DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

PALYNOFACIES ANALYSES OF COAL BEARING SEDIMENTS IN THE ÇANAKKALE-ÇAN BASIN (NW TURKEY)

by
Rıza Görkem OSKAY

April, 2009
İZMİR

PALYNOFACIES ANALYSES OF COAL BEARING SEDIMENTS IN THE ÇANAKKALE-ÇAN BASIN (NW TURKEY)

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"PALYNOFACIES ANALYSES OF COAL BEARING SEDIMENTS IN THE ÇANAKKALE-ÇAN BASIN (NW TURKEY)"** completed by **RIZA GÖRKEM OSKAY** under supervision of **PROF. DR. FUNDA AKGÜN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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PALYNOFACIES ANALYSES OF COAL BEARING SEDIMENTS IN THE ÇANAKKALE-ÇAN BASIN (NW TURKEY)

ABSTRACT

This study deals with palynofacies analyses of coal bearing Miocene sediments in the Çanakkale-Çan basin which is the most important coal basin in Biga Peninsula. For this purpose palynofacies analyses were carried out on core samples from three boreholes in the basin with the aim of define the facies, depositional energy, redox conditions and paleoenvironment.

For the palynofacies analyses palynological kerogen categories were counted and five types of palynological kerogen were identified for analyses. These kerogens are; amorphous organic matter (AOM), opaque equidimensional phytoclast, opaque lath phytoclast, translucent phytoclast and palynomorphs. The studied sedimentary successions showed a rich palynological kerogen content. The phytoclast group shows a moderate abundance in lower parts of sedimentary successions in boreholes. In upper successions, the AOM group shows a moderate abundance and the abundance trend increases toward the top, there is a clear increase in the palynomorph group.

Based on composition, distribution and abundance of palynological kerogen types, and the cluster, four palynofacies associations (PA) were recognized. The AOM group is dominant in PA 2, 3 and 4, whereas the phytoclast group shows a moderate abundance in PA 1. The palynomorph group shows the lowest value in PA 1 and highest value in PA 3. The palynofacies analyses of the studied successions allowed environmental reconstruction. PA 1 indicates oxic proximal conditions due to occurrence of swamp elements palynomorphs and non fluorescent AOM, and high proportion of phytoclast. PA 2 and 3 corresponds distal anoxic environment because of dominance of dull to moderate heterogeneous fluorescent AOM and high proportion of opaque lath phytoclasts. PA 4 indicates distal dysoxic-anoxic environment owing to dominance of strong fluorescent well preserved AOM, fragmented bisaccate pollen grains.

Keywords: Palynofacies, palynological kerogen, Çanakkale-Çan Basin.

ÇANAKKALE-ÇAN HAVZASI (KB TÜRKİYE) KÖMÜR İÇERİKLİ TORTULLARININ PALİNOFASİYES ANALİZİ

ÖZ

Bu çalışmada, Biga yarımadasındaki en önemli kömür havzası olan Çanakkale-Çan havzasındaki kömür içerikli Miyosen yaşlı tortulların palinofasiyes analizlerinin incelenmesi amaçlanmıştır. Çan havzasında yapılan üç adet sondajdan derlenen karot örneklerinin fasiyesi, ortam enerjisi, redoks koşulları ve paleoortamını bulunması amacıyla palinofasiyes analizleri yapılmıştır.

Palinofasiyes analizleri için palinolojik kerojen kategorileri sayılmıştır ve beş tip palinolojik kerojen tanımlanmıştır. Bunlar; amorf organik madde (AOM), opak eşboyutlu phytoklast, opak lat phytoklast, saydam phytoklast ve palinomorftur. Örneklerin derlendiği sedimanter istifler zengin palinolojik içerik sunmuşlardır. Kuyulardaki sedimanter istiflerin alt kısımları, ortaç bir yoğunlukla phytoklast grubunu içermektedir. AOM grubunun sedimanter istifinin üstü kısımlarına doğru yoğunluğu artmaktadır ve en baskın olmaktadır. Palinomorf grubu ise üst kısımlara doğru belirgin bir artış sunmaktadır.

Palinolojik kerojen tiplerinin yoğunluğu, içeriği ve dağılımı ve sayısal analiz sonuçlarına dayanılarak dört adet palinofasiyes topluluğu (PT) olarak ayrıtlanmıştır. PT 2, 3 ve 4'de AOM grubu baskın iken phytoklast grubu PT 1'de ortaç yoğunluktadır. Palinomorf grubu PT 1'de en düşük, PT 3'de en yüksek değeri sunmaktadır. Palinofasiyes analizleri, paleoortam yorumlanmasına olanak sağlamıştır. PT 1, bataklık elemanı palionomorfların ve flüoresan özelliği göstermeyen AOM'ların varlığından ve yüksek oranda phytoklast (opak eş boyutlu ve saydam phytoklast) içeriğinden dolayı oksik proksimal ortamı işaret etmektedir. PT 2 ve 3 sönük ve ortaç heterojen flüoresan AOM'ların baskınlığı ve yüksek orandaki opak lat phytoklastklardan dolayı distal anoksik ortamla ilgilidir. Yüksek flüoresan sunan iyi korunmuş AOM'ların baskınlığı, parçalanmış bisakkat polen tanelerin varlığından dolayı, PT 4 distal disoksik-anoksik ortamlarla ilişkilidir.

Anahtar kelimeler: Palinofasiyes, palinolojik kerojen, Çanakkale-Çan havzası.

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CHAPTER ONE
INTRODUCTION

1.1 Study Area

The study area is located in the southwest of Çan, in the Çanakkale province in the southwestern part of the Marmara Region (Figure 1.1). The study areas can be reached by Çanakkale–Balıkesir highway.

1.2 Previous Studies

1.2.1 Previous Studies On Study Area

Previous studies were purposed geological, economical and palaeontological properties of basin (Hezarfen, 1976; Can, 1984; Siyako et al., 1989; Ediger, 1990; Gökmen et al., 1993; İnaner & Nakoman, 2004, Gürdal, 2008).

Akyol (in Lebkücher, 1970) investigated palynological properties of Kalkim-Çanakkale coal seams. The author determined age of coal as early Miocene due to *Leiotriletes dorogensis* and *Verrucatosporites favus* low percentage.

Hezarfen (1976) investigated economical and geological properties of Çan basin. Researcher was put forward first geological map and mineable reserve of Çan lignite deposit.

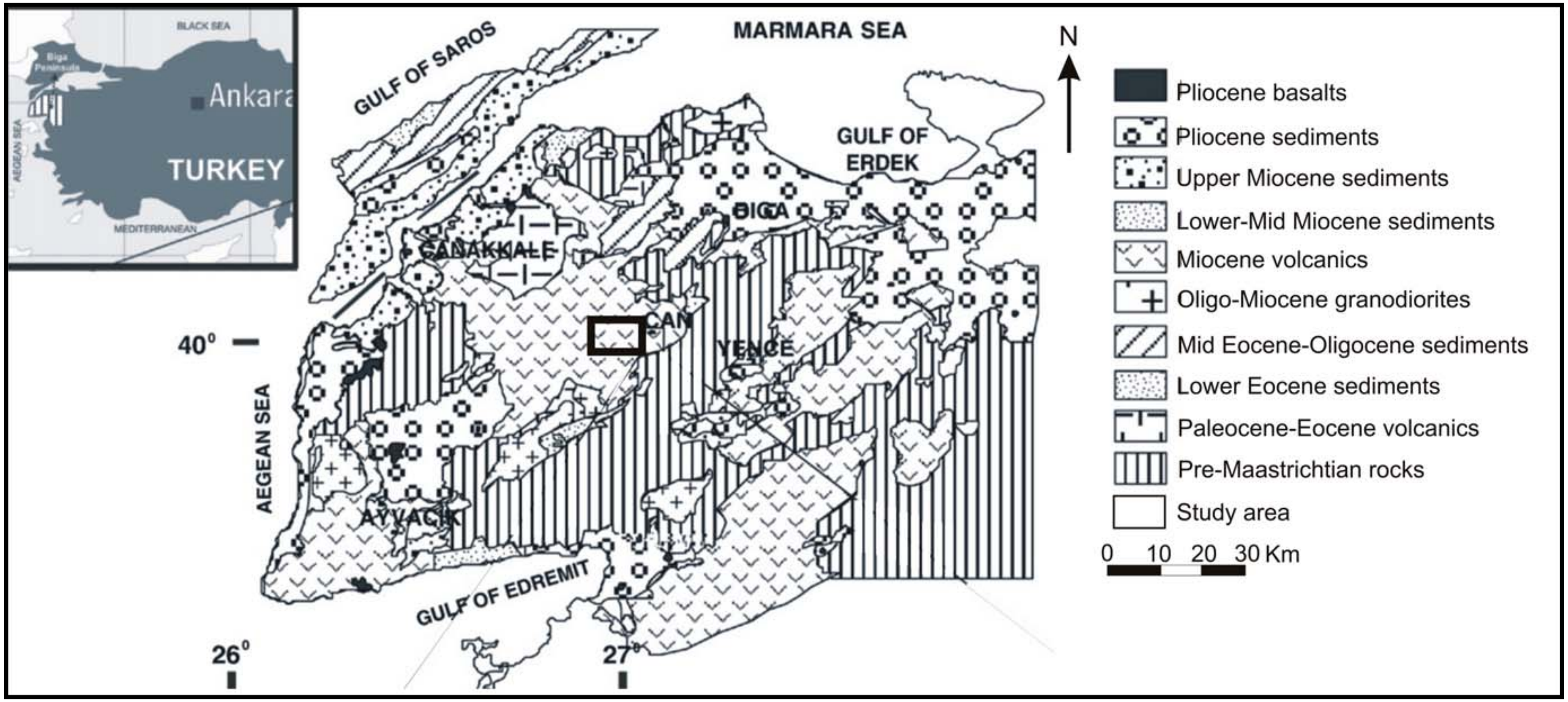


Figure 1.1 Location and geology maps of the Çanakkale-Çan lignite deposit (simplfied from Siyoka et al., 1989)

Ercan (1979) studied Cenozoic volcanism in western Anatolia, Thrace and Aegean Isles. Researcher show that volcanism around Biga-Çanakkale-Bayramiç region is started Middle Eocene and generally consist of green coloured andesitic lava and tuff.

Köksoy and Ataman (1980) investigated southern Marmara lignite. They have put in forward geological properties and economical potentials of seven coal bearing basins in southern Marmara. These basins are; Etili-Çomakli-Çan, Yenice-Tabanköy-Pazarköy-Sebepli, Şamlı, Kepsut-Bigadic, Mustafakemalpasa-Manyas-Gonen, Susurluk. In these basins Neogene aged rocks are divided into subgroups as; sedimentary rocks which are bearing coal and volcanic rocks by authors. Sedimentary rock, which are overlain unconformably basement rocks, consist of sandstone and conglomerate at the base, and tuffs with intercalation of siltstone and marl. At the top; coarse, blocked and cross-bedding pebbly sandstone is overly all of them. Volcanic rocks are andesine, andesitic basalt and volcanic breccias. Authors indicated that southern Marmara lignite is deposited by controlling of volcano sedimentation. Due to this property they are rare coal basins in the world.

Siyako et al. (1989) studied geology and hydrocarbon potential of Tertiary aged units in Biga and Çanakkale peninsulas. Authors grouped into four sequences separated by major uplifting and erosional duration; Maastrichtian-Early Eocene, Middle Eocene-Oligocene, Miocene and Pliocene-Quaternary. According to authors inner part of Biga Peninsula (Bayramiç-Çan region) terrestrial units were deposited simultaneously with Early-Middle Miocene volcanic. These terrestrial units around Çan (named as Çan Formation) consist of bituminous shale, siltstone, sandstone, tuff and coal. They mention that these units deposited in little lacustrine basins which are isolated by faults.

Ediger (1990) investigated paleopalynology of coal bearing sediment in Biga Peninsula. The author found 4 spores, 29 pollen, 15 fungal spores and 4 Incertae Cedis taxa. These taxa suggested that an Early Miocene aged (15-20 Ma.) for the coal-bearing sediments and also can be correlated with Eskihisar Association (Benda, 1971). In that study author think that, volcanic activity at Neogene period could have cooled the climate. Because of palynological data shows a marked reduction in forest taxa that required milder climates.

Okay et al. (1990) studied geological and tectonic evolution of the Biga Peninsula. Authors are determinated four distinct pre-Tertiary NE-SW trending tectonic zones in the Biga and Gelibolu peninsulas, which from northwest to southwest are; the Gelibolu, the Ezine, the Ayvacik-Karabiga, the Sakarya Zone. These four units strongly deformed during Triassic and Karakaya Complex unconformably overlain by Upper Jurassic and Cretaceous units. The following the deposition of a thick clastic sequence during the Upper Cretaceous/Oligocene period, these sequence was a major and erosion in the Late Oligocene. This was followed by an extensional and calc-alkaline magmatism of Early-Middle Miocene.

Ercan et al. (1995) studied Tertiary volcanism of Biga, Gökçeada, Bozcaada and Tavşan Islands. Researchers distinguished Tertiary volcanic six main groups; Balıklıçeşme (Eocene), Çan (Oligocene), Kirazlı (Upper Oligocene), Behram (Lowe-Middle Miocene), Hüseyinfakı (Middle Miocene) and Ezine (Upper Miocene). Geochemical and isotopic studies show all volcanic, which are occurred during Eocene-Middle Miocene period, are calcalkene, only the Upper Miocene volcanic is alkenes. These data showed volcanic are related with regional tectonics. Calcalkane volcanism relate pressure tectonics, alkenes volcanic is related with extensional tectonic.

İnaner and Nakoman (2004) studied properties of the Çan lignite deposit. According to authors physical properties of lignite are generally hard, bright, black colored. Because of their physical properties, lignite is classified as ksilot lignite (Duparque classification, 1926) and black lignite (Francis classification, 1961). Çan lignite is contained high amount of sulphur and also they have low calorific values. The basin has one mineable coal seams and total mineable reserve of basin is approximately 73 million tones.

Gürdal (2008) investigated geochemistry and the coal quality parameters of Çan basin. The Çan coals are characterized by broad variation of ash, high total sulphur contents, the V content is higher than the world coal value and some volatile elements such as As, B and U are slightly enriched in some coal samples, and high gross calorific values according to researcher.

1.2.2 Previous Studies On Palynofacies

Palynology is the branch of science concerned with the study of pollen, spores, and similar palynomorph, living and fossil. Term "palynology" suggested by Hyde & Williams (1944) is based on ancient Greek “Palinos” which means to strew or sprinkle. Today palynology is used in many fields (e.g. Geology, Archaeology, Palaeontology, and Medicine). In the beginning palaeopalynology was only investigated pollen and spores. But today palaeopalynology comprise fossilized pollen, spore and microorganism which have cutin origin organic membrane.

The term palynofacies was coined by Combaz (1964) encompass the total complement of acid-resistant organic matter recovered from sedimentary rock. After palynofacies term developed, palaeopalynology have been become important in hydrocarbon explorations and paleoenvironmental reconstruction. Due to these reasons various researchers had developed different methods for palynofacies analysis (eg. Burges., 1974; Habib, 1979; Parry et al., 1981; Boulter & Riddick, 1986; Boulter, 1994; Dabros & Mudie, 1986; Hart, 1986, 1994; Kovach, 1988; Lorente 1986, 1990; Van Bregen et al. 1990; Tyson, 1989a, 1990, 1993, 1995; Kovach & Batten, 1994; Sebag et al., 2006; Weller et al., 2006).

