Review of Palaeobotany and Palynology 6 : 189-348.

Guha DK & Mohan M 1965. A note on Upper Cretaceous microfauna from the Middle Andaman Island. Bulletin of the Geological, Mining and Metallurgical Society of India 33 : 1-4.

Haq BU 1985. A synoptic overview of 200 million years of ocean history. *In* : Haq BU & Milliman JD (Editors)—Marine Geology and Oceanography Arabean Sea and Coastal Pakistan : 201-231 Van Nostrand Reinhold, New York.

Hutchison CS 1989. *Geological evolution of South-east Asia*. Oxford Monograph 13 : 368. Clarendon Press, Oxford.

Jafar SA & Tripathi SKM 2001. Late Triassic palynomorphs from the Andaman-Nicobar Basin, Andaman Sea, India. Modern Geology 24 : 205-219.

Kar RK 1983. On the original homeland of *Ceratopteris* Brong. and its palaeogeographical province. Geophytology 12 : 340-341

Kar RK 1985. The fossil floras of Kachchh IV Tertiary palynostratigraphy. Palaeobotanist 34 : 1-279.

Karunakaran C, Ray KK & Saha SS 1964. A new probe into the tectonic history of the Andaman and Nicobar Islands. *In* : Proceedings of the 22nd International Geological Congress, New Delhi 4 : 507-515.

Karunakaran C, Ray KK & Saha SS 1968. Tertiary sedimentation in the Andaman-Nicobar geosyncline. Journal of the Geological Society of India 9: 32-39.

Krishnan MS 1982. *Geology of India and Burma*. C.B.S. Publication, New Delhi : 536.

Krutzsch W 1959. Einige neue Formgattungen und-Arten von sporen und Pollen aus der Mitteleuropäischen Oberkreide und dem Tertiär. Palaeontographica 105B : 125-157.

Krutzsch W 1962. Stratigraphisch bzw. Botanisch wichtige neue Sporen-und Pollen-formen aus dem deutschen Tertiär. Geologie 11 : 265-307.

Kumar A 1990. Late Triassic dinoflagellate cysts and acritarchs from the Andaman Island: discussion. Modern Geology 14 . 245-253.

Kumar P & Soodan KS 1976. Early Palaeocene planktonic foraminifera from the Baratang Formation, Middle Andaman Island. *In* : Proceedings of the VIth Indian Colloquium on Micropaleontology & Stratigraphy, Varanasi, India : 145-150.

Kunihiro I & Kunio K 1991. Japan in Early Cenomanian and Campanian times relative to Tethys and Artic waters–ostracode implications. *In* : Kotaka T *et al.*, (Editors)—Proceeding of the Symposium Shallow Tethys 3 . 179.

Mandal J 1996. Palynofossils from the Tertiary (Barail Group) of Nagaland : palaeoecological interpretation and age. Palaeobotanist 45 . 98-108.

Mandal J, Chandra A & Kar RK 1994. Palynofossils from the Kadamtala coal, Middle Andaman, India. Geophytology 23 209-214.

Mandal J, Chandra A & Kar RK 1996. Palynological findings from the mud volcanoes of Baratang Island (Andaman and Nicobar Islands), India. Geophytology 25 . 77-81.

Mandal J & Kumar M 2000. Stratigraphic significance of some angiosperm pollen from the Tinali Oilfield, Upper Assam, India. Palaeobotanist 49 : 197-207.

Mathur YK & Mathur K 1980. Barail (Laisong) palynofossils and Late Oligocene nannofossils from the Andaman Islands, India. Geoscience Journal 1 : 51-66.

Mehrotra NC & Sarjeant WAS 1990. Late Triassic palynomorphs from the Andaman Islands : a reply to A. Kumar. Modern Geology 14 255-264.

Metcalfe I 1988. Origin and assembly of south-east Asian continental terrains. *In* : Audley-Charles MG & Hallem A (Editors)—*Gondwana and Tethys*, Geological Society Special Publication 37 . 101-118.

Morley RJ 1982. Fossil pollen attributed to *Alangium* Lamarck (Alangiaceae) from the Tertiary of Malaysia. Review of Palaeobotany and Palynology 36 : 65-94.

Morley RJ 1991. Tertiary stratigraphic palynology in Southeast Asia : current status and new directions. Geological Society of Malaysia 28 : 1-36.

Muller J 1968. Palynology of the Pedwan and Plateau Sandstone formations (Cretaceous-Eocene) in Sarawak, Malaysia. Micropaleontology 14 : 1-37.

Pandey J 1972. Depositional environmental and geological history of the Baratang Formation, Andaman Islands. *In* : Proceedings of the IInd Indian Colloquium on Micropaleontology & Stratigraphy, Lucknow, India : 66-76.

Pandey J 1986. Some recent paleontological studies and their implications on the Cenozoic stratigraphy of Indian subcontinent. Bulletin of the Oil and Natural Gas Commission 23 : 1-44.

Pandey J & Rao VK 1976. Late Cretaceous planktonic foraminifera from the Middle Andaman Islands. *In* : Proceedings of the VIth Indian Colloquium on Micropaleontology & Stratigraphy, Varanasi, India : 182-205.

Pandey J, Agarwal RP, Dave A, Maithani A, Trivedi KB, Srivastava AK & Singh DN 1992. Geology of Andaman. Bulletin of the Oil and Natural Gas Commission 29 : 19-103.

Potonié R 1960. Sporologie der eozänen Kohle von Kalewa in Burma. Senckenbergiana Lethia 41 : 451-481.

Rad UV, Exon NF & Haq BU 1992. Rift to drift history of the Wombat Plateau, northwest Australia etc. Proceedings of the Ocean Drilling Programme, Science Research 122 : 765-800.

Rajsekhar C, Badve RM & Kundal P 1990. Cretaceous planktonic foraminifera from the cherty limestone of Baratang Island, India. Journal of the Geological Society of India 35 : 357-365.

Rao MR 1996. A Early Miocene palynofloral assemblage from Turavur bore-hole, Alleppy District, Kerala - its palaeoecological and stratigraphical significance. Geophytology 25 155-163.

Ray KK 1982. A review of the geology of Andaman and Nicobar Islands. Geological Survey of India Miscellaneous Publication 41/2 : 110-125.

Reimann KU & Thaung A 1981. Results of palynostratigraphical investigation of the Tertiary sequence in the Chindwin Basin, North-western Burma. *In* : Proceedings of the IVth International Palynological Conference, Lucknow, India 3 : 380-395.

Rich TH & Vickers-Rich P 1999. Palaeogeographic implications of Early Cretaceous Australian Placental mammals. PINSA 65/3 315-327.

Shanfu Zhou 1999. New genus *Intubidinium* and geologic age of the Lower member of Taizhou Formation. Paleopalynological Research and Application . 93-106 (in Chinese).

Sharma J & Mehrotra NC 1984. Discovery of Late Triassic sediments from Andaman Islands: some new palynological evidences. Bulletin of the Oil and Natural Gas Commission 21 : 69-73.

Sharma J & Sarjeant WAS 1987 Late Triassic dinoflagellate cysts and acritarchs from the Andaman Islands, India. Modern Geology 11 : 255-264.

Singh A, Misra BK, Singh BD & Navale GKB 1992. The Neyveli lignite deposits (Cauvery Basin), India: organic composition, age and depositional pattern. International Journal of Coal Geology 21 : 45-97.

Thanikaimoni G, Caratini C, Venkatachala BS, Ramanujam CGK & Kar RK 1984. Selected Tertiary angiosperm pollens from India and their relationship with African Tertiary pollen. Institut Francis de Pondichéry, Travaux de la Section Scientifique et Technique 19 : 1-93.

Venkatachala BS, Caratini C, Tissot C & Kar RK 1989. Palaeocene-Eocene marker pollen from India and tropical Africa. Palaeobotanist 37 : 1-25.

Williams GM, Stover LE & Kidson EJ 1993. Morphology and stratigraphic ranges of selected Mesozoic–Cenozoic dinoflagellate taxa in the Northern Hemisphere. Geological Survey of Canada paper 92-10 : 1-137.

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Koshalia, an *Incertae sedis* fossil from the Subathu Formation (Late Ypresian), Himachal Pradesh, India

SAMIR SARKAR AND VANDANA PRASAD

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.
Email: sarkarsamir@yahoo.co.uk; vanprasad@yahoo.co.uk

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ABSTRACT

Sarkar S & Prasad V 2003. *Koshalia*, an *Incertae sedis* fossil from the Subathu Formation (Late Ypresian), Himachal Pradesh, India. Palaeobotanist 52(1-3) : 113-116.

A new form genus *Koshalia* has been instituted from the Subathu Formation (Late Ypresian) of Shimla Hills, Himachal Pradesh. This taxon is represented by only one species viz., *K. enigmata* and possess subsphaerical, multilayered, shield-shaped thyriothecia. The exact affinity of the recorded fossil is not known, it may probably a fruiting body of some unknown affinity.

Key-words—*Koshalia*, Fruiting body, Subathu Formation (Late Ypresian), Himachal Pradesh, India.

भारत के हिमाचल प्रदेश प्रान्त के सुबाथू शैलसमूह (अन्तिम वायप्रीज़ियन) से प्राप्त *कोशलिया* नामक एक *इनसर्टाइ सेडिस* पादपाश्म

समीर सरकार एवं वन्दना प्रसाद

सारांश

हिमाचल प्रदेश की शिमला पर्वत श्रेणियों के सूबाथू शैल समूह (अन्तिम वायप्रीज़ियन) से एक नवीनतम वंश प्ररूप *कोशलिया* खोजा गया है। यह वर्गक मात्र एक प्रजाति *के एनिग्माटा* द्वारा निरूपित है तथा इसमें उपगोलीय, बहुस्तरित, ढाल की आकार का थाइरियोथीशिया विद्यमान है। अंकित पादपाश्म की सुनिश्चित बन्धुता ज्ञात नहीं हो सकी है, परन्तु यह सम्भवतः कुछ अज्ञात बन्धुता का फल काय हो सकता है।

संकेत शब्द—*कोशलिया,* फल काय, सुबाथू शैलसमूह (अन्तिम वायप्रीज़ियन), हिमाचल प्रदेश, भारत.

INTRODUCTION

DURING the course of palynological investigation of the Palaeogene sediments of Shimla Hills, Himachal Pradesh, a large number of specimens of fruiting bodies of unknown affinity were recovered from the Late Ypresian sediments of the Subathu Formation, exposed along the Koshalia Nala near Koti in the Sirmaur District, Himachal Pradesh (Fig. 1).

The fruiting body referred to the newly established form genus *Koshalia* is distinctive and morphologically different from the known form genera of fruiting body. In morphological character *Koshalia* has subsphaerical, multilayered, shield-shaped thyriothecia, 9-10 cells arranged in compact rings around a small ostiole. *Koshalia* is an important constituent of the *Cordosphaeridium* spp. Assemblage Zone which identifies the Late Ypresian-Early Lutetian transition in the section (Sarkar & Prasad, 2000).

GEOLOGICAL SETTING

The Palaeogene succession of Shimla Hills consists of Subathu, Dagshai and Kasauli formations in ascending order of stratigraphy. About 110 m thick succession of the Subathu Formation are exposed along the Koshalia Nala near Koti in the Sirmaur District of Himachal Pradesh (Fig. 2). The Late Ypresian sediments of the Koshalia *Nala* has been dated using larger foraminifera and calcareous nannofossils (Bagi, 1992, Jafar & Singh, 1992). The basal part of the Late Ypresian sequence comprises mostly grey splintery shales with few thin storm sand layers. The middle horizons contain mostly hard splintery shales, intercalated with thin sandstones layers. The Early Lutetian sequence is about 20 m thick. It is characterised by a thick limestone bed (1-2 m) at the base. It contains mostly green splintery shales. The overlying red bed sequence mostly comprises siltstones. The fruiting body yielding horizon consists of light grey calcareous shale just below *Assilina Spira Abradi* band. The type material and the slides are housed in the Museum of the Birbal Sahni Institute of Palaeobotany, Lucknow.

KOSHALIA gen. nov.

Type Species—*Koshalia enigmata* sp. nov.

Generic Diagnosis—Thyriothecia subsphaerical, multilayered, 90-150 μm in diameter, 9-10 cells arranged in compact rings around an ostiole, marginal cells extremely large, Size 35-45 x 65-85 μm, inner cells small, subcircular, size 8-15 x 10-20 μm.

Generic Description—Thyriothecia subsphaerical, multicellular, multilayered, cells arranged in compact rings, number of rings three, ostiolate, ostiole centric, circular, 6-10 μm in diameter, 3-4 dark coloured cells present around the ostiole, individual cells radially arranged, interconnected to form a shield-shaped body, marginal cells extremely large, broader than long, cell wall thickened on the ventral surface, cell wall scabrate to infra punctate. Perforation in individual cells absent.

Comparison—*Koshalia* gen. nov. is distinguished from any other known form genera of fruiting body in having multilayered, subsphaerical, shield- shaped thyriothecia, 9-10 cells arranged in compact rings and possess extremely large marginal cells.

Etymology—The genus has been named after the Koshalia Nala, the geographic location from where it has been recorded .

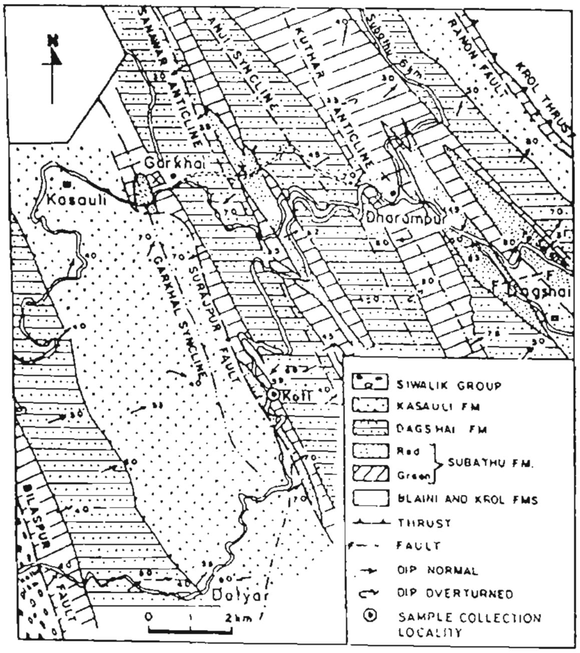

Fig. 1—Shows the geological map of the area of investigation (after, Mathur & Juyal, 2000).

Affinity—The affinity of this genus is not definitely known, however, overall morphology points towards fruiting body of some unknown affinity.

Remarks—Apparently, the recovered fruiting bodies show close resemblance with microthyraceous ascostromata as well as foraminiferal test. However, careful observations have revealed that they neither belong to fungi nor to foraminifera because of its characteristic cell arrangement. Morphological variability is also very prominent among the recovered specimens.

KOSHALIA ENIGMATA sp. nov.

(Pl. 1·1-4)

Holotype—Fig. 2, Slide No. BSIP 12243, co-ordinates 54 x 104.

Dimensions (Holotype)—Size of thyriothecia 100 μm in diameter, Size of the marginal cells 38-40 x 65-70 μm; Size of the innercells 8-12 x 10-15 μm.

Type Locality—Koshalia Nala near Koti, Shimla Hills, Himachal Pradesh, India.

Horizon & Age—Subathu Formation, Late Ypresian.

Diagnosis—Thyriothecia subsphaerical, multicellular, multilayered, 9-10 cells arranged in compact rings, 3-4 cells in each layer, ostiolate, marginal cells extremely large, overall size range 90-150 μm in diameter.

Description—Thyriothecia subsphaerical, multilayered, overall size range 90-150 μm in diameter, multicellular, 9-10 cells arranged in compact rings to form a shield-shaped body, 3-4 cells arranged radially around an ostiole in each layer, ostiole centric, 6-10 μm in diameter, margin thickened, inner cells subcircular, small, thick walled, marginal cells extremely large, cell wall thin, scabrate to infrapunctate. Perforation absent in individual cells.

Etymology—The affinity of the specimens is not known so it has been named as enigmata.

Remarks—Most of the specimens are very thick walled, therefore cell structures are visible only in over macerated samples.

DISCUSSION

The present study shows that *Koshalia* is mainly associated with land derived palynofossils especially with palm pollen viz., *Neocouperipollis* spp., *Palmidites* spp. and microthyraceous ascostromata in the Late Ypresian sediments of the Subathu Formation. The association with palm pollen indicates that present fruiting bodies are terrestrial in origin and were transported from near by coastal areas during regressive phase of the Subathu Sea. Microthyraceous fossil

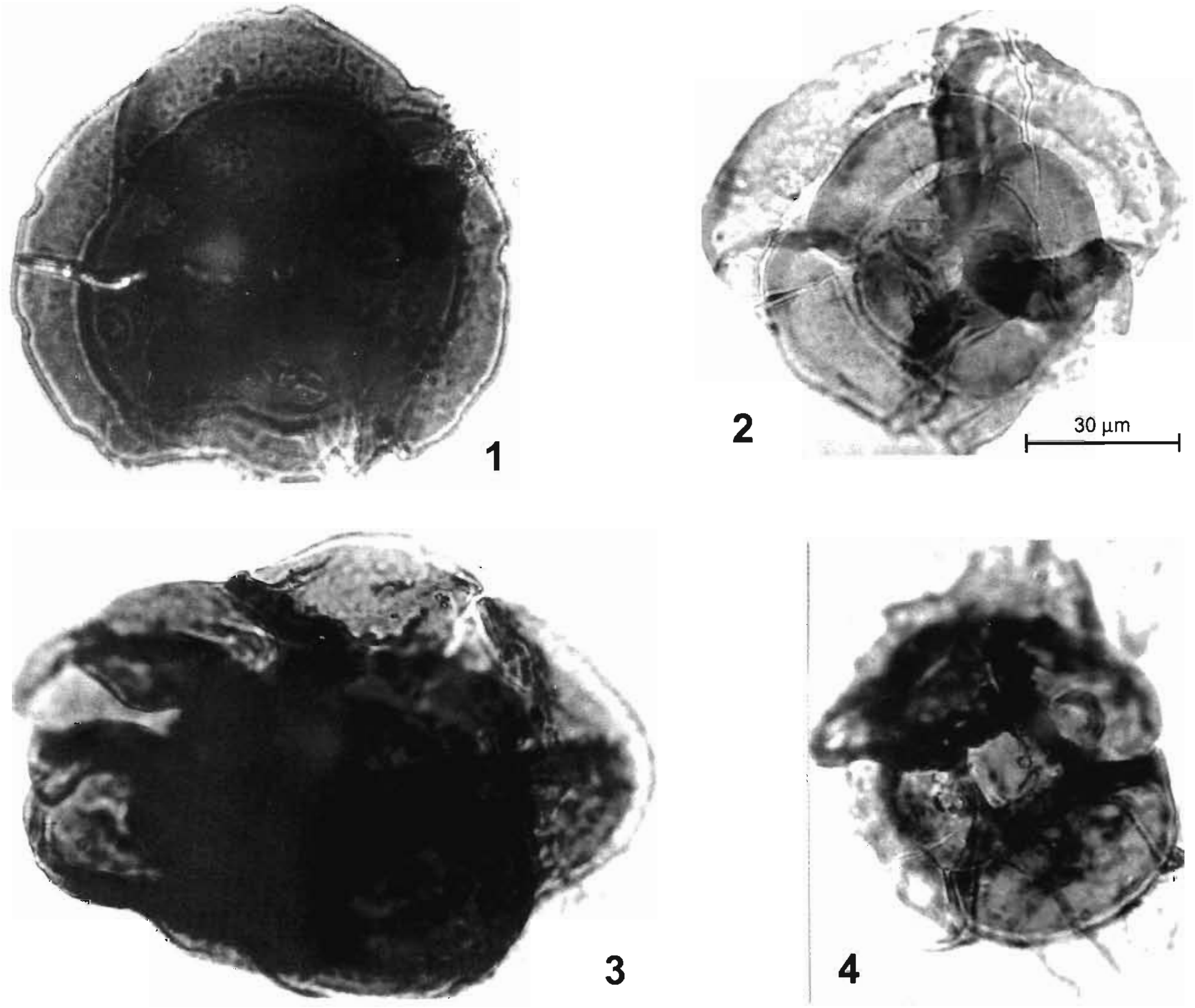

PLATE 1

(All photomicrographs are magnified x ca.700. Co-ordinates of specimens in slides refer to the stage of Laborlux Microscope No. 402040)

Koshalia enigmata gen. et sp. nov.

