SYSTEMATIC STUDY OF THE ORGANIC MICROCONSTITUENTS OF THE MAIN SEAM OF NEYVELI LIGNITE, SOUTH INDIA

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ABSTRACT

This paper deals in detail a systematic description of the characteristic features of the organic microconstituents of the main seam of Neyveli lignite and its qualitative and quantitative assessment. The study suggests two distinct lignite types formed variably from two different sets of source material. Each lignite type has distinct physico-chemical properties. Such findings have bearing on various lignite utilization projects.

INTRODUCTION

Lignites (also known as brown coals) are intermediate in composition between peat and bituminous coals. Most of the lignites were formed from comparatively recent (Cenozoic) plant communities growing at or above water level of an original peat basin in an area of intermittent but progressive subsidence. In lignites, all microbial activity gets terminated with burial or shortly afterwards under earth cover. Differences in composition that occur after termination of microbial activity are purely geochemical or physicochemical in nature which are caused by diagenetic or metamorphic processes, in contrast to biochemical process of decay and decomposition occurring in peat deposits. Lignites contain high moisture, soluble waxes and resins and less carbon contrary to coals.

Many lignite types may be differentiated by megascopic and microscopic characters. Considerbale differences may exist from one deposit to another or even within one deposit.

Earlier, only chemical and physical studies were carried out for industrial and technological utilization. However, it was found that these investigations are not entirely satisfactory. In recent years brown coal microscopy, both biopetrological and palynological studies are being used for prospecting and utilization effectively. Several countries (other than India) particularly East Germany has made use of brown coal petrology and palynology extensively in technology and industry for sheer necessity owing to dearth of hard coals. In our country also there are regions where no coal deposit of economic importance occur, instead, there are areas (Neyveli, Tamil Nadu in South India; Panandhro in Kutch, Gujarat; Akri, Palana in Bikaner, Rajasthan in western India, Kashmir in northern India and Dhansiri lignite, Assam in eastern India) which possess rich brown coal deposits as the main fossil fuel resources. They are the potential areas where lignite microscopy can profitbaly be utilized for fuel evaluation. In this paper, a biopetrological evaluation is made on the main seam of the biggest lignite deposit of India, situated in Neyveli near Pondicherry, South India.

The main seam is of varying thickness and extends up to a maximum of 15 meters in the field. The top and the bottom surface of the seam shows variations in its thickness with in the field. However, top surface appears to be more uniform than bottom in most part of the area. There are no structural disturbances or features like folds or fault, in the area. The seam is immediately overlain by a bed of white clay (1.5 m thick). Above this clay bed lie thick sandstone strata referred to as Cuddalore Formation. There are two aquifer beds below the seam separated by a bed of clay. The geological and stratigraphical details of the Neyveli lignite area have already been described (BALASUNDER, 1968).

The lignite samples are generally compact, massive or blocky. Some transition zone of soft lignite type is seen in the upper portion of the main seam. The lignite generally shows brown or black colour but on drying, it becomes light brown to brown or even brownish black. The main seam contains some megafossils and pollen grains of angiosperms (NAVALE, 1973, 1974a, 1974 b). The chemcial analysis (Proximate and ultimate) of the main seam is given in the following table.

PROXIMATE ANALYSIS

Moisture	44.00—60%	55.00% (average)
Ash	1.76—4.58%	2.50%—3.00% (average)
Volatile Matter (dry ash free basis)	51.23—57.94%	
Fixed Carbon (dry ash free basis)	42.56—48.77%	
Calorific Value K calories/K gm	2222—3356	2600 (average)
Bulk density gm/c.c.	1.161	

ULTIMATE ANALYSIS

Carbon	69.30%
Hydrogen	5.65%
Sulphur	1.20%
Oxygen	23.45%
Nitrogen	0.40%

MATERIAL AND METHOD

Four lateral sections of the main seam were considered for maceral, microlithotype and reflectance analyses. Ten samples at regular intervals, collected from each lateral sections were grouped into top, middle and bottom (overall) samples, embedded in resin (araldite mixture) and 12 pellets of the overall samples were prepared for microscopic study. The statistical analyses of the organic microconstituents were made according to I.C.C.P. (1971, 1975) recommendations.

MACERAL

Description of macerals, in the present study, has been made under three maceral groups—huminite, liptinite and inertinite according to I.C.C.P. (*loc. cit.*) recommended terminology for lignites. The Table-1 below provides a summary the basic lignite macerals.

HUMINITE GROUP

To describe structural organic constituents of brown coals (lignite) SZADECZKY KARDOSS (1948-1949) for the first time used the term huminite. This was adopted by the Nomenclature Subcommission of the I.C.C.P. since 1970 to desigante a group of macerals of lignite.

Table 1—Summary of the Macerals of brown coal (Lignite)

Maceral Group	Maceral Subgroup	Maceral	Submaceral
HUMINITE	Humotelinite	Textinite	
		Ulminite	Texto-Ulminite Eu-Ulminite
	Humodetrinite	Attrinite Densinite	
	Humocollinite	Gelinite	Porigelinite Levigelinite
		Corpohuminite	Phlobaphinite Pseudophlobaphinite
LIPTINITE		Sporinite Cutinite Resinite Suberinite Alginite Liptodetrinite Chlorophyllinite Bituminite	
INTERTINITE		Fusinite Semifusinite Macrinite Sclerotinite Inertodetrinite	

The huminite maceral group originates essentially from humic materials derived from lignin and cellulosic fractions of peat forming plant communities. In this group, a non-humic sub-maceral phlobaphinite which is a derivative of catehol-tannins is also included. Depending upon the state of preservation of vegetal matter, three maceral subgroups viz., humotelinite—(consists of intact cell walls of tissues or isolated individual cells in humic state of preservation), humodetrinite—(consists of fine humic detritus intimately mixed with humic gel) and humocollinite—(comparises amorphous humic gel or of intensely gelified plant tissues and humic detritus) have been designated. Further divisions of maceral subgroup into macerals and submacerals is based on the degree of gelification and/or form and origin (Table-1).

TEXTINITE

Chemical and microbiological coalification product of the cell walls of resistant plant tissues or organs which have withstood oxidation is the textinite. Resistance to cell walls may be imparted by resin, cutin, suberin or tannin impregnations. Textinite comprises of ungelified plant cell walls both isolated intact individual cells and cell tissues with varying shapes and sizes and generally having open lumen. In tissues, the cell walls may be deformed, collapsed or even torn, but as long as the cell form is still recognizable, the cell walls are termed as textinite.

Textinite maceral occurs quite commonly in Neyveli lignite and exhibits a variety of cellular structure of tissues variously preserved.

Pl. 1, Fig. 1—a transverse section of a wood shows orderly arranged cells. The cells are of different shapes and sizes mostly having open lumen and almost all are intact. But at places, lateral and horizontal walls are broken. Intercellular spaces as well as secondary wall thickening are also very clearly visible. The cell walls show a normal textinite reflectance.

Pl. 1, Fig. 2—shows fragmentation and differential collapsing of cell walls whose other characters are still preserved. Probably due to uneven compression, cell walls have fused together and formed thick bands of pure textinite. Between bands, partially compressed rows of cells are observed. Here again the textinite shows a normal reflectance.

Pl. 1, Fig. 3—in the upper part, typical tabular bark cells are arranged in rows, whose cell walls, though partially crumpled, are still intact showing relatively weaker reflectance than the previous two textinites described. In this case cell lumens are not empty but are filled with phlobaphinite material. Below these bark cells partly gelified band of textoulminite is recognized.

Pl. 1, Fig. 4—section shows a bark tissue having tabular to cresent shaped cells. Cell walls are almost intact showing normal textinite (textinite B) reflectance. The lumen of the cells are either empty or fitted with some extreneous material.

Two varieties based on relative reflectance have been distinguished in the textinite maceral of the Neyveli lignite—textinite A (Pl. 1, Fig. 3) has a lower reflectance and textinite B (Pl. 1, Figs. 1, 2, 4) shows same or higher reflectance than the associated humodetrinite (always higher than the textinite A). The low reflecting textinite A represents comparatively a lesser degree of humification, and cellulose content in the maceral is still high (Teichmüller *in* Stach *et al.* 1975).