Habib (1979) has recognized structured and unstructured (amorphous) palynodebris categories in authors' studies of Mesozoic sediments of the western central Atlantic. The structured debris is defined as particles which can be identified recognizable botanical structure. These particles are cellular plant cuticles and pitted tracheal elements (well preserved and carbonized). Unstructured particles don't have any internal or external form. Three unstructured debris are recognized by author; Shredded amorphous, globular amorphous and black angular amorphous.

Parry et al. (1981) used their own classification of organic material in their study of Middle Jurrasic deltaic sediments in North Sea. They recognized eight categories; black wood (opaque angular to blocky fragments), brown wood (translucent angular to blocky fragments), cortex (non epidermal and non vascular stem or root tissue), cuticle, resin, terrestrial palynomorphs, marine palynomorphs and freshwater palynomorphs. They noticed that organic matter (kerogen) particle distributions within in any sediment were depend on the palynolgocial input and the energy conditions of the depositional environment.

Boulter & Riddick (1986) studied Palaeogene material from the North Sea and created their own classification. Components of this classification are; amorphous matter, phytoclast, reworked palynowafers, dinocysts, bisaccete pollen, fungi and algae. Palynowafer category divided into subdivisions; specks, comminuted debris, degraded bundles, unstructured debris, degraded debris, parenchyma, leaf cuticle, well preserved wood, brown wood and black debris. Their study showed that palynowaffers are most commonly deposited in the submarine fan lobes and channel comploexes and amorphous matter takes place in the lower energy basin plain sediments.

Van Bregen et al. (1990) designated organic matter as palynological organic material. Palynological organic material was divided into three major groups; palynomorphs, structured palynodebris (wood remains, cuticles, plant tissue, animal remains, fungal remains), structureless palynodebris (transparent, yellow –brown, black-brown, black, rest).

Tyson (1993) created ternary kerogen plot, which is based on relative numeric frequency data, to use paleoenvironmental interpretations.

Tyson (1995) revised the palynofacies terms and presented an informal classification. Author defined palynofacies term as “a body of sediment containing a distinctive assemblage of palynological organic matter thought to reflect a specific set of environmental conditions or to be associated with a characteristic range of hydrocarbon-generating potential”.

1.3 Purpose and Scope

Generally detail palynofacies studies have been concentrated on low energy and fine grained marine sediments due to petroleum source rock potential. This type of sedimentary rocks is related to low oxygen conditions (dysaorobic or anaeorobic) where organic matter can better preserved. In addition to this some palynofacies studies are focused on organic poor rocks such as carbonate deposited in oxidizing environments (Gorin & Steffen, 1991; Steffen & Gorin, 1993 a, b; Pittet & Gorin, 1997; Bombardiere & Gorin, 1998). Several palynological kerogen trends and parameters have been used in these studies. Also these parameters can be use for lacustrine sediments (e.g.: Del Papa et al., 2002; Martin-Closas et al., 2005). Because in lacustrine environments the proximal-distal trend is one of the most important controls palynologial matter/kerogen distributions as marine environments (van der

Zwan et al., 1993; Tyson, 1995; Del Papa et al., 2002; Mustafa and Tyson, 2002; Martin- Closas et al., 2005).

This study is based on the succession recovered from three boreholes (Hs-2, Et-17 and Et-12) in the Çanakkale-Çan basin. The objectives of this study were to: define (1) the facies, (2) depositional energy, (3) redox conditions, (4) and paleoenvironment of the coal bearing sediments. To achieve these aims following investigations were carried out: (i) palynological kerogen classification, to support the identification of palynofacies, (ii) identification of palynofacies intervals in the studied, (iii) integration of palynology, sedimentary successions in boreholes and palynofacies data.

CHAPTER TWO
STRATIGRAPHY

2.1 Regional Geological Setting

The basement rocks of study area are Cretaceous- Paleocene aged Cetmi Melange. Çetmi Melange are overlying by thick cover volcanic and sedimentary rocks of Tertiary. Tertiary volcanism were occurred Lower Eocene to Upper Miocene (Ercan et al., 1995, Okay &Satir, 2000).

In inner parts of Biga Peninsula (Bayramiç- Çan regions) terrestrial units, which were deposited simultaneously with Early- Middle Miocene volcanics (Doyran Volcanics), were called as Çan Formation (Figure 2.1 and 2.2). Ezine Volcanics overlie unconformably the Doyran Volcanics and Çan Formation. The overlying Pliocene is made up of agglomerates and blockstone, conglomerate, and sands. Holocene sediments represented by gravel terraces and alluvium (Gökmen et al., 1993).

2.2 Çetmi Mélange

Çetmi Melange crops out in the northeast of study area. Çetmi Melange has been named after Çetmi village (Northwest of Küçükkuyu) where it exposes well (Okay, 1987). The Melange consists of slices/blocks of altered basaltic-andesitic and pyroclastic rocks (spilites), blocks of upper Trassic pelagic and neritic limestones, grewacke-shale matrix (Eraly-Middle Albian), sandstone-shale alternations, slices of serpentinite, slices of micaschist-ecologite and Bajocian to Aptian radiolarite (Beccaleto, 2004). According to foraminifera, radiolarian and poorly preserved sporomorph association age of the melange is Late Albian-Early Cenomanian (Brinkmann et al., 1977 Beccaleto, 2004). Çetmi Melange is uncomfortably overlain by Doyran Volcanics (Siyako et al., 1989).

2.3 Doyran Volcanics

Doyran Volcanics are widely exposed in the study area and consists of andesite, tuff and agglomerate. Doyran Volcanics dated at 17-23 Ma. by the K/Ar method (Borsi et al. 1972; Krushensky, 1976; Okay et al., 1990). Doyran Volcanics are angularly overlain by Ezine Volcanics (Siyako et al., 1989; Okay et. al., 1990).

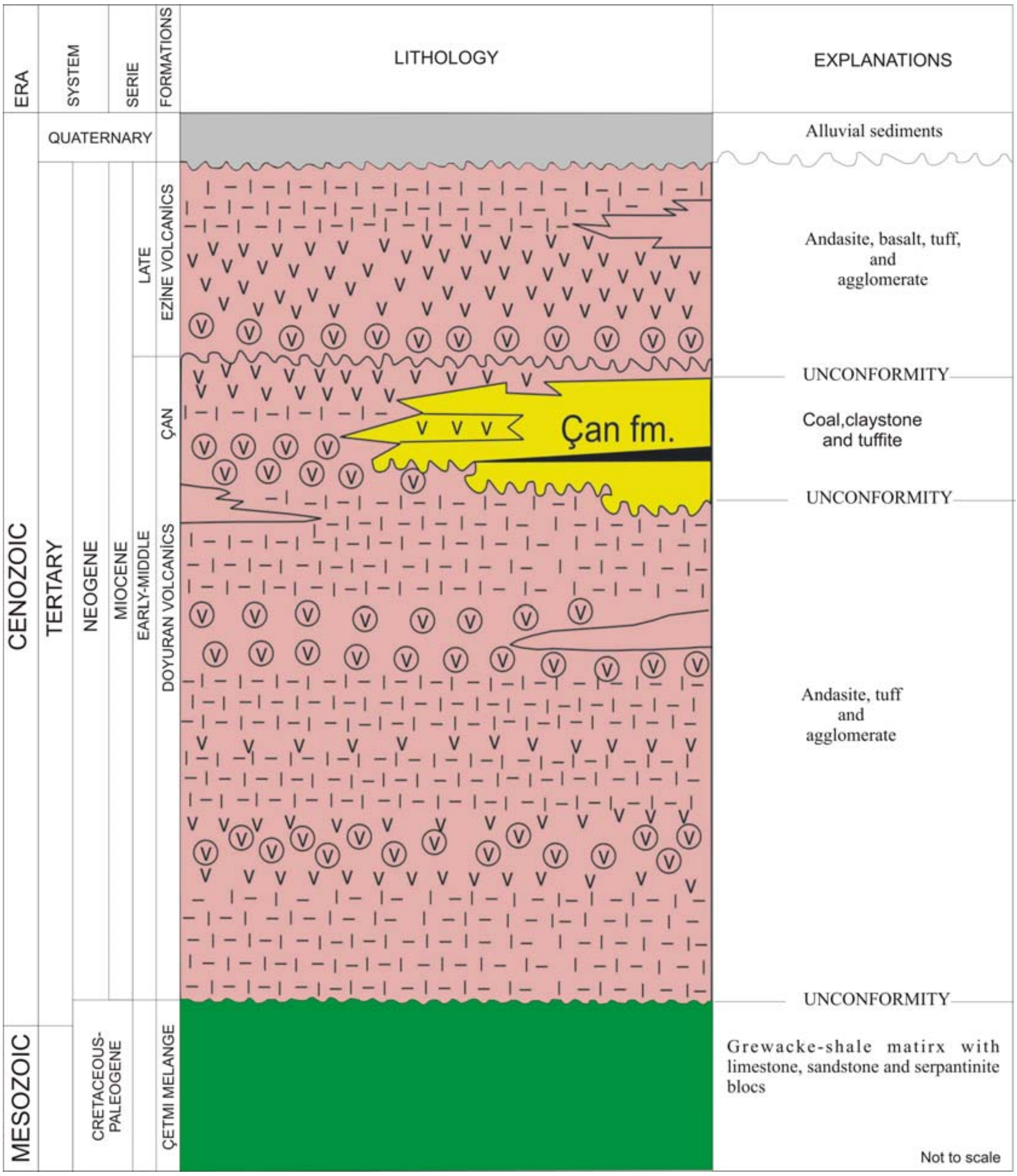


Figure 2.1 Generalized stratigraphic columnar section of the Çanakkale-Çan Basin (simpilified from Üçbaş, 2008)

2.4 Çan Formation

The Çan Formation is chiefly exposed between Çan and Etili. The Formation consists of bituminous shale, siltstone, sandstone, tuff and coal. The Formation was deposited in a small lacustrine basin which is isolated by faults (Siyako et al., 1989). According to sporomorph association obtained from coal and shale, age of the Çan Formation is dated by Akyol (in Hezarfen, 1976), Benda&Meulenkamp (1979), Can (1984) and Ediger (1990) as Early-Middle Miocene. Çan Formation intercalated with Doyran Volcanics, and is angular overlain by Ezine Volcanics.

2.5 Ezine Volcanics

Ezine Volcanics consists of andesite, basalt, tuff and agglomerate. According to K/Ar method Ezine Volcanics is dated as Late Miocene (11.0±0.4-8.32±0.19 Ma) (Borsi et al.. 1972; Krushensky, 1976; Okay et al.., 1990; Ercan et al., 1995; Altunkaymak & Genç, 2007). Ezine Volcanics overlay the Doyran Volcanics and Çan Formatin along an angular unconformity (Figure 2.2).

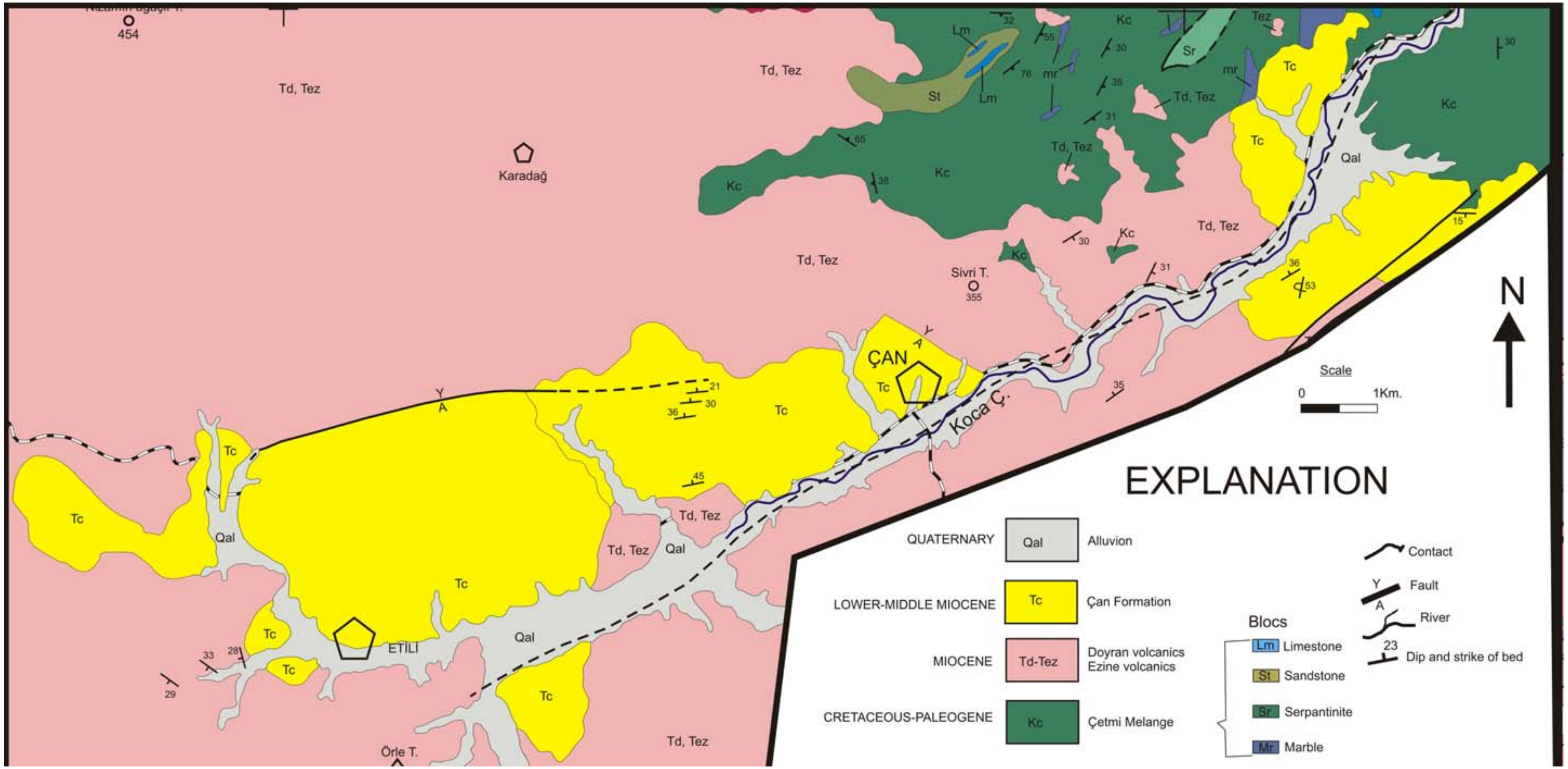


Figure 2.2 Geological map of the Çanakkale-Çan Basin (simplified from Üçbas, 2008)

CHAPTER THREE
MATERIAL AND METHODS

3.1 Material

This study was carried out using 51 core samples from Hs-2, ET-7, ET-12 boreholes drilled in Etili-Çan region (Figure 3.1). The cores are stored at Dokuz Eylül University Department of Geological Engineering.