1. Slide No. BSIP 12242, co-ordinates 30 x 106 (Young fruiting body, dorsal view).
2. Slide No. BSIP 12243, co-ordinates 54 x 104 (Holotype, ventral view).
3. Slide No. BSIP 12243, co-ordinates 57 x 103 (Mature fruiting body, dorso-lateral view).
4. Slide No. BSIP 12243, co-ordinates 49 x 112 (Showing ostiole, ventral side).

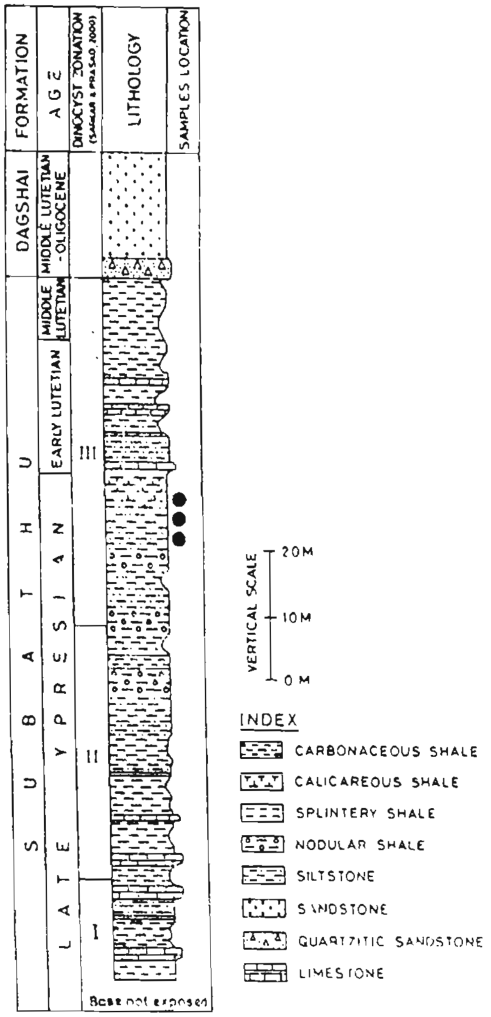

Fig. 2—Shows the location of samples in the litholog (modified after, Bhatia & Singh, 1991).

fungi are generally considered to be a good indicator of warm and humid climate. The members of the microthyriaceae are epiphyllous parasites in tropics, subtropics and warm temperate regions (Ram Ratan & Chandra, 1982) and found generally in the tropical evergreen and deciduous forest. The occurrence of these fruiting bodies with microthyraceous ascostromata clearly suggests that the prevalent climate was very warm and humid.

Acknowledgements*—The authors are grateful to Professor Anshu Kumar Sinha, Director, Birbal Sahni Institute of Palaeobotany, Lucknow for allowing us to publish this paper and for encouragement through out the study. We are thankful to Professor SB Bhatia (Retd.) Centre for Advance study in Geology, Panjab University, Chandigarh for his invaluable help in making the necessary collections from the river Section as well as for providing foraminiferal data from the unpublished dissertation of H Bagi.*

REFERENCES

Bagi H 1992. Contribution to the Ostracode and smaller foraminiferal fauna of the Subathu Formation of parts of Shimla Hills - Unpublished Ph.D. Thesis, Panjab University, Chandigarh . 1-265.

Bhatia SB & Singh RY 1991. Workshop on SEM Applications in Micropalaeontology, Guide to Field Excursion to Koshalia Nala, Indian Geologist Association, Panjab University, Chandigarh : 1-3.

Jafar SA & Singh OP 1992. K/T boundary species with Early Eocene nannofossils discovered from Subathu Formation, Shimla Himalaya, India. Current Science 62 409-413.

Mathur NS & Juyal KP 2000. Atlas of Early Palaeogene invertibrate fossils of the Himalayan foothills belt. Wadia Institute of Himalayan Geology Monograph 1 : pp257.

Ram Ratan & Chandra A 1982. Isolated thyriothecia from the surface (Bottom) sediments of the Arabian Sea. Geophytology 12 : 260-263.

Sarkar S & Prasad V 2000. Palaeoenvironmental significance of dinoflagellate cysts from the Subathu Formation (Late Ypresian–Middle Lutetian) of Koshalia Nala section, Shimla Hills, India. Himalayan Geology 21 : 167-176.

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Kalviwadithyrites, a new fungal fruiting body from Sindhudurg Formation (Miocene) of Maharashtra, India

M.R. RAO

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.
E-mail: rao_mr_2000@yahoo.com

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ABSTRACT

Rao MR 2003. *Kalviwadithyrites*, a new fungal fruiting body from Sindhudurg Formation (Miocene) of Maharashtra, India. Palaeobotanist 52(1-3) : 117-119.

A rich palynoflora consisting of fungal remains, pteridophyte spores and angiosperm pollen has been recovered from Sindhudurg Formation exposed at Kalviwadi, Sindhudurg District, Maharashtra. In this assemblage, a fungal fruiting body *Kalviwadithyrites* is proposed as new and it could not be accommodated in any of the known fossil fungal genera.

Key-words—Fungal fruiting body, Sindhudurg Formation, Miocene, Maharashtra (India).

भारत के महाराष्ट्र प्रान्त के सिन्धुदुर्ग शैलसमूह (मायोसीन) से प्राप्त *कालवीवेडाइथाइराटीज़* नामक एक नवीन कवकीय फल काय

मुलागलापल्ली रामचन्द्र राव

सारांश

महाराष्ट्र के सिन्धुदुर्ग के कालवीवाड़ी में अनावरित सिन्धुदुर्ग शैलसमूह से कवकीय अवशेषों, टेरिडोफाइटी बीजाणुओं तथा आवृतबीजी परागकणों से युक्त एक सम्पन्न परागाणु वनस्पतिजात खोजा गया है। इस समुच्चय से प्राप्त *कालवीवेडाइथाइराइटीज़* नामक एक कवकीय फल काय नूतन प्राप्ति के रूप में प्रस्तावित किया जाता है तथा इसे किसी अन्य ज्ञात अश्मित कवक वंश के साथ नहीं रखा जा सकता ।

संकेत शब्द—कवकीय फल काय, सिन्धुदुर्ग शैलसमूह, मायोसीन, महाराष्ट्र (भारत).

INTRODUCTION

THE Ratnagiri beds were first reported by Wilkinson (1871) from a number of well sections along the Ratnagiri Coast, Maharashtra. Subsequently, the Sindhudurg Formation was formally described a lithostratigraphic unit by Saxena (1995) for a distinct sequence of grey to bluish clays with carbonaceous and lignite seams, which are well developed in the Konkan Coast of the Ratnagiri and Sindhudurg Districts of Maharashtra. Earlier this sequence was informally referred to as the Ratnagiri beds (Wilkinson, 1871; Saxena *et al.*, 1992).

The Sindhudurg Formation is located at Kalviwadi (Lat. 16°24'30" N: Long 73°26'10" E) about 0·6 km east of Mondtor bus stop near Tembhavi Village in Devgarh Taluk of

Sindhudurg District. The section consists of grey clay at the base succeeded by lignite, ironstone band, grey clay and laterite (Fig. 1). The samples collected from the lignite and clay have yielded a variety of fungal remains and spore-pollen. The present study deals with the fungal fruiting body.

SYSTEMATICS

Genus—KALVIWADITHYRITES gen. nov.

Type Species—KALVIWADITHYRITES SAXENAE sp. nov.

Generic Diagnosis—Cleistothecium sub circular to circular in shape, dimidiate, non-ostiolate. Two types of cells present, pores absent. No hyphae present. Marginal cells rectangular to polygonal in shape, larger in size, covers outer part; central cells thickness 2 or 3 layered, squarish and isodiametric.

Comparison—The present genus closely compares with *Phragmothyrites* Edwards emend. Kar & Saxena (1976) and *Microthyriacites* Cookson (1947) in being circular, non-ostiolate and showing in no free hyphae but distinguished from the former by having two types of cells. *Notothyrites* Cookson (1947) differs in being ostiolate. *Parmathyrites* Jain & Gupta (1970) is distinguishable in having spines formed from the peripheral cells. *Siwalikiathyrites* Saxena and Singh (1984) is differentiated by its smaller size and lacking two sets of cells. *Ratnagiriathyrites* Saxena & Misra (1990) resembles the present genus in having non-radial cells but differs in its hexagonal porate cells.

KALVIWADITHYRITES SAXENAE sp. nov.

(Pl. 1·1-3; Fig. 2)

Holotype—Pl. 1.1, size 108 x 100 µm, Slide No. BSIP 12689.

Type Locality, Horizon & Age—Kalviwadi, Sindhudurg District, Maharashtra, Sindhudurg Formation, Miocene.

Description—Cleistothecium circular- sub-circular. Size range 105-115 x 95-110 µm. Dimidiate, non-ostiolate, No free hyphae. Fruiting body made up of two sets of cells, pores absent. Marginal cells rectangular to polygonal in shape, 9-12 x 10-17 µm in diameter, light brown in colour. Central cells thickness 2 or 3 layered, squarish and isodiametric, 4-10 µm in diameter, darker in colour.

Affinity—Unknown.

Derivation of name—This species is named in honour of Dr RK Saxena, Birbal Sahni Institute of Palaeobotany, Lucknow for his well known work on fossil fungi.

DISCUSSION

The palynoflora recorded from the Sindhudurg Formation consists of 35 genera and 43 species comprising to fungal remains, pteridophyte spores and angiosperm pollen. The assemblage contains profuse fungal remains represented by fruiting bodies (*Phragmothyrites, Microthyriacites, Notothyrites, Parmathyrites, Kutchiathyrites* and *Lirasporis*), spores (*Inapertisporites, Dyadosporonites, Dicellaesporites, Meliola, Multicellaesporites, Pluricellaesporites* and *Involutisporonites*) and also some hyphae. In addition to the above, *Kalviwadithyrites*, a fungal fruiting body recorded from the lignitic sediments has been proposed as new.

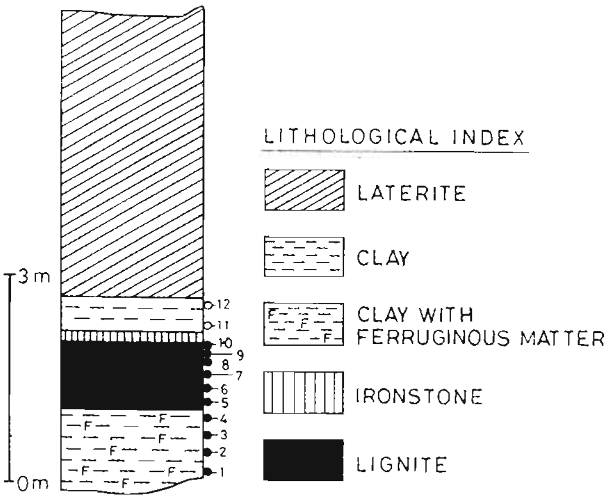


Fig. 1—Lithological details of Kalviwadi section (Sindhdurg Formation), Maharashtra.

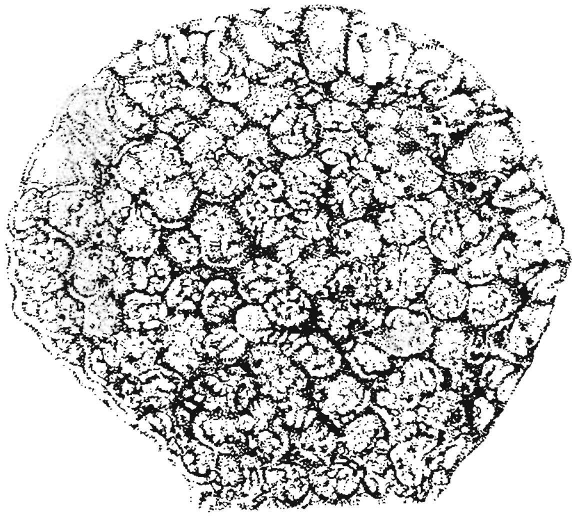


Fig. 2—*Kalviwadithyrites saxenae* gen. et sp. nov. x 1000.

The assemblage also contains pteridophyte spores (*Striatriletes susannae*, *Dictyophyllidites* sp., *Lygodiumsporites lakiensis*) and angiosperm pollen (*Quilonipollenites ornatus*, *Lakiapollis* spp., *Tricolporopollis* spp., *Dermatobrevicolporites* sp. and *Perfotricolpites neyvelii*). *Heliospermopsis*, a salt gland of mangrove plant has also been recovered. Qualitative and quantitative analyses reveal that the fungal remains are dominant over pteridophyte spores followed by angiosperm pollen. The rich representation of fungal fruiting bodies and spores are typical of microthyriaceous epiphyllous fungi. Their occurrence in the present assemblage indicates the existence of a terrestrial plant ecosystem and supported by a warm and humid conditions with heavy rainfall. This view is also corroborated by the representation of pteridophyte spores and some angiosperm pollen.

Acknowledgements—*The author is thankful to Professor David Dilcher, Florida of Natural History, University of Florida, for critically going through the slides and giving critical comments and valuable suggestions.*

REFERENCES

Cookson IC 1947. Fossil fungi from Tertiary deposits in the southern hemisphere. Proceedings of Linnanean Society NSW 72 : 207-214.

Jain KP & Gupta RC 1970. Some fungal remains from the Tertiaries of Kerala. Palaeobotanist 18 : 177-182.

Kar RK & Saxena RK 1976. Algal and fungal microfossils from Matanomadh Formation (Palaeocene) Kutch, India. Palaeobotanist 23 : 1-15.

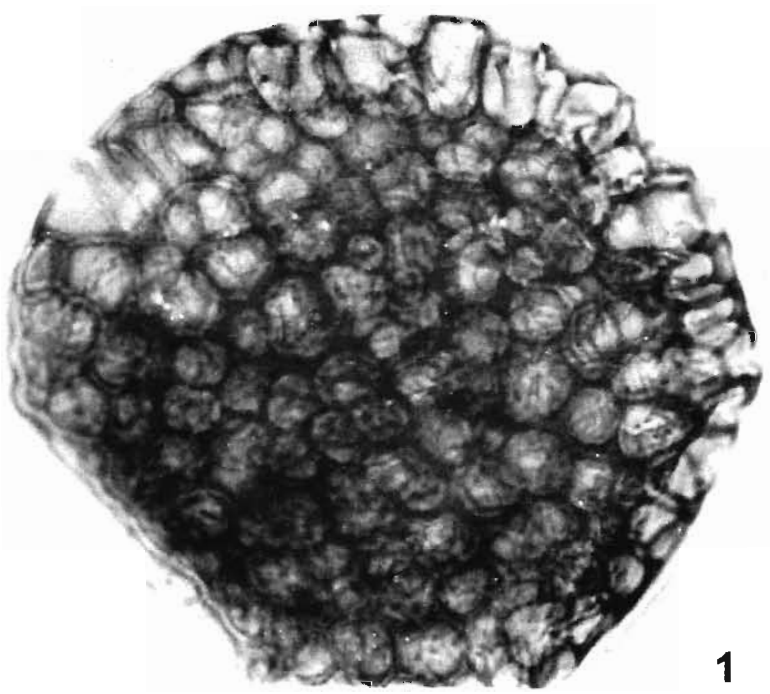
Saxena RK 1995. Sindhudurg Formation- A new lithostratigraphic unit in Konkan area of Maharashtra. Geophytology 24 : 229-232.

Saxena RK & Misra 1990. Palynological investigation of the Ratnagiri beds of Sindhu Durg District, Maharashtra. *In* : Jain KP &Tiwari RS (Editors)—Proceedings of Symposium "Vistas in Indian Palaeobotany". Palaeobotanist 38 : 263-276.

Saxena RK, Misra NK & Khare S 1992. Ratnagiri beds of Maharashtra -lithostratigraphy, flora, palaeoclimate and environment of deposition. Indian Journal of Earth Sciences 19 : 205-213.

Saxena RK & Singh HP 1984. Palynology of the Pinjor Formation (Upper Siwalik) exposed near Chandigarh, India. Palaeobotanist 30 : 325-339.

Wilkinson GJ 1871. Sketch of geological structure of the western Konkan. Records of the Geological Survey of India 4 : 44-47.



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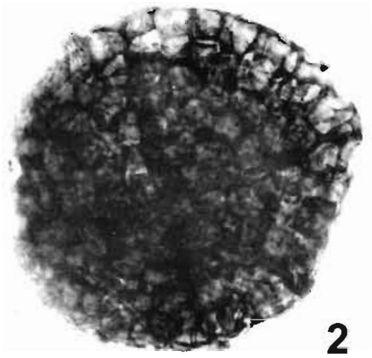

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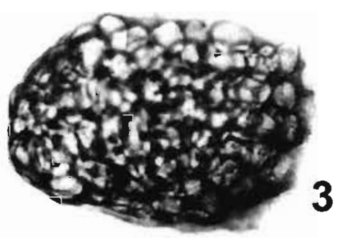

3

PLATE 1

(Co-ordinates refer to the stage of BH2 Olympus microscope no. 217 267)

1 *Kalviwadithyrites saxenae* gen. et sp. nov. x 1000. Slide No. BSIP 12689, co-ordinates 14.0 x 151.0 (Holotype).

2-3. *Kalviwadithyrites saxenae* gen. et sp. nov x 500. Slide Nos. BSIP 12689, co-ordinates 8.0 x 137.7; 12690 co-ordinates 7.7 x 156.0.

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Early Holocene pollen data from Mikir Hills, Assam, India

S.K. BERA

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.

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ABSTRACT

Bera SK 2003. Early Holocene pollen data from Mikir Hills, Assam, India. Palaeobotanist 52(1-3) : 121-126.