ULMINITE

Ulminite is produced by alteration of textinite through biochemical and/or geochemical gelification. It consists of partly or totally gelified plant cell walls both as isolated single cells and tissues. Size and shape of the cells are variable and the lumens are partly or wholly closed. The cell wall thickness in ulminite, is generally larger than in the textinite of the same cell type, due to swelling. Original cell wall structures (layering, intercellular spaces, pits, etc.) are partly or completely obscured due to homogenization. Shrinkage fissures in ulminite is typical. It often displays higher reflectivity than the textinite in the same lignite and corresponding varieties.

Based on the degree of gelification, two submacerals can be differentiated in the Ulminite : (1) Textoulminite—partly closed cell lumens, faintly visible, cell wall structure still recognizable in tissues, (2) Euulminite—cell lumens completely obscured, structure of the cell walls no longer discernible, in tissues, cell structure only faintly visible, more or less similar in appearance to the telinite of the bituminous (hard) coals.

The maceral ulminite occurs very commonly in the Neyveli lignite and shows variation in the degree of gelification. In the bottom part Pl. 1, Fig. 3 lies a thick band of gelified material showing partial obliteration of cell lumens. Most of the cells are indistinct but few faint outlines of cell walls are recognizable. There are still some empty cell lumens present which indicate incomplete gelification. The maceral shows huminite reflectance and represents the submaceral texto-ulminite. Pl. 1, Fig. 5, exhibits a tissue section showing recognizable cellular pattern. The cells are characterized by faintly discernible cell walls while cell lumens are only partially closed. In this case also, gelification is still incomplete representing submaceral texto-ulminite. Pl. 1, Fig. 6 displays complete gelification of the botanical structure. No cell wall or cell lumen is distinguishable but only very faint cellular pattern could be observed.

ATTRINITE

Attrinite is essentially made up of fine (mostly $<$ 10 microns) huminitic detritus derived from cell wall fragments (even $>$ 10 microns) and formless, porous huminitic material. These different, motsly intimately mixed constituents are more or less loosely packed and display a spongy nature. Attrinite forms ungelified humic ground mass for other macerals of lignite (brown coal).

Strong structural decay and decomposition of vegetal matter, chiefly of herbaceous type and angiospermous woods having lesser resistance lead to the formation of the huminitic detritus of attrinite. Formation of detrital attrinite is indicative of relatively aerobic condition.

Attrinite (sub-group humodetrinite) is more commonly occurring maceral in the present lignite. Pl. 1, Fig. 7 shows partly porous, loosely packed and partly flocculated huminitic groundmass intimately interspersed with huminite and other kinds of formless detrital particles of varying shapes ($<$ 10 μm to 10 μm). In Pl. 1, Fig. 8, porous and spongy nautre rendered by fine detrital fragments are still discernible while fungal spore and sclerotia, the inertinitic constituents, are impregnated in it.

DENSINITE

Fine (mostly $<$10 microns) huminitic detrital particles of varying shape including cell wall debris (even $>$10 microns) as well as, dense formless and nearly homogeneous huminitic material constitute densinite. These constituents are densely packed (contrary to attrinite) due to gelification over at least areas larger than 15 μm^2. Densinite provides groundmass for the impregnation of other lignite macerals. The densinite is produced from gelification of attrinite.

Densinite (subgroup-humodetrinite) is a common maceral occurring in the Neyveli lignite. The densinite is characterized by higher degree of gelification than attrinite which is evident in Pl. 1, Fig. 9 where gelified huminitic groundmass and detritals are intimately mixed with each other while inertinite macerals (sclerotinite and fusinite) of larger size are impregnated in it. Pl. 1, Fig. 10 shows fine huminitic detrital particles closely mixed with gelified humic substance giving rise to a more or less homogeneous mass.

GELINITE

Gelinite is a maceral of subgroup humocollinite. It consits predominantly of precipitated humic gels which have no definite form and show, without etching, a homogeneous structure. The gelinite occurs as infilling substance and assumes the shape of the structure it fills up. Fragments of gelinite smaller than 10 microns in diameter are not recorded as gelinite. Depending upon the texture, two submacerals can be distinguished in the gelinite : (1) Porigelinite---finely porous to microgranular in appearance, (2) Levigelinite-homogeneous (structureless) but with indistinct striated appearance, when the gelinites filling cell lumens are indistinguishable from infillings of phlobaphinites, they are grouped with the later. Gelinites have a tendency to fissuring (dessication cracks) and generally possess smooth grain boundaries.

In the present material gelinite is represented mostly by submaceral levigelinite which occurs as bands of gelified tissues having a homogeneous appearance (Pl. 1, Fig. 11) possessing a higher reflectivity than the associated humodetrinite. Often these structureless gelinite occurs as lenses or thin bands in association with humodetrinite (Pl. 2, Fig. 12) and shows its typical dessication cracks.

CORPOHUMINITE

Corpohuminite is a maceral (subgroup-humocollinite) of huminite group. It consists of isolated or *in situ* primary phlobaphinitic excretions or secondary huminitic cell fillings, provided the latter is not considered as gelinite. It shows reflectivity of huminite. The corpohuminite cell fillings essentially have spherical, elliptical, rod-or plate like shape. The surface of the maceral is smooth, porous, cavernous or pitted. The corpohuminite can be differentiated into two submacerals : (1) Phlobaphinite-tannin derived primary cell excretions, (2) Pseudophlobaphinite—secondary cell fillings originated from humic colloids.

The phlobaphinite originates from tannin-rich cell excretions. The excretionary material is deposited in cortical, parenchymatous or medullary-ray cells but more specially in bark tissues.

The maceral corpohuminite occurs commonly in the present material in the form of tabular, rounded and elliptical bodies both *in situ* and isolated conditions in cortical, peridermal and in rootlet tissues. In Pl. 1, Fig. 1, scattered phlobaphinite bodies of various shapes are exhibited. Their surfaces are smooth and reflectivities are same as of associated textinite. In cork cells (Pl. 1, Fig. 3—top portion) phlobaphinite occurs as infilling substance while cell walls are textinitic, relatively thicker and possess lower reflectivity than the former. While in Pl. 2, Fig. 13 there are several rows of tabular to crescent shaped cork cells with phlobaphinite fillings, the cell walls have been rendered very thin represented by suberinitic walls, forming an outer circle enclosing a smaller circle consisting of smaller cells (phlobaphinitic) and few randomly oriented cells.

LIPTINITE (EXINITE) GROUP

Liptinites (Exinites) are the coalification product of relatively hydrogen-rich plant materials, e.g. sporopollenin (sporin-in fossils), cutin, suberin, resins, waxes, fats and oils, etc.) A fraction of liptinite also originates from bacterial degradation products of proteins, cellulose and other carbohydrates. Liptinites are subdivided into following macerals-sporinite, cutinite, resinite, suberinite, alginite, liptodetrinite, chlorophyllinite and bituminite (Table-1). The liptinite macerals possess characteristically lower reflectivities than the macerals of huminite or inertinite groups.

SPORINITE

Sporinite is formed from outer coverings (exines and perines) of pollen and spores which are very resistant to decay and decomposition. Generally it is observed in sectional view as thin elongated strips having a streak inside represented by lumen.

In the present lignite sporinite has been observed, but its quantity is so less that even locally it could never be of some importance. Although maceration of samples have yielded variety of spore and pollen grains (Ramanujam, 1966 ; Navale & Misra, 1979) surprizingly they are but very rarely observed on the polished surface study.

CUTINITE

Cuticular layers and cuticles serving as protective covering of leaves and stems form the cutinite maceral. The cutinite occurs as one sided serrated strips of varying thickness. They may be intact quite long, folded and crumpled, arranged in rows or as single isolated piece. Cuticular layers and cuticles being composed of cutin, wax and pecten (cuto-cellulose) are very resistant to maceral decay and hence they are found preserved with very little alteration during early coalification.

The maceral cutinite, as in the case of sporinite, is also a rarely occurring maceral in the Neyveli lignite. It is observed as intact or broken, thin strips with serrated margin on one side. The cutinite also could not become locally important. However, few leaf sections showing huminitic reflectivity have been observed (Pl. 2, Fig. 14) which distinctly show cuticles of upper and lower sides, inside which are loosely arranged textinitic meso-phyll cells. Such sections display all the structural details very clearly but appear to have more huminitic (humotellinite) characters than liptinitic.

RESINITE

Since most of the resinites are excretionary product, the maceral is primarily found as *in situ* cell fillings or isolated bodies. It is observed as circular, oval or rod shaped on polished sections. It can also occur as layers, cleats and as fillings in fissures and pore spaces. It has characteristically lower reflectance than huminite or inertinite. Sometimes, due to oxidation, it assumes reflectivity of huminite or inertinite under such conditions it is not recorded as resinite.