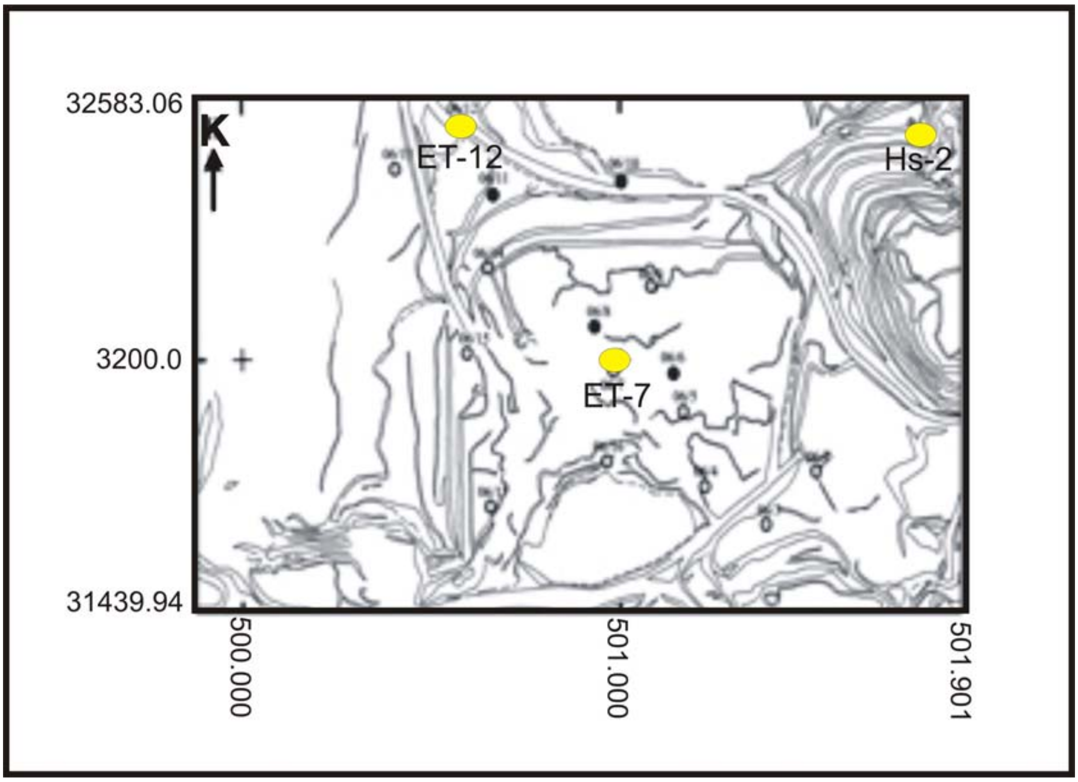


Figure 3.1 Map of the Çanakkakle-Çan Basin showing the location of three studied boreholes.

3.2 Methods

3.2.1 Sample Preparation

The palynofacies samples are processed following procedures according to Batten and Morrison (1983);

- Dilute hydrochloric acid (HCl) (32%) was added to the sample to remove any carbonate. After 3 hours when the reaction ceased, the acid was siphoned off and the sample was washed three times with distilled water to free it from HCl.
- Dilute cold hydrofluoric acid (HF) (40%) was added to the sample to remove any silicates. After 12 hours the residue was then washed several times.

Additionally dilute nitric acid and ultrasonic vibration applied some samples. The remaining residue was then sieved through a 10 µm nylon sieve prior to mounting on slides. Slides were microscopically studied in normal transmitted light and incident blue-light fluorescence.

3.2.2 Palynofacies Analysis

Palynolofacies analysis is based on palynofacies model of Tyson (1995). Quantitative analysis was based on 500 grains (palynological kerogen) counted for each slide. The main criteria used for describing and classifying amorphous organic matter presented in Table 3.1 and for the most common types of those in Table 3.2. Phytoclast are described and classified according to Table 3.3 and the most common types of phytoclast in Table 3.4 (Tyson, 1995). After counting palynological kerogen, counting results were plotted in AOM-phytoclast-palynomorph (APP) ternary plot according to their relative numeric frequency (Figure 3.2).

Cluster analysis forms discrete groupings that are based on the abundance of palynological keroegen. The results are clearly displayed in dendrograms which, when combined, allowed assessment reasons for clustering.

Table 3.1 The main criteria used for describing and classifying phytoclast particles according Tyson (1995, Table 20.4, p. 350)

Property	Characteristic	Description
Edge translucency	1	Opaque (Black)
	2	Translucent
Translucent colour	3	Orange-brown (±black thickenings)
	4	Yellow
Fluorescence	5	Moderate-strong green-yellow colours
	6	Weak but clearly present
	7	Absent or negligible
Microstructure	8	Cellular (one cell layer thick)
	9	Cellular (several cell layers thick)
	10	Pits, ribs, thickenings
	11	Fibrous (without other microstructure)
	12	None apparent (massive, but recognizably a fragment of a larger organized body)
Form/Symmetry	13	Acicular (length:width≥2)
	14	Laths or blades (length:width≥2-3)
	15	Equant (equdimensional; length:width≤2-3)
	16	Planar (thins sheets)
	17	Irregular
	18	Thin, ± branched, tubules (± partitions)
Angularity	19	Angular
	20	Rounded
	21	Irregular
Outline	22	Sharp, ± clear internal structure
	23	Frayed, splintered (especially on short sides)
	24	Embayed, corroded and/or diffuse outline
	25	Pseudoamorphous (ghost or reclit structure and/or with only characteristic outline)
Size	26	Variable
	27	Consistently smaller than most other phytoclasts of the some transcluceny

Table 3.2 Important common types of phytoclasts organic particles recognized in transmitted white light and incident blue light fluorescence Tyson (1995, Table 20.5, p. 351)

Characteristics (from Table	Probable origin
1, 7, 10,14, 19> 20/21, 22, 26	Carbonized tracheid debris (largely charcoal?)
1, 7, 12, 14-15, 19-20, 22, 24, 26-27	Worm and transported oxidized or carbonized wood
2, 3, 7, 10, 14, 19, 22, 26	Tracheid (wood) debris
2, 3, 7, 12, 14/17, 19-21, 22-25, 26	Gelified plant tissue (no intraparticle porosity)
2, 3, 7, 9, 14/15/17, 21, 23, 26	Poorly lignified cortex tissues
2, 4>>3, 5, 8, 16-17, 19, 22/24, 26	Cuticle (epidermal tisssues)
2, 4, 5-6, 12, 16-17, 19, 22/24, 26	Membranous material (often degraded cuticle)
2, 3, 7, ±8, 18, 22, 27	Fungal hyphae
2, 3, 6, 12, 14-17, 19-21, 24-25, 26	Poorly lignified tissues bacterially modified under subaqueous reducing conditions)

Table 3.3 The main criteria used for describing and classifying amorphous organic matter according to Tyson (1995, Table 20.6, p. 352)

Property	Characteristic	Description
Lustre	1	Hyaline/vitreous (and also isotropic)
	2	Glossy
	3	Matt
Colour	4	Grey to grey brown
	5	Orange-brown
	6	Grey to grey-brown
Heterogeneity (in white light)	7	Particles internally homogenous (but± lighter at their margins)
	8	With only numerous small opaque speckles
	9	Clotted, lumpy structure (lumps not recognizable)
	10	With obvious inclusions
Heterogeneity (under fluorescence)	11	Particles internally relatively homogeneous
	12	Clearly heterogeneous
Form and relief	13	Flat, irregular sheets (with irregular edges)
	14	Irregular with common angular (inorganic) crystal imprints
	15	Granular to spherulitic (not specked as 8)
	16	Pelletal (consistently rounded elongate/oval shapes of relatively uniform size)
	17	Rounded, bead-like; sharp margins
	18	Rounded, low relief grains with clear margin
	19	Globular and fluffy with diffuse margins
	20	Relatively angular laths or shards (with or without conchoidal or other fracture surfaces)
Cohesiveness	21	Forms coherent particles
	22	Tends to disintegrate and become finely dispersed over slide
Fluorescence characteristic (green-yellow colours)	23	Particle, or particle matrix not fluorescent
	24	Particle matrix shows weak-moderate fluorescence
	25	Particle matrix shows strong fluorescence
	26	Whole particle uniformly highly fluorescent
Pyrite content	27	Pyrite inclusions absent
	28	Pyrite inclusions rare
	29	Pyrite inclusions common to abundant
Typical association	30	Kerogen assemblage phytoclast/sporomorph dominated
	31	Kerogen assemblage mixed
	32	AOM dominates kerogen assemblage

Table 3.4 Important common types of AOM organic particles recognized in transmitted white light and incident blue light fluorescence Tyson (1995, Table 20.7, p. 353)

Characteristics (from Table	Probable origin
1-2, 4-5, 7, 11, 17/20, 21, 26, 27, 30	Resin particles
2, 4-5, 8-10, 12, 15/16/19, 21, 24-25, 28-29, 31-32	Well preserved plankton/bacterial-derived AOM varies with actual source and preservation state
3, 6, 8-10, 12, 13-14, 22>21, 23, 27-28, 30-32	Degraded plankton/bacteria-derived AOM
3>2, 4-5, 7, 11, 18, 21, 23, 27-28, 30	Liberated particles of cell-filling gels (corpohuminites etc., often from root or bark material)
2, 4-5, 7, 11, 13, 21, 25, 26, 27-29, 32	Well preserved bacterial mat AOM?

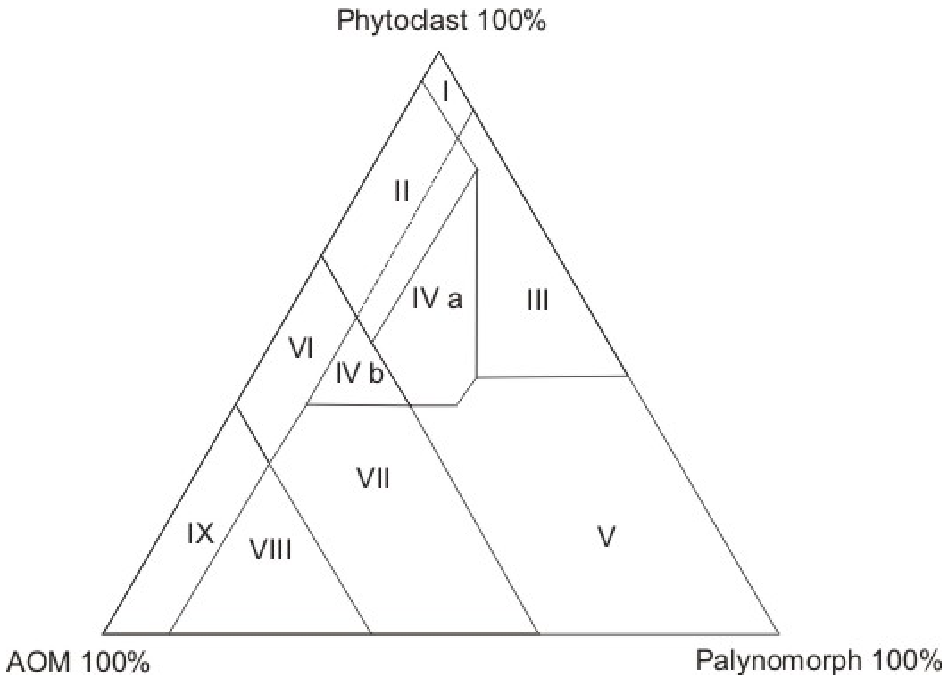


Figure 3.2 Ternary AOM-phytoclast-palynomorph plot (Tyson, 1995); I: Highly proximal shelf or basin, II: Marginal dysoxic-anoxic basin, III: Heterolithic oxic shelf (proximal shelf), IV: Shelf to basin transition, V: Mud-dominated oxic shelf (Distal shef), VI: Proximal suboxic-anoxic shelf, VII: Distal dysoxic-anoxic shelf, VIII: Distal anoxic shelf, IX: Distal suboxic-anoxic basin.

3.2.2.1 Fluorescenc Microscopy

Fluorescence observations generally use in evaluating the proportion of highly oil-prone constituents and preservation state of AOM and palynomorphs and hence hydrocarbon potential. Fluorescent light emitted by surface of particles and gives greater and more three-dimensional appreciation of morphology than transmitted light (Tyson, 1995). The fluorescence is caused by chemical composition of organic matter (photons emitted by fluorophores or chromophors) (Waterhouse, 1998). Two types of fluorescence are emitted by organic molecules; autofluorescence, and thermochemical fluorescence (Bujak & Davies, 1982).

Using fluorescence microscopy has excellent meaning to detecting the presence of small, translucent palynomorphs (e.g. some algae) or palynomorphs and phytoclast smothered by AOM (unoxidized preparation) (McPhilemy, 1988). Fluorescence properties are affected by preservation state as well as organic matter source (Tyson, 1995). But palynological constituents have different fluorescence properties (Tyson, 1990) (Table 3.5). Samples were analyzed to estimate the fluorescent parameters which based on the qualitative preservation scale of organic matter (Tyson, 1995) (Table 3.6).

Table 3.5 Blue-light Fluorescence relationship to palynological constituents

	Blue-light Fluorescence		
Translucence	None	Weak Fluorescence	Strong
Translucent	Woody tissue Cortex tissue Foram. Linings Fungal hypae Degraded AOM Oxidized Palynomorphs	Sporomorphs Dinocysts Acritarchs Cyanobacteria Fresh AOM Cuticles	Chlorococcale algae Resins Prasinophyte algae
None	Charcoal Oxidized wood	NONE	NONE

Table 3.6 Qualitative preservation scale of the organic matter according to Tyson (1995, Table 20.3, p. 347)

Scale point	Description
1	Kerogen is all none fluorescent (expect perhaps for rare fluorescing palynomorphs - especially telalginitic algae-or cuticle) 1a. 'AOM' very rare or absent 1b. 'AOM' present (common to abundant)
2	Most palynomorphs fluoresence but the matrix of autochtonous (plankton derived) 'AOM' remains predominantly non-fluorescent. 2a. Palynomorphs show dull orange-yellow fluorescence. 2b. Palynomorphs show dull yellow-green fluorescence.
3	Most palynomorphs fluoresce and a matrix of autochthonous AOM shows dull fluorescence.
4	As 3, but AOM matrix shows moderate and heterogeneous fluorescence (i.e. visible but clearly less than that of *in situ* palynomorphs).
5	As 3, but AOM matrix shows strong but heterogeneous fluorescence (intensity approaches nearly to *in situ* palynomorphs).
6	Matrix of autochthonous AOM shows fairly homogeneous and very strong fluoresecence (bright yellow, like telalginite).

CHAPTER FOUR
PALYNOLOGICAL KEROGEN

4.1 Classification Sedimentary Organic Matter

Properties of sedimentary organic matter (SOM) is important to understand palynofacies analysis, thus prescience will work. Deposition conditions of fine grained sediments especially clays is suitable for SOM. SOM can easily absorbed by clay, because of large sized surface area and due to this property it is not suitable for oxygen entrance. In that reasons SOM can be protected. For all, effecting waves and currents, clay and organic matter can easily separate from sand. In sand depositional conditions oxygen can easily enter and bacterial activity is high and that conditions SOM can easily degraded. Degradation and protection of SOM is depend on chemical (Eh, pH), biological (bacterial activity) and physical (morphologic changes during transportation) properties of deposition conditions. Fine grained sediments, which are enriched organism, deposited in shallow, anoxic and low energy conditions, are generally enriched SOM (Bozdağan et al., 1993).