The pollen analytical studies of a 1·5 m deep soil profile (12210±110 years BP at 80 cm level) from Kaki Forest Division in Mikir Hills of Assam have been carried out. The pollen investigation of surface samples was made to understand the pollen/vegetation relationship in the forest. However, the study of surface samples does not fully cohere with the present day set up of vegetation. Palynological studies of the sediment profile indicate that since the last 15,000 years there have been three stages of vegetational developments followed by a reducing environment at the beginning (150-120 cm) reflecting directly on brief phases of climate such as arid, semi arid and warm and humid. The abundance of grasses both cultivated as well as wild throughout the pollen diagram has revealed the existence of an open savanna forest for a long period. The arboreal vegetation is represented by mixed tropical and subtropical trees and shrubs. Both monolete and trilete ferns are well documented in the assemblage. Occurrence of some degraded pollen and spores indicate the biodegradation of microbiota as evidenced by the presence of fungal spores and hyphae in almost all the sediments.

The low occurrence of extra regional plant taxa like *Pinus, Picea, Abies, Larix, Betula* and *Alnus* in the sediments is indicative of long distance transportation of pollen from high elevation.

Key-words—Early Holocene, Pollen, Mikir Hills, Assam.

भारत के असम प्रांत की मिकिर पर्वत श्रेणियों से प्राप्त प्रारंभिक होलोसीन युगीन परागाणविक आंकड़े

समीर कुमार बेरा

सारांश

असम की मिकिर पर्वत श्रेणियों के काकी वन प्रभाग से प्राप्त एक 1·5 मीटर गहरी मृत्तिका परिच्छेदिका (80 सेमी स्तर पर 12210 ± 110 वर्ष पूर्व का) परागाणविक विश्लेषण किया गया। वन में परागकणों/वनस्पतियों के संबंध को समझने हेतु पृष्ठीय नमूनों का परागाणविक विश्लेषण किया गया। पृष्ठीय नमूनों का अध्ययन वनस्पतियों के वर्तमान परिदृश्य से पूर्णतः संगत नहीं है। अवसादी परिच्छेदिका का परागाणविक अध्ययन इंगित करता है कि विगत अन्तिम 15,000 वर्षों में वनस्पतियों के विकास की तीन प्रावस्थाएँ रही हैं, जिनके पश्चात क्रमश प्रारंभ में (150-120 सेमी) एक न्यूनीकृत पर्यावरण आया, जिसका प्रत्यक्ष प्रभाव जलवायु की विभिन्न प्रावस्थाओं, जैसे—शुष्कता, अर्द्ध शुष्कता तथा आर्द्रता एवं उष्णता पर पड़ा। कृषि से प्राप्त घासों तथा जंगली घासों की संपूर्ण परागकण आरेख में प्रचुरता से एक दीर्घ अवधि हेतु विवृत सवाना वनों की उपस्थिति प्रदर्शित हुई है। वृक्षीय वनस्पतियाँ सम्मिश्र उष्णकटिबन्धीय एवं उपोष्ण कटिबन्धीय वृक्षों तथा गुल्मों द्वारा

निरूपित हैं। एक अरीय तथा त्रिअरीय दोनों ही पर्णांग (फ़र्न) समुच्चय में सुस्पष्टतः अभिलेखित हैं। कुछ निम्नीकृत परागकणों तथा बीजाणुओं की प्राप्ति सूक्ष्मजीवजातों का जैवनिम्नीकरण इंगित करती है, जो प्रायः सभी अवसादों में कवकीय बीजाणुओं तथा कवक तन्तुओं (हाइफी) की उपस्थिति से अभिपुष्ट है।

क्षेत्र से बाहर के क्षेत्रीय पादप वर्गकों, जैसे—*पाइनस, पाइसिया, एबीज़, लैरिक्स, बीटुला* तथा *एलनस* की अवसादों में कम प्राप्ति परागकणों के उच्च उन्नयन से दूरस्थ परिवहन का परिचायक है।

संकेत शब्द—प्रारंभिक होलोसीन, परागकण, मिकिर पर्वत श्रेणी, असम.

INTRODUCTION

POLLEN bearing sediments found in lakes provide a record of past vegetation presumably arranged in a stratigraphic column. Thus, description of the deposits depends greatly upon a quantitative determination of the relative proportion of pollen type at various levels. Interpretation of pollen deposit assumes that frequencies of pollen types deposited reflect changes in proportions of species or genera in the surrounding vegetation. These changes are often interpreted as the result of climatic change one of the major factors affecting species composition of vegetation. Therefore, with the acquired knowledge of the extant vegetation one may reconstruct the vegetational history and palaeoenvironment of the Quaternary period in terms of the ecological status of the dispersed pollen grains and spores.

Hitherto, no information is available on recent pollen spectra and Quaternary vegetational history on North eastern Hill region especially from Mikir Hills of Assam. Although preliminary works have been carried out at Cinnamara (Gupta, 1971), Upper Assam (Bhattacharya & Goswami, 1981; Bhattacharya & Chanda, 1982, 1988; Bhattacharya, 1985; Bhattacharya *et al.*, 1986) and Mikir Hill (Bera, 2000).

It is therefore, supposed that pollen analysis would be valuable for tracing the Quaternary vegetational history of the Mikir Hills and for revealing changes in palaeoclimate and ecology.

The typical subtropical monsoon climate prevalent in the area is characterised by the excessive moisture content of the air throughout the year. Two distinct climates i.e., Winter and summer can be recognised. The altitudinal range varies from 78 m asl to 1282 m asl. The soil within the Kaki Forest varies from sandy loam to fine silt and clayey loam. It is generally deep except on some hill slopes where rock occurs near the surface. In the hilly region the soil is derived by the decomposition and weathering of mostly gneiss or sandstone. The characteristic red loam is readily apparent. Clayey soil and fine silt are found in the depression and hollows in water logged location and exposure of the soil on the ridges and slopes losses its fertility very quickly due to washing away of the fine material with organic and mineral matter. The texture of the soil is governed to a large extent on the vegetational cover and on past history of biotic activities. Soil under semi evergreen formation are comparatively richer in organic contents. The soil along the ridges and steeper slopes of the hills are usually sandy and gritty having shallow depth.

The forest types are of moist semi evergreen and moist mixed deciduous in the region. The moist semi evergreen formation occurred in Dhansiri, Disama, Daldaliya and partly in Kaki Forest areas and along nallahs and depressions where sufficient moisture and sunlight are available. The forest is dominated by principal arboreal taxa like *Tetrameles nudiflora, Stereospermum personatum, Amoora wallichii, Artocarpus chaplasa, Mesua ferrea, Phoebe goalparenses, Canarium resiniferum, Terminalia chebula, Gmelina arborea, Cinnamomum glanduliforum*, etc.

Moist mixed deciduous formation is predominant in Kaki reserve forests. The major arboreal taxa found growing luxuriantly in the region are *Terminalia bellerica, Bombax ceiba, Schima wallichii, Adina cordifolia, Lagerstroemia*

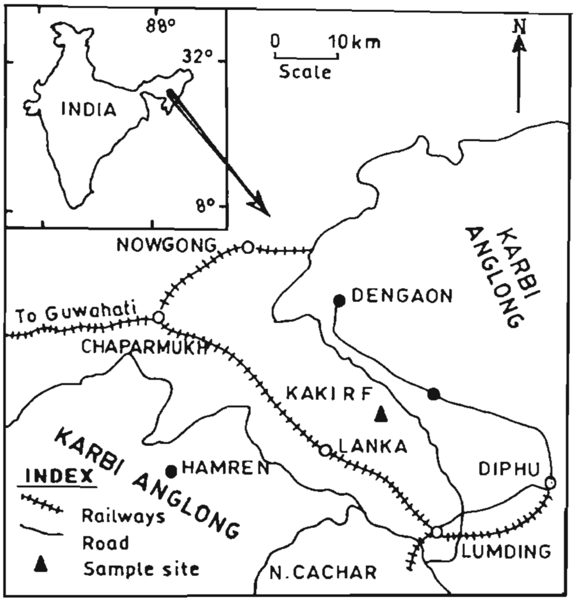

Fig. 1—Showing the site of sampling.

perviflora, Sterculia villosa, Dillenia pentagyna, Albizia odoratissima, Anthocephalus cadamba, Bauhinia variegata, Holarrhena antidysenterica, Eugenia jambolana, Emblica officinales, Kydia calysina, Eupatorium odoratum, Zizyphus sp., *Murraya koenghii, Laportea crenulata, Clerodendron viscosum*, etc. Among climbers *Mikenia* spp. is predominant. Due to extensive felling of important plant taxa, the condition of the major crops of the formation have deteriorated and natural regeneration is almost absent caused by repeated grazing by the cattle of the neighbouring villages.

The main object involves undertaking of moss, soil and mud as surface samples collected in a transect at 100 m interval from within the forest into the open land with a view to understand the pollen/vegetation relationship in Mikir Hill forests which could help in ascertaining various climatic cycles to a great extent involving various controlling factors in the past through the palynostratigraphical study of sediment profile (Fig. 1).

MATERIAL AND METHODS

The modern surface samples were collected from within and outskirt of the forests. Moss cushion 1-4 were collected in a transect from within the forest to the edge. Sample numbers 5 and 6 were collected from near a swamp in open land whereas, mud samples 7 and 8 were collected from cultivated areas. The samples were collected in air tight double polythene bags. After several trials one 1·5 m soil sediment profile was collected by trenching in a dry cracked swampy areas within the forest. Due to hard stratum it was not possible to dig deeper sediments more than 1 to 1·5 m depth. Lithologically entire profile is divisible into three distinct lithozones viz., the upper clayey, middle organic mud and lower comparatively much thicker zone of sandy clay. The samples were chemically processed by conventional acetolysis method (Erdtman, 1943). The pollen counts vary from 150-250 depending upon the productivity of sample. The frequency percentages have been calculated in terms of total plants pollen counts. The plant taxa are grouped as arboreals, nonarboreals, ferns and drifted, etc. and arranged accordingly in the pollen spectra and diagram.

POLLEN/VEGETATION RELATIONSHIP

Pollen study of eight surface samples i.e., moss cushions, soil and mud procured from forested as well as open land in and around Kaki Forest Division in Mikir Hills of Assam has revealed that pollen spectra does not fully cohere with the modern vegetation set up both qualitatively and quantitatively. However, among arboreals *Ardisia, Artocarpus, Dillenia, Terminalia*, Oleaceae, Malvaceae, Anacardiaceae and Meliaceae are the only elements recorded within the values of 4-22 per cent out of which the extra regional taxa such as *Pinus, Alnus* and *Larix* are represented at the 6-10 per cent.

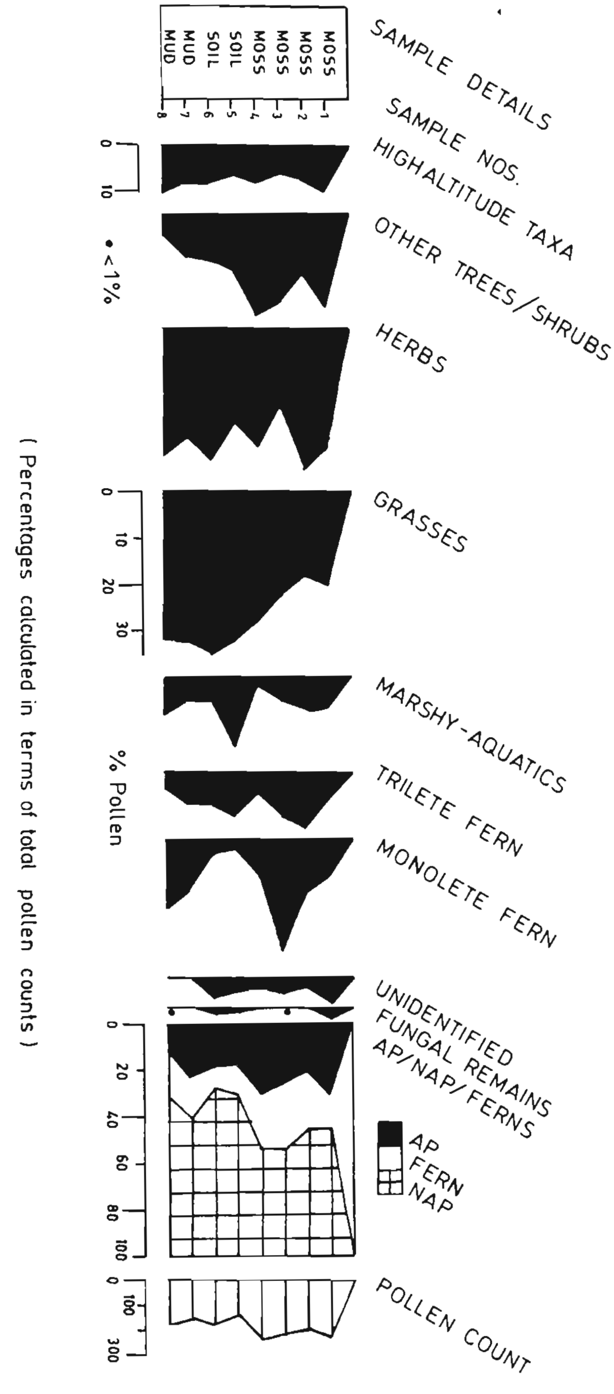

Fig. 2—Pollen spectra from Kaki Forest, Mikir Hills, Assam.

Ground vegetation is largely dominated by grasses under 18-35 per cent followed by other herbaceous elements like Asteraceae (4-15 %), Chenopodiaceae/Amaranthaceae (2-4 %), Lamiaceae, Apiaceae, Rubiaceae, Ranunculaceae and

Impatiens within the value of 1-3 per cent. Whereas, *Brassica nigra* (4.5-6.5 %) is recorded only in the samples collected from near the cultivated land. Cyperaceae, *Polygonum serrulatum* and *P. plebejum* are the main marshy elements whereas, *Potamogeton, Typha* and Liliaceae represent the aquatic vegetation. Monolete as well as trilete fern spores are mainly derived from the species of *Polypodium, Davallia, Pteris, Pteridium, Polytrichum,* etc. A large number of saprophytic fungi have been encountered in all the samples (Fig. 2).

DESCRIPTION OF POLLEN DIAGRAM

The constructed pollen diagram has been divided into three distinct vegetational phases followed by a barren zone at the beginning (150-120 cm) at the base of the profile on the basis of changing pollen sequences. The pollen assemblages are designated as M I, M II and M III whereas, the barren zone as BZ. The vegetational phases are separately described as follows (Fig. 3).

Phase M I (120-90 cm) : Grass-Brassicaceae–Tubuliflorae–Caryophyllaceae–Chenopodiaceae/ Amaranthaceae–Fern assemblage

This phase is characterised by the high values of grasses along with moderate value of Tubuliflorae, Caryophyllaceae and Chenopodiaceae/Amaranthaceae. Among others like Euphorbiaceae, Cyperaceae and *Justicia* are encountered in sporadic to low values. Cerealia and Brassicaceae are also reported in the scenario. Monolete fern spores are reported in relatively high values than that of trilete fern spores. The overall assemblage indicates the existence of open grassland with luxuriant growth of ferns. The occurrence of fungal remains along with a few degraded pollen and spores are indicative of microbial activity in the sediments.

Phase M II (90-50 cm) : Grass–Tubuliflorae–Lamiaceae–Chenopodiaceae/Amaranthaceae–Oleaceae–Terminalia–Syzygium assemblage

Among nonarboreals grasses maintain slightly low values than the preceding one. Whereas, Tubuliflorae, Lamiaceae, Ranunculaceae, *Impatiens,* etc. are recorded in low to moderate values. The invasion of arboreal taxa like *Terminalia, Syzygium, Artocarpus, Zizyphus,* Oleaceae, etc. have occurred for the first time in this phase. Among others *Adina,* Anacardiaceae, Fabaceae, Malvaceae and Liguliflorae are recorded sporadically. Fern spores both monolete and

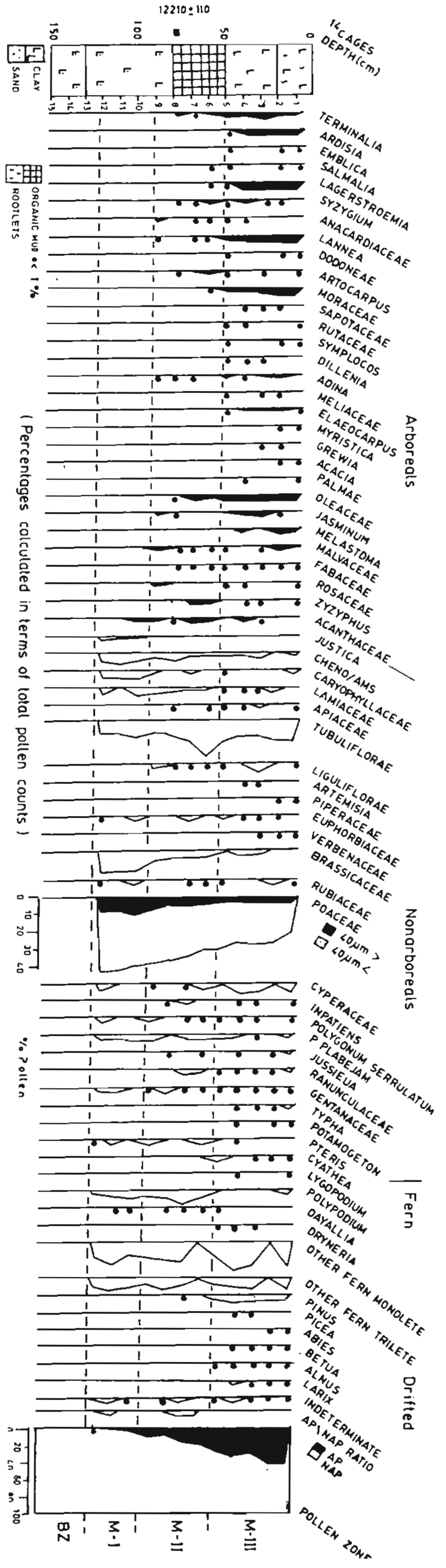

Fig. 3—Pollen diagram from Kaki Forest, Mikir Hills, Assam.

trilete maintained the same value as in the preceding one. The overall pollen assemblage indicates the savanna type of vegetation. The occurrence of fungal spores associated with degraded palynomorphs are supportive of the indication of biological degradation of microbiota.

Phase M III (50-0 cm) : Grasses–Cyperaceae–Tubuliflorae–Terminalia–Ardisia–Lagerstroemia–Elaeocarpus–Moraceae–Oleaceae-Fern assemblage

Grasses along with Tubuliflorae and Cyperaceae show relatively low values than the preceding phase. *Polygonum, Impatiens*, Ranunculaceae and Euphorbiaceae are reported sporadically. The values as well as numbers of the arboreal taxa are reported relatively high in the pollen assemblage and the important taxa are *Terminalia, Ardisia, Lagerstroemia, Lannea*, Moraceae, etc. Whereas, *Elaeocarpus, Melastoma, Adina* and Oleaceae are some of the taxa reported in low value. *Emblica, Syzygium, Dillenia*, Sapotaceae and Fabaceae are reported sporadically. Fern spores both monolete and trilete maintain the same value as in the preceding phase. *Larix, Picea, Abies, Betula* and *Alnus* are first time appeared in the assemblage which are not growing in the region. The fungal remains and some biodegraded pollen spores are encountered in low values in the assemblage. The overall assemblage indicates the establishment of arboreal vegetation during the phase.