The resinite occurs as infilling material in the Neyveli lignite. Most it has been observed as circular, oval or elongated bodies scattered in the humodetrinite (Pl. 2, Fig. 15). The resinite also occurs as cell fillings but at places their higher concentration probably indicate degradation of the woody materials.

SUBERINITE

The maceral suberinite has only been recorded from Tertiary lignites and coals and also from a few Mesozoic coals. Suberinite is named after "suberin" which is similar to cutin and occurs mainly in brak tissues and also on surfaces of roots, stems and fruits serving as protective covering against dessication. In cork tissues only the suberin layer of the cell walls is usually found preserved in lignites and coals.

In the Neyveli lignite the maceral suberinite is mostly found associated with phlobaphinites. The suberinite is generally observed as dark coloured streak like cell walls surrounding elongated, tabular or crescent shape phlobaphinite filled lumens of bark tissue or root cells (Pl. 2, Fig. 13).

ALGINITE

The maceral alginite occurs only in certain specific lignites and coals. It is normally not found in normal humic lignites or in bituminous coals. It is easily differentiated from other macerals of exinite group by its relatively darker colour in reflected light on polished surface. Alginite originates specially from resistant oil rich algae. Typical alginite is found only in sapropelic lignites and coals and also in oil shales.

In the macerates of the Neyveli lignite samples, common occurrence of *Botryococcus*, an oil secreting, planktonic, polymorphous colonial recent green alga, has been observed. Pl. 1, Fig. 16 shows a colony of *Botryococcus* in which several small, oval or pear shaped individual bodies are distinctly visible embedded in a ground mass.

BITUMINITE

The maceral bituminite is a characteristic component of sapropelic and other subaquatic, mainly liptinite lignites and coals. It lacks definite shape and occurs autochthonously as "schliren" in the bedding. Bituminite is found as finely dispersed granular matter forming groundmass for other macerals and also in the form of streaks. It is presumed that Bituminite, probably, is a decomposition product of algal, animal planktonic, bacterial lipids and other similar sources.

In the present lignite, minute, disseminated dark grey granular matter has been observed associated with humodetrinite (attrinite) which appear very much like bituminite but it needs confirmation.

INERTINITE GROUP

The inertinite is designated for certain micro-constituents of lignites and coals which are more or less non-reactive in a particular sense (e.g. carbonization) contrary to the macerals of huminite and liptinite groups. Inertinite originates mainly from the same source material which produces huminite. The difference lies only in the process of its formation-fusinization. During this process relatively greater degree of aromatization and condensation is attained on the subsequent of which inertinites are rendered higher reflectivity than the corresponding huminites. Fusinization is caused by charring, oxidation, mouldering and fungal attack on the surface of the peat or before deposition.

Some times, high reflectivity of the inertinites is pre-existing in the parent plant, e.g. in fungo-sclerotinite, which is derived from dark coloured cell walls. Inertinite originates also from macerals of huminite and liptinite groups during geo-chemical coalification, e.g. some part of micrinite is produced by coalification of former liptinitic constituents. The inertinite group is subdivided into following lignite macerals-fusinite, semifusinite, macrinite, sclerotinite and inertodetrinite

FUSINITE AND SEMIFUSINITE

The distinction between fusinite and semifusinite is made primarily on the degree of their fusinization attained. Owing to their almost identical origin these two macerals are considered together in the description. Genetically fusinites can be differentiated into following types :

(*a*) *Pyrofusinite*—A part of fusinite and semifusinite owe its origin to wood or peat fires. With large fires (e.g. forest fire) oxygen deficiency ensues frequently resulting into incomplete combustion and incineration. In swamps also the fire is extinguished by moisture of the swamps. Such fires consequently produce charred woods or peats and thus pyrofusinite results representing fossil charcoal. Fusinites or semifusinites of high but varying reflectivities, thus, developed are dependent on the degree of charring by such fires.

Occasional drying out of swamp surface may cause "ground burning" resulting in the formation of large amount of ash (fusinite). Also during "subsurface burning" underneath the peat surface "charring nests" are formed.

Pyrofusinite is very brittle and tends to disintegrate into fine fragments. It is characterized by well preserved thin cell walls having high reflectivity, yellowish colour and strong relief. It occurs as macroscopically visible streaks, lenses and bands.

(*b*) *Degradofusinite* (*Oxyfusinite*)—This type of fusinite is mostly not visible macroscopically and are generally associated with dull bands. Cell structures in such fusinites are only poorly preserved, their reflectivity is mainly semifusinitic with whitish appearance. Probably dessication and relatively higher oxygen influx (dehydration and oxidation) at the peat surface produce degradofusinites.

Mouldering of wood by wood destroying fungi also produces degradofusiniite. Sometimes "subsurface oxidation" by oxygen-rich migrating ground water specially in Karst region can also cotnribute to the formation of oxyfusinites.

(*c*) *Rank fusinite*—A part of fusinite forms by fusinitization during geochemical coalification of huminitic-liptinitic constituents. Such fusinite is referred to as "rank fusinite". The rank fusinite is characterized by well preserved cell structures and its reflectivity is relatively low.

(*d*) *Primary fusinite*—Comprises of cell walls or tissues already possessing high reflectivity, (e.g. fungo-sclerotinite) of inertinite even before deposition. Not only fungi and lichens, but also higher plants deposit very resistant black material ("phytomelanes") in cell membranes (e.g. wall of the fruits and roots of modern compositae) which renders a fusinitic characters to the cell walls or tissues involved.

Fusinite and semifusinite observed in the Neyveli lignite generally represent degradofusinite and rank fusinite. Pl. 1, Fig. 9 shows broken pieces of fusinitic material along with sclerotinite. The reflectance of fusinite and sclerotinite appears almost same. Cell walls are collapsed and lumens are empty. Pl. 2, Fig. 17 shows a group of cells, probably epidermal cells, most of which appear to be filled with phlobaphinitic or gelinitic material while some partially closed lumens are still visible. Cell walls are of grey colour and they are very thin. Such structures, wherever observed, show fusinitic reflectance. Occasionally semifusinitic or fusinitic cell walls have been observed which show poorly preserved thick walled cells with empty cell lumens and exhibit relatively higher reflectance than associated huminite macerals (Pl. 2, Fig. 18). Fusinitized bark cells have also been observed in this lignite.

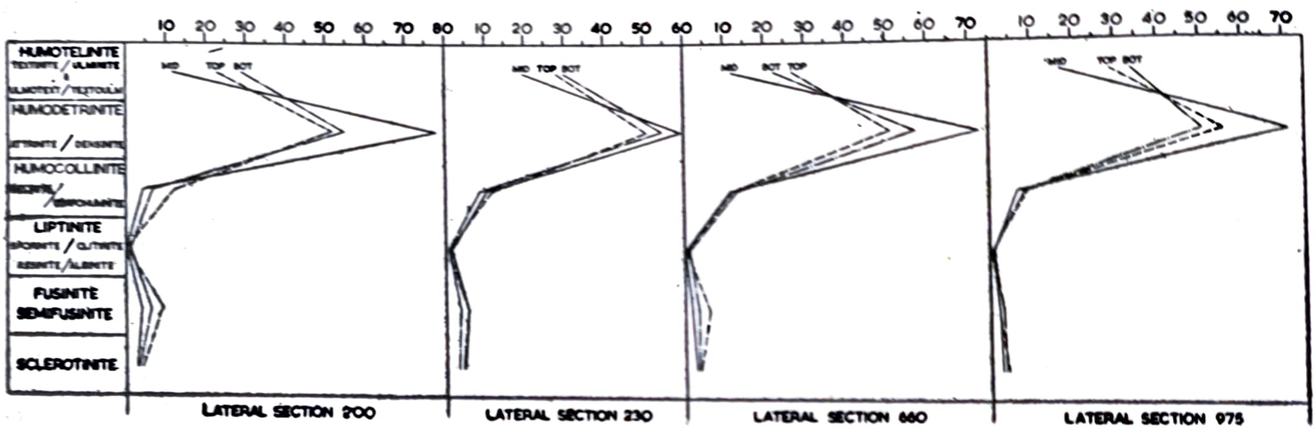
SCLEROTINITE

The sclerotinites of Tertiary lignites and coals are exclusively of fungal remains. The term sclerotinite (STACH, 1952) designates all strongly reflecting fungal remains—hyphae, mycelia, plectenchyme, spores and sclerotia (resting fungal bodies). Fungal spores, sclerotia, plectenchyme (fungal tissues) etc., only of dark colour, produce sclerotinite. The dark colour and high reflectivity of fungal remains are rendered by "melanins" not by chitin which is skeletal material of fungal cell walls. Apart from exhibiting high reflectivity the sclerotinites are characterized by a high relief and high polishing hardness.