The classification of sedimentary organic material has been the subject of discussion in many papers, but no generally accepted system has emerged (Table 4.1). However, generally accepted palynological kerogens are (Table 4.2);

1. Amorphous organic matter,
2. Phytoclasts (Wood, Cuticles, Charcoal),
3. Palynomorphs (Terrestrial or marine).

Table 4.1 A correlation of some published transmitted light kerogen classifications (simplified from Tyson, 1995)

<table>
<tr><th></th><th colspan="2">Tyson, 1995</th><th>Boulter, 1994</th><th>Hart, 1994</th><th>Masran& Pocock, 1981</th><th>Parry et al., 1987</th><th>Burges, 1974</th><th>Tec., 1985</th><th>Tissot.,1978
Pure kerogen type</th></tr>
<tr><td>Amorphous</td><td colspan="2">Amorphous</td><td>Amorphous</td><td>Amorphous</td><td>Amorphous (Resin)</td><td>Resin</td><td>Amorphous</td><td>Coal Mac.</td><td>I-II</td></tr>
<tr><td>Acritarchs</td><td rowspan="3">Phytoplankton</td><td rowspan="8">Palynomorphs</td><td rowspan="2">Algal</td><td rowspan="3">Protistoclast</td><td>Acritarchs</td><td>Marine Palynomorphs</td><td rowspan="3">Algal</td><td rowspan="3">Alginite</td><td rowspan="3">I</td></tr>
<tr><td>Algae</td><td>Algae</td><td>Freshwater Algae</td></tr>
<tr><td>Dinocysts</td><td rowspan="2">Palynomorph</td><td>Dinoflagellates</td><td>Marine Palynomorphs</td></tr>
<tr><td>Spore&Pollen</td><td>Sporomorph</td><td>Phytoclast</td><td>Spoer&Pollen</td><td>Terrestrial Palynomorphs</td><td>Herbaceous</td><td>Lipitinite</td><td>II</td></tr>
<tr><td>Chitinozoa</td><td rowspan="3">Zoomorphs</td><td rowspan="4">?</td><td rowspan="3">?</td><td rowspan="3">?</td><td rowspan="2">?</td><td rowspan="4">?</td><td rowspan="3">?</td><td rowspan="3">?</td></tr>
<tr><td>Scolecodonts</td></tr>
<tr><td>Microforaminiferae</td><td>Foraminiferea Lining</td></tr>
<tr><td>Fungal</td><td>Fungal Spore</td><td>Scleratoclast</td><td>Fungi</td><td>?</td><td>İnertinite</td><td>IV</td></tr>
<tr><td>Woody tissue</td><td colspan="2" rowspan="4">Phytoclast</td><td rowspan="4">Palynowafer</td><td rowspan="4">Phytoclast</td><td rowspan="3">Terestrial (Leaf, Root)</td><td>Brown wood</td><td>Woody</td><td>Vitrinite/ Huminite</td><td>III</td></tr>
<tr><td>Cuticle</td><td>Cuticle</td><td>Herbaceous</td><td>Lipitinite</td><td>II</td></tr>
<tr><td>Fungal debris (Hypae)</td><td></td><td>?</td><td>?</td><td>?</td></tr>
<tr><td>Opaque</td><td>Chorcoal</td><td>Black wood</td><td>Coaly</td><td>İnertinite</td><td>IV</td></tr>
</table>

Table 4.2 Classification of sedimentary organic matter (based on Tyson, 1995 and Ergovac & Kostic, 2006)

Category				Constituent/Source
Structureless organic matter	AOM			Derived from high degradation of phytoplankton or bacteria of organic matter
	Humic gel			Degraded higher plant debris, humic cell-filling material
	Resin			Derived from higher plants of tropical and subtropical forest
Structured organic matter	Fragmentary particle/ Clast	Phytoclast	Opaque	Charcoal, Biochemically oxidized wood
			Translucent	Cuticle, cortex tissue of root/stem, woody tissues (Gymnosperm/Angiosperm tracheids)
		Zooclast		Animal-derived fragments (esp. Arthpod exo-skeletal, organic linings of bivalve shells and ostracode carapaces)
	Discrete individual or colonial entity	Palynomorph	Sporomph	Spores and pollen
			Zoomorph	Foraminiferal test linings, scoledonts, chinitnozoa
			Phytoplankton	Dynocysts, acritarchs, botryococcales

4.2 Palynological Kerogen Classification

4.2.1 Amorphous Organic Matter

Amorphous organic matter (AOM) is grey, pale yellow, orange or brown coloured, transparent or semi transparent, shapeless and structure less palynological matter. This group is consists of AOM, humic gels (intra/extra cellular) and resin fragments (Table 4.3; Figure 4.1).

Table 4.3 Classification of the AOM group (based on Tyson, 1995 and Carvalho, 2001)

AOM Group	Origin	Description
AOM	Derived from phytoplankton Or degradation of bacteria.	Structureless material. Colour: yellow-orange-red; orange-brown; grey. Heterogeneity: homogeneous; with "speckles"; clotted; with inclusions (palynomorphs, phytoclasts, and pyrite). Form: flat; irregular; angular; pelletal (rounded elongate/oval shape).
Humic gel	Derived from biodegradation of plants	Structureless particle, homogenous, rounded, sharp to diffuse outline, non fluorescent
Resin	Derived from higher plants of tropical and subtropical forest	Structureless particle, hyaline, homogeneous, non-fluorescent or fluorescent, rounded, sharp to diffuse outline.

Most of AOM is produced as organic aggregates (with palynomorphs and phytoclasts) or faecal pellet material (Riley, 1970; Porter & Robbins, 1981). Also amorphous matter is produced by benthic filamentous cyanobacteria of well lit shallow waters, and by sulphur bacteria of oxygen deficient environments (Williams, 1984; Glikson & Taylor, 1986). Generally low (dysoxic) bottom water oxygen values areas correlated with relative and absolute abundance of AOM. In oxygen deficient basins with high AOM preservation, allochthonous terrestrial material is only dominant near fluvio-deltaic sources, or within turbidities (Tyson, 1984, 1987).

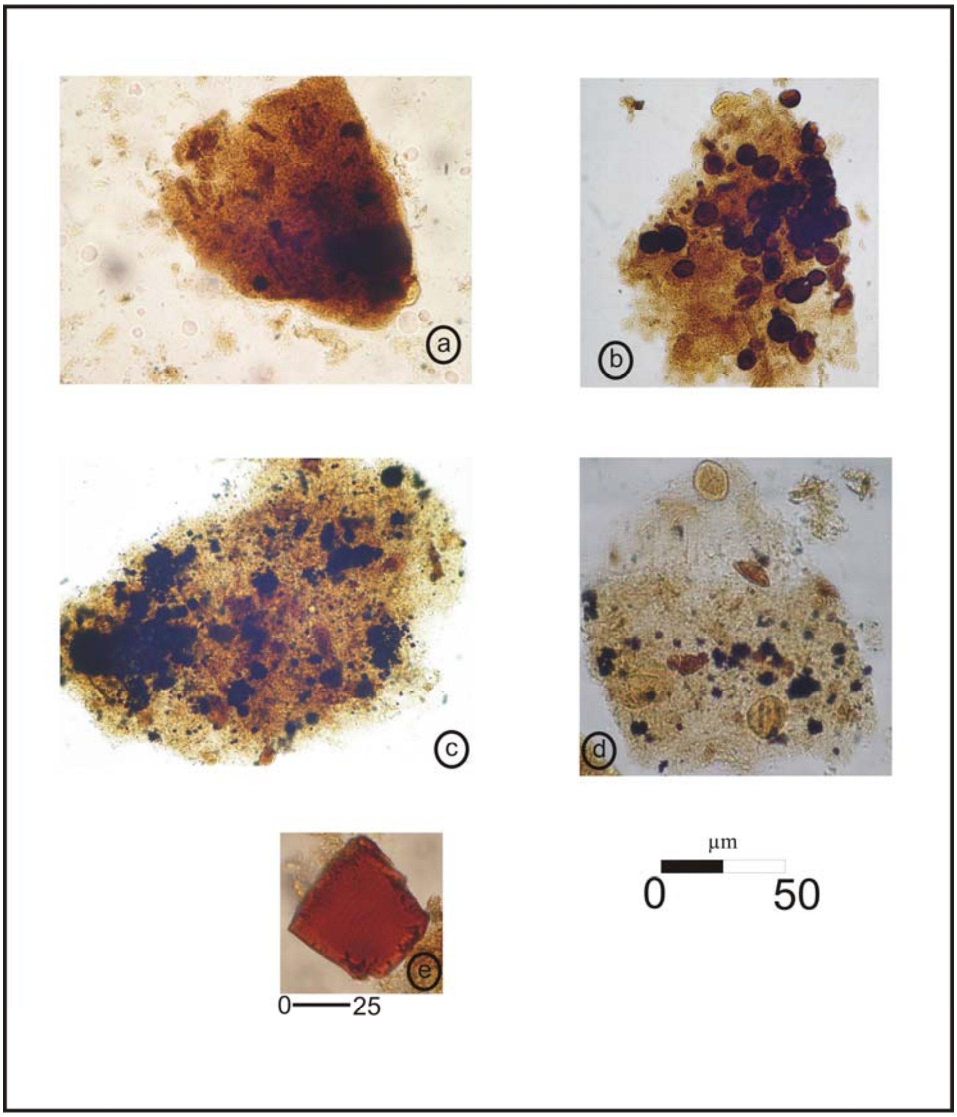


Figure 4.1 Amorphous organic matter; a. Semi-translucent brown coloured AOM with pyrite specks and smother to palynomorph; b, c, d. Translucent yellow AOM smother to palynomorph and phytoclast; d. Resin.

The level of fluorescence intensity of matrix of AOM reflects the general redox status of depositional environment (Tyson, 1995). Fluorescence ratio is increases in stable dysoxic or anoxic bottom conditions. Stable conditions generally show distal characteristics (Tyson, 1993, p. 180). Pasley et al. (1991) showed that non-fluorescent or weakly fluorescent AOM is typically for regressive facies, but moderate and strong fluorescent AOM is most common in transgressive facies. In proximity to fluvio-deltaic environment (prodeltaic, delta front and interdistributary bay deposits) non-fluorescent to moderate AOM is common (Figure 4.2), in distal facies (distal prodeltaic and lacustrine deposits) moderate to high fluorescent AOM is dominant (Del Pappa et al., 2002).

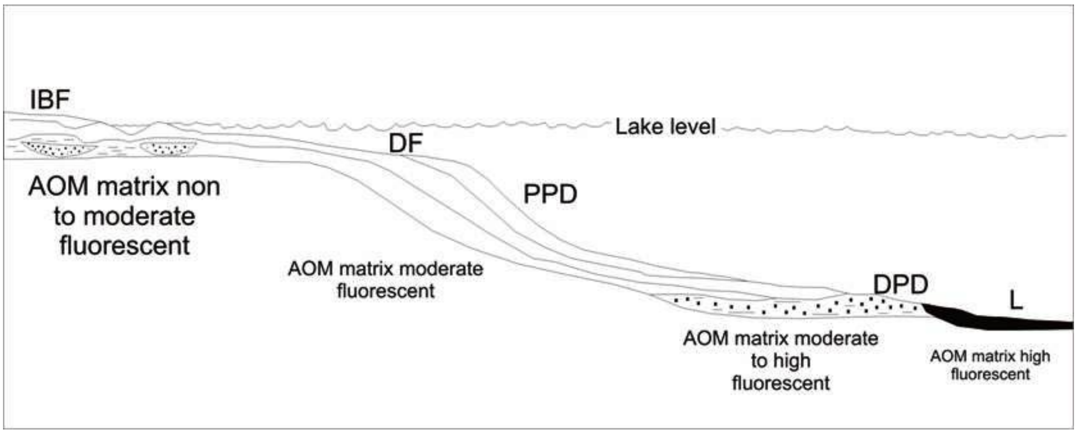


Figure 4.2 Types of kerogen and fluorescent AOM distribution according to paleoenvironment (IBF: Interdistrubitary bay facies, DF: Deltaic facies, PPD: Proximal prodelta facies, DPD: Distal prodelta facies, L: Lacustrine facies) (simplified Del Papa et.al, 2002).

4.2.2 Phytoclast (Phyt)

Phytoclasts are structured plant fragments (Table 4.4). These structured fragments are (Batten, 1996);

- Wood (Opaque and translucent)
- Cuticle
- Charcoal or black debris
- Fungal hypae

Van der Zwan et al. (1990) was classified structured plant as palynomaceral. This classification has four subdivions;

- Palynomaceral 1: orange-brown or dark brown structured or structureless material, irregular in shape, variable in preservation and of dense appearance.
- Palynomaceral 2: brown-orange structured material of irregular shape. Its buoyancy is considered to be higher than palynomaceral-1.

- Palynomaceral 3: consists of pale, relatively thin, irregular shaped, usually structured material. It includes structured plant material, mainly of cuticular origin and degraded aqueous plant material. It is considered the most buoyant of palynomacerals1-3.
- Palynomaceral-4: consists of black or almost black equidimensional or bladeshaped material, which is usually uniformly opaque and structureless. It includes compressed charcoal and geothermally fusinized material. Bladeshaped palynomaceral-4 is extremely buoyant and can be transported over long distances. Equidimensional palynomaceral-4 is intermediate in character to palynomacerals 1 and 2 and thus has lower buoyancy.

4.2.2.1 Opaque Phytoclast (Phyt-O)

Opaque pyhtoclast is derived from the oxidation of woody material during long distance transport or the in situ post depositional bio-oxidation during seasonal fluctuations in water table conditions (Pocock, 1982). Opaque phytoclast is divided into two sub groups (Figure a, f, g); opaque equidimensional (length: width≤3) and opaque lath (length: width≥3). A large amount of equidimensional particles suggests close proximity as a result of short transport. These equidimensional particles are sorted according to their buoyancy, where smaller particles are deposited in distal environment (Steffen & Gorrin, 1993 b).

Many researchers indicated association between high ratio of opaque phytoclasts and relatively coarse-grained, high energy, organic poor facies such as; distributary channel sands, point bars, levees, proximal crevasse splay deposits, shore face, offshore and submarine (Fisher, 1980; Denison and Fowler, 1980; Parry et al., 1981; Batten, 1982; Boulter and Riddick, 1986; Bustin, 1988).

Table 4.4 Classification of the phytoclast group (based on van der Zwan, 1990 and Carvalho, 2001)

Phytoclast Group		Origin	Description	Palynomaceral Group	Coal Maceral Equivalent
Opaque	Equidimensional (O-Eq)	Derived from the lignocellulosic tissues of terrestrial higher plants or fungi.	Black particle from wood material. Long axis less than twice the short axis. Without internal biostructures	Palynomaceral 4	Inertinite
	Lath (O-La)		Black particle from wood material. Long axis more than twice the short		
Translucent	Wood trachieds with pits (Tw)		Brown particle from woody tissue with visible internal structures.	Palynomaceral 2	Vitrinite
	Wood trachieds with out pits (Tp)		Brown particle from woody tissue without internal structures.	Palynomaceral 1	
	Cuticle (Cu)		Thin cellular sheets, epidermal tissue, in some case with visible stomata.	Palynomaceral 3	Cutinite
	Fungal hyphae (Fh)	Derived from fungi	Individual filaments of mycelium of vegetative phase of eumycote fungi.		