HISTORY OF VEGETATION AND CLIMATE

North-eastern India which today possesses a diversified and luxuriant vegetation has not received much attention regarding its palaeovegetational succession and palaeoclimatic oscillation excepting the study of one brick kin quarry dated back to about 18,000 years BP from Lakhimpur District of Upper Assam (Bhattacharya & Chanda, 1988). Hitherto, no work has been done from Mikir Hills region and adjoining areas. This is the first comprehensive attempt in this direction.

One 1·5 m deep sediment profile collected from Kaki Forest Division of Mikir Hills, has solitary date of 12210±110 years BP at 80 cm level but on extrapolation of date based on the rate of sedimentation reveals palaeovegetational scenario covering last 15,000 years BP.

The vegetation scenario in Mikir Hills began with a vast stretches of grassland during 13,000 years BP before which no biota was observed at the lower part of the profile (150-120 cm), indicative of reducing environment which precludes the pollen deposition. The grass is the dominant constituent in which the cerealia (10-12 %) along with other culture pollen viz., Asteraceae, Caryophyllaceae, Chenopodiaceae-Amaranthaceae, etc. indicate the clue for land clearance for agricultural practice. The other major elements associated with grassland such as *Polygonum* spp., Lamiaceae, *Justicia* and Gentianaceae are encountered in low to moderate value. Ferns are represented by tropical/subtropical genera.

The overall vegetation scenario is suggestive of arid climatic regime. A few biodegraded fern spores especially, *Pteris* sp. along with the occurrence of a number of fungal remains indicate the biodegradation of spores in the sediments. During the period 13,000-6000 years BP the invasion of a number of arboreal taxa in the scenario along with the predominance of non-arboreals reflects the open savanna type of vegetation. The grass curve although tends to slightly decrease, Cerealia and other cultural pollen like Caryophyllaceae, Tubuliflorae, *Artemisia*, Chenopodiaceae-Amaranthaceae, etc. are indicative of continuous agricultural practice during the phase. Among the arboreal taxa like *Terminalia*, Anacardiaceae, *Syzygium*, Oleaceae, *Zizyphus* and Acanthaceae, etc. are encountered in low to moderate values whereas, *Salmalia, Lagerstroemia*, Oleaceae and Malvaceae are recorded in sporadic to low values. Ferns are constantly maintaining their stable values in the whole column. The appearance of degraded *Pinus* pollen along with a few monolete fern spores are suggestive of biodegradation in sediments during the phase.

The overall vegetation scenario indicates semi arid climatic condition during this phase. In the last phase during 6,000 years BP till date the establishment of tropical forest occurred as evidenced by the appearance of a number of arboreals in the vegetation scenario could perhaps be the result of the impact of enhanced precipitation inducing amelioration of climate in the region. The major arboreal taxa recorded in good values are, *Terminalia, Ardisia, Lagerstroemia, Lannea*, Moraceae, *Adina, Elaeocarpus, Melastoma*, etc. whereas, others like *Emblica, Syzygium*, Sapotaceae, Meliaceae, *Dillenia, Artocarpus*, Fabaceae and *Zizyphus* are encountered in sporadic to low values.

Non-arboreal vegetation is dominated by grasses along with low value of Cerealia, Asteraceae, Chenopodiaceae-Amaranthaceae, etc. whereas, other herbaceous taxa like Cyperaceae, Piperaceae, Verbenaceae, Apiaceae, *Typha* and *Potamogeton* are recorded for the first time either sporadically or in low values. The presence of Palm pollen in one sample still needs further investigation. Among ferns both monolete and trilete spores played an insignificant role in the vegetational association because of their local origin. The appearance of *Pinus, Picea, Abies, Larix, Betula* and *Alnus* may have been transported from higher elevation. Low occurrence of fungal spores and absence of degraded pollen in the assemblage are indicative of less chance for biodegradation during sedimentation.

The overall vegetation scenario indicates the warm and humid climatic conditions where the establishment of tropical and sub tropical forests occurred and probably last till date. In question the interpretation of pollen diagram depends on the following factors : (a) the relative frequency of pollen-spores production by different taxa in different years, (b) the extent of pollen dispersal, (c) various mode of pollination viz., anemophilous, entomophilous or amphiphilous, (d) long distance pollen transport, (e) differential depositional environments during sedimentation, etc. The above said factors may not apply to the study as the sedimentation did not take place in a typical peat-bog environment but possibly occurred in a vast flood plain as evidenced by the nature of the soil profile (silty clay) and the presence of pollen-spores in low frequency in the sediments. The recorded pollen-spores show good state of preservation although in low amount. In some cases the pollen spectra were masked with exotic pollen taxa growing in upper reaches. The overall pollen analytical results reflect a mixed assemblage of ferns, conifers and Angiosperms. Ferns are represented by tropical/subtropical genera which included *Pteris, Cyathea, Lycopodium, Polypodium, Davallia, Dryneria, Athyrium, Microlepia, Pteridium, Osmunda,* etc. The conifers are found to be psychophilic and possibly transported through river as well as upthermic winds from higher reaches and incorporated in sediments. The Angiosperms are described as mostly mixed tropical deciduous elements excepting a few subtropicals.

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REFERENCES

Bera SK 2000. Modern pollen deposition in Mikir hills, Assam. Palaeobotanist 49 325-328.

Bhattacharya K 1985. Pollen analysis of a few Quaternary deposits of Upper Assam with reference to dating, vegetation history and biostratigraphy. Ph.D. Thesis. Calcutta University.

Bhattacharya K & Chanda S 1982. A brief report on partial late Quaternary vegetational history and biostratigraphy of Digboi, Assam. Transactions of Bose Research Institute 45 72-76.

Bhattacharya K, Chanda S & Barui NC 1986. Vegetational History and biostratigraphy of late Quaternary sequence of Tinsukia, Upper Assam, India. Bulletin of Geological Mining & Metallurgical Society of India 54 : 202-209.

Bhattacharya K & Chanda S 1988. Late-Quaternary vegetational history, Palaeoecology and Biostratigraphy of some deposits of Brahmaputra Basin, Upper Assam, India. Journal of Palynology 23-24 : 225-237

Bhattacharya K & Goswami AB 1981 Pollen analysis of a Quaternary deposit of Ledo-Matikhad, Upper Assam. *Proceedings of 68 th Session, Indian Science Congress* : 59-60 (Abstract).

Erdtman G 1943. An introduction to pollen analysis. Waltham, Mass. USA.

Gupta HP 1971. Pollen analytical investigations of some upper Pleistocene samples from Tocklai, Cinnamara, Assam. Palaeobotanist 18 : 234-236.

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Holocene history of vegetation and climate of fresh-water Punlota (Degana) Lake in Eastern Rajasthan, India

CHHAYA SHARMA[1], CHANCHALA SRIVASTAVA[1] AND D.N. YADAV[2]

[1]*Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.*
[2]*Bhabha Atomic Research Centre, Trombay, Mumbai 400 085, India (Formerly at BSIP as CSIR's Research Associate).*

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ABSTRACT

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Pollen analysis of 2 m deep sedimentary profile from fresh-water Punlota Lake situated at the outskirt of Degana township in district Nagaur (Eastern Rajasthan), has revealed that around 9,000 years BP, the region had predominantly non-arboreal vegetation, depicting arid climatic conditions. Around 4,200 years BP, savannah type-vegetation covered the region demonstrating increase in the frequency of fern as well as fungal spores- indicating warm and moist conditions. Around 3,000 years BP, savannah vegetation witnessed reduction in tree taxa, ferns and grasses with simultaneous increase in Cyperaceae, Chenopodiaceae, etc., depicting decrease in the warm and moist conditions. Uppermost part of the investigated profile has revealed more or less similar conditions as witnessed in the preceding phase, except for the increase in Poaceae and Caryophyllaceae, reflecting comparatively drier climate.

Simultaneous elemental analysis of the profile reveal that all major (Al, Fe, Ca and Mg) and trace (Mn, Ba, Sr, Pb, Cu, Ni and Zn) elements change in their concentration at the middle of the profile or about 1 m depth from the surface i.e., around 4,200 years BP. Most of these elements abruptly increase by a factor of two or three at this section and maintain relatively higher values up to the surface. Higher elemental abundance above 1 m boundary in the sediment could arise due to accelerated weathering as well as in consequence to the enhancement in the rainfall.

Coupling radiometric data with major change in elemental abundance indicate maximum precipitation around 4,200 years BP, in the region which very well corroborate with the present palynological studies- the first radiocarbon dated Holocene profile from the fresh-water lake in Rajasthan.

Key-words—Holocene, Palaeoclimate, Modern pollen rain, Fresh-water, Punlota, Eastern Rajasthan.

भारत के पूर्वी राजस्थान की ताजी जलीय पुनलोटा झील की वनस्पतियों का होलोसीन इतिहास तथा जलवायु

छाया शर्मा, चंचला श्रीवास्तव एवं दीनानाथ यादव

सारांश

पूर्वी राजस्थान के नागौर जिले के देगाना कस्बे के बाहरी क्षेत्र में अवस्थित ताजी जलीय पुनलोटा झील से प्राप्त 2 मीटर गहरी अवसादी परिच्छेदिका के परागाणविक विश्लेषण से ज्ञात हुआ है कि विगत 9,000 वर्ष पूर्व के दौरान इस

क्षेत्र में अवृक्षीय वनस्पतियों की प्रधानता थी, जो शुष्क जलवायुविक स्थितियों का द्योतक है। 4.200 वर्ष पूर्व के आस-पास इस क्षेत्र को सवाना प्ररूप की वनस्पतियों ने आच्छादित कर लिया, जो फर्न (पर्णांग) तथा कवकीय बीजाणुओं की आवृत्ति में वृद्धि का परिचायक है तथा उष्ण एवं आर्द्र स्थितियाँ इंगित करता है। 3,000 वर्ष पूर्व के दौरान साइपरेसी, चीनोपोडिएसी, इत्यादि में समकालिक वृद्धि के साथ सवाना वनस्पतियों के वृक्ष वर्गकों, फ़र्न तथा घासों में कमी प्रेक्षित की गयी, जो उष्ण एवं आर्द्र स्थितियों में वृद्धि का संकेतक है। अन्वेषित परिच्छेदिका के ऊपरी भाग में पूर्ववर्ती प्रावस्था की भाँति की ही स्थितियाँ (पोएसी तथा कैरियोफिल्लेसी में वृद्धि के अतिरिक्त) प्रेक्षित की गयी हैं, जो अपेक्षाकृत शुष्क जलवायु का परिचायक है।

परिच्छेदिका के समकालिक तत्त्वीय विश्लेषण से प्रदर्शित होता है कि परिच्छेदिका के मध्य अथवा सतह से 1 मीटर गहराई पर अर्थात 4.200 वर्ष पूर्व के आस-पास सभी प्रमुख तत्त्व (As, Fe, Ca तथा Mg) एवं सूक्ष्म मात्रिक तत्त्व (Mn, Ba, Sr,Cu, Ni, तथा Zn) अपने सान्द्रण में परिवर्तनशील हैं। इनमें से अधिकांश तत्त्व इस परिच्छेद पर एक अथवा दो कारकों से आकस्मिक वृद्धि करते हैं तथा सतह तक अपेक्षाकृत उच्चतर कोटि बरकरार रखते हैं। अवसाद में 1 मीटर सीमा के ऊपर उच्चतर तत्त्वीय प्रचुरता त्वरित अपक्षयण तथा वृष्टि के परिणामस्वरूप हो सकती है।

रेडियोमितीय आंकड़ों को तत्त्वीय प्रचुरता में हुए बड़े परिवर्तनों से सम्बद्ध करने पर इस क्षेत्र में 4,200 वर्ष पूर्व के आस-पास अधिकतम वर्षण इंगित होता है, जो वर्तमान परागाणविक अध्ययनों अर्थात राजस्थान की ताजे जलीय झील से प्राप्त प्रथम रेडियोकार्बन आयुर्निधारित होलोसीन परिच्छेदिका के अध्ययन के सुसंगत है।

संकेत शब्द—होलोसीन, पुराजलवायु, आधुनिक परागकण वर्षा, ताजा-जलीय, पुनलोटा, पूर्वी राजस्थान।

INTRODUCTION

RAJASTHAN, in western India, is known for it's desert (part of the Thar Desert), surrounded by the Arabian sea in the west and Aravalli mountains in the east. The initiation of desert climatic condition with its temporal change in geographical coverage has always been an important topic of research for geologists, ecologists and palaeo-climatologists. It constitutes a significant phyto-geographical region of India. The Quaternary palaeo-floristic succession and climatic oscillations of the region are mainly known through the studies on the palaeo-environmental changes carried out by Singh *et al.* (1972, 1974), Vishnu-Mittre (1978), Bryson and Swain (1981), Swain *et al.* (1983), Wasson *et al.* (1983), Sharma and Chauhan (1991), Dhir *et al.* (1992) and Deotare *et al.* (2000). The Holocene vegetation history of this desert region has been reconstructed through the combined pollen sequences worked out from the salt-lake deposits at Lunkaransar, Didwana and Sambhar situated in western Rajasthan, corroborated by the pollen analytical data from Pushkar – the fresh water lake situated about 11 km from Ajmer city at the foothills of Aravalli hills, besides some analysed soil samples from the Indus Valley site Kalibanghan (Singh, 1971; Misra & Rajaguru, 1986). Modern pollen rain in the desert has been interpreted in the light of the prevailing vegetation (Singh *et al.*, 1973). Among the investigated sites in Thar desert, Didwana salt lake basin alone contained the sedimentary deposits which revealed the palaeo-environmental changes during the critical transition period from the Late Pleistocene (LGM) to the early Holocene (Singh *et al.*, 1990). Saxena (1984) also investigated the profiles from Kanodwala and Pokharan Ranns – both situated in south-west Rajasthan and from Budha-Pushkar which is hardly 2 km from the main lake Pushkar in addition to the two re-investigated profiles- Didwana and Pushkar.

The present study is focussed on the reconstruction of late Quaternary climate and vegetation based on geo-chemical and palynological results of Punlota freshwater lake sediment deposit from eastern Rajasthan, India. This lake bed has thick soil deposits with considerable amount of organic matter. At present, the lake basin is being extensively used for crop production by the local population. Both pollen grain analysis as well as geo-chemical measurements of major and trace elements have been made for the sedimentary profile so as to derive information on palaeo-vegetational, palaeo-ecological and palaeo-climatic changes that have taken place over the desert region, especially around the sampling sites.

PHYSIOGRAPHY

Rajasthan is endowed with several saline and fresh-water natural lakes, many of them lying in the desert region. The origin, evolution and geographic distribution of these lakes are attributed to the past climatic conditions, coupled with tectonic activities in the region. The region east of Aravalli Range, because of higher rainfall (50-60 cm per year) as compared to the region west of the Aravalli Range or the main desert (below 10 cm per year), is studded with a number of fresh-water lakes- many of them transformed long back into artificial reservoirs. Pushkar (26°29' N, 74° 33'50 E) which lies in the semi-desert plain close to the foothills of Aravalli Range

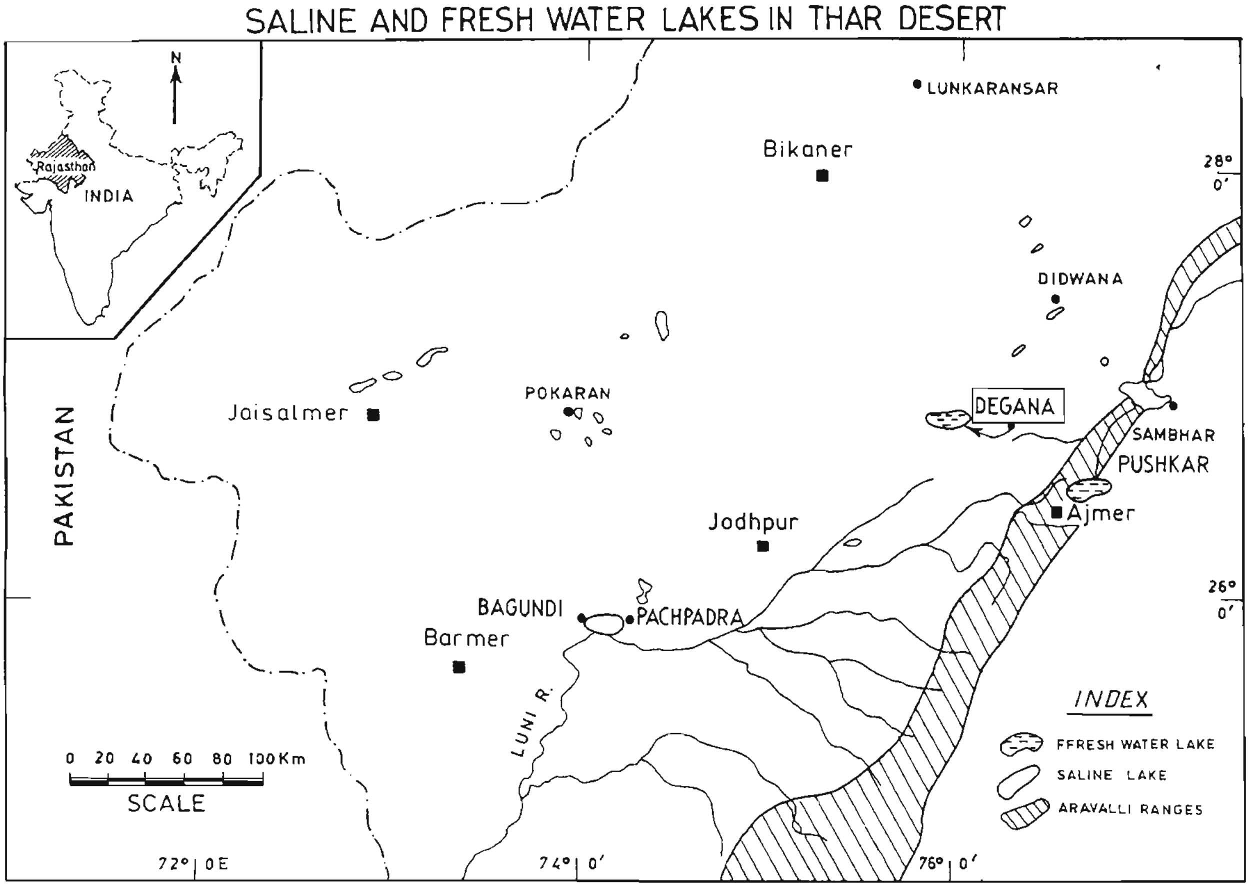


Fig. 1—Map showing the location of the investigated lake site and surface samples.

at the outskirts of Ajmer township happens to be the only other fresh-water lake in Rajasthan which has been earlier pollen analysed though the column remains undated.