Fungal spores, sclerotia and plectenchyme are commonly obesrved in this lignite. Size and shape of the bodies vary and they are often seen flattened due to compression. Based on morphographic characters, quite a few forms have been recognized and they are comparable to already described forms (NAVALE, 1971). Apart from one to three-celled teleutospores already recorded, four to six celled teleutospores have also been observed (Pl. 2, Figs. 19, 20). It is observed that with the increase in number of cells in such spores, outer wall, as well as, parting walls between cells become thinner. *Sclerotites brandonianus* (Pl. 1, Fig. 9; Pl. 2, Fig. 21), *Sclerotites crassitesta* (Pl. 2, Fig. 22) showing a single large lumen surrounded by a thick wall which progressively becomes spongy towards periphery and *Sclerotites multicellatus* (Pl. 2, Fig. 23) having about 40 chambers, have quite frequently been recorded. An uncommon form of sclerotinite—*Coronasclerotes africanus* recorded earlier in the Neyveli lignite by Navale (*loc. cit.*) has also been observed.

DISTRIBUTION OF MACERALS

Distribution of various maceral groups and macerals in the four lateral sections of the Neyveli lignite is given in graph-1.



GRAPH-1: FREQUENCES OF MACERALS IN TOP, MIDDLE & BOTTOM PARTS OF THE MAIN SEAM OF THE NEYVELI LIGNITE

In the top part of the lateral section 200, huminite group forms 86.50 percent by volume of the lignite which itself is distributed in 22.75 percent of humotelinite, 51.75 percent of humodetrinite and 12.00 percent of carpohuminite. Inertinite group forms 13.50 percent while liptinite is absent altogether. The middle part of the seam has only 93.75 percent of huminite, distributed to humotelinite 11.75 percent, humodetrinite 77.75 percent and corpohumonite 4.25 percent. Liptinite group is absent while inertinite content is 6.50 percent. In the bottom portion of the section, huminite percentage is 90.10 constituted by 29.00 percent of humotelinite, 54.50 percent humodetrinite and 6.50 percent corpohuminite. Liptinite constitutes 1.00 percent while inertinite contains 9.00 percent.

In Lateral Section 230 of the lignite seam, the top portion contains 90.00 percent of the huminite macerals constituted by 28.00 percent of humotelinite, 50.50 percent of humodetrinite and 11.50 percent of corpohuminite. Liptinite and inertinite contents are 0.50 percent and 9.50 percent respectively. The middle part of the section is composed of 88.75 percent of huminite group formed by 19.75 percent of humotelinite, 59.00 percent humodetrinite and 10.00 percent corpohuminite. Liptinite group is represented by 1.25 percent while inertinite macerals are 10.00 percent by volume. The bottom portion consists of 93.00 percent of huminite group distributed in 30.00 percent humotelinite, 54.50 percent humodetrinite and 8.50 percent corpohuminite. Liptinitic constituents are only 0.50 percent wherein inertinite macerals account 6.50 percent by volume.

The top part of third Lateral Section-660, contains 90.00 percent of huminite group formed by 27.00 percent of humotelinite, 51.00 percent of humodetrinite and 12.00

percent of corpohuminite by volume. Liptinite group constitutes only 0.50 percent and inertinite group is represented by 4.50 percent by volume. The middle portion is characterized by 96.00 percent of huminite group represented by 12.00 percent of humotelinite, 72.50 percent of humodetrinite and 11.50 percent of corpohuminite by volume. Liptinite macerals in this portion were found lacking while inertinitic constituents are represented by 4.00 percent by volume. The bottom portion of the section is formed by 92.50 percent of huminite group which itself is constituted by 22.50 of corpohuminite. Liptinite macerals present in the section form only 1.00 percent of the total while inertinite fraction is represented by 6.50 percent by volume.

In the fourth Lateral Section 975 of the lignite, the top part is formed by 93.50 percent of huminite group differentiated into 29.00 percent of humotelinite, 55.50 percent of humodetrinite and 9.00 percent of corpohuminite by volume. Liptinite form only 0.50 percent of the total and the inertinite macerals are represented by 6.00 percent only. The huminite group, in the middle part comprises of 94.75 percent by volume of the total and is represented by 17.00 percent of humotelinite, 71.00 of humodetrinite and 6.75 percent of corpohuminite. The macerals of liptinite group form only 0.75 percent of the total and the inertinite macerals constitute 4.50 percent by volume. The bottom part of the lateral section is composed of 93.00 percent of the huminite constituents distributed into 34.00 percent of humotelinite, 50.50 percent of humodetrinite and 8.50 percent of corpohuminite by volume. The liptinite group is represented by only 0.50 percent of the total and the macerals of inertinite group constitute 6.50 percent by volume.

MICROLITHOTYPES

Microlihtotypes or typical maceral associations of lignite, like coal, are subdivisible into three groups, viz., monomaceral, bimaceral and trimaceral microlithotypes depending on the presence of maceral of one, two or three maceral groups. For the purpose of delimitation of various microlithotypes in the lignite, the convention of minimum band width of 50 microns has been retained (as in microlithotypes of hard coals) and instead of "5 percent rule", recommended by the I.C.C.P., 1963, for hard coals, "10 percent rule" has been proposed (Navale, & Misra, 1980b). Because the peat forming vegetal source material during early stages of coalification is largely immature in lignite stage, macerals show relatively better structural details, less compaction and degradation than the coal. The immature macerals occupy comparatively larger surface areas causing lot of variation in microlithotype composition and hence the quantitative limit of accessory macerals in lignite microlithotypes has been enhanced.

Categorization of lignite microlithotype is made under three microlithotype groups viz., humite, liptite (exinite) and inertite. These three microlithotype groups of lignite are similar to microlithotype groups (vitrite, liptite (exinite) and inertite) of hard coals in the sense that the former are the precursors of the later, the differences being only in their degree of coalification. However, the durite microlithotype group, typical of Palaeozoic coals is absent in lignites. Where as detrital fraction (humodetrinite), a very characteristic and ubiquitous component of lignite, sometimes forming major part, has been considered as detrite microlithotype group (Navale & Misra, *loc. cit.*).

HUMITE GROUP

Bands more than 50 microns thick constituted by huminite macerals are termed as "humite". Broad bands of humite are generally formed from stems, branches or lignified tree roots. In forest swamp facies, humite is abundantly represented in broad bands. Sometimes, many stems and stumps can be seen in the lignite seam with naked eyes. In such cases the preserved woody remains are called "Xylite".

The preservation of stems and branches as humite requires protection from atmospheric oxygen which is furnished by high ground water level. Apart from atmospheric protection, some part is also played by the individual resistance of the source material, for example, angiospermic source material is relatively less resistant than that of coniferous woods. Consequently xylites of angiosperms are uncommon in Tertiary lignites and coals while conifer xylites are abundant in forest swamp facies.

The humite microlithotype group can be subdivided into ιwo subgroups (NAVALE & MISRA, 1980a)—(*a*) humotelite—consisting of textite and ulmite microlithotypes and (*b*) humocollite—represented by gelite and corpohumite microlithotypes.

In the Neyveli lignite, the microlithotype group humite is represented by textite, ulmite, gelite and corpohumite microlithotypes. Gradational microlithotypes in the group like ulmotextite, textoulmite etc. have also been observed and are categorized under textite and ulmite respectively.

TEXTITE-ULMITE

In textite microlithotype, tissues with distinct cellular structures and partially collapsed cell walls forming bands (Pl. 1, Figs. 1, 2, 4) are quite common. Gradational changes between textite and ulmite microlithotypes have been observed as ulmo-textite and textoulmite. The textoulmite is displayed as partially gelified textite with discernible cell walls where cell lumens are still incompletely filled with gelified mtaerial (Pl. 1, Figs. 3, 5). Gelified tissues with complete obliteration of botanical structures forming ulmite microlithotype is found in the present samples (Pl. 1, Fig. 6).