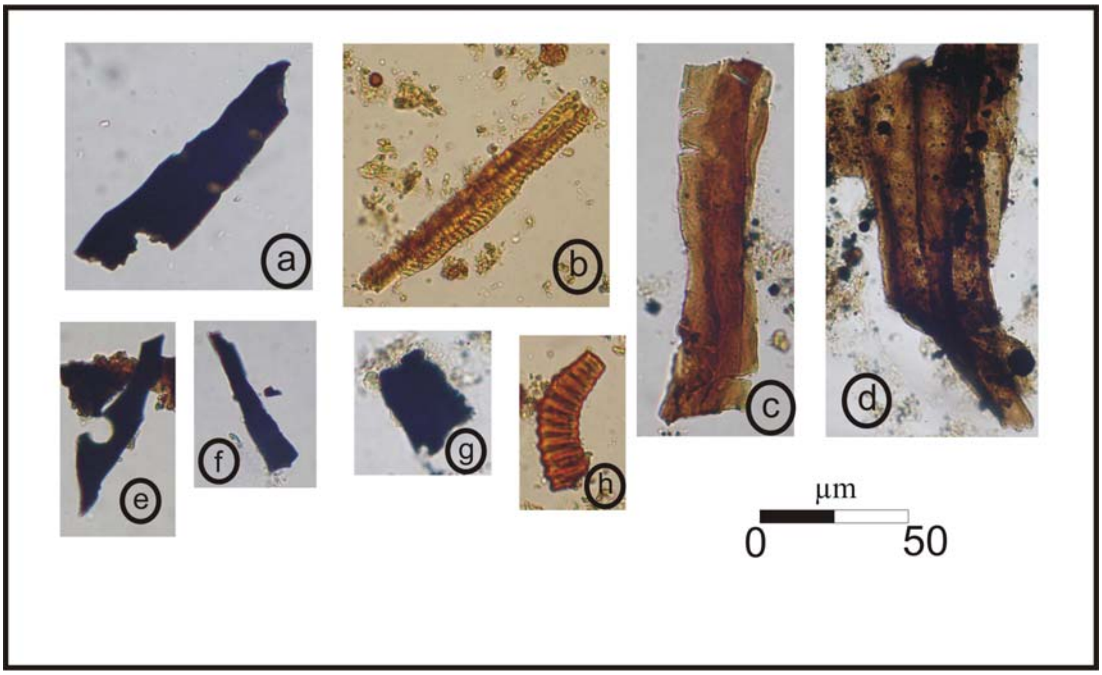


Figure 4.3 Phytoclast; a, e, f. Opaque lath phytoclast; g. Opaque equidimensional phytoclast; b, c, d. Translucent wood; h. Gymnospermae fragment.

Charcoal is also including opaque phytoclast group. Sedimentary charcoal is primarily the product of pyrolysis of mainly land plant matter during wildfires (Harris, 1958, 1981; Batten 1975; Scott and Jones, 1994). Wildfires occur in swamps and bogs. The formation of charcoal requires high temperatures and lack of oxygen (Cope, 1981).

Separation of charcoal is difficult from non charcoalified black detritus and reworked coal particles. Charcoal fragments are regularly perforated (bordered pits) or partly split into splintery shards (Figure 4.3 a). Because of their porous structure charcoal particles can easily become waterlogged, due to this property make charcoal buoyant. Charcoal fragments are associated with buoyant palynomorph (*Botryococcus* and *Pinus* pollen) in distal facies of lacustrine (Batten, 1996).

4.2.2.2 Translucent Phytoclast (Phy-T)

Translucent phytoclast are wood trachieds (with or without pits), cuticles, and fungal hypae. Translucent particles are deposited in nearshore environments without a prolonged transport.

Wood fragments are originated in vascular and mechanical support tissue of plants (xylem). Lignified structures, trachieds, are common and fragmentary in palynological preparations. Angiosperm wood lack of tracheids and doesn´t contain as much lignin as gymnosperm wood. Because of that property, angiosperm wood less resistant to degradation (Batten, 1996). Wood tracheids are orange to brown coloured, tubular, coarse prominent bordered pits ore without pits. (Figure 4.3 b-d) Many fragments of trachieds seem as banded phytoclasts with an angular outline (black and shades of brown) (Figure 7 d-e). A difference in thickness is caused these bands (Batten, 1996).

Cuticles are yellow coloured, the outermost covering of epidermal cells of leaves and steams of higher plants (Figure 4.4). Cutin is more vulnerable to degradation than lignite. According to studies in modern leaf litters have shown that they can't generally transported very far before they are destroyed (Spicer, 1991). Cuticle fragment is abundant in fluvio-deltaic and lacustrine environments. Relatively large sized cuticle fragments are characteristic for prodelta facies. Also delta top embayment prodelta, and distributary facies have high percentage of cuticle fragments (Batten, 1974; Parry et al., 1981; Nagy et al., 1984).

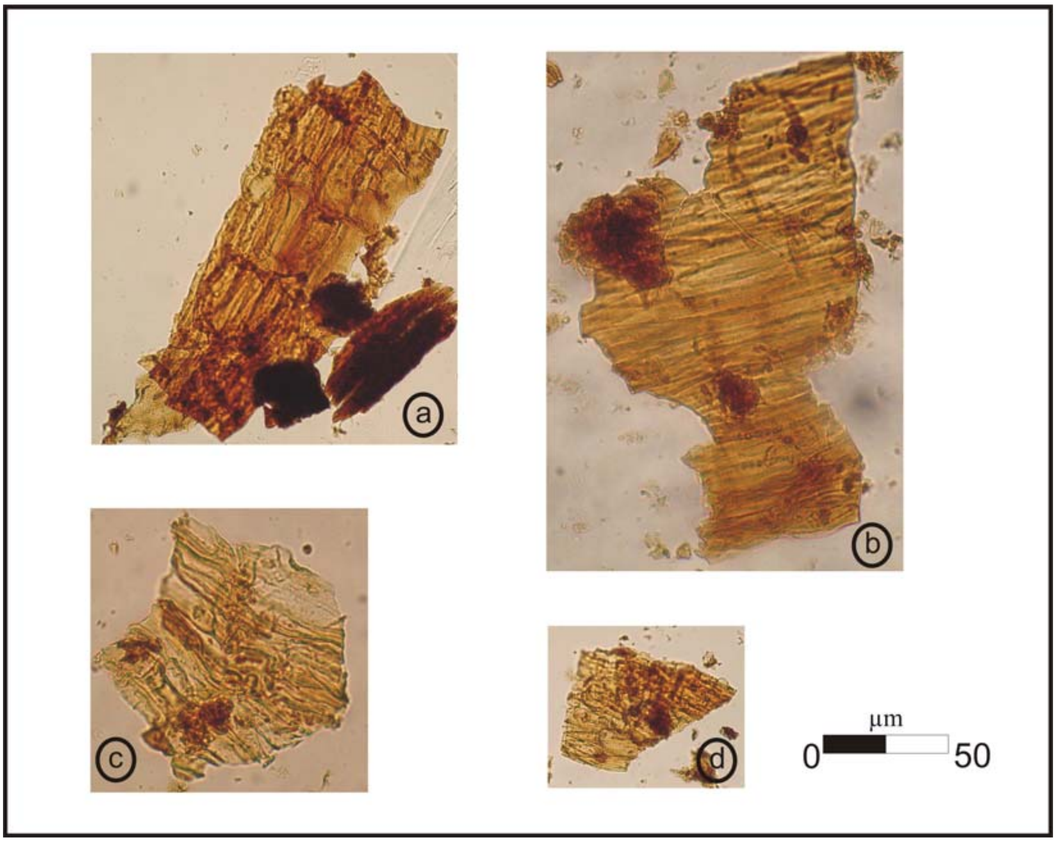


Figure 4.4 a, b, c, d. Cuticle fragments.

In proximal deposition conditions, pyhtoclast have high percentage and various particle sizes owing to their parent flora is near and short transport of particles. Other factors, such as oxidizing conditions and the relative resistance of lining tissues (resistant nature of lignin) are also associated with the proximity of the source area (Tyson, 1995). Generally, large amounts of phytoclast particles are deposited by rivers in estuaries and delta environments, both close to shorelines.

4.2.3 Palynomorphs (Pal)

The palynomorph group is subdivided into the sporomorph subgroup, which is further subdivided in spores and pollen (Saccate or non-saccate) grains; the phytoplankton subgroup, which consists of organic-walled micro plankton and the zoo morph subgroup, composed of foraminifera test linings and scolecodonts (Table 4.5). Table 4.5 Classification of the palynomorph group (based on Carvalho, 2001)

Palynomorph group		Origin
Sporomorph	Spores	Terrestrial palynomorph produced by pteridophyte plants and fungi.
	Pollen	Terrestrial palynomorph produced by Gymnosperm and Angiosperm plants.
Zoomorph	Foraminiferal test linings	Organic linings of benthic Foraminifera.
	Scolecodonts	Mouth parts of some oolychaete worms (mostly marine).
Phytoplankton	Acritarchs	Small microfossils of unknown and probably varied biological affinities.
	Dinoflagellate Cysts	Resting cysts produced during the sexual part of the life cycle of Class Dinophyceae survives.
	Prasinophytes	Fossilising structures produced by small quadriflagellate algae
	Chlorococcale Algae	Exclusively colonial freshwater algae (*Botryococcus* and *Pediastrum*)

The palynomorph group is the least abundant of the three main groups; therefore its occurrence is controlled by AOM and phytoclast dilution (Tyson, 1993). Large amounts of palynomorphs, dominated by sporomorphs, indicate proximity of terrestrial sources associated with oxygenated environments. Consequently, a small amount of AOM is observed as a result of low preservation rates. With moderate proximity to land large amounts of palynomorphs can also be found, although without dilution of phytoclasts (Tyson, 1995).

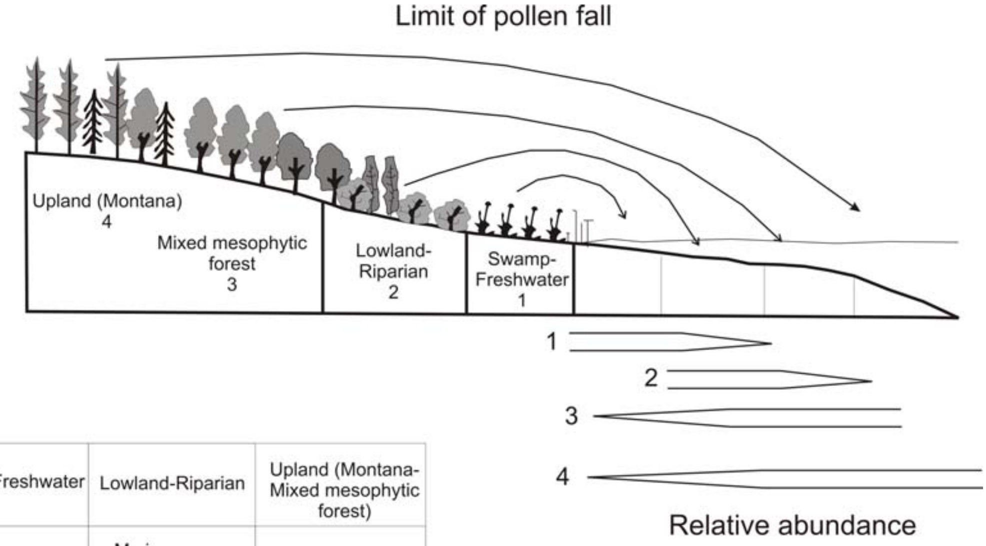
When sporomorophs fall into water, their size and transporting capability may affect sorting in deposition environment (Figure 4.5). The most abundant spores belonged to the genus Osmunda (e.g. *Baculatisporites primaries*) in proximal facies. Because they are heavier than pollen grains and have no structures for flotation such cinguli or coronae (Barron and Rengifo, 2007).

Saccete pollen grains, especially bisaccete conifer pollen, are buoyant sporomorphs. Due to buoyant character they are easy transported sporomorphs (Hopkins, 1950). Percentage of bisaccate pollen in offshore is relatively high (Figure 4.5) (Tyson, 1993). Although bisaccate pollen grains, once water-logged behave like other denser pollen, and duration of flotation of bisaccete grains is correlated with sacci size. Smaller ones are increasing distance offshore and some large and denser (*Abies* and *Picea*) ones are never carried very far from river mouths (Mudie, 1982). Large numbers of broken bisaccate pollen grains, which must spent long period afloat, were found in the deep lacustrine sediments (Martin- Closas et al., 2005; Barron and Rengifo, 2007). Bisaccete pollen grains can carry long distance by wind, may dominate any depositional environment where anemophylous pollen dominated, as in arid areas or distal offshore settings (Melia, 1984; Courtinatn, 1989).

Percentage of small simple spherical pollen tends to increase in an offshore direction like saccete pollen. It can be used as an indicator of relative proximity to fluvio-deltaic source area (Muller, 1959; Habib, 1979).

The anemophilous pollen of riparian trees that grew near the lake shore (e.g. *Alnus*) may have fallen with predominance into water by gravity (Figure 4.5). Due to this property the intensity of riparian trees pollen deposition is high in near shore (Barron and Rengifo, 2007).

Tetrads and pollen masses are common in prodelta facies. Distribution of fungal macerals in Cenozonic brown coals appears to be associated particularly with the *Gramineae* and *Cyperaceae*, which are important peat forming of the angiosperms (Teichmüller, 1982).



Swamp-Freshwater	Lowland-Riparian	Upland (Montana-Mixed mesophytic forest)
Spranganiaceae Nymphaceae Taxodiaceae Cupsressaceae Polypodiaceae Osmundaceae	Myricaceae Juglandaceae Corylaceae *Alnus* *Carya* *Tilia* *Ulmus* *Ptreocarya* *Castanea* *Engelhardtia*	Fagaceae Quercus *Pinus* *Abies*

Figure 4.5: Distribution of palynomoroph in depositional zone (modified from Traverse, 2002; Akgün et al., 2007; Kayseri& Akgün, 2008)

CHAPTER FIVE
PALYNOFACIES ANALYSIS

5.1 Palynofacies Analysis Associations

Five types of palynological kerogen are identified in the studied bore holes (Table 5.1). These types were observed in all samples studied from the three boreholes. Owing to their low abundance resin are not used in the definition the palynofacies associations.

Table 5.1 Palynologıcal kerogen types identified in the studied bore holes.

Palynological Kerogen Types	Description
Phy-OE	Predominance of the phytoclast group with a high content of opaque equidimensional particles.
Phy-OL	Predominance of the phytoclast group with a high content of opaque lath particles.
Phy-T	Predominance of the phytoclast group with a high content of translucent particles.
Pal	Predominance of the palynomorph group.
AOM	Predominance of the amorphous organic matter group.

To interpret the pattern of distribution of palynological kerogen types, their abundances were submitted to cluster analysis. The cluster for borehole Hs-2, based on the abundance of the kerogen groups, revealed two superclusters. These are: supercluster A, which is subdivided into A1 and A2, and supercluster B, subdivided into B1, B2 and B3. The phytoclast group is mainly included in cluster A (up to 45%). A1 presents abundance of translucent phytoclast particles with a moderate abundance of AOM (Phy-T/AOM). The A2 cluster is a combination of a moderate abundance of opaque equidimensional phytoclast particles with a moderate AOM group (Phy-OE/AOM). The high abundances of the AOM group occur in supercluster B. B1 is characterized by high abundances of the AOM group (up to 70%). B2 is composed AOM group abundance with a high abundance of palynomorph group (AOM/Pal). In B3 group occurs with an abundance of AOM and a moderate abundance of opaque lath phytoclast particles (AOM/Phy-OL) (Figure 5.1).