However, the present investigated profile is from another fresh-water lake Punlota from Rajasthan. It lies about 12 km S-W to Degana town in district Nagaur (26°50.4' N, 74°21' E), eastern Rajasthan (Fig. 1). The lake now is just a dried up patch of flat land subjected to extensive crop cultivation in the vicinity of the lake bed.

VEGETATION

The vegetation around the present site is xerophytic, typical of semi-arid climatic regions of Rajasthan. *Euphorbia caducifolia* and *Calotropis procera* are the two prominent xeric species characterising the shrubby elements. *Euphorbia caducifolia* is the most commonly occurring species inhabiting hillocks as well as the plains and distributed evenly throughout Rajasthan, whereas *Calotropis procera* prefers mostly open sandy plains. Arboreal components of the xerophytic vegetation of Rajasthan are chiefly *Prosopis cineraria, Acacia nilotica, A. leucophloea, A. senegal, Ailanthus excelsa, Azardirachta indica, Tamarix dioica, Ficus glomerata, Salvadora persica, Balanites roxburghii* and *Anogeissus pendula*, the last one generally occupying the montane habitats. Other commonly seen shrubby elements, often attaining the habit of a small tree, are *Mimosa hamata, Acacia jacquemontii, Dichrostachys cinerea, Leucaena glauca, Capparis decidua, Leptadenia pyrotechnica, Ziziphus nummularia*, etc. *Crotalaria burhia, Sericostoma pauciflorum, Aerva pseudotomentosa*, etc., sometimes form gregarious patches on stabilized sand-dunes.

The ground flora is rich in grasses whereas main ephemeral or seasonal species are *Cleome viscosa, Polygala erioptera, Arnebia hispidissima, Achyranthes aspera, Alysicarpus* spp., *Boerhavia diffusa, Borreria hispida, Corchorus* spp., *Hibiscus* spp., *Justicia simplex, Kickxia ramosissima, Peristrophe paniculata, Pedalium murex, Sida* *cordifolia, Heliotropium* spp., *Spergula fallax, Tephrosia* spp., *Trianthema portulacastrum, Tribulus terrestris, Tridax procumbens, Vernonia cinerea, Xanthium strumarium, Zornia gibbosa*, etc. (Bhandari, 1990).

METHODS

Sample location & Sampling technique

As stated, the freshwater palaeolake-Punlota, was selected for the present study. The lake site (26°50.4' N, 74°21' E) is situated about 12 km south-west to Degana Town in Nagaur District of Rajasthan (Fig. 4). For sampling, the place was visited during Feb.'98 and a trench (0.90 x 1.00 x 2.00 m) was dug at the lake margin. Soil samples were collected by scooping one of the walls of trench using a steel scraper at the marked positions from the surface. Following this technique, soil samples were collected at every 10 cm (depth) interval for geo-chemical and palynological investigations. In addition, 3 samples were taken at every 50 cm (depth) interval for radiocarbon analysis Fig. 2. These samples were collected up to a depth of 2.00 m from the surface and well preserved in clean polythene bags for laboratory analysis.

In addition, 3 surface samples were gathered from the vicinity of the lake site to evaluate the modern pollen deposition pattern so as to provide a comparative data-base for interpretation of pollen diagram in terms of past vegetation and climate.

Geo-chemical and pollen analysis

For geo-chemical analysis, the moist soil samples were dried at ~ 100°C in an oven for 2 days, powdered, homogenised by thorough mixing and then stored in clean polyethylene vials. About 0·5 gm sample HNO_3 medium by HF- HNO_3 – $HClO_4$ acid treatment using clean teflon beakers (Yadav, 1995). A few duplicate samples were also prepared following above method so as to ascertain precision of major and trace elemental determination. About a dozen major and trace elements viz., Ca, Mg, Fe, Al and Sr, Ba, Zn, Pb, Ni, Mn, V were measured using Induced-Coupled Plasma Atomic Emission Spectrophotometer (ICP-AES) of JY 38 S Jobin Yvon model at Chemistry laboratory, Physical Research Laboratory, Ahmedabad. Other two major elements, viz., Na and K, were measured using Atomic Absorption Spectrophotometer (AAS). The accuracy of analytical measurement was checked with respect to NOVA PRL control standard and MAG-1 international standard. In all the above analytical measurements, the precision for most elements was found to be less than 5% whereas accuracy was within 10% of analytical uncertainty.

Pollen/spores from surface and profile samples were extracted as per conventional acetolysis technique (Erdtman, 1943). Pollen count in most of the samples in both cases varied from 150-450. However, the counting ranged from 80-100 in a few cases due to the poor pollen yield. Percentage of the recovered pollen/spores was calculated in terms of total terrestrial pollen and the encountered taxa were arranged in the constructed pollen diagram in a sequence i.e., arboreals, non-arboreals, ferns, aquatics, etc.

Lithology and Radiocarbon dates

The rate of sedimentation calibrated on the basis of the three radiocarbon dates, is apparently uniform (Fig. 2), approx. 1 cm/46 years for the zone below the middle of the litho-column and 1 cm/53 years for the above 100 cm zone.

RESULTS

Modern Pollen Vegetation Relationship

Pollen analysis from the three surface samples has revealed the dominance of non-arboreals, such as Poaceae, Cyperaceae, Cheno/Ams, Caryophyllaceae, Acanthaceae, Liguilifloreae, Tubulifloreae, *Xanthium strumarium*, Malvaceae, Mimosaceae, Convolvulaceae, Rosaceae, Brassicaceae, *Polygonum*, etc.

Arboreals are represented by the sporadic encounter of pollen of few taxa viz., *Ephedra, Ziziphus, Holoptelea* and Oleaceae, besides the pollen of *Pinus roxburghii* transported to the site from some distant locality (Fig. 3).

Overall pollen assemblage reflects more or less the existing vegetation around the site but many important taxa characteristic of xeric/scrubby vegetation in the region remain un-represented.

Depth (cm)	Lithology	Lab No.	Sample No. (Depth)	Radiocarbon dates
0-50	black clay with organic matter	BS-1516 S-2201	40-50 cm	2320±140 Yr. B.P.
50-100	black clay with organic matter	BS-1477 S-2161	90-100 cm	4180±150 Yr. B.P.
100-150	silty clay			
150-200	sandy clay	BS-1450 S-2119	190-200 cm	8730±500 Yr. B.P.

Fig. 2—Lithology and Radiocarbon dates.

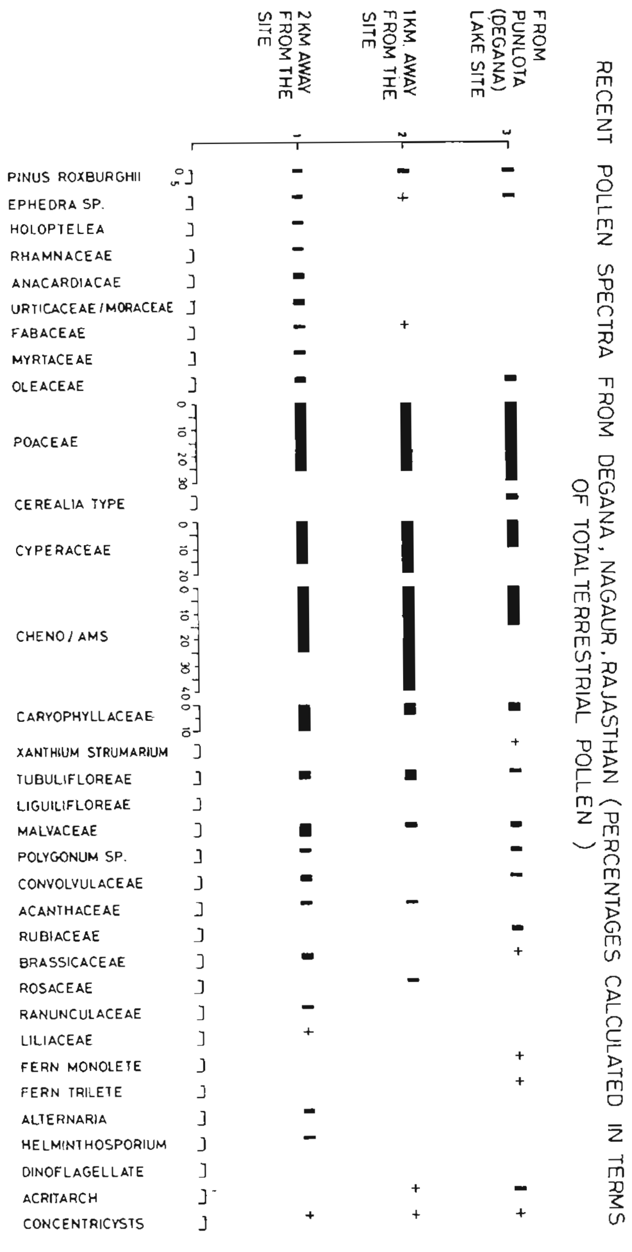


Fig. 3—Recent pollen spectra from Degana, Eastern Rajasthan.

Description of pollen diagram

The pollen diagram is divided bottom upwards into four pollen assemblage zones viz., I, II, III and IV, based on the fluctuations seen in the representation of prominent arboreals and non-arboreals. Each pollen zone is prefixed by DG , the abbreviation for Degana, signifying the popularly known investigated site (Fig. 4).

Pollen zone DG-I (200-175 cm): Poaceae-sedges-Cheno/Ams-Oleaceae-Ephedra Assemblage

The bottom of this pollen zone radiocarbon dated to 8,730±500 years BP, revealed the vegetation scenario covering the time span of about 700 years i.e., period between 9,200 and 8,050 years BP, depicting dominance of non-arboreals and poor representation of arboreals. Among the non-arboreals, Poaceae (40-50%), Cyperaceae (25-30%), Cheno/Ams (10-15%), Caryophyllaceae (2-5%) are the major constituents, whereas *Cerealia* (5%), Tubulifloreae and *Polygonum* (3% each), Liliaceae (3%), Malvaceae, Acanthaceae (2% each) are represented sporadically in low values. *Potamogeton* (1%) is the sole encountered representative of aquatic vegetation. Ferns (monolete and trilete), are scantily present.

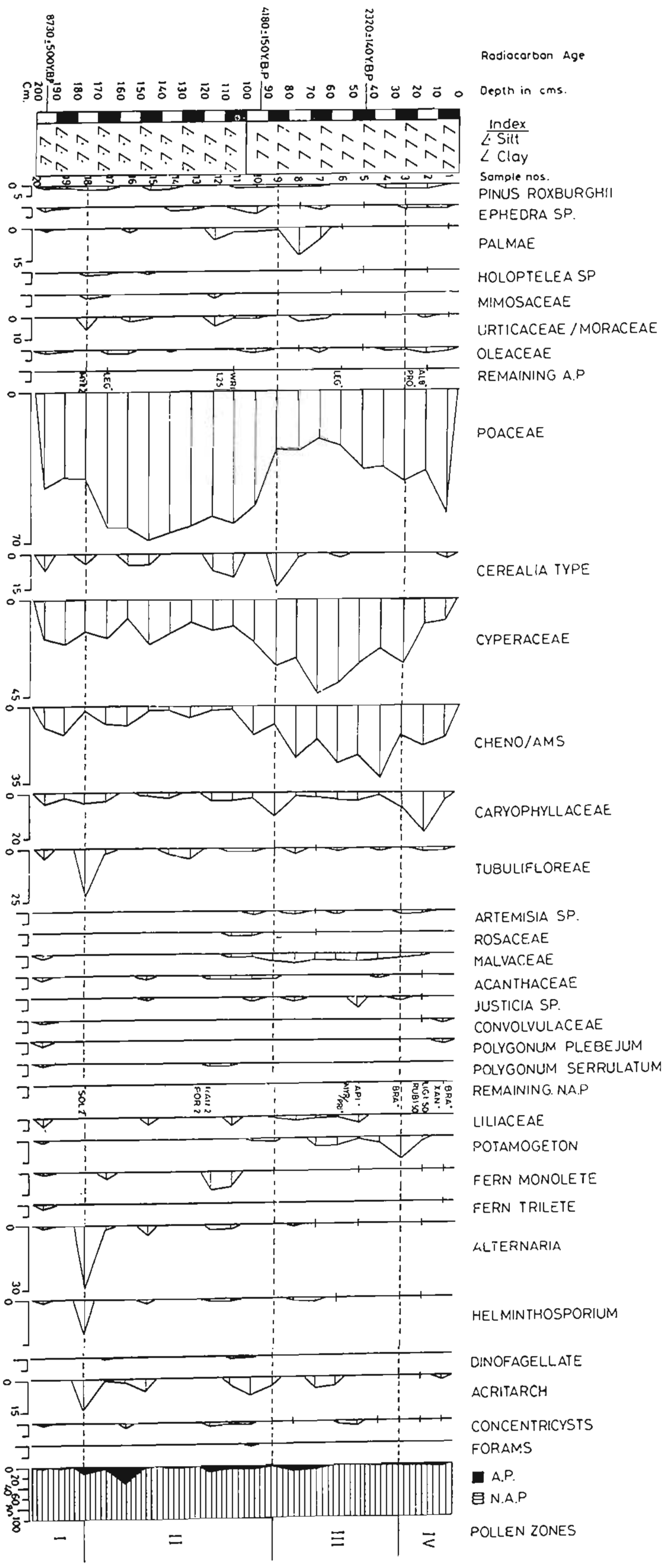
Pollen zone DG-II (175-85 cm): Poaceae-Cyperaceae-Cheno/Ams-Ephedra-Mimosaceae-Urticaceae/Moraceae Assemblage

This pollen zone, radiocarbon dated 4,180±150 years BP for the middle of the investigated litho-column encompassing the time span of next over 4,000 years, covering the period between 8,050 to 3,810 years BP, revealed a better representation of arboreals as well as non-arboreals as compared to the preceding pollen zone. Poaceae (35-70%) and Cyperaceae (15-35 %) also exhibit comparatively higher values in this zone. Cheno/Ams (5-25%) and Tubulifloreae (5-25%), together with fern spores (monolete 2-5%) though with increased presence, were recorded in fluctuating frequencies. *Helminthosporium* (2-20%), Acritarch (5-15%) and other fungal spores (5-35%), also exhibit much increased values whereas dinoflagellates (2%) are met with for the first time in this zone.

Among the arboreals, *Ephedra* (2-10%), Urticaceae/Moraceae, Palmae (2-5% each), Oleaceae (2-3%), showed increasing trend in their frequencies as compared to the pollen zone DG-I. Mimosaceae and *Holoptelea* (2% each) appear for the first time in this zone, though with low frequencies.

Pollen zone DG-III (85-25 cm): Sedges-Poaceae-Cheno/Ams-Palmae -Urticaceae/Moraceae Assemblage

This pollen zone radiocarbon dated to 2,320±140 years BP, at 40-50 cm depth demonstrates a steep decline in Poaceae (25-35%) and Caryophyllaceae (5%) in the upper half during 3,810 to 1,325 years BP, whereas Cyperaceae (30-45%) and Cheno/Ams (25-35%) exhibit simultaneous improvement. Other



POLLEN DIAGRAM FROM PUNLOTA LAKE, DEGANA IN NAGAUR DISTRICT, RAJASTHAN
(Percentages calculated in terms of total terrestrial pollen)

taxa, such as Malvaceae (2-4%), Acanthaceae (2-5%), *Artemisia* and Liliaceae (2% each), together with the aquatic element *Potamogeton* (2-5%) are recovered in increased frequencies.

Pollen zone DG-IV (25-0 cm): Poaceae-Cyperaceae-Cheno/Ams-Ephedra-Oleaceae-Urticaceae/Moraceae Assemblage

This pollen zone covering the period of last 1,325 years BP exhibits an increasing trend in grasses (50-70%), followed by Caryophyllaceae (5-20%) and associated with a corresponding decline in Cyperaceae (10-30%) and Cheno/Ams (15-20%). Other constituents of the ground flora, such as *Artemisia*, Malvaceae, Acanthaceae and aquatic element-*Potamogeton,* also turn more sporadic in this zone. Likewise, the arboreal taxa viz., *Ephedra, Holoptelea* and Palmae, also register considerable decline at the commencement of this zone.

Geo-chemical data

Study on trace and major elemental geo-chemistry has been made so as to couple the geo-chemical data with palynological findings. These results will address the issues of vegetational and climatic changes during Holocene Period.

Data on more than a dozen major and trace elemental concentration of sediment section at every 10 cm depth interval are presented here. Among these elements Fe, Mn and V are redox sensitive, while Zn, Ni, Pb, Cu, Al and Ba are heavy metals being insensitive to changing oxidising and reducing conditions of the prevailing environment. The other elements, viz., Ca, Mg, Na and K, are weathering derived and precipitate in lake environment as authigenic minerals. Because of wide variations in geo-chemical properties of these elements, their

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Fig. 4—Pollen diagram from Punlota (Degana) Lake.
Abbreviations used-

A. P.	Arboreal pollen
ALB	*Albizzia*
PRO	*Prosopis*
LEG	Legume
WRI	*Wrightia*
MYR	Myrtaceae
N. A. P.	Non-arboreal pollen
BRA	Brassicaceae
XAN	*Xanthium*
LIG	Liguiliforeae
RUB	Rubiaceae
API	Apiaceae
MYR	Myrtaceae
PRI	Primulaceae
RAN	Ranunculaceae
POR	*Portulaca*
SOL	Solanaceae

	Ca	**Mg**	**Fe**	**Al**	**Sr**	**Ba**	**Zn**	**Ni**	**Pb**	**Mn**	**V**	**Cu**	**Na**	**K**
Ca	1	0.793	0.703	0.746	0.881	0.705	0.599	0.573	0.311	0.853	0.672	0.624	-0.695	0.181
Mg		1	0.982	0.963	0.667	0.888	0.913	0.914	0.478	0.897	0.883	0.921	-0.909	0.254
Fe			1	0.960	0.561	0.902	0.934	0.952	0.541	0.839	0.876	0.940	-0.912	0.270
Al				1	0.557	0.820	0.833	0.854	0.488	0.814	0.786	0.836	-0.859	0.395
Sr					1	0.629	0.529	0.476	0.316	0.793	0.634	0.521	-0.492	0.031
Ba						1	0.904	0.904	0.549	0.894	0.862	0.899	-0.832	0.096
Zn							1	0.983	0.495	0.842	0.874	0.975	-0.901	0.092
Ni								1	0.525	0.804	0.874	0.979	-0.901	0.165
Pb									1	0.346	0.289	0.470	-0.380	0.147
Mn										1	0.815	0.844	-0.839	0.038
V											1	0.906	-0.821	0.056
Cu												1	-0.933	0.042
Na													1	-0.034
K														1

Fig. 5—Inter-elemental correlation matrix for major and trace elements.