GELITE AND CORPOHUMITE

Gelite microlithotype in the Neyveli lignite is seen under the microscope, as bands of gelified tissues possessing almost a homogeneous appearacne (Pl. 1, Fig. 11). Often the gelites have also been observed in this bands or in lenses associated with detrite (Pl. 2, Fig. 12). The corpohumite micrclithotype is chiefly formed by several rows of tabular to crescent shaped cells of bark tissue. Cell walls of such bark cells are either textinic (Pl. 1, Fig. 3, top part) or suberinitic (Pl. 2, Fig. 13) while the infilling substance is always phlobaphinite. Aggregations of isolated phlobaphinitic materials have also been recorded.

LIPTITE (EXINITE) GROUP

Microlithotypes of liptite group individually occur very rarely. Mostly they are found associated with humite and inertite microlithotype groups. It is subdivided into sporite, cutite, resite, algite and liptidetrite.

In the present lignite, microlithotypes of liptite group have not been observed in enough quantities to become locally significant.

Inertite group

The microlithotype group inertite is constituted by different macerals of inertinite group accounting more than 95 percent by volume. The monomaceral fusite is of two types—soft and hard fusite. In soft fusite both cell cavities and interstices between cell walls are practically free from mineral inclusions. While cell cavities and interstices of hard fusite are partly or completely filled with mineral substances. Semifusite though rarely, like fusite may contain mineral impregnations.

Occurrence of fusite and semifusite is indicative of "fire-horizons, Tmeporarily drying of peat surface exposed to the influence of atmospheric oxygen and other oxidation processes causing fusinitization. Dry conditions and rich oxygen supply at the peat surface also favour the occurrence of sclerotite microlithotype.

Fusite and Semifusite

Of all the microlithotypes of inertite group only fusite, semifusite and sclerotite are observed in bands (50 microns) forming monomaceral microlithotypes of this group.

Fusite and semifusite microlithotypes are not present in appreciable amount in this lignite. Nevertheless, sometimes locally fusinitized (Pl. 2, Fig. 17) and semifusinitized (Pl. 2, Fig. 18) materials have been observed in enough quantities to form fusite and semifusite microlithotypes, respectively.

Sclerotite

Fungal, spores, hyphae and resting fungal bodies sclerotinites when occur in clusters having 50 microns band width and constituting more than 95.00 percent by volume, form the sclerotite microlithotype. In this lignite sclerotinites are sometimes quite large (> 200 microns in diameter) are individually enough to form the microlithotype (Pl. 1, Fig. 8 ; Pl. 2, Fig. 22).

BIMACERAL ASSOCIATION

Detrite

The detrite microlithotype is a bimaceral group (Navale & Misra, 1980b). It consists chiefly of detrital particles and minutely divided porous gel loosely or densely packed forming a spongy (attrite) or dense (densite) huminitic ground mass for macerals of other groups to be impregnated in it. The impregnating macerals may be liptinite and/or inertinite groups, and also some resistant macerals of huminite group like corpohuminite may also occur along with them. The quantitative variation in the detrite may be 60-90 percent huminite macerals, 10-40 percent liptinite and/or inertinite macerals and up to 10 percent accessory macerals. The detrite microlithotype group may show a range of variation between huminitic groundmass and impregnating macerals in the following manner (though it appears more theoretical at present).

(*a*) Exclusively huminitic detritus and huminitic groundmass—no impregnated macerals.

(*b*) Huminitic detritus and groundmass < impregnated macerals of liptinite and/or inertinite groups.

(*c*) Huminitic detritus and huminitic groundmass—impregnated macerals of liptinite and/or inertinite groups.

(*d*) Huminitic groundmass and detritus > impregnated macerals of liptinite and/or inertinite groups.

The above contention in a way, is also corroborated by the fact that the desmocollinitic groundmass of clarite and durites in hard coals is a coalification product of humodetrinite particularly of densinite and detrogelinite of the lignite stage (Teichmüller, 1975 in Stach *et al.*). It may therefore, be assumed that the clarites and durites of hard coals must have contained appreciable amount of impregnated exinite and inertinite macerals respectively in the humodetrinitic fraction during early stage of coalification, i.e. in peat and lignite stages.

The Neyveli lignite contains good amount of detrite microlithotypes. Pl. 1, Figs. 7, 8 exhibit typical porous or spongy nature of huminitic groundmass of attrite in which detrital particles of huminite and inertinite macerals are impregnated. The densite microlithotype (Pl. 1, Figs. 9, 10) shows relatively higher degree of gelification of the degraded huminitic groundmass in which are impregnated sclerotinite and detrital fusinite macerals of inertinite group.

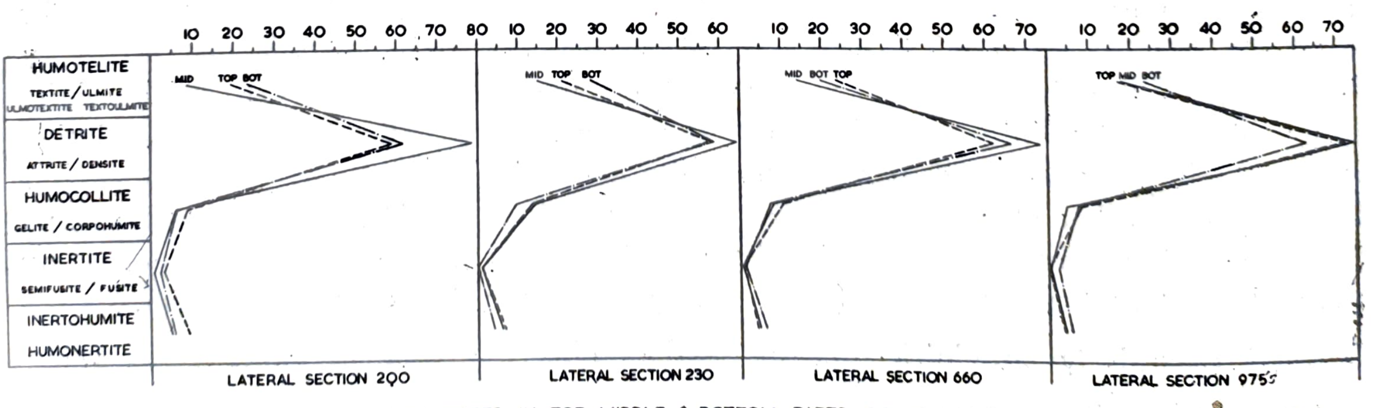
Humo-inertite and Inerto-humite

These microlithotypes form with the association of inertinite and huminite macerals. The inertinite macerals (fusinite, semi-fusinite and also sclerotinite) being the chief constituents accounting for 60-90 percent of the bulk while huminite macerals make up 10-40 percent and the accessorymacerals may range up to 10 percent (Fig. 1). The association is like vitrinertite of hard coals on the contrary if the association is dominated by huminite macerals (60-90 percent huminite) and inertinite amounts to 10-40 percent with accessory macerals up to 10 percent by volume the microlithotype is termed inertohumite.

In the above two microlithotypes, the association of the macerals are such that their identities have not been obscured by degradation particularly when association is between sclerotinite (including fungal spores) and various huminite macerals.

DISTRIBUTION OF MICROLITHOTYPES

Distribution of microlithotype groups and various microlithotypes in four lateral sections of the Neyveli Lignite is given in graph-2.



GRAPH-2: FREQUENCIES OF MICROLITHOTYPES IN TOP, MIDDLE & BOTTOM PARTS OF THE MAIN SEAM OF THE NEYVELI LIGNITE

In Lateral Section-200, the top part of the lignite seam contains 28.50 percent of humite microlithotype group constituted by 7.00 percent of textite (ulmotextite), 11.50 percent of ulmite (textoulmite), 4.00 percent of gelite and 5.00 percent of corpohumite. The detrite microlithotype group forms 58.50 percent of the total. It is the chief constituent of this lignite represented by 40.50 percent of attrite and 17.50 percent of densite. Liptite group is not represented in this part of the seam. Inertite group is represented by 3.50 percent of fusite, semifusite and sclerotite. Apart from this inertohumite is 5.00 percent and humo-inertite is 4.50 percent. The middle part of the section contains 12.25 percent of humite formed by 2.00 of textite and ulmotextite, 6.75 percent of ulmite and textoulmite, 2.25 percent of gelite and 4.00 percent of corpohumite. The detrite constitutes 78.50 percent of the bulk and is distributed at 55.50 percent of attrite and 23.00 percent of densite. Liptite group, as in top part, is not represented here also. Inertite group is formed by 1.00 percent of fusite only. Inertohumite and humoinertite form 4.00 and 1.25 percent respectively. The bottom part of the seam in this section contains 30.00 humite formed by 9.50 percet of textite and ulmotextite, 14.00 percent of ulmite and textoulmite, 2.50 percent of gelite and 4.00 percent of corpohumite. 61.50 percent of the detrite group is formed by 42.75 percent of attrite and 18.75 percent of densite. Liptite group is unrepresented while inertite forms 2.50 percent in which fusite is 0.50 percent and semifusite and sclerotite are 2.00 percent. Inertohumite and humoinertite are 4.00 and 2.00 percent respectively.