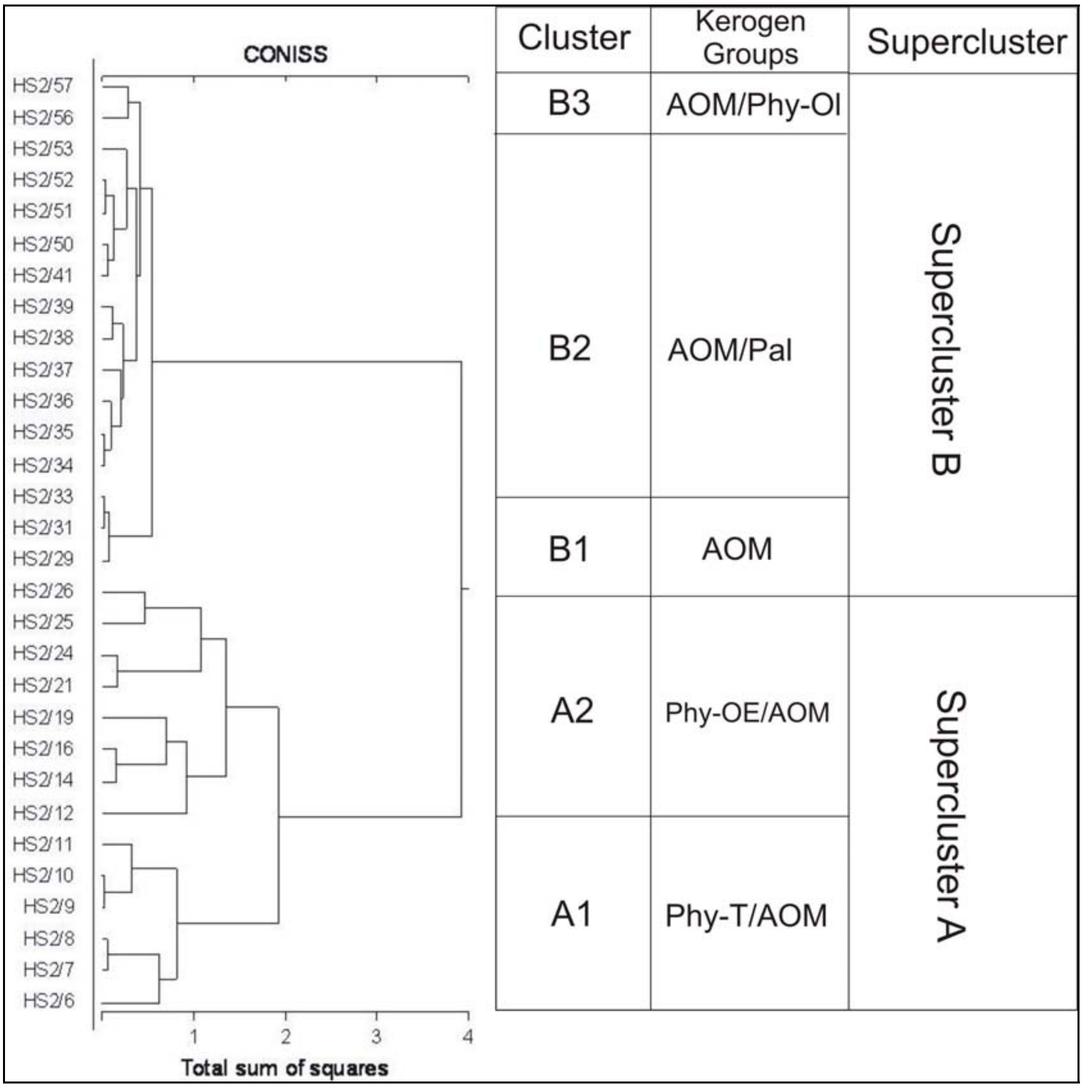


Figure 5.1 Dendrograms of Hs-2 borehole.

For borehole Et-12, the cluster analyses revealed two superclusters (A and B). Supercluster A is composed of only one cluster distinguished by abundances of opaque equidimensional phytoclast particles and a moderate abundance of AOM group (Phy-OE/AOM). Supercluster B was subdivided into B1 and B2. B1 is represented by moderate to high abundance of AOM group and high percentage of palynomorph group (AOM/Pal). In B2 group based on the abundance of AOM group and a moderate of opaque lath phytoclast particles (AOM/ Phy-OL) (Figure 5.2).

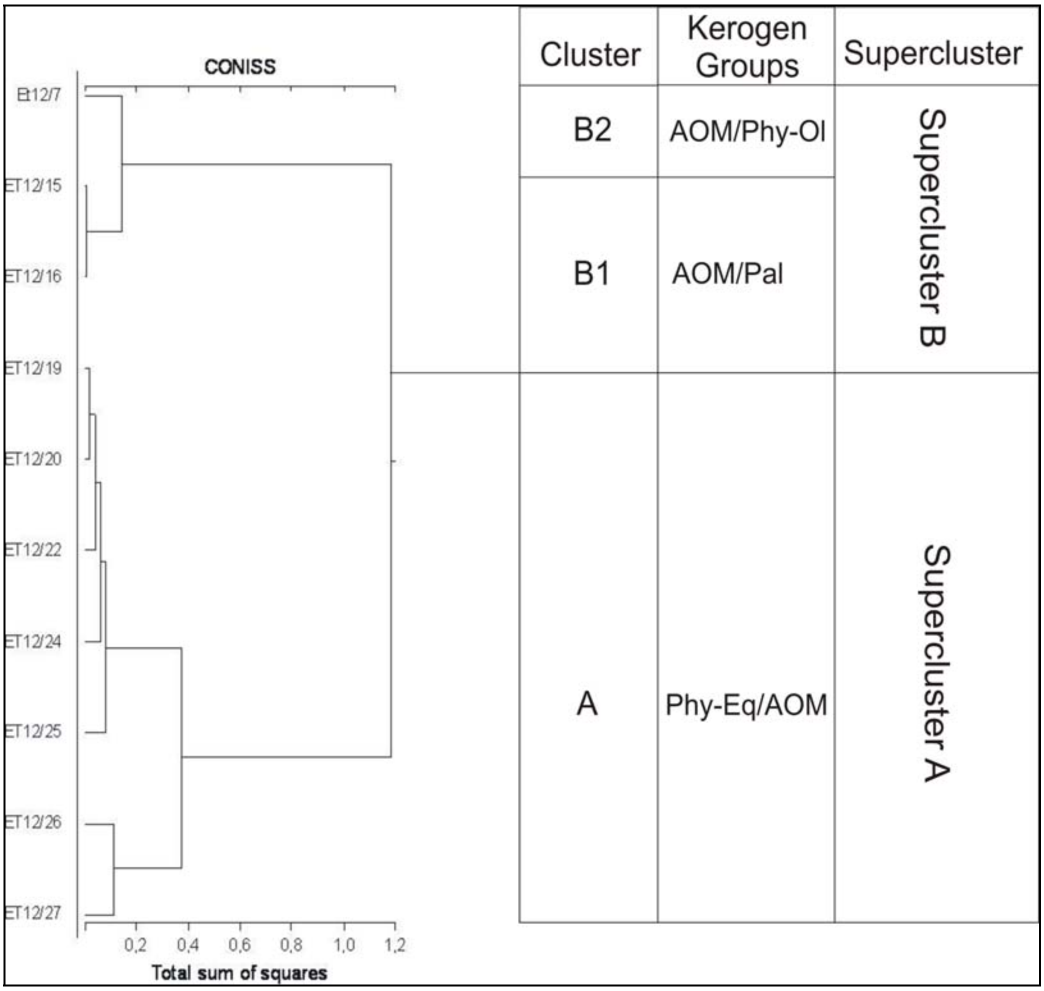


Figure 5.2 Dendrograms of ET-12 borehole.

In borehole ET-7 two supercluster were revealed (A and B). Supercluster A is characterized by abundance of opaque equidimensional phytoclast particles and AOM group (Phy-OE/AOM). Supercluster B was subdivided into B1 and B2, in which cluster B1 is composed moderate to high abundance of AOM group with high percentage of palynomorph group (AOM/Pal), and B2, in which AOM group is combined with a moderate abundance of opaque lath phytoclast particles (AOM/ Phy-OL) (Fıgure 5.3).

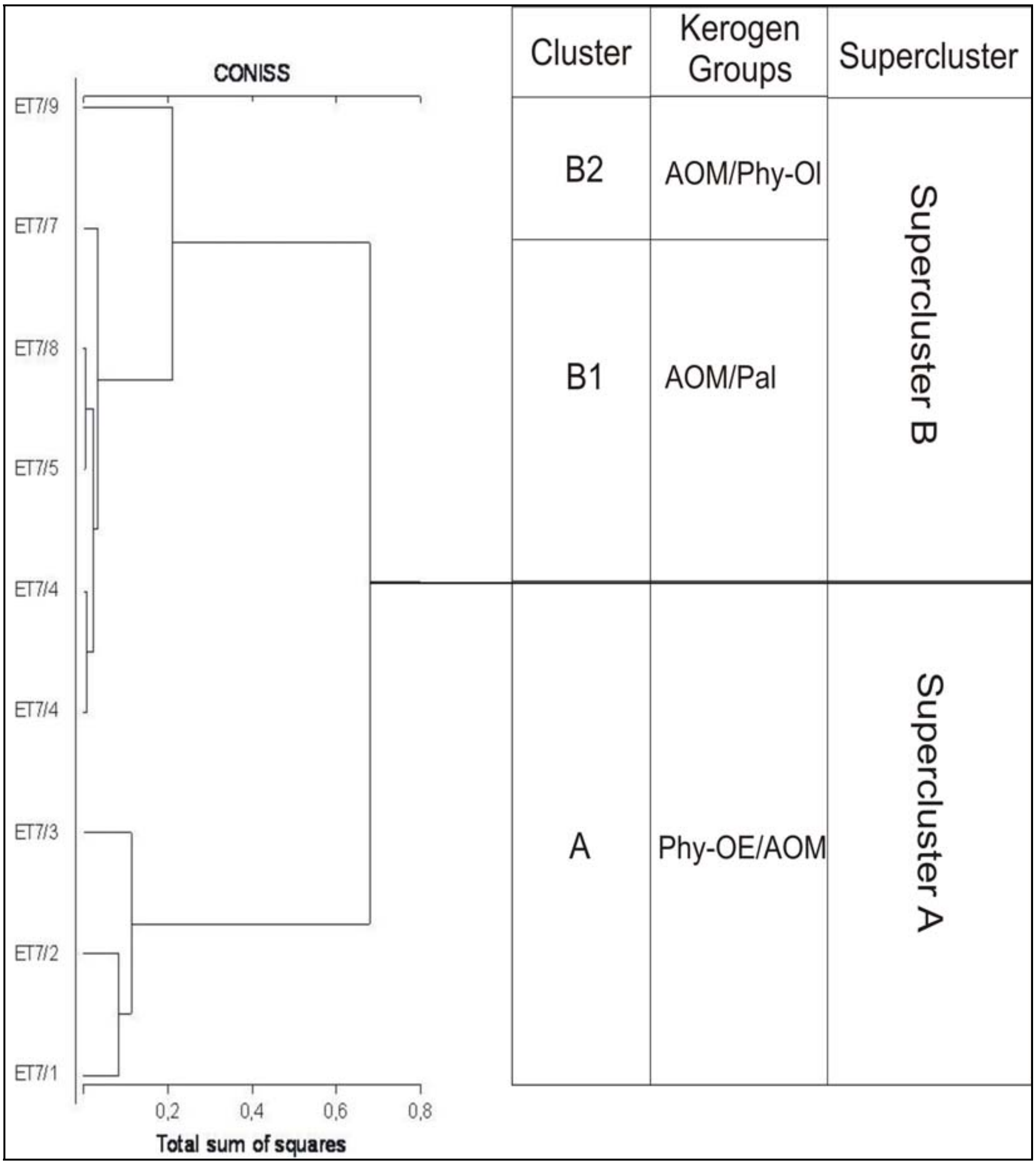


Figure 5.3 Dendrograms of ET-7 borehole.

5.2 Palynofacies Associations

Four palynofacies associations were grouped according to composition and abundance of palynological kerogen and the clusters (Table 5.2). In all samples, amorphous organic matter is abundant palynofacies type (some samples AOM made up to 70% of organic matter). AOM is generally light brown, yellow colored and associated with pyrite. Numerous pollen grains and phytoclast are smothered by a sheet of light brown colored AOM. Phytoclasts are generally wood fragments (various sized and type); cuticle and a few fungal hypae are found. The palynomorph values are range from 1% to 26%. Bisaccate, *Alnus*, *Momipites* spp., *Quercus* spp. and, *Castanea* spp. Pollen grains are common palynomorphs. Spore and fungal spore are rare.

Table 5.2 Palynofacies associations in boreholes.

Palynofacies Associations	Kerogen Group	Description	Palynofacies Units
Palynofacies association 1	Phy-T/AOM	Predominance of the phytoclast group with a high content of translucent particles combined moderate content of the AOM group.	H-II
	Phy-OE/AOM	Predominance of the phytoclast group with a high content of equidimensional phytoclast particles combined moderate content of the AOM group.	H-III, E12-I, E7-I
Palynofacies association 2	AOM	Predominance of the AOM group	H-IV
Palynofacies association 3	AOM/Pal	Predominance of the AOM group combined with palynomorph group.	H-I, H-V, E12-II, E7-II
Palynofacies association 4	AOM/Phy-OL	Predominance of the AOM group combined with lath opaque phytoclast particles.	H-VI, E12-III, E7-III

5.1.1 Palynofacies Association 1

A highly diverse of phytoclast (cuticle, well preserved wood, tracheid, angiosperm wood fragments, poor preserved wood, fungal hypae) is characterises this association. Association has a high phytoclast proportion (35-55 %) and size of phytoclast is large. Cuticle fragments are large sized (up to 200 μm). However palynomorph species are variable, palynofacies association 1 has a very low palynomorph proportion (1-9%). In this association brown coloured humic gels are common. AOM particles are brown-yellow coloured semi translucent particles with inclusions (pyrite crystals, pollen grains and phytoclast fragments). Non to dull fluorescent AOM matrixes are dominant in this association (Qualitative Preservation scale 2a-2b; Tyson, 1995).

5.1.2 Palynofacies Association 2

AOM made up 60-77% of the organic matter in this association. AOM particles are translucent or semi-translucent, yellowish to dark brown coloured algal derived AOM with inclusions (pyrite crystals, pollen grains and palynomoprhs). Opaque phytoclasts are dominant in phytoclast group. Small sized cuticle fragments are preserved (up to 20 μm). Bisaccete pollen grains have relative abundance in the palynomorph group.

5.1.3 Palynofacies Association 3

This association has higher palynomorph proportion than other associations (12-28%). AOM particles are semi-translucent, brown to yellow coloured, large sized gelified heteregeonous algal derived AOM with inclusions. Poor preserved and small lath shaped opaque phytoclasts are common. Large sized well preserved wood fragments are rare. Additionally small sized cuticle fragments are present.