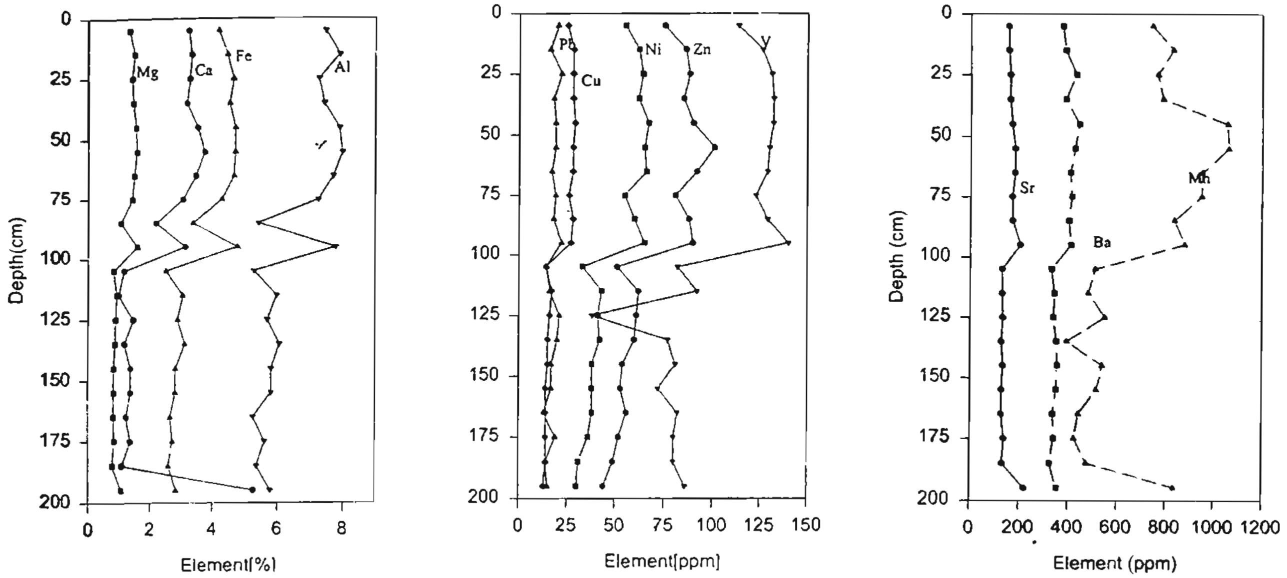

Fig. 6—Diagram showing down-core variation of elements in Punlota (Degana) Lake sediments.

study is expected to bring out interesting phases and history of environment that the lake would have experienced since the geological past. The discordance in their variations will have implication to their contrasting geo-chemical properties, whereas their similar trends down the sediment profile will have implication to a common cause, the influence of weathering and prevailing palaeo-climatic conditions. With this concept in mind, varieties of major and trace elements have been measured along the sedimentary profile to interpret their variations in terms of the palaeo-climatic conditions.

Among various elements studied, Ca, Mg, Fe, Al, Na and K are the major elements with their concentrations in range of 1-7 %, whereas rest other elements' concentrations are in trace level with their range 20-1000 ppm (Fig. 5). The elemental variations down the sediment profile is shown in Fig. 4. Most of the major elements viz., Al, Fe, Ca and Mg and trace elements viz., Mn, Ba, Sr, Pb, Cu, Ni, Zn, V (Cox, 1992) show distinct changes in their concentration at about 1.00 m depth interval from the surface of profile. The concentrations of these elements abruptly increase by a factor of two to three at this section compared to that down and above the sediment profile. Such an increase in elemental concentration is like that of addition of spike in the sediments. Sudden increase in elemental concentration at 1.00 m boundary of the profile could arise due to high influx of eroded material into the lake basin from the catchment area.

DISCUSSION AND CONCLUSION

Pollen analysis of the sedimentary profile from fresh-water Punlota (Degana) Lake has yielded significant proxy data to interpret the palaeo-climatic and palaeo-vegetational changes in the region since early Holocene. Around 9,000 years ago, the vegetational condition was open type (**Pollen zone I**) with dominance of non arboreal pollen (NAP), especially grasses indicating somewhat dry climatic condition. This inference is also supported by the geo-chemical results showing relatively high concentration of Na down the profile below 1.00 m depth section (Fig. 6). Commencement of favourable climate started showing more abundance of arboreal and non arboreal pollen species during the time interval between 9,000 to 4,200 yrs BP (**Pollen zone II**). The inferred climatic condition in this zone is semi-arid. The geo-chemical results of Al and several other major and trace elements also indicate maximum fluvial input along with allochthonous minerogenic matter into the lake system at about 4,200 yrs BP, i.e., at 1.00 m boundary from the surface of profile. Thus, at 4,200 yrs BP, the lake level was maximum and soil erosion was more, thereby indicating heavy rainfall in the region. This is further supported by the prevalence of Savannah type vegetation (**Pollen zone III**) with an increase in arboreal vegetation along with swampy non-arboreal elements such as *Potamogeton* and acritarch during the time period 4,200 to 2,000 yrs BP. The inferred climatic condition in this pollen zone is moist and humid. The relative decrease in several major and trace elements including Al (Fig. 6) compared to previous pollen zone with scanty distribution of arboreal and non-arboreal vegetation marked by increase in Poaceae and Caryophyllaceae in **Pollen zone IV** (Fig. 4) represents semi-arid environmental condition being prevalent during the period 2,000 yrs BP to present.

According to earlier finds by Singh *et al.* (1972, 1974) improvement in climate has also been recorded in Rajasthan desert though for a wider temporal range i.e., from 9,000 to 5,000 years BP. Similarly, during 5,000 to 3,000 years BP, the Rajasthan desert also experienced 50 cm more rainfall than what prevailed earlier in the region. The plant taxa indicative of increase in summer and winter precipitation came in prominence during the mid-Holocene and declined during the late-Holocene in harmony with the witnessed decline in lake level (Singh *et al.*, 1990).

Parallel and changing climatic trend witnessed for entirely different phytogeographical regions falls within the limit of the "Period of Climatic Optimum" which has been recorded globally for the period 7,000 to 3,000 years BP.

Holocene is the period during which major climatic fluctuation has been inferred globally. The onset of arid climate occurred in two phases i.e., during 4,700-3,700 and 2,000-1,700 BC. Both phases had fairly wide impact not only on the Indian subcontinent resulting in the desertification of western Rajasthan but also in other countries, mainly Africa in the development of Sahara and Nubian deserts. The commencement of global desertification is dated back to 5,400 BP i.e., 3,400 BC which greatly affected the regional precipitation and consequently the river systems too. The change from wetter to arid conditions destroyed steadily the vegetation and indirectly the climate over the region (Sankaran, 1999).

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REFERENCES

Bhandari MM 1990. Flora of the Indian desert (Revised Edition).

Bryson RA & Swain AM 1981. Holocene variations of monsoon rainfall in Rajasthan. Quaternary Research 16 : 135-145.

Cox Keith G 1992. The Interpretation of Magmatic Evolution. *In:* Brown GC, Hawkes CG & Wilson RCL (Editors)—Understanding the Earth, a new Synthesis : 115-131. Cambridge University Press.

Deotare BC, Kajale MD, Kusumgar S, Gogte VD, Ramesh R, Rajaguru SN, Donahue D & Juli T 2000. Pleistocene Holocene climatic changes in arid core of the Thar Desert: A case study of Kanod Playa, District Jaisalmer, Rajasthan. PAGES Workshop on South Asian Palaeo-environments : 48-51. Pune, India.

Dhir RP, Kar Amal, Wadhwan SK, Rajaguru SN, Misra VN, Singhvi AK & Sharma SB 1992. *In.* Singhvi AK & Kar Amal (Editors)—Thar Desert in Rajasthan : Land, Man and Environment : 1-191. GSI, Bangalore.

Erdtman G 1943. An introduction to pollen analysis. Waltham, Mass: J. Engelhorn.

Misra VN & Rajaguru SN 1986. Environment et culture de l'homme prehistorique dans le desert du Thar, Rajasthan, Inde. Anthropologie 90 : 407-437. Paris.

Sankaran AV 1999. Saraswati-the ancient river lost in the desert. Current Science 77/8 : 1054-1060.

Saxena AK 1984. Studies in the vegetational history of the central and south-western region of the Rajasthan Desert. Ph.D. dissertation, University of Lucknow, Lucknow.

Sharma Chhaya & Chauhan MS 1991. Palaeo-vegetation and Palaeo-environmental inferences from the Quaternary palynostratigraphy of the western Indian plains. Man and Environment 16 : 65-71.

Singh G 1971. The Indus Valley culture seen in the context of post-glacial climate and ecological studies in north-west India. Archaeology & Physical Anthropology Oceania 6 : 177-189.

Singh G, Chopra SK & Singh AB 1973. Pollen rainfall from the vegetation of north-west India. New Phytology 72 : 191-206.

Singh G, Joshi RD, Chopra SK & Singh AB 1974. Late Quaternary history of vegetation and climate of the Rajasthan Desert, India. Philosophical Transactions of the Royal Society of London, B. Biological Sciences 267/889 : 467-501.

Singh G, Joshi RD & Singh AB 1972. Stratigraphic and radio-carbon evidence for the age and development of three salt-lake deposits in Rajasthan, India. Quaternary Research 2 : 496-505.

Singh G, Wasson RJ & Agrawal DP 1990. Vegetational and seasonal climatic changes since the last full glacial in the Thar Desert, north-western India. Review of Palaeobotany and Palynology 64 : 351-358. Elsevier Science Publishers, Amsterdam.

Swain AM, Kutzbach JE & Hastenrath S 1983. Estimate of Holocene Precipitaion for Rajasthan, India, based on pollen and lake-level data. Quaternary Research 19 : 1-17.

Vishnu-Mittre 1978. Palaeoecology of the Rajasthan desert during the last 10,000 years. Palaeobotanist 25 : 549-558.

Wasson RJ, Rajaguru SN, Misra VN, Agrawal DP, Dhir RP, Singhvi AK & Rao KK 1983. Geomorphology, late Quaternary stratigraphy and palaeoclimatology of the Thar dunefield. Zeitschrift Geomorphologie Supplement 45 : 117-151.

Yadav DN 1995. Chemical and isotopic studies in coastal areas of the Arabian sea and saline lakes of Rajasthan (India). Ph.D. dissertation, M.S. University, Baroda.

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Conference Report

International Conference CSCOP-TSOP 2002- Emerging Concepts in Organic Petrology and Geochemistry, Canada [including Dr Archie G. Douglas Symposium]

31 August-4 September, 2002
The Banff Centre, Banff, Alberta, Canada

The conference was held at The Banff Centre, Banff (near Calgary), Alberta, Canada during August 31st to September 4th, 2002 under the Chairmanship of Dr Martin G. Fowler, an eminent Organic Geochemist of Geological Survey of Canada, Calgary. This event was a part of the on-going series of annual meetings held by The Society for Organic Petrology (TSOP) and was organised and hosted by The Canadian Society for Coal Science and Organic Petrology (CSCOP) under the Secretarial control of the Elsevier Science (The Netherlands). The conference was sponsored by Elsevier Science and the European Association of Organic Geochemists. The conference was also co-sponsored by— CDX Canada Company, Integrated Geochemical Interpretation Limited, Canadian Forest Oil, Zeiss Company, JP Petrographics, Natural Resources Canada (Geological Survey Calgary), Petrologic Services- Coalbed Methane Geology, Suncor Energy, SUNOCO- a Suncor Energy Company, and Fording Coal Limited.

Over 150 delegates attended the CSCOP-TSOP conference from 25 countries of six continents— Australia, Austria, Brazil, Canada, China, Croatia, Czech Republic, Denmark, France, Germany, Greece, India, Italy, Japan, Kuwait, Lithuania, New Zealand, Nigeria, Norway, Saudi Arabia, Taiwan, Thailand, The Netherlands, United Kingdom, and United States of America, representing a variety of academic, industrial and governmental institutions reflecting the breadth of scientific community. The overall activities and arrangements of the conference were excellent.

Saturday, August 31st was specified for registration and pre-conference workshop/short course on the topic "*A prediction of total organic carbon contents and hydrogen indices in marine sediments*" conducted by Dr Richard V. Tyson, University of Newcastle upon Tyne, UK. About 32 candidates (including one of us- BDS) from different countries attended the course. This one-day course was focused on the numerical prediction of the two most fundamental petroleum source rock parameters—Total Organic Carbon (TOC) and Hydrogen Index (HI). The course reviewed the main fundamental controls on the organic content of marine sediments- organic matter input (carbon fluxes), organic matter preservation and sediment dilution, and showed how these parameters interact to produce a given TOC. It was also described how marine sediment data have been used to understand these relationships and to define empirical correlations that can be used to predict TOC in unknown situations.

The prediction of HI was approached in two different ways: from versus TOC trends, and from the modelling of palynofacies (or organic petrological) data. It was also showed that how improved HI predictions can be obtained using total fluorescence preservation scale to assess the variable preservation state of the marine organic matter, and also by modelling lateral variations in the supply of terrestrial organic matter. Course delivery was mainly in the form of lectures, but some practical exercises were also included (example calculations). There was also a demonstration of TOC and prediction spread-sheets developed by course tutor. The course was informative and educative and got participants well-versed with the methodology.

The scientific presentations began on Monday, September 2nd with address by the Chairperson of the conference—Dr M.G. Fowler. The Elsevier Science published an abstract volume containing 110 abstracts of scientific papers. Altogether 68 contributed papers were selected for oral presentation (including 11 for *Dr Archie G. Douglas Symposium*) under following six themes:

1. Shallow Thinking

(Papers related to— Recent sediments, peats, weathering, palaeo-archaeology, Ocean-drilling program, environmental applications of organic geochemistry and organic petrology, C-N-S cycles)

2. Solid Bitumen and Pyrobitumen

(Papers related to— Alteration by biodegradation and thermochemical sulphate reduction, organic-inorganic interactions, physical and chemical properties and evolution)

3. Sources (and sinks) of Natural Gas

(Papers related to— Coal bed methane, CO2 sequestration, non-marine and marine kerogen, coal and bitumen origins for gas)

4. Novel Analytical Approaches

(Papers related to— Confocal laser scanning microscopy, CSIA, thermo-gravimetric-gas chromatographic analysis, modelling, organo-stratigraphy and hydrocarbon fluid inclusions)

5. Petroleum Systems

(Papers related to— Characterisation of migration pathways, organic geochemical and organic petrological analysis of the source, carrier and reservoir system)

6. Coal and Environment

(Papers related to— Trace elements, coal petrography, coals as source rocks, green house gases)

Two parallel sessions for oral presentation were organised on September 2nd and 4th. A symposium (on September 3rd) was also included in honour of Dr Archie G. Douglas for celebrating years of Organic Geochemistry. "Treibs Award-2002" was awarded to him for his service in the field of Organic Geochemistry, as both scientist and a mentor.

Besides the symposium, we attended selected papers of sessions related to our own research interest as well as modern trends of research. Some of the important papers presented under different sessions were focussed on Natural gas hydrates, Organic petrology and Organic geochemistry, Oil biodegradation, Sequence stratigraphy, Chemotaxonomy and Spectroscopy.

Besides 40 posters were displayed dealing with Coal depositional environments, Fluorescence Microscopy, Microfacies analysis, Heavy metals and CBM and Plant (OM) degradation.

Major Results Reported

CE Barker (USA), RM Bustin (Canada) and JC Clough (USA) explained *Significant methane storage capacity in solid bitumen* and opined that a metamorphosed oil reservoir can contribute significant quantities of shale gas (in Alaska) and make for an excellent drilling target. Bustin and Barker also presented "*Experimental and field evidence for formation of methane hydrates (Clathrates) in coal*" based on high pressure methane sorption isotherm analysis of coal of varying rank and moisture content at temperature as low as 0°C. This shows that at least part of the coal moisture is available to form clathrates. P.K. Mukhopadhyay and his co-workers of Canada while evaluating the "*Coal bed methane and natural gas potential in Carboniferous coal basins from Nova Scotia*" suggested that the permeability and porosity is partially dependent on coal composition and maturity but is primarily related to the structural stress.

B Cramer, P Gerling and E Faber of Germany presented "*A general model for generation and stable carbon isotope characteristics of natural gas from humic source rocks*" based on dry, open-system, temperature programmed pyrolysis experiments, on-line coupled to a combined gas chromatograph-isotope ratio mass spectrometer, performed on a variety of low mature sediments containing humic organic matter (including coals), differing in geological age, palaeogeography and maceral composition. PD Jenden (Canada) and Y Tang (USA) in their paper "*Carbon isotope geochemistry and the distribution of Devonian oil and gas reserves, western Canada*" derived the first relationships between in-place oil and gas volumes and carbon isotopic compositions of thermogenic $C_1 - C_3$ hydrocarbon gases.

TI Eglinton and his associates of USA demonstrated "*New techniques for the characterisation of products from pyrolysis of complex sedimentary macromolecules*" by developing two approaches—(i) involves the coupling of flash (Curie point) pyrolysis with comprehensive two-dimensional gas chromatography (GCxGC) and time-of-flight mass spectrometry (TOF-MS), and (ii) involves the isotopic characterisation of individual pyrolysis products. MM Cross of UK and his associates reported "*Experimental determination of thermochemical sulphate reduction (TSR) reaction kinetics and mechanism*" and concluded that the kinetic data and reaction mechanisms determined are generic and therefore have application in a range of geological settings. GL Couloume and his co-workers of Canada reported "*Compound specific hydrogen isotope analysis: new insights into hydrocarbon reaction mechanism and biodegradation*" illustrated with two examples of applications.

LD Stasiuk of Canada illustrated the practical advantages of using "*Laser scanning fluorescence microscopy*" in organic petrology, and presented results conducted on a suit of samples including Precambrian, Ordovician and Devonian potential source and carrier bed rocks and coals. M Hawke (Canada) and J Dehmer (Spain) while reviewing "*Are maceral ratios reliable predictors of coal depositional environments?*" stressed that the existing concept of maceral ratios needs to be re-examined.

KA Kvenvolden of US Geological Survey, California while reviewing the "*Natural gas hydrate*" concluded that even if the magnitude of the gas-hydrate-carbon (an alternative energy resource) reservoir has been over-estimated by as much as an order of magnitude, it still constitutes a major sink and source of organic carbon in the geosphere.

The facts established through paper (*Fluorescing macerals— an update* ...... by BK Misra & BD Singh) about Indian coals (Permian, Lower Palaeocene and Oligocene) and lignites (Lower Eocene and Miocene) are—(i) the increase in the liptinite/sporinite content, in Permian coals, normally coincides with the increase in mineral matter content. This finding led to the recognition of semi-cannel or cannel coal bands in the dull bands, (ii) the resinite present in coals and lignites are of certain distinctive types, (iii) the alginite maceral (*Botryococcus*, lamalginite, etc.) also contributes in coal/lignite formation, (iv) degraded resinite, algal matter and bacterial biomass are responsible for the formation of perhydrous vitrinite/ huminite, and (v) in Gondwana coals, a certain fraction of semifusinite maceral is of fluorescing type. Highly experienced organic petrologists and geochemists present stressed the need of total organic content (TOC) analysis through geochemical methods for source rock potential for light hydrocarbons, especially of Indian Gondwana coals.