In the lateral section-230, the top part of the lignite seam consists of 34.50 percent of humite constituted by 8.75 percent of textite and ulmotextite, 12.35 percent of ulmite and textoulmite, 2.00 per cent of gelite and 11.50 percent of carpohumite. The detrite fraction amounts to 58.00 percent in which 35.50 percent is attrite and 22.50 percent is densite. Liptite group is not represented while inertite group represented by fusite is only 1.00 percent. Inertohumite and humoinertite are 4.50 and 2.00 percent respectively. In the middle part of this lateral section 6.50 percent of textite and ulmotextite, 8.50 percent of ulmite and textoulmite, 3.00 percent of gelite and 11.00 percent of corpohumite together form 29.00 percent of humite group. The detrite fraction, 64.00 percent, is constituted by 38.00 percent of attrite and 27.00 percent of densite. Microlithotypes of liptite group is not recorded here. Fusite is only 1.00 percent representing inertite group. Inertohumite forms 4.50 percent while humoinertite is only 1.50 percent. The bottom part of the section is comprised of 37.50 percent of humite microlithotypes distributed in 12.00 percent of textite and ulmotextite, 16.00 percent of ulmite and textoulmite and 9.50 percent of corpohumite while gelite is absent in this part. The detrite fraction amounts to 58.50 percent formed by 31.50 percent of attrite and 27.00 percent of densite. Liptite and inertite microlithotypes are absent in this portion of the section. Inertohumite and humoinertite are 3.00 and 1.00 percent respectively.

In the top part of the lateral section 660 the humite percentage is 33.75 by volume being formed by 10.00 percent gelite and 5.00 percent corpohumite. 61.50 percent of detrite group is constituted by 33.00 percent of attrite and 28.50 percent of densite. Liptite microlithotypes are altogether absent while inertite is represented only 0.75 percent of fusite. Inertohumite and humoinertite are 2.75 and 1.25 percent respectively. The middle part of the section contains 22.00 percent of humite microlithotypes. Among the recorded are 5.00 percent of textite and ulmotextite, 9.00 percent of ulmite and textoulmite, 5.00 percent of gelite and 3.00 percent of corpohumite. The detrite fraction accounts for 73.00 percent being constituted by 38.50 percent of attrite and 34.50 percent of densite microlithotypes. Microlithotypes of liptite group are not represented while inertite fraction is also very meagre being constituted by 0.50 percent of fusite only. Inertohumite and humoinertite form 2.50 percent and 2.00 percent respectively. In the bottom part of the section 8.00 percent of textite and ulmotextite, 11.75 percent of ulmite and textoulmite, 2.00 percent of gelite and 5.50 percent of corpohumite together form 27.25 percent of humite microlithotypes. Detrite group sharing the major part of the bulk is 65.75 percent in which attrite is 32.50 percent and densite is 33.25 percent. As usual the liptite group is unrepresented and the inertite fraction is formed by 1.00 percent of fusite only. Inertohumite and humoinertite are 3.50 and 2.50 percent respectively.

In the top part of the lateral section 975 of the lignite seam, 7.00 percent textite and ulmotextite, 9.75 percent of ulmite and textoulmite, 3.25 percent of gelite and 4.05 percent of corpohumite together constitute 24.50 percent of humite microlithotypes. Detrite fraction constituting the major part is 72.00 percent in which attrite and densite microlithotypes are 33.00 and 39.00 percent respectively. Both liptite and inertite microlithotypes are not recorded in this part of the section. Inertohumite and humo-inertite are 2.00 and 1.50 percent respectively. The middle part of the section contains 22.00 percent of humite microlithotypes being individually constituted by 6.50 percent of textite and ulmotextite and 11.00 percent of ulmite and textoulmite, 1.50 percent of gelite and 3.00 percent of corpohumite. Detrite microlithotypes are the chief constituents accounting for 74.00 percent of the bulk of which 34.25 percent is attrite and 39.75 percent densite. Liptite group is altogether absent here while only 0.25 percent of fusite represents inertite microlithotype group. Inertohumite and humoinertite are 1.75 and 2.00 percent respectively. In the bottom part of the section humite group accounts for 30.25 percent being distributed individually into 9.50 percent of textite and ulmotextite, 13.50 percent of ulmite and textoulmite, 4.25 percent of gelite and 3.00 percent of corpohumite microlithotypes. 27.25 percent of attrite and 35.00 percent of densite microlithotypes together form 62.25 percent of detrite group. Microlithotypes of liptite group are not represented while 1.25 and 1.00 percent of fusite and semifusite respectively constitute inertite fraction. Inertohumite and humoinertite are 2.75 and 2.50 percent respectively.

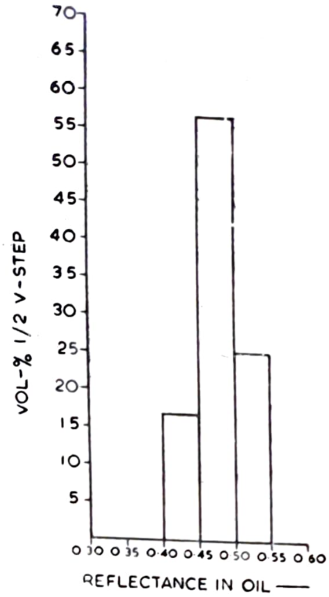
MATURITY OF THE SEAM

Rank (degree of maturity) determination of the lignite seam of all the four sections was carried out by microphotometric method following the procedure described already by NAVALE AND MISRA (1980-a) and I.C.C.P., 1971, recommendations. Reflectance measuremenets, in oil, were made individually on all the twelve lignite pellets considered in the present study and are exhibited in the form of reflectograms (1-4) prepared after clubbing top, middle and bottom pellets of each lateral section. Carbon and volatile matter contents (Table-2) were directly obtained by plotting reflectance valves on the standard curve (KÖTTER, 1960) and the rank thus determined indicates that the lignite has attained sub-bituminous-B (ASTM) or hard brown coal (German Standard) stage during coalification. The microphotometric study has revealed that there is hardly any variation in the degree of maturation of the lignite seam either vertically or laterally.

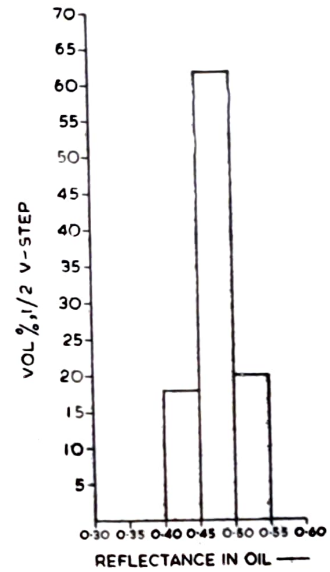
RESUME AND SYNTHESIS

Based on the quantitative evaluation of macerals and microlithotypes present in the main seam of the Neyveli lignite the following conclusions have been made (Graph 1 and 2).