5.1.4 Palynofacies Association 4

Association four ahows lowest phytoclast proportion (8-23%), for all that AOM made up 65-71% of the organic matter. AOM particles are brown to yellow coloured, translucent algal derived well preserved AOM. AOM matrixes show homogenous, strong orange, yellow fluorescence intensity (Qualitative Preservation scale 4 to 5; Tyson, 1995). Resin fragments are also presented (orange to yellow fluorescing colour). Bisaccete pollen grains are dominant in the palynomorph group. Most bisaccete pollen grains were generally broken. Poor preserved wood fragments and opaque phytoclast are abundant. These phytoclast particles are very small sized.

5.3 Palynofacies Properties of Hs-2 Borehole

In the Hs-2 borehole six palynofacies units were recognized to interpret the distribution of palynological kerogen types in the sedimentary succession. The sedimentary succession of lower part of Hs-2 borehole is characterized by moderate contents of phytocalst group. Upper parts have high amount of AOM group and there is a clear increase in palynomorph group (Figure 5.5).

5.3.1 Palynofacies Unit H-I

This unit is characterized by the abundance of the AOM group combined with a moderate numbers of palynomorph. The phytoclast group is predominatly made up of opaque lath particles (Table 5.3).

The AOM group is consists of mainly orange-brown coloured and heterogeneous (with obvious inclusions) particles. These particles show moderate fluorescence (Qualitative Preservation scale 4). Unit H-I is observed in greenish gray coloured claystone sample (Figure 5.4).

Table 5.3 Palynofacies distribution of Unit H-I

Sample No	Palynological Kerogen Groups			Phytoclast Group						AOM Group	
				Opaque		Translucent				AOM	Humic
	AOM	Phyt	Pal	O-La	O-Eq	Tw	Tp	Cu	Fh		
Hs-2/3	54,2	21,8	24	16,8	1	0,8	2,2	0	1	50,2	4

5.3.2 Palynofacies Unit H-II

Unit H-II is characterized by an abundance of the AOM group combined with the phytoclast group that mainly consist of translucent particles (Table 5.4). The well presereved wood particles show the highest value in the bore hole. Opaque particles are present and are composed basically of O-Eq particles. The AOM group is consisting of AOM and humic gel particles. AOM particles are common and generally brown-greyish brown coloured heterogonous AOM particles. These AOM particles matrixes' show non to dull fluorescence (Qualitative preservation scale 2(a-b)-3). Humic gel particles are dark brown to grey brown coloured and show non fluorescence (Qualitative preservation scale 2). This unit is observed in clayey lignite and lignite samples

Table 5.3 Palynofacies distribution of Unit H-II

Sample No	Palynological Kerogen Groups			Phytoclast Group						AOM Group	
				Opaque		Translucent				AOM	Humic
	AOM	Phyt	Pal	O-La	O-Eq	Tw	Tp	Cu	Fh		
Hs-2/6	49	42,6	8,4	2,2	9	14	15	0	2,4	44	5
Hs-2/7	53,2	40,9	6	2	6	19	8	4,3	1,6	32,6	20,6
Hs-2/8	57,3	34	8,7	0,8	2,5	19,5	6,8	1,7	2,7	33,8	23,5
Hs-2/9	55,9	42,1	2	8,9	10	17	1,8	2,3	2,1	47	8,9
Hs-2/10	57	42	1	5,2	10,8	20	3	1,5	1,5	50	7
Hs-2/11	57,5	35,6	6,9	3,1	5,7	21,7	3,3	0	1,8	51,1	6,4

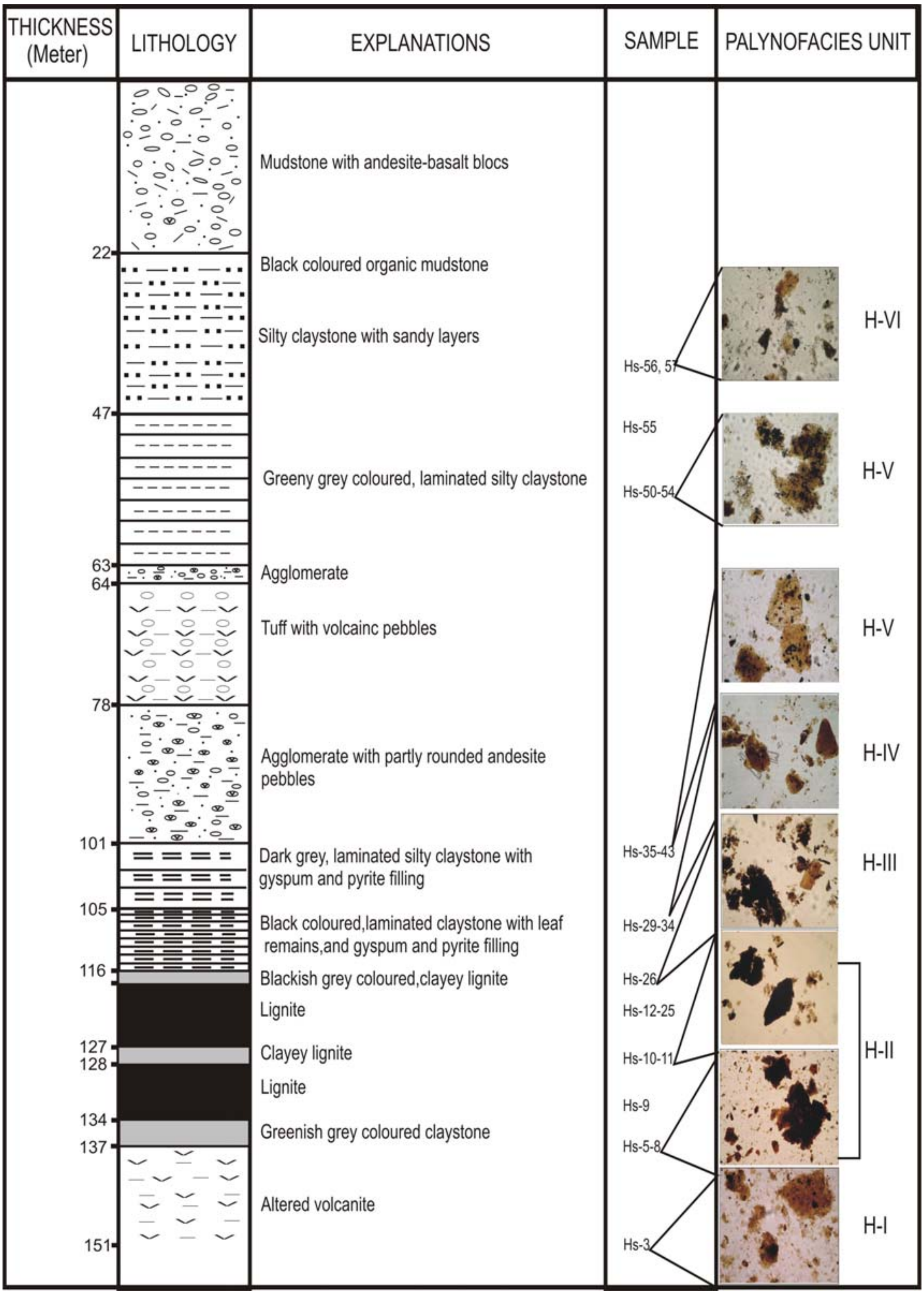


Figure 5.4 Stratigraphic profile of Hs-2 borehole.

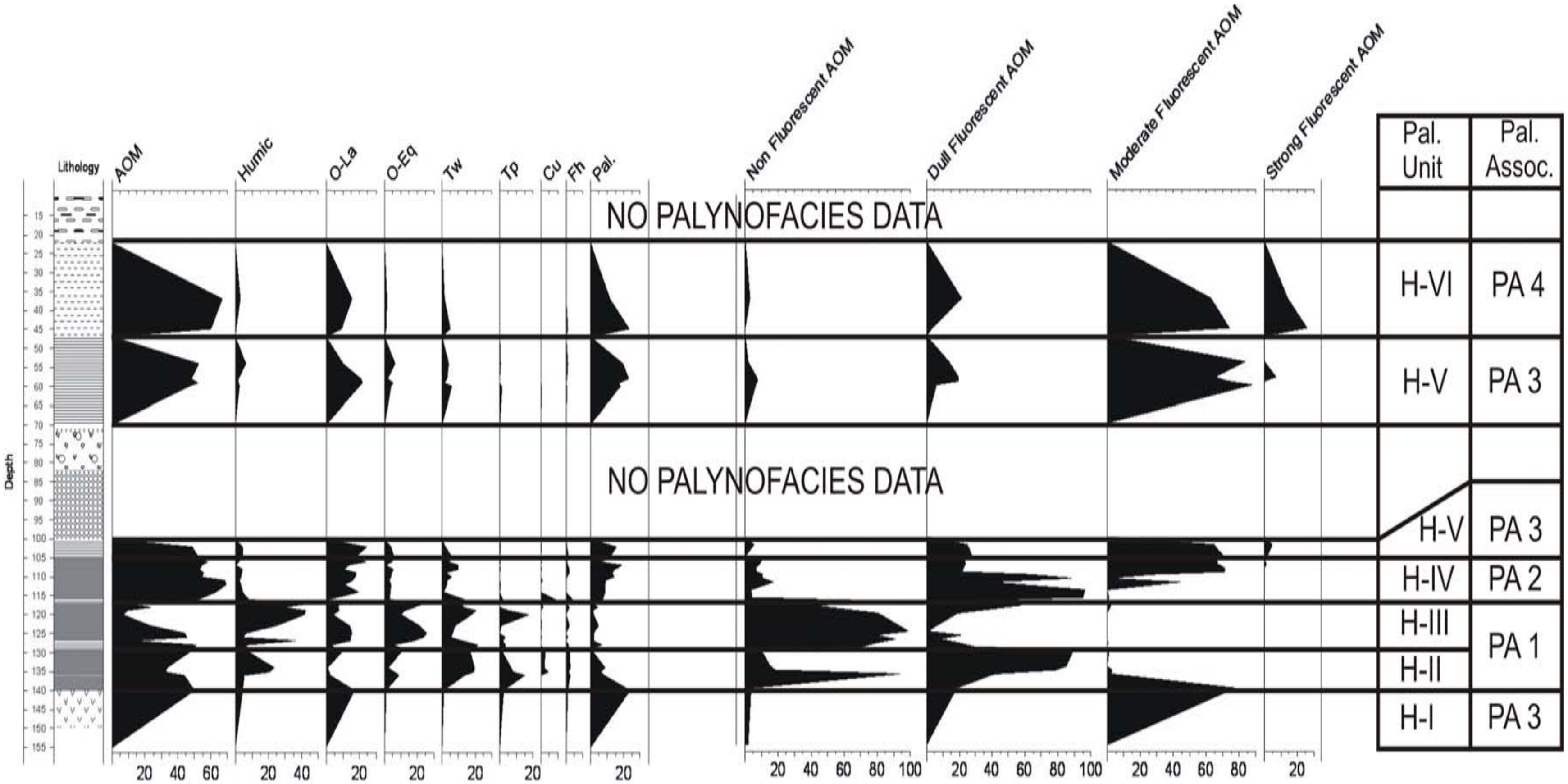


Figure 5.5. Stratigraphic distrubution of palynological kerogen categories in Hs-2 borehole.

5.3.3 Palynofacies Unit H-III

Like Unit H-II, this unit characterized by an abundance of the AOM group combined with the phytoclast group. In this unit the phytoclast group is composed mainly of O-eq particles, despite the frequency of translucent phytoclast particles (Table 5.4). O-eq particles are large sized. As previous unit, the AOM group consists of AOM and humic gels. Latter show the highest abundance in the whole section. Unit H-III is also characterized by extremely low abundances of the palynomorph group. Unit is observed in clayey lignite and lignite samples.

Table 5.4 Palynofacies distribution of Unit H-III

Sample No	Palynological Kerogen Groups			Phytoclast Group						AOM Group	
				Opaque		Translucent				AOM	Humic
	AOM	Phyt	Pal	O-La	O-Eq	Tw	Tp	Cu	Fh		
Hs-12	51,1	46,9	2	14,6	18	12,3	2	0	0	15	36,1
Hs-2/14	50	48,2	1,8	14,5	23,5	5,5	3,2	0,5	1	45,5	4,5
Hs-2/16	50,2	47,84	1,96	15,7	25,54	6,6	0	0	0	44,2	6
Hs-2/19	48,23	46,89	4,88	14,25	21,3	7,81	0,98	0,4	2,15	23,43	24,8
Hs-2/21	48,47	49,95	1,58	4	10,54	17,7	17,7	0	0	7	41,47
Hs-2/24	51,8	46,8	1,4	7,5	12,4	20,4	5,5	0	1	9,3	42,5
Hs-2/25	53,6	42	4,4	7,4	18,4	13	0	1,2	2	23,6	30
Hs-2/26	54,3	44,7	1	8	24,5	12,2	0	0	0	7,6	46,7

5.3.4 Palynofacies Unit H-IV

AOM group is characteristically the dominant group which reaches high values (up to 72%). The phytoclast group is mainly composed O-La particles. O-Eq particles are low abundance (Table 5.5). Althoughn translucent particles are rare, cuticle fragments show the highest value recorded in Hs-2 bore hole. The palynomorph group trendline increase upwards. The AOM group is consist of yellowish brown-brown coloured algal derived AOM particeles with obvouis incluions (pyrite crystal, palynomorph and phytoclast). These AOM particles matries' show heteregenous, dull to moderate fluoresence (Qualitative preservation scale 3-4). Unit IV is found in laminated claystone samples.

Table 5.4 Palynofacies distribution of Unit H-IV

Sample No	Palynological Kerogen Groups			Phytoclast Group						AOM Group	
				Opaque		Translucent				AOM	Humic
	AOM	Phyt	Pal	O-La	O-Eq	Tw	Tp	Cu	Fh		
Hs-2/28	60	33	7	1,5	3	14	2	8,8	4	52	8,3
Hs-2/29	67,05	24,34	8,62	19,61	3,72	1	0	0	0	62,94	4,11
Hs-2/31	72,61	18,47	8,92	10,91	3,96	3	0,6	0	0	69,44	3,17
Hs-2/33	68,44	22,56	9	15,8	3	2,96	0	0,8	0	61,73	2,17

5.3.5 Palynofacies Unit H-V

This unit is dominated by the AOM group, which is associated with a relatively high content of palynomorph group. O-La particles are the most abundant in the phytoclast group (Table 5.5). Trendline of O-La particles are increase upwards. The AOM group is consist of yellowish to dark brown coloured, semi-translucent, sharp margined heterogeneous algal derived well-preserved AOM particles. These particles show heterogeneous, moderate to high fluorescence (Qualitative preservation scale 4).