AK Varma, P. Singh and AK Singh while evaluating "*Petrographic conditions for CBM ... ... of East Bokaro and North Karanpura coalfields, India*" found relationship between fuel ratio and total gas content. Estimated methane content (Kim's equation) shows correlation with vitrinite/ inertinite + mineral matter. The telinite content exhibits inverse correlation with gas generated. They opined that total gas content of the coal seams is not entirely controlled by the volume of methane generated. The desorbed gas content shows very good correlation with total gas content and with residual gas content. *In situ* estimated gas content through Kim's equation also indicates very good correlation with total gas content. *In situ* methane content appears to depend on maceral vitrinite content. They emphasised that more research work should be carried out on these coalfields for coal bed methane exploration.

Four field trips for the CSCOP-TSOP 2002 conference—(1) Upper Cretaceous Geology near Drumheller and the Tyrrell Museum of Paleontology, (2) Day hike to the Burgess Shale (Cambrian), a UNESCO World Heritage Site, (3) Sightseeing tour of the Banff to Lake Louise Area, and (4) Rocky Mountain Geology, hydrocarbon source rocks and coal, were arranged to cover a broad spectrum of geological features and scenery of the Rocky mountains, foot-hills and plains regions of western Canada. In the world renowned Royal Tyrrell Museum, history of life has been charted from its' genesis, some 3.5 billion yrs. ago, through recent times with displays from many of the rich fossil localities of western Canada.

Impact of the Conference

Participation was an excellent opportunity to interact and exchange the ideas with the scientific community dealing with Organic Petrology and Organic Geochemistry at international level. This meeting of the Society of Organic Petrology was the best scientific gathering, from almost all coal and petroleum producing countries, which covered current trends of studying organic constituents within organic-enriched recent sediments and ancient hydrocarbon source, reservoir rocks and coals. Important discussions on different aspects delivered by renowned organic petrologists and geochemists and the interaction and exchange of views, especially on various methodologies in optical microscopy and geochemical techniques, with the specialists were of immense benefit regarding the current concepts and modern techniques.

The significant feature of the conference was the special attention to modern researches and views in the field of organic-rich (coal/petroleum) sequences. Combined studies of organic geochemistry and organic petrology was emphasised and recommended. This covered wide range of interesting topics that show how both the studies can be applied to answer questions on topics as diverse as the origin of natural gas and petroleum, the impact of coal utilisation on health, microbial alteration of petroleum and the impact of climate and environment on the deposition of organic-rich sediments.

Coals are considered as good source rocks for petroleum and natural gas resources all over the world. The scope of coal biopetrology/organic petrology gained importance only recently in developed countries for exploration of oil and natural gas and coal bed methane because of being relatively inexpensive and less time consuming and result-wise quite acceptable. In the case of microscopic study, under fluorescence mode has been found to be very reliable in categorising and quantification of hydrogen-rich coal micro constituents in comparison to that under normal incident light.

Therefore combining the two modes of studies, economic suitability of coals/lignites, preparation and beneficiation properties and prospects of coal bed methane can be suggested in a better manner. Similarly, estimation of kerogen- organic matter dispersed in sedimentary rocks in terms of nature, type and maturity utilising both modes of studies, provides very good results for oil and natural gas prospects in sedimentary sequences. Several coal and oil companies/institutions in developed countries are utilising this kind of study effectively. For coal, to act as a source rock for petroleum two separate criteria must be met. The coal must be capable of—(1) generating hydrocarbon in response to thermal stress (catagenesis), and (2) release these hydrocarbons to a porous migration conduit or reservoir (expulsion or primary migration), with the bitumen saturation threshold as 30 kg hydrocarbon/ tonne of coal, noting that inertinite falls well below, vitrinite up to and liptinite exceeds this level.

In fact no ideal technique exists for evaluation of petroleum generation potential combining detailed organic petrological analyses with organic geochemical analyses can be used to constrain the limitations on both sets of techniques, leading to more robust petroleum generation models. In addition, these types of studies could allow prediction of source potential and kinetics parameters for various organic facies identified by organic petrology. Thus, taken together a more secure interpretation can be made concerning maturation, generation and expulsion of oil and gas. The combined use of organic geochemical and stable isotope data as proxies for palaeoecology and climatic changes during earth's history is receiving increasing attention.

In India, this branch of science, with multidisciplinary approach, has not received its due importance yet. Advancements made in the field of applied Organic Petrology and Organic Geochemistry (for oil and natural gas exploration and coal bed methane) should be utilised in the national interest of fuel science. More and more scientists should be encouraged and opportunity should be provided to attend such international conferences in order to understand the recent trends in researches and technologies at global level.

Bhagwan D. Singh[1] and Atul K. Varma[2]
[1]Birbal Sahni Institute of Palaeobotany,
53 University Road, Lucknow 226 007

[2]Department of Applied Geology,
Indian School of Mines, Dhanbad 826 004

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Chandra Dutt Pant Award 2002

Introduction by Anshu K. Sinha

I deem it a matter of great pleasure to introduce Dr. Rashmi Srivastava, Scientist 'C', the recipient of Chandra Dutt Pant Award 2002. The award was instituted in the year 1952. Mrs. Srivastava is a hard working and dedicated scientist. Besides being a good scientist, she takes keen interest in extra-curricular activities of the Institute. Her devotion to the Science has brought dividends in the form of this award.

The award includes Gold Medal and a Citation. It is awarded every alternate year for the best piece of research work carried out by Scientist 'C' during the last three years.

Mrs. Srivastava was born on 19th October 1957 at Lucknow, where she had her entire education. She received her Masters Degree in Botany from the University of Lucknow in the year 1977. Thereafter she joined research under Prof. B. S. Trivedi, FNA, at Botany Department, Lucknow University for her Ph. D. In 1980 she did Proficiency Certificate course in French Language from the same University.

Rashmi started her career in the Birbal Sahni Institute of Palaeobotany (BSIP) as Junior Scientific Assistant in March 1981 and worked on Lower Cretaceous Flora of South Rewa Gondwana Basin, India. In 1985, she was promoted as a Senior Scientific Assistant. Since then she has been working on morphotaxonomy of Upper Cretaceous–Tertiary plant megafossils of India and their palaeoclimatic and phytogeoraphical significance. In the same year she was awarded Ph.D. Degree on the topic "Contributions to the fossil woods of Deccan Intertrappean flora of Madhya Pradesh".

Dr. Rashmi Srivastava carried out work on sedimentary sequences associated with Deccan Traps of Madhya Pradesh, Maharashtra and Gujarat. She also worked on floristics, morphotaxonomy, palaeoclimatology and phytogeography of Neogene plant fossils of Warkalli Beds, Kerala; Ratnagiri Beds, Maharashtra; Pre-Siwalik and younger sediments of lesser Himalayas of Himachal Pradesh and Jammu region and made extensive collection of plant megafossils from different Deccan Intertrappean and other Tertiary exposures of India. She is also associated with a DST Sponsored Project entitled "Cretaceous megafloral and coprolitic derived plant assemblage from the Deccan trap associated sedimentary sequences in Dongargaon–Pisdura area, Maharashtra" as Co-Principal Investigator.

She was selected to visit Japan in 1998 under International Scientific Exchange Programme between Indian National Science Academy (INSA) and Japan Society for Promotion of Science (JSPS). During her stay in Japan she worked on Oligocene fossil wood of Fukuoka Prefecture, Kyushu Island and published a paper with Prof. M. Suzuki. She has also worked on the fossil woods of Indonesia and developed a collaborative programme with Japanese and Indonesian scientists, which is under progress.

Rashmi has visited different palaeobotanical centres of Japan and delivered lectures in different Institutions. She was invited to present paper on Systematic Anatomy of fossil woods in the Tertiary flora of India during International Wood Anatomy Conference held at Rotorua, New Zeland in 1994. She has about 40 publications to her credit in leading National and International Journals.

Rashmi is actively engaged in planning and development of National Fossil Park at Ghughua, Madhya Pradesh for which she contributed to the preparation of a lay out plan and identified fossil specimens exhibited in the park.

Rashmi is a sincere worker with devotion and conviction to palaeobotanical researches. She is lively, amicable and a good singer.

Rashmi deserves the honour being bestowed on her - *Chandra Dutt Pant Medal* for the year 2002 and I wish her all success in her life.

Response by Rashmi Srivastava

I was delighted when I heard that I had been selected for the Chandra Dutt Pant Medal 2001 in recognition of my research work for the last three years. I am indeed honoured and would like to express my gratitude to all those who helped me achieve this prestigious award. November 14th, 2002 was a red letter day in my career, when the Chandra Dutt Pant Medal was awarded to me. I would like to take this opportunity to thank Prof. Anshu Kumar Sinha, Director, Birbal Sahni Institute of Palaeobotany, Lucknow for his continuous encouragement and the members of selection committee who found me worthy of this honour.

I could recollect my memories of 25 years back, when I was a M. Sc. student and got married to a Palaeobotanist of the BSIP, Dr. Ashwini Kumar Srivastava. At that time, it was

my great desire to opt Palaeobotany as a career and accordingly I pursued research in Palaeobotany under Prof. B. S. Trivedi of the Botany Department, Lucknow University, on fossil woods from Deccan Intertrappean beds of Madhya Pradesh soon after passing M.Sc.

I was fortunate enough to get a job in BSIP as Junior Scientific Assistant in March, 1981. Since then I worked on Lower Cretaceous flora of South Rewa Gondwana Basin, India; Deccan Intertrappean flora of Central India and Gujarat and many Neogene exposures of Kerala, Maharashtra and Extra-Peninsular area. Besides, I also got an opportunity to work upon Japanese and Indonesian material.

I'll forever be indebted to my guide, Prof. B.S. Trivedi and my senior colleague Dr. J. S. Guleria, who shaped my scientific career with their able guidance which enabled me to achieve what I am today. I also offer deep gratitude to my senior Drs. R. N. Lakhanpal and N. Awasthi for giving valuable suggestions whenever needed.

I would like to dedicate this award to my parents for inculcating in me the discipline and zeal to work hard and softly for nothing but the best. I am extremely grateful to my husband Dr. Ashwini K. Srivastava for being so supportive and encouraging.

I would also like to put a word of thanks for my daughter Swapnil for providing a peaceful and conducive atmosphere at home and volunteering to do house hold work, including cooking whenever I had some urgent work on hand. And at last but not the least I want to thank all my colleagues for their help without which all this would have not been possible.

From the Archives
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PALAEOBOTANICAL ASPECTS OF GEOCHRONOLOGY

FREDERICK E. ZEUNER
Professor of Environmental Archaeology, University of London

> *"In this age of specialization, which inevitably tends to confine thought to compartments, one is apt to overlook or to underrate the bearing of one branch of science upon another."*
>
> BIRBAL SAHNI
> in *Current Science*, August 1936, p. 57

THE late Professor Birbal Sahni belonged to the comparatively small band of workers in natural sciences who believe in the necessity of borderline research. He himself was both a botanist and a geologist, and a well-known authority in these subjects. But it is less widely known that he was an archaeologist also. It must not be thought, however, that his familiarity with these subjects meant that he was, so to speak, playing about in these different fields according to his moods. Quite the contrary; he deliberately sought to solve problems of one branch of science by the methods of the other. The theory of Continental Drift, for instance, was studied from the point of view of the distribution of fossil plants, or, in archaeology, the early cultivation of rice provided the link with botany. It is not surprising, therefore, that Professor Sahni showed an especial interest in geochronology, that young branch of geology which occupies itself with the construction of absolute time scales for the prehistoric and geological past. He realized that there are great possibilities in the Himalayas for the study of annual deposits of the *varve* type and their connection with pollen analysis, and he was equally convinced, when a committee on the measurement of geological time by means of radioactivity methods was instituted in India, that palaeobotany would be able to contribute usefully to this kind of work.

Strictly speaking, geochronology is concerned with time scales. But its methods are to a large extent based on the study of the biotopes of the past, and their succession in time. This is so because important chronological information is obtained from the composition of the faunas and floras of successive strata. They may indicate changes in climatic or other external conditions and thus provide us with a scale of climatic fluctuations. As these aspects are investigated, however, valuable ecological information is obtained about past *environments*. For this reason geochronology and the study of environments of the past (palaeoecology) are closely connected. This is particularly the case in the late geological periods, the Pleistocene and Holocene, when man was already in existence. The study of his environment thus becomes *prehistoric ecology* and for the technical reasons mentioned it is linked with that branch of geochronology which correlates absolute time scales with climatic sequences.

Although faunal evidence plays a part in the reconstruction of past climates, floral evidence is very important from the Tertiary onwards. In the late Pleistocene it provides relative time scales by way of pollen analysis which have in some areas been dated in years by the counts of varves (laminated glacial melt-water deposits). In the Holocene of south-western North America floral evidence in the form of tree rings has been used in the establishment of a chronological scale linked with the present-day calendar. This usefulness of botanical evidence is largely due to the fact that genera and species are closely related to, and often identical with, recent ones, so that one appears justified in applying the principle of actualism.

On the other hand, climatic inferences are difficult to obtain from pre-Tertiary material. Some progress has been made in the Permo-Carboniferous, and even the arid conditions of the European Triassic are confirmed by the flora, as Mägdefrau's study of *Pleuromeia* has shown. The present paper, however, is not primarily concerned with these earlier periods; it is intended to show, by means of examples, how botanical research contributes to palaeoecology and geochronology from the Tertiary onwards, and particularly so in connection with early man.

IDENTIFICATION OF FOSSILS

The most obvious application of botany to prehistoric ecology is the identification of fossil plants. In prehistoric and early historic dwelling sites, quantities of charcoal are found. Under Indian conditions, wood is probably rare, since the termites or white ants are likely to destroy all wood that has not become unpalatable as the result of impregnation with mineral salts. Metal salts have a preserving effect on wood. Thus iron nails and other iron objects supply hydrated iron oxide which preserves the cell structure of wood exceedingly well, as for instance in buried boats of the Anglo-Saxon and Viking periods of the British Isles (*ca.* A.D. 700-1200). Similarly, according to Pittioni, many wooden tools like shovels and ladders were preserved in copper mines of the Bronze Age in Austria (1500-500 B.C.) as the result of impregnation with copper salts. That wood survives in very dry climates, even in the hot zones, is well known, for instance, from Egyptian graves of predynastic and later age (from at least 3500 B.C. onwards). But very little rainfall is needed to support termites, so that in monsoon and tropical rain climates the limiting factor is temperature decreasing with altitude. Bacterial action also decreases with temperature. The forests of Mount Kenya in Africa contain quantities of dead wood at altitudes above 7,000 ft. In India, the large high valleys of the Himalayas are likely to be favourable to the preservation of wood.

Preservation of wood other than by mineral salts or dryness is usually associated with boggy situations, since water excludes air and thus retards the decomposition of wood. Bogs altogether furnish many other remains of plants, like leaves, seeds and pollen, and, as the deposits of bogs grow, a stratified series is formed which often indicates climatic changes.

In Europe, peat sections frequently contain prehistoric objects and evidence of living sites in the form of wooden floors, etc. No such finds have as yet been made in India, but they are to be expected in suitable localities. For the reasons stated they are most likely to occur in bogs at altitudes of over 5,000 ft., where ponds and lakes were gradually filled in with vegetation, and a search should be made for bogs containing archaeological remains in Kashmir, Nepal and elsewhere.

In this connection, another problem deserves to be mentioned. It is that of the formation of peat in humid-tropical climates. Such peats have hardly, if ever, been investigated, though they must exist today, for instance, in the deltas of large rivers, since there is fossil evidence from coal deposits that they existed in the past. The most instructive case known to me is that of the Eocene brown-coal deposits of the Geiseltal near Halle in Germany.

This vast area was investigated by a number of workers under the leadership of Weigelt. Unlike the vast majority of humus accumulations, the Eocene Geiseltal swamp was saturated with water containing calcium carbonate, and flora and fauna were fossilized under alkaline conditions. The biotope has been described somewhat as follows. Vast inundation forests separated the permanent water-courses from the rock of the rims of the basin. They were dry and parched in the dry season. When the floods of the rainy season arrived, organic mud, washed from the dry and powdery surface of the ground, was swept away and re-deposited in layers. Dead wood and other remains of organisms were impregnated with calcium carbonate, and thin layers of this material were frequently formed. Pollen is well preserved, as are even the cuticles of the leaves and pigments and muscle fibres of animals. The climate was tropical, and the flora comprised palms, Sapindaceae, Anonaceae, Papilionaceae, Proteaceae and other families, including conifers.

It is conceivable that similar seasonal swamps have been forming in suitable localities in the lowlands of India during the Pleistocene and later. They would afford the material for an investigation of tropical climatic fluctuations contemporary with the Ice Age and the Postglacial.

In all this work, the essential prerequisite is the correct identification of the plant remains which in many cases are fragmentary and poorly preserved. Wood and charcoal are the most frequent type of macroscopic material from prehistoric sites. For their identification it is necessary to have an identified charcoal collection and a set of wood blocks and sections on microscopic slides, including cross, radial and tangential sections. This is a comparatively simple matter in Europe where the number of species is small. But in India it will require patience and devotion to obtain and prepare the necessary material, though the Forest Research Institute, Dehra Dun, is fortunate in already possessing a virtually complete collection of samples of Indian woods.

That archaeological material will not be wanting is exemplified by the result of Professor Sahni's visit to Harappa (*ca.* 2500 B.C.). Charcoal of a species of conifer was discovered which showed that the inhabitants of this prehistoric city were trading with the peoples of the mountains whence the wood must have been imported.

CLIMATIC INTERPRETATION OF FLORAS

Floras, as found in geological and archaeological deposits, are often interpreted as indicating certain climatic conditions. This is done in two ways. It is assumed that each of the species required the same climate in the past as it does at the present. This assumption is probably approximately correct for the latest geological periods, especially the Holocene and the later Pleistocene. In the earlier Pleistocene, some of the species may not yet have been completely adapted to the climatic conditions in which they are encountered today, and still less so in the Tertiary. The animal world has furnished incontestable evidence for this state of things, and it must be admitted as a serious possibility for plants also. The main field of application, therefore, is in the Holocene, and the entire climatic sequence from the Late Glacial to the present day, as established in Europe and North America, is based on the assumption that no adaptive changes have taken place in that comparatively short space of time of, say, 20,000 years.

But the same assumption has been made not only for interglacial and early Pleistocene floras, where it is still yielding consistent results, but also for the Tertiary, where it is impossible to decide how consistent the results are. The information on Tertiary climates provided by text-books is, in large measure, based on estimates made long ago by O. Heer in Switzerland and which presuppose that genera like *Salix*, *Cinnamomum*, etc., lived under similar climatic conditions as they do today. This approach does not necessarily lead to wrong results, but as a method it is unsatisfactory. Harrassowitz summed up the situation as follows: We have found that in the determination of Tertiary climates one always starts from present-day conditions. One could, with equal justification, start from the past, which was tropical. In fact, this approach would be more logical. In using the usual method one forgets that plants are adaptable.