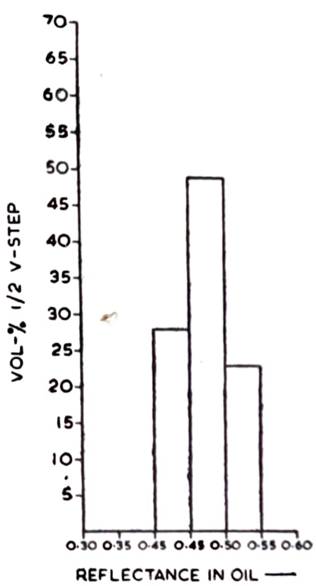
There is a definite decreasing tendency of humodetrinite fraction—51.75% and 54.50% (L. S. 200), 50.50% and 54.50% (L.S. 230), 51.00% and 57.00% (L. S. 660) and 55.50% and 50.50% (L. S. 975) and increasing proportion of humotelinite and humo-



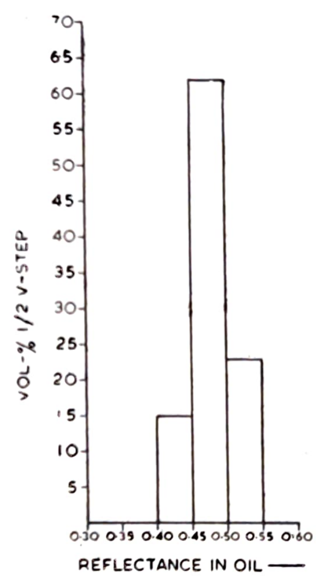
Reflectogram 1
Neyvelilignite Seam, L.S. 200, Ro—0.47%



Reflectogram 2
Neyvelilignite Seam, L.S. 200, Ro—0.47%



Reflectogram 3
Neyvelilignite Seam, L.S. 200, Ro—0.47%



Reflcctogram 4
Neyvelilignite Seam, L.S. 200, Ro—0.47%

Table-2

Sample	Range of Reflectance measurements (in oil %)	Highest ½-V-step frequency %	Reflectance (in oil%) calculated max. mean	Estimated Approx. values from standard curve: Carbon Content %(d.a.f.)	Estimated Approx. values from standard curve: Volatile matter %(d.a.f.)	Rank ASTM/German (Din)
Lateral Section-200	0.43-0.52	0.45-0.49	0.47	74.00	47.50	Sub-bituminous-B
Lateral Section-230	0.43-0.53	0.45-0.49	0.47	74.00	47.50	or Hard brown
Lateral Section-660	0.42-0.53	0.45-0.49	0.47	74.00	47.50	coal (Lignite)
Lateral Section-975	0.43-0.53	0.45-0.49	0.47	74.00	47.50	

collinite fractions 34.00% and 35.00% (L. S. 200), 39.50% and 38.50% (L. S. 230), 29.00% and 35.50% (L. S. 660) and 38.00% and 42.50% (L. S. 975) respectively in top and bottom parts of all the four lateral sections of the lignite seam. On the contrary, in the middle part of all the four lateral sections of the lignite seam humotelinite and humocollinite fractions have reduced percentages—16.00% (L. S. 200), 29.75% (L. S. 230), 23.50% (L. S. 660) and 23.75% (L. S. 975) while humodetrinite fraction alone ranks the highest —77.75% (L. S. 200), 59.00% (L. S. 230), 72.50% (L. S. 660) and 71.00% (L. S. 975). Almost identical increasing and decreasing tendencies of frequencies of microlithotypes of humite and detrite groups are also observed in the top, middle and the bottom portions of the four lateral sections of the lignite seam.

The preceeding observations have also been corroborated, to a greater extent, by degradational effects evidenced on tissues, pollen and spores by fungal and other biodegradational agencies in the macerate analysis of the lignite samples.

From the foregoing evidences it may be generalized that petrographically the top and the bottom part of the seam are of similar nature and contain relatively higher amount of woody (coaly) lignite while the middle part is distinctly more detrital in nature. The seam is, thus, divisible into three petrologic facies in descending order-huminite dominant (humotelinite and humocollinite rich), detrinite dominant (humodetrinite rich) and huminite dominant (humotelinite and humocollinite rich). The three facies which are distinguishable biopetrographically appear to be genetically interrelatable and they are differentiated on the basis of dominance of humotelinite/collinite and detrinite (humodetrinite) maceral fractions of huminite group. Macerals of huminite group originate, primarily, from similar vegetal source material and broadly under more or less identical environmental patterns. The dominance of humotelinite/collinite content indicates that the top and the bottom parts of the lignite seam enjoyed, basically, anaerobic condition during coalification and soon after deposition degradational effects of combined fungal and other biological agencies were warded off gradually due to increasing toxicity in the peat and hence the detrinite fraction in these parts are comparatively less than in the middle part. On the contrary, the middle part of the lignite seam, apparently, experienced relatively a little more oxidative condition which is corroborated by the dominance of high detrital and fungal effected detrinite (humodetrinite) content. Demarcation of facies in the lignite seam has made it possible to differentiate two lignite types—peaty consisting of humic detritus and humic groundmass and woody (coaly) types, as has already been suggested by NAVALE (1971, 1974b).

From the present study and also from palynological analysis of the lignite samples, it appears that the entire lignite seam originated, without any perceptible break, under a single *megaphase* of deposition throughout which there was but very little change in the nature of vegetal source material while facies variations in the seam were governed chiefly by environmental factors (anaerobic/relatively oxidative/anaerobic) and they are recognizable as separate *phases* of the *megaphase*. The term *megaphase* introduced here stands for complete sequence of events during deposition of the thick lignite seam where time factor is immaterial. While the *phases* are recognized as fluctuations either due to environmental factors or due to source material within the single megaphase.

Recognition of *phases* in the lignite seam suggests feasibility of separation of lignite types for selective utilization.

REFERENCES

BALASUNDER, N. K. (1968). Tertiary deposits of Neyveli lignite field. *Semin. Gretaceous-Tertiary Formations of South India*, 1966, *Bangalore, Geol. Soc. India, Semin. Vol. Memo.* **2** : 256-262.

International Handbook of Coal Petrography (1963) : *Int. Committee for Coal Petrology*, 2nd ed., *Centre National Recherche Scientifique* : Paris.

International Hand Book of Coal Petrography (1971, 1975) : *Int. Committee foi Coal Petrology Suppl.*, 2nd. ed., *Centre National Recherche Scientifique* : Paris.

KÖTTER, K. (1960). Die Mikroskopische Reflexionsmessung mit dem photomultiplier und ihre Anwendung auf die Kohlenuntersuchung. *Brennst Chemie* **41** : 263-272.

NAVALE, G. K. B. (1971). Petrology of Neyveli lignite, South India. *C.r. 6th Cangr, Intern. Stratigr. Geol. Carb., Sheffield* **3** : 1207-1223.

NAVALE, G. K. B. (1973). Some contribution to the Palaeobotany of Neyveli lignite, South India. *Palaeobotanist* **20**(2) : 179-189.

NAVELE, G. K. B. (1974a). Botanical resolution of some microstructures of Neyveli lignite, South India. *Palaeobotanist* **21**(3) : 359-364.

NAVALE, G. K. B. (1974b). On the nature and composition of Neyveli lignite, South India. *Geophytology*. **4**(1) : 95-1011

NAVALE, G. K. B. & MISRA, B. K. (1979). Some new pollen grains from Neyveli lignite, Tamil Nadu, India. *Geophytology*, **8**(2) : 226-239.

NAVALE, G. K. B. & MISRA, B. K. (1980a). Maturation studies of some Indian coals and lignites and their bearing on oil and gas prospecting. *IVth Int. Palynol. Conf. Lucknow* (1976-77) **2** : 551-564.

NAVALE, G.K.B. & MISRA, B.K. (1980b). Classification of composite microlithotype of lignites. *Geophytology*, **10**(1) : 54-75.

RAMANUJAM, C. G. K. (1966). Palynology of the Miocene lignite from South Arcot district, Madras, India. *Pollen Spores* **8**(1) : 149-203.

STACH, E. (1952). Heutinger stand der genetischen Deutung der Kohlen-refuge-bestandteile. *C. r. 3rd Congr. Intern. Stratigr. Geol. Carb. Masstricht Heerlen.* **2** : 585-590.

SZADECZKY-KARDOSS, E. (1948/1949). Über Systematik und Unwandlungd er Kohlengemengteile. *Univ. techn. Wiss. Spron. Mitt. Berg-u* Huttenmann. 17 : 176-193.

TEICHMÜLLER, M. (in stach *et al.*, 1975) : *Stach's Text Book of Coal Petrology*. *2nd ed.*, Geb ruder Brontregar. Berlin. Stuttgart : 1-428.

EXPLANATION OF PLATES

(All photomicrographs taken on polished surface under incident light ×250).

PLATE 1

1 & 2. Textinite showing well preserved cellular structure in sectional view with mineral filled cell cavities.

3. Textinitic bark cells (top & bottom part) with phlobaphinite filled cell cavities and textoulminite (in the middle) having partly gelified structure.