As regards insect faunas, which depend on vegetation, Zeuner says that the curious mixture of diverse climatic elements in the insect fauna of the Miocene cannot be explained by assuming an average climate expressed, for instance, as the mean of the various requirements of the modern relatives of the Tertiary forms. The "mixture" is due to the fact that some forms, which in that period lived under subtropical conditions, appear in recent times as adapted to a cooler climate. These elements constitute the recent holarctic fauna (and flora), whilst the less adaptable ones have become restricted to suitable areas or died out altogether.

Since the Upper Miocene, central Europe has experienced climatic fluctuations on a large scale. As a result, a considerable proportion of the fauna of that time withdrew to more southerly regions. Others were able to adapt themselves to the changing climate and shifted their areas of distribution but little, though their morphological characters were modified more or less profoundly. Finally, a third portion of the fauna of the Upper Tertiary was unable either to spread to climatically more suitable regions or to adapt itself, and it became extinct. The outcome of these processes is the wide scattering of the relatives of Tertiary forms as we encounter it at the present day.

For these reasons, the climatic interpretation of floras (as of faunas) should, wherever possible, be based on structural or physiological adaptations to certain types of environment or climate. Examples illustrating this method will be given presently (p. 453). At this point it is necessary further to emphasize the complexity of the situation by referring to the influences of migration rates and of earth movements on the climatic character of a flora.

Floras of Pleistocene or Holocene age often have a composition different from the present-day flora of the locality, and this is usually explained in terms of climate. Some differences, however, are due to geographical factors of migration. The genus *Thuja*, for instance, was present in Europe in the Last Interglacial (at the Mousterian site of Ehringsdorf near Weimar, central Germany). *Rhododendron ponticum* occurred in the Alps during the Great Interglacial (at Hoetting near Innsbruck, Austria), and is now restricted to a few localities in Spain, apart from its main area on the Black Sea. Both plants grow well in the present climate of western and central Europe, and in England *Rhododendron* has established itself as an escape from parks in many places. Clearly their absence from the wild flora is not due to climatic causes, but rather to the short duration of the Postglacial period, which has not afforded enough time for re-immigration from their refuge areas. A fossil flora, therefore, must not be interpreted simply as a function of the climate. Its geographical position and the time which was available for the immigration of species has to be taken into consideration.

Occasionally it becomes necessary to regard earth movements as an interpretation preferable to the more usual one of climatic fluctuations. An example will make this clear. Following a suggestion of Birbal Sahni, G. S. Puri has described the flora of the Pleistocene Karewa formation of Kashmir in a number of interesting publications. The material which came from an elevation of 10,600 ft. revealed a flora characteristic of subtropical rain-forest conditions, and most of its constituents are consistent with an altitude of 4,000-6,000 ft. This discrepancy can be explained in one of two ways. Either the climate was such in Karewa times that the flora in question could grow some 5,000 ft. higher up than at the present, or the beds containing the flora were lifted up by earth movements after they had been formed. That climatic changes occurred in the course of the formation of the Karewa beds is likely, since varved deposits are included in this series. They suggest glacial phases. It is easy to interpret a cold flora found at an unusually low elevation by assuming a glacial phase. But in India it is much more difficult to explain a warm flora at an unusually high elevation, as it would imply the gratuitous invention of a period considerably hotter and moister than the present. This is the case of the Karewa flora, and tectonic upheaval has nearly always been regarded as the correct explanation of its occurrence at an altitude of over 10,000 ft. Sahni and others have shown that this upheaval was connected with the formation of the Pir Panjal range.

The Karewa series has an added interest in that its upper members have yielded a few flakes which appear to be human artefacts. Sahni collected this evidence in 1936 to show that part of the Himalayan uplift is younger than the appearance of man in India.

In the preceding paragraphs some of the factors have been indicated which might affect the apparent climatic aspect of a fossil flora. It is necessary to be on the look-out for such factors and if possible to make allowance for them before climatic inferences are drawn. But in many localities, for instance peat-bogs, the climatic factors have dominated the others, and it has been possible to reconstruct from them climatic sequences which have become the framework of stratigraphy from the climax of the third phase of the Last Glaciation onwards. This applies mainly to Northern Europe. A similar stratigraphy has been developed in North America. Nothing has yet been done in India, although suitable peat-deposits exist in many places in the Himalayas and possibly in the high mountains of the Peninsula also. It would be well worth while to tackle this problem of the Indian Holocene succession, and I feel sure that it would amply reward the investigators, as it might afford a possibility of correlating climatic fluctuations north and south of the Gangetic plains.

CHRONOLOGICAL METHODS

Several of the methods used in geochronology, either directly or indirectly, are based on the investigation of plant-remains, and it will be worth while to regard them briefly from the Indian point of view.

TREE-RING ANALYSIS

The study of the variation of ring-widths in cross-sections of trees and their correlation has been developed into a successful method of dating ancient human dwellings in the southwestern United States. There, the climate has for the last two or three thousand years been relatively dry, and annual ring-growth has been a function mainly of the amount of rainfall. The rings, therefore, provide clear records of droughts. By correlating the inner rings of a modern tree with the outer ones of a log coming from a somewhat older tree, overlaps can be recognized, and, provided sufficient material is available, ring sequences can be developed for certain periods of the past which are of considerable value in chronology. The tree-ring chronology of south-western North America already goes back about 2,000 years.

In India, this method would afford excellent opportunities for geochronological work wherever wood and ancient timber are preserved. The termites and high temperatures combined with rainy seasons, however, are very destructive, and the chances of finding wooden structures preserved are moderately good only in the neighbourhood of the desert areas. Dry areas at great altitudes are far more promising, and it is conceivable that the archaeology of Central Asia will one day be dated by means of tree-ring chronologies.

Pollen Analysis

The chronology of the Postglacial of Europe is largely based on the combination of countings of glacial varves with sequences of climatic phases established by means of pollen-analysis. This micro-botanical method of investigating peat and other vegetable deposits has largely replaced the earlier macroscopic identification of remains, though the latter has, of course, not been abandoned. Pollen-analysis affords means of estimating quantitatively many more constituents of a flora than can be recognized by macroscopic examination. On the other hand, it is mainly restricted to wind-pollinated species.

Pollen-analysis is bound to play an important part in the establishment of the Postglacial or Holocene sequence of climatic fluctuations in India. This work is, however, complicated by the very large number of genera and species composing Indian forests compared with the small numbers occurring in Europe. It will be necessary to study the recent pollen of relevant species before work on pollen-bearing deposits can be undertaken. For a start, the most promising areas will lie in the temperate forest zone of the Himalayas. Here it will be necessary to look for peat bogs and ancient lake beds.

Glacial varved clays, i.e. clay or silt deposits with an annual rhythm of deposition, are known from the Himalayas. They occur, for instance, in the Karewa series. Norin, moreover, has carried out some counts in Himalayan varve-deposits. A beginning has thus been made towards the establishment of a varve-chronology for India. Much work will have to be done before a well-correlated and dated record has been compiled. It might one day provide an absolute chronology for the Indian Holocene (and thus the later Stone Age and the Metal Ages). But whether it will ever be possible to establish a direct long-distance correlation of varve-series from India and from Sweden remains extremely doubtful for climatic reasons. Norin is probably too optimistic in considering this possible, and it is safer for India to stand on her own feet in this respect.

The chances are relatively high in northern India that polliniferous varved clays will one day be found. Such deposits have recently been described by Welten from Switzerland. Whilst varved clays are normally very barren, pollen is occasionally found in varved deposits in high mountain ranges, where the seasonal changes (including a frosty winter) are very marked and where trees grow not far from glaciers. Such cases are likely to occur in the Himalayas. It will be worth while to look for them, since such deposits afford a possibility of linking varve counts directly with pollen spectra.

MESOZOIC AND PALAEOZOIC CHRONOLOGY

In the epochs preceding the Pleistocene, palaeobotanical research is at present important mainly as a method of establishing detailed stratigraphical subdivisions. That micro-botanical investigation of sediments will play an increasingly significant part in this work has been pointed out repeatedly by Sahni, particularly with reference to the age of the Deccan Trap and the Purple Sandstone of the Salt Range. The statistical analysis of spores and pollen from such early rocks is possible, and the day may come when short-period fluctuations of the climate are found in the Permo-Carboniferous as they have been found in the Pleistocene and Holocene.

ANATOMY AND CLIMATE

It has been pointed out that the practice of determining the climate of a remote period (Tertiary and earlier) by assuming that species and genera have not changed their climatic requirements in the course of time is open to criticism. There is a wide field open for the palaeobotanist who wants to substantiate the climatic requirements of fossil plants by an investigation of their anatomical and physiological adaptations. To take a simple example, tall-growing broad-leaved evergreen plants are sensitive to frosty winters, because evaporation continues from the large surfaces of the leaves while the roots are unable to obtain water from the frozen soil. The presence of such plants in a fossil flora, therefore, suggests that the winters were mild.

Another example is the density of venation of dicotyledonous leaves. It is a function of evaporation (among other factors). Huber, Maximov and others have established that the density of venation on foliage increases (a) with the height above the root, (b) with the intensity of sunshine, (c) with a decrease in atmospheric humidity (so that of two plants of the same species the specimen occupying the drier habitat has the denser venation), and (d) with increased aridity of the soil (so that for instance of two related species the one living in the drier soil has the denser venation). The modifications caused by (c) and (d) afford a means of obtaining climatic information from the structure of fossil leaves, provided that the venation is sufficiently well preserved. Some years ago, the present writer made an attempt to determine the climate of the Upper Miocene of Oeningen (Baden) from such evidence. Briefly, it was found that temperate trees in ordinary localities had venation densities indicated by the following values (total length of veins in mm. per square centimetre): *Juglans regia*, 568, 569; *Acer pseudoplatanus*, 611. In sunny positions, the figures are higher: *Quercus pubescens*, 795; *Acer campestre*, 905. In an extremely dry and hot locality in the central Kaiserstuhl Hills in the rift valley of the Rhine, the following values were obtained: *Juglans regia*, 1296; *Quercus pubescens*, 1095. Mediterranean species have values of the following order: *Quercus coccifera*, 924; *Quercus ilex*, 1031; *Acer monspessulanum*, 1324.

By comparison, the Upper Miocene leaves exhibited venation densities of this order: *Acer trilobatum*, 999; *Quercus neriifolia*, 898; *Populus latior*, 1114; *Cinnamomum scheuchzeri*, 1266; *Cercis cyclophylla*, 1591. These figures correspond to those of Mediterranean species. Evaporation, therefore, appears to have been more intense in Baden in the Upper Miocene than at the present. This information, combined with other evidence, provides an interesting picture of the local climate of the time. Evergreen species suggest that frost was rare or absent, and " dripping tips " were about as frequent in Oeningen as they are in the temperate flora today. Rainfall, therefore, is likely to have been ample, perhaps seasonally, in spite of the high evaporation rate deduced from the density of venation. The climate, thus, seems to have been a subtropical or Mediterranean one with a dry and a wet season. The luxuriance of the Oeningen flora, however, was due to local conditions, for it was growing on the edge of a lake.

There are many other ways in which anatomical features lend themselves to a climatic interpretation. Sahni, for instance, has alluded to the possible use of the structure of the stomata, and their number is known to be connected with the rate of evaporation. W. N. Edwards has found that the percentage of dicotyledonous trees with entire leaf-margins increases as one passes from cold forests to the tropics, and that the Middle Eocene flora of Alum Bay, Isle of Wight, with a percentage figure of 80-90, is strongly suggestive of tropical rain-forest conditions.

This kind of approach to the problem of past climates is undoubtedly full of promise. It will bring immediate reward in the form of ecological information, and in the course of time is likely to contribute to chronology also.

VEGETATION AND MAN

One of the non-botanical methods used in the reconstruction of past environments, and one, which is important in the establishment of the climatic chronology of the Pleistocene, is palaeopedology or the study of fossil soils. Soils are known to be mainly determined by the type of rock on which they form and by the climate. But these two factors also determine the type of vegetation. Certain types of soils, therefore, are indicators of certain types of plant associations and, where these soils occur in the fossil state, they suggest that such plant associations were present at the time of their formation. Since the artefacts of early man are frequently found on buried land-surfaces, valuable information may be gained from the soils about the vegetation from which prehistoric man obtained his living and some of his raw materials.

In northern Gujarat, for instance, a very constant horizon of a reddish soil is found on top of fluviatile gravels and sands containing an Acheulian industry. This soil is different from the brown steppe soils which are forming at the present day and resembles the reddish soils of the dry forests of the foothills of the Deccan and Rajputana. The inference is that a similar type of forest covered the plains of northern Gujarat in that period.

Other examples could be given. It should be obvious, however, that the prerequisite for such work is a careful mapping of present-day plant-associations in relation to the soils on which they grow. This is a task for the plant ecologist, who can thus contribute valuable information to the study of ancient environments and, indirectly, to geochronology. A survey of types of natural vegetation in relation to soils is most desirable in India not only for the investigations which form the subject of this paper; it would undoubtedly be well worth while from the purely economic point of view.

CULTIVATION OF PLANTS

A field of environmental archaeology in which botanical research plays the dominant part is concerned with the change-over from the economic stage of food collection to that of food production. It is marked by the subjugation of certain food plants to the control of man, with the manifold modifications this process has produced in their morphology. Archaeological investigations yield interesting material for the study of which a trained botanist is not always available. In Europe, knowledge of the types of grain cultivated by the farmers of the Neolithic and the Bronze Age has been advanced considerably in recent years. In India, almost everything remains to be done, though material is not wanting. In the mound of Khokra Kot near Rohtak in the Jumna valley, Sahni found the shapes of the husk of rice impressed in clay which resemble *Oryza sativa* var. *plena*, a kind which has more than one grain in each spikelet. Moreover, actual cuticles recovered from terracottas after chemical treatment showed cells and stomata. The evidence thus strongly suggested to Sahni that this variety of rice was grown by the Yaudheya tribes about 2,000 years ago.

TIME ASPECTS OF EVOLUTION

The considerations contained in the preceding paragraphs are concerned, directly or indirectly, with the development of chronologies. *Absolute* chronologies (in years) to which the palaeobotanist contributes are based either on the counting of annual growth-rings or of annual layers (varves), or on rates of weathering or astronomical rhythms. With the time-scales obtained from the rates of radioactive disintegration of minerals the palaeobotanist is not immediately concerned, although he is often able to contribute to stratigraphy (or *relative* chronology) without which the age estimates would be meaningless.

It is possible, moreover, to reverse one's attitude, to accept the time-scales which have been suggested for the period since the beginning of the Cambrian and to apply them to the evolution of life as evidenced by palaeontology. In this way, some indication is obtained of time-rates of evolution, such as the "life-times" of species and genera, and the rates of production of new species observable in various groups in arbitrarily fixed periods of unit-time. It is indeed important for the worker on evolution to be able to express such changes as a function of time. Most of the work has so far been done on groups of animals; only Small has considered plants, particularly diatoms. A very wide field is here open to the palaeobotanist and valuable results are bound to come forth from the chronological study of the evolution of groups of plants the classification of which has been worked out with care.

CONCLUSION

The term *geochronology* was coined by H. W. Williams in 1893 to describe studies in which the geological time-scale is applied to the earth and its inhabitants. It is only fair to continue using the term in the wide sense which was originally given to it, and this has been done in the present paper. Later on, however, the term became associated with one restricted method, viz. the counting of glacial varves as practised by de Geer in Sweden. But the great American geologist Charles Schuchert maintained the comprehensive meaning of the word when, in 1931, he interpreted geochronology as the age of the earth on the basis of sediments and life. Both Williams' and Schuchert's definitions emphasize the close relationship between geochronology and stratigraphy, and the stratigraphy of terrestrial sediments is in no small measure based on palaeobotany. Birbal Sahni was right, therefore, in emphasizing that indirectly, and to a smaller extent directly, palaeobotany is destined to be one of the major factors in the further development of geochronology.

REFERENCES

EDWARD, W. N. (1936). The Flora of the London Clay. *Proc. Geol. Assoc. London.* **47**: 22-31.

HUBER, B. (1924). Die Beurteilung des Wasserhaushalts der Pflanze. *Jahrb. wiss. Bot.* **64**:1.

MÄGDEFRAU, K. (1931). Zur Morphologie und phylogenetischen Bedeutung der fossilen Pflanzengattung *Pleuromeia*. *Beih. bot. Centralbl. Dresden.* **48** (II, 1): 119-40.

MAXIMOV, N. A. (1931). The physiological significance of the xeromorphic structure of plants. *J. Ecol.* **19**: 273.

NORIN, E. (1928). Late Glacial Varves in Himalaya connected with the Swedish Time-Scale. *Geogr. Ann. Stockholm.* 1927 (3): 157-61.

PITTIONI, R. (1951). Prehistoric Coppermining in Austria: Problems and facts. *Univ. London Inst. Arch. Ann. Rep.* **7**: 16-43.

PURI, G. S. (1947). Fossil Plants and the Himalayan Uplift. *J. Indian bot. Soc.* 1946: 167-84.

SAHNI, B. (May 1936). Antiquities from the Khokra Kot Mound at Rohtak in the Jumna Valley. *Current Science.* **4** (11): 796-801.

Idem (July 1936). The Karewas of Kashmir. *Current Science.* **5** (1): 10-16.

Idem (August 1936). The Himalayan Uplift since the Advent of Man: Its Culthistorical Significance. *Current Science.* **5** (2): 57-61.

Idem (1937). Wegener's Theory of Continental Drift with Reference to India and Adjacent Countries. *Proc. 24th Indian Sci. Congr., Hyderabad*: 502-520.

Idem (1938). Recent Advances in Indian Palaeobotany. *Proc. 35th Indian Sci. Congr., Calcutta*: 133-76.

Idem (1947). Palaeontology and the Measurement of Geological Time. *Current Science.* **16**: 203-6.

SMALL, J. (1950). Quantitative Evolution XVI. Increase of species-number in Diatoms. *Ann. Bot.* (n.s.). **14** (53): 91-113.

WEIGELT, J. (1930). Zur erdgeschichtlichen Problematik der älteren Braunkohlenformation Mitteldeutschlands. *Jahrb. Hallesch. Verb. Halle a. Saale* (n.s.). **9**: 5-12.

WELTEN, M. (1944). Pollenanalytische, stratigraphische und geochronologische Untersuchungen aus dem Faulenseemoos bei Spiez. *Veröff. geobot. Inst. Rübel, Zürich.* **21**: 201. pp.

ZEUNER, F. E. (1931). Die Insektenfauna des Böttinger Marmors. *Fortschr. Geol. Palaeont., Berlin.* **9** (28):160.

Idem (1932). Die Nervatur der Blätter von Oeningen und ihre Auswertung für das Klimaproblem. *Centralbl. Min. etc.* (B) 1932 (5): 260-4.

Idem (1949). Time in Evolution. *Proc. R. Inst., London.* **34**:294-305.

Idem (1950). Dating the Past. 2nd ed., pp. 474. *London.*

Idem (1950). Stone Age and Pleistocene Chronology in Gujarat. *Deccan Coll. Mon. Ser. Poona.* **6.** 46 pp.