4. Bark tissue with texinitic cell walls and mineral filled cavities.

5. Textoulminite showing partial gelification.

6. Ulminite displaying complete gelification.

7. Attrinite

8. Attrinite with *Sclerotites multicellatus* sp.

9. Densinite with *Sclerotites bradonianus* sp.

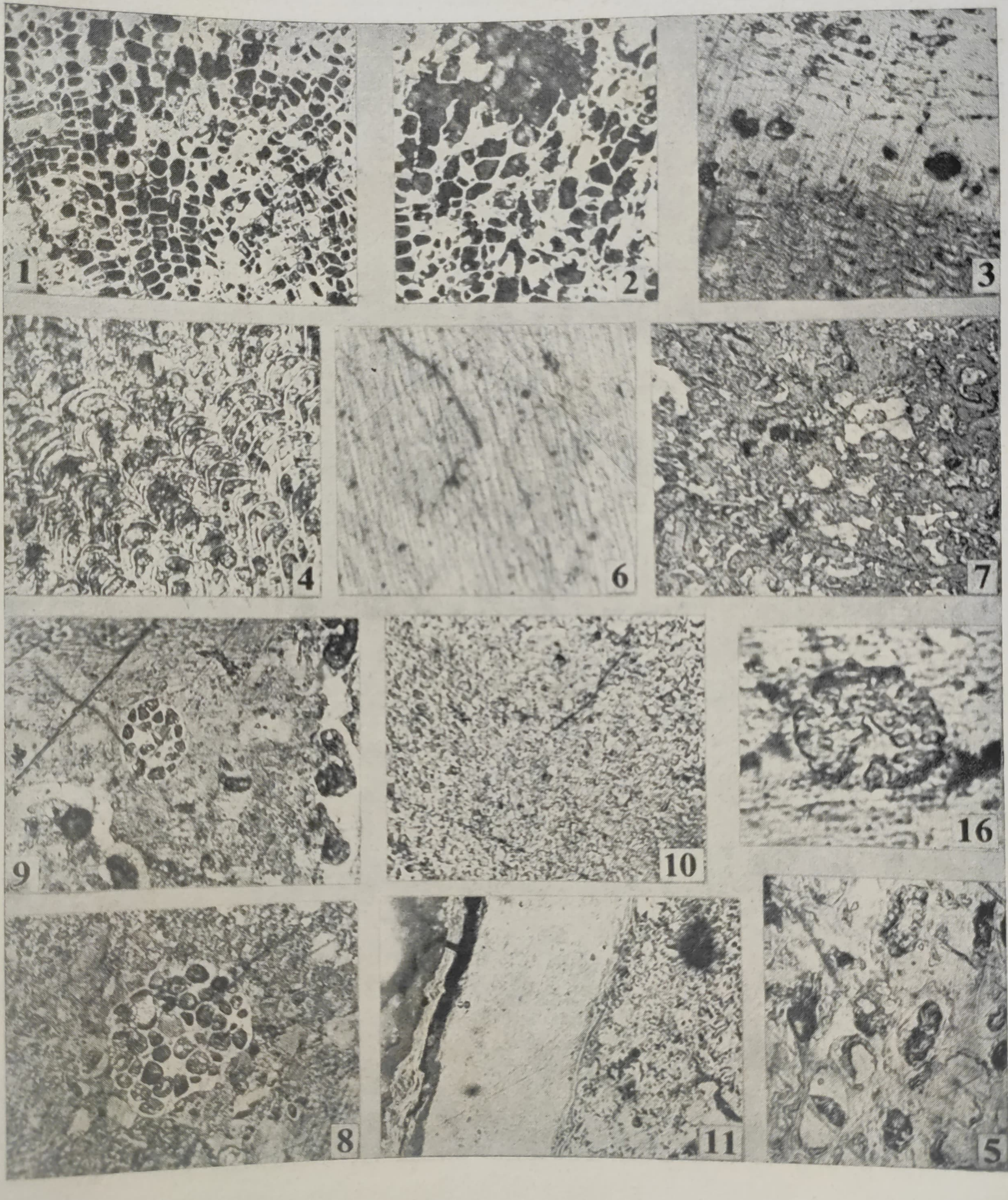
10. Densinite

11. A band of homogeneous gelinite

16. A single *Botryococcus* (planktonic oil secreting alga) colony.

PLATE 2

12. Structureless gelinite associated with humodetrinite.
13. Rows of cork cells with phlobaphinitic infillings and suberinitic (dark coloured) thin cell walls.
14. Sectional view of a leaf with well preserved cellular structures.
15. Resin bodies and fungal spores in humodetrinitic (Attrinite) groundmass.
17. Fusinite with mineral filled cell cavities.
18. Semifusinite with mineral filled cell cavities.
19. Four celled teleutospore.
20. Six celled teleutospore with mineral filled cavities.
21. *Sclerotites bradonianus* sp. with empty lumens.
22. *Sclerotites crassitesta* sp. with mineral filled cavity.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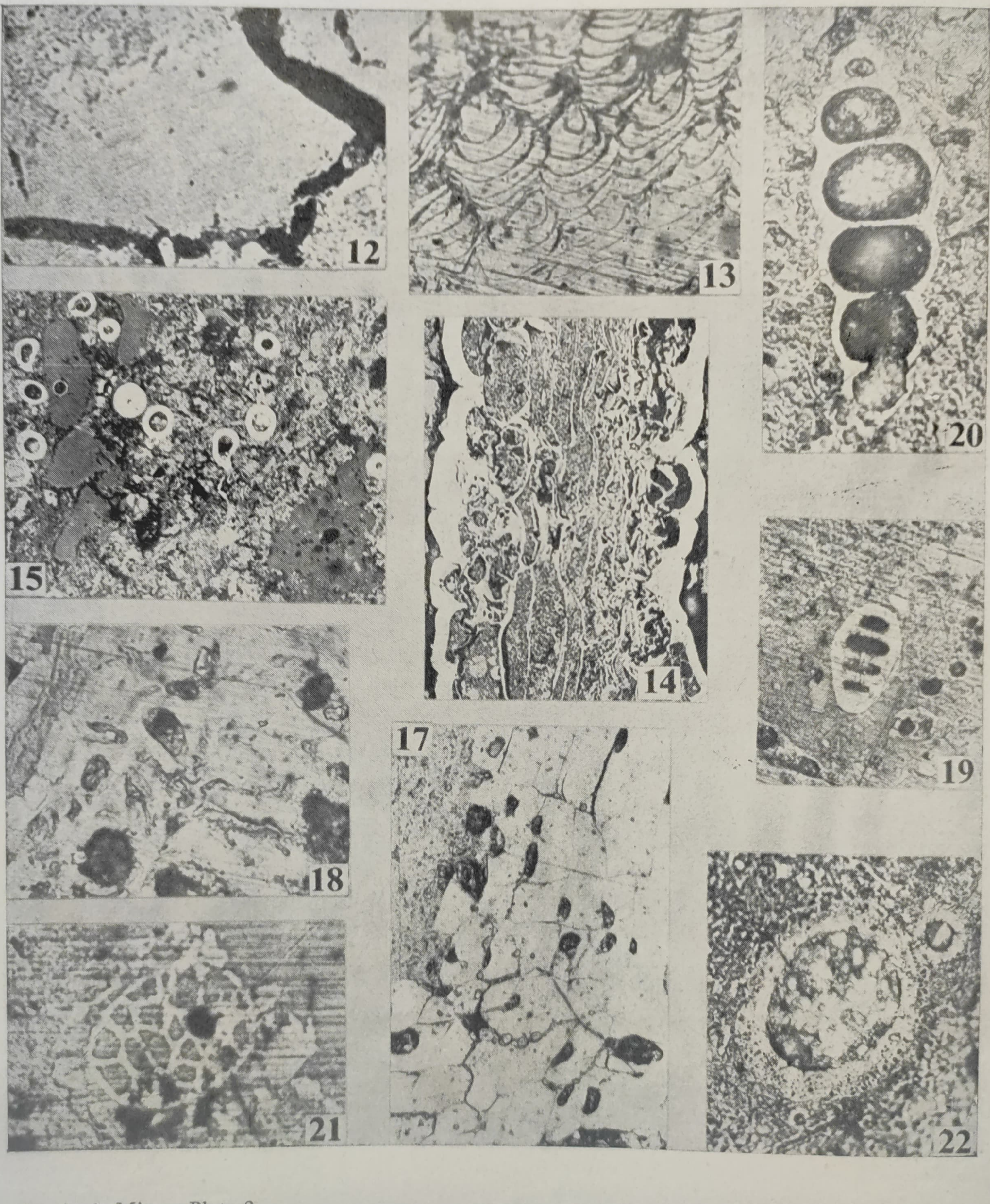
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