Table 5.5 Palynofacies distribution of Unit H-V

Sample No	Palynological Kerogen Groups			Phytoclast Group						AOM Group	
				Opaque		Translucent				AOM	Humic
	AOM	Phyt	Pal	O-La	O-Eq	Tw	Tp	Cu	Fh		
Hs-2/34	57,93	27,78	14,29	17,41	3,91	5,68	0	0	0,78	54,8	3,13
Hs-2/35	59,75	26,91	13,34	17,93	4,38	2,6	0	0	2	55,77	3,98
Hs-2/36	57,4	28,2	14,4	10,7	5,4	9,7	0,2	0,2	2	53,4	4
Hs-2/37	55,25	25,94	18,81	13,66	1,38	9,9	0	0	1	54,85	0,4
Hs-2/38	59,6	34,07	6,33	24,02	4,65	3,72	0,37	0,37	0,37	58	1,6
Hs-2/39	57,04	31,39	11,57	17,34	5,97	6,35	0	0	1,73	52,8	4,24
Hs-2/41	52,82	31,55	15,63	24,41	3,9	1,95	0,39	0,2	0,7	48,82	4
Hs-2/50	49,22	32,92	17,86	20,14	4,03	6,13	1,58	0,52	0,52	46,95	2,27
Hs-2/51	54,12	29,06	16,82	21,8	5,73	1,53	0	0	0	52,4	1,72
Hs-2/52	50,5	26,64	22,86	20,95	2,27	2,85	0	0	0,57	48,5	2
Hs-2/53	58,8	21,8	19,4	10	6,4	4	0,2	0	1,2	52,8	6

5.3.6 Palynofacies Unit H-VI

Unit H-VI is strongly dominated by the AOM group with an abundance of opaque pyhtoclast. The phytoclast group is predominatly made up of opaque lath particles (Table 5.6). The AOM group is consists of mainly grey brown-yellow grey coloured, and heterogeneous AOM particles with obvious pyrite inclusions. These AOM particles matrixes' are showed strong and homogenous fluorescence (Qualitative preservation scale 4). Resin fragments are present in this unit. Unit is observed in silty claystone and mudstone samples.

Table 5.6 Palynofacies distribution of Unit H-VI

Sample No	Palynological Kerogen Groups			Phytoclast Group						AOM Group	
				Opaque		Translucent				AOM	Humic
	AOM	Phyt	Pal	O-La	O-Eq	Tw	Tp	Cu	Fh		
Hs-2/56	60,6	15,96	23,44	9	0,96	5	0	0	1	60,2	0,4
Hs-2/57	69,77	18,6	11,63	15,5	1,55	1,55	0	0	0	66,86	2,91

5.4 Palynofacies Properties of ET-12 Borehole

The succession of lower part of ET-12 bore hole is characterized by moderate abundance of phytoclast group. The AOM group reaches moderate to high values in upper parts, and its abundance trend increases toward the top. There is significant increase in trend of palynomorph group through upper parts (Figure 5.7). In this borehole three playnofacies units were distinguished after the cluster analysis (units E12-I to E12-III).

5.4.1 Palynofacies Unit ET12-I

The phytoclast group is characteristically the dominant group which is composed mainly of O-Eq particles. O-La phytoclast particles are common and show an increasing trend towards upwards. Translucent phytoclast particles are presented mainly of Tw particles. The palynomorph group occurs in low abundances and decreasing through upper parts (Table 5.7). The AOM group constituted mainly of humic gel particles which are dark brown-brown coloured homogenous particles. These particles are showed non fluorescence (Qualitative preservation scale 2). AOM is composed of dark-yellowish brown coloured heterogeneous particles which matrixes are showed heterogeneous and dull fluorescence (Qualitative preservation scale 3). This unit is observed in clayey lignite and lignite samples.

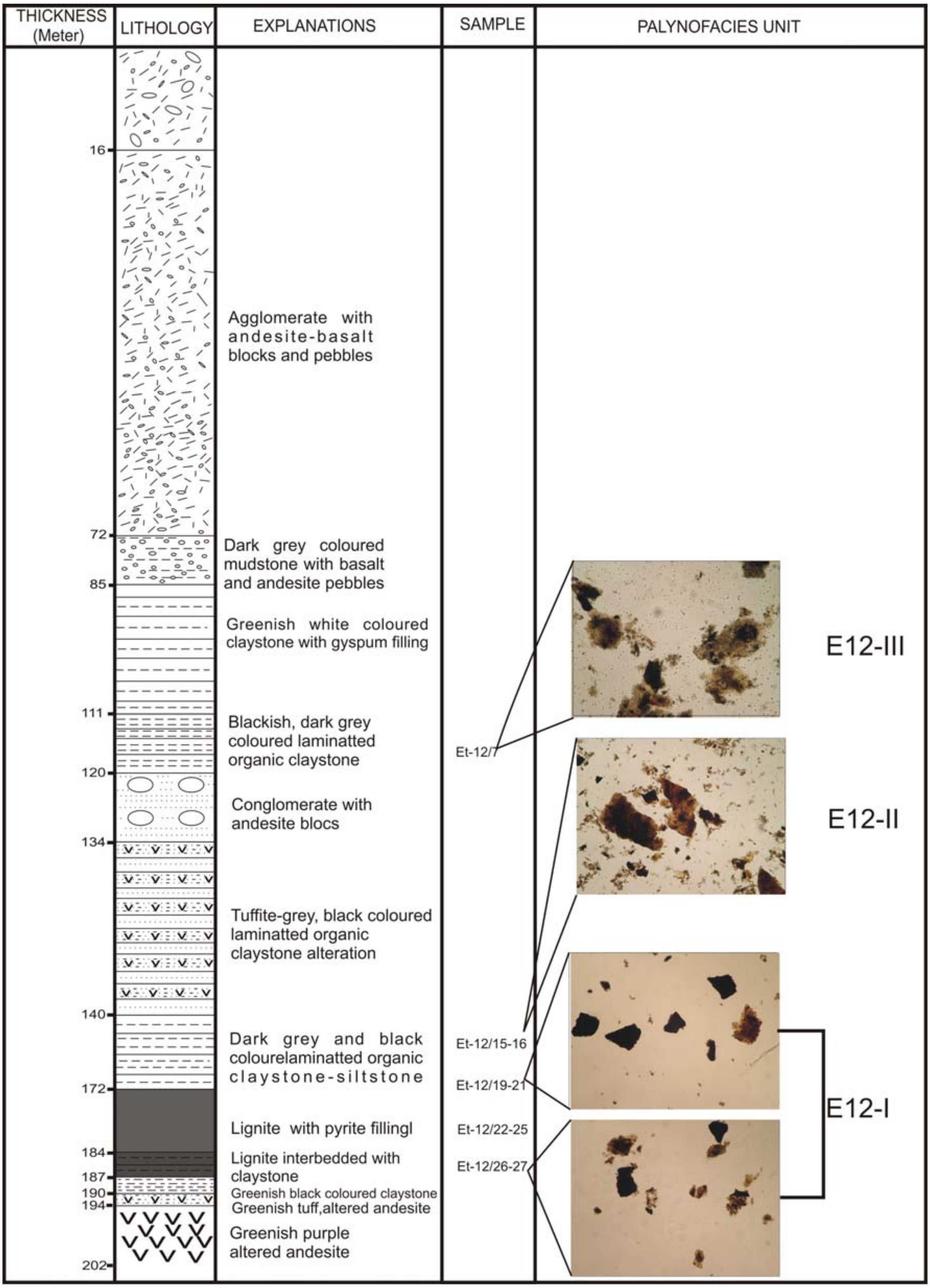


Figure 5.6 Stratigraphic profile of E-12 borehole.

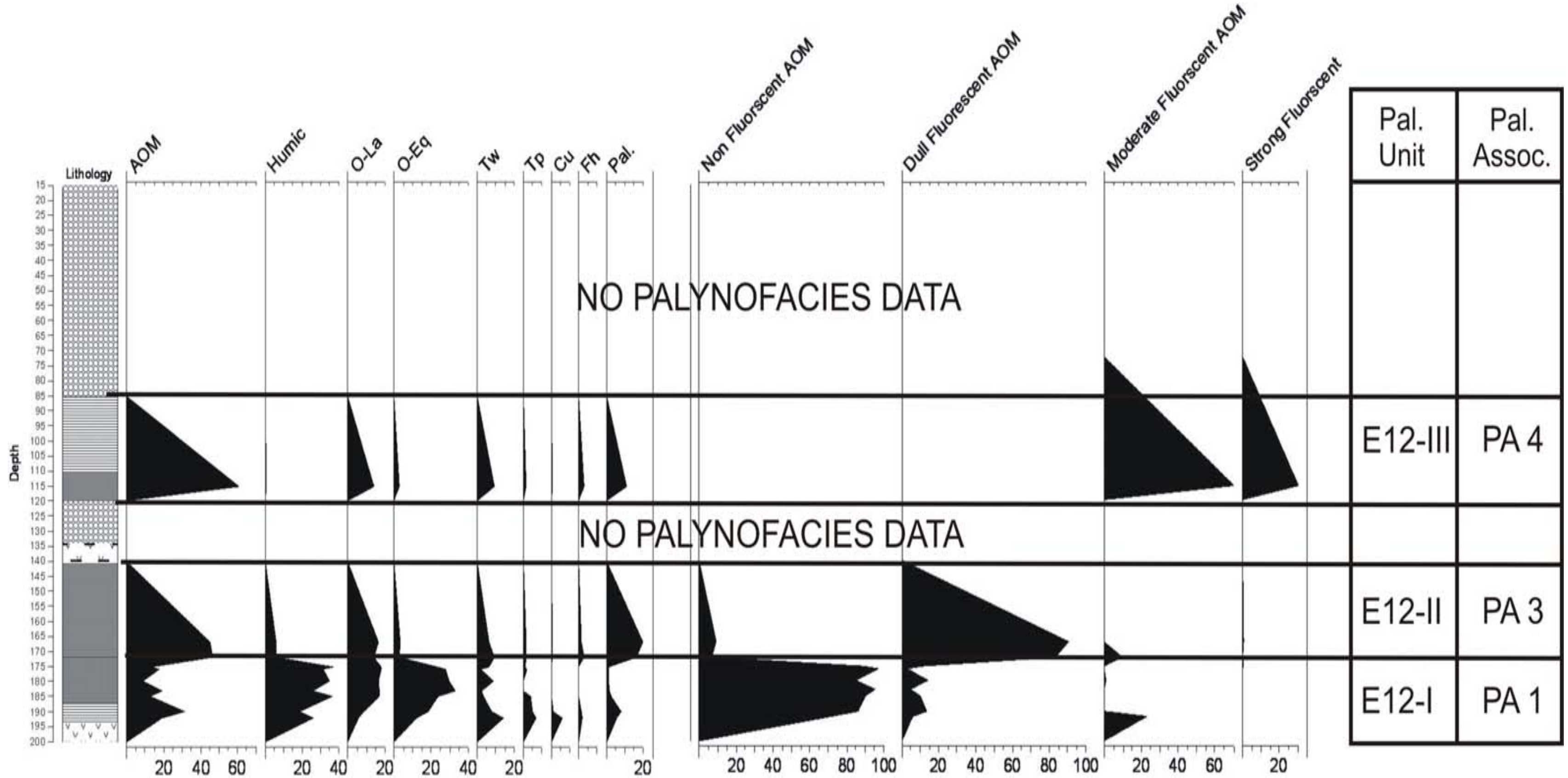


Figure 5.7. Stratigraphic distrubution of palynological kerogen categories in ET-12 borehole

Table 5.7 Palynofacies distribution of unit Et12-I

Sample No	Palynological Kerogen Groups			Phytoclast Group						AOM Group	
				Opaque		Translucent				AOM	Humic
	AOM	Phyt	Pal	O-La	O-Eq	Tw	Tp	Cu	Fh		
Et-12N-27	45,3	46,7	8	5,77	11,95	14	7	6	1,99	19,3	26
Et-12N-26	50,09	42,05	7,86	8,45	18,27	7,86	4,72	1,18	1,57	31,43	18,66
Et-12N-25	49,4	47,84	2,76	17	23,71	3,16	3,75	0,2	0	12,84	36,56
Et-12N-24	45,5	52,78	1,72	16,9	33	2,5	0	0,38	0	19,2	26,3
Et-12N-22	43,56	44,73	1,17	16,4	29,88	8,78	0,2	0	0	8,8	34,76
Et-12N-20	49,59	49,41	1	17,85	27,77	1,79	2	0	0	17,85	31,74
Et-12N-19	49,9	48,94	1,16	17,86	23,3	6,4	0,97	0,4	0	13	36,9

5.4.2 Palynofacies Unit ET12-II

Unit ET12-II is characterized by an abundance of AOM group. Additionally unit has high palynomorph proportion (Table 5.8). Opaque lath particles are the most abundant in the phytoclast group; however fungal hypae show the highest value in this bore hole.

Yellowish to dark brown coloured semi-translucent AOM particles are common and their matrixes show heterogeneous and moderate fluorescence (Qualitative preservation scale 3). Non fluorescent humic gel particles are present. This unit is observed in organic claystone samples.

5.4.3 Palynofacies Unit ET12-III

Predominance of AOM group with a combination of an abundance of opaque pyhtoclast is characterized for this unit. Opaque phytoclast particles are mainly consist O-La particles (Table 5.9).

The AOM group is consists of grey brown coloured heterogeneous (pyrite inclusions common to abundant) AOM particles with an abundant pyrite inclusions. These particles show strong and heterogeneous fluorescent intensity. Unit is found in claystone samples.

Table 5.8 Palynofacies distribution of unit Et12-II

Sample No	Palynological Kerogen Groups			Phytoclast Group						AOM Group	
				Opaque		Translucent				AOM	Humic
	AOM	Phyt	Pal	O-La	O-Eq	Tw	Tp	Cu	Fh		
Et-12N-16	52,36	31,39	16,25	13,8	2,8	9,5	1,51	0,75	3	46,5	5,86
Et-12N-15	51,07	29,29	19,64	16,5	3,14	6,28	1,37	0,6	1,4	45,18	5,89

Table 5.9 Palynofacies distribution of unit Et12-III

Sample No	Palynological Kerogen Groups			Phytoclast Group						AOM Group	
				Opaque		Translucent				AOM	Humic
	AOM	Phyt	Pal	O-La	O-Eq	Tw	Tp	Cu	Fh		
Et-12N-7	61,58	27,42	11	13,8	2,83	9,5	1,51	0,75	3	61	0,58

5.5 Palynofacies Properties of ET-7 Borehole

In the lower part of the sedimentary succession a moderate abundance of the phytoclast group is observed. The AOM group is markedly more abundance in upward succession. Abundance trend increases toward the top. The palynomorph group, as in Hs-2 and ET-12 bore hole, shows a marked increase in the upper parts (Figure 5.9). Cuticle fragments are very rare in section. Three palynofacies units were after cluster analysis (E7-I to E7-III).

5.5.1 Palynofacies Unit ET7-I

Unit ET-I is characterized by the highest phytoclast value whole studied bore holes (up to 54%). The phytocalst group is constituted mainly of O-Eq particles; also opaque lath particles are common. Translucent particles are rare but show the highest peak in this bore hole (Table 5.10).

The AOM group is composed AOM and humic gels. Yellowish to greyish brown coloured heterogeneous AOM particles are common whose matrixes show non to dull heterogeneous fluorescence (Qualitative preservation scale 2 (a-b) to 3). Humic gels are opaque to semi-translucent brown coloured particles. The Unit ET7-I are distinguished in lignite samples.

Table 5.10 Palynofacies distribution of unit E7-I

Sample No	Palynological Kerogen Groups			Phytoclast Group						AOM Group	
				Opaque		Translucent				AOM	Humic
	AOM	Phyt	Pal	O-La	O-Eq	Tw	Tp	Cu	Fh		
ET-7/N-1	50,98	45,69	3,33	16,3	24,31	3,14	1,18	0,2	0,6	33,14	17,84
ET-7/N-2	44,83	54,19	0,97	16,4	23,59	12,3	1,95	0	0	15,59	29,2
ET-7/N-3	52,6	43	4,4	14	23,8	3,6	1,6	0	0	38,8	13,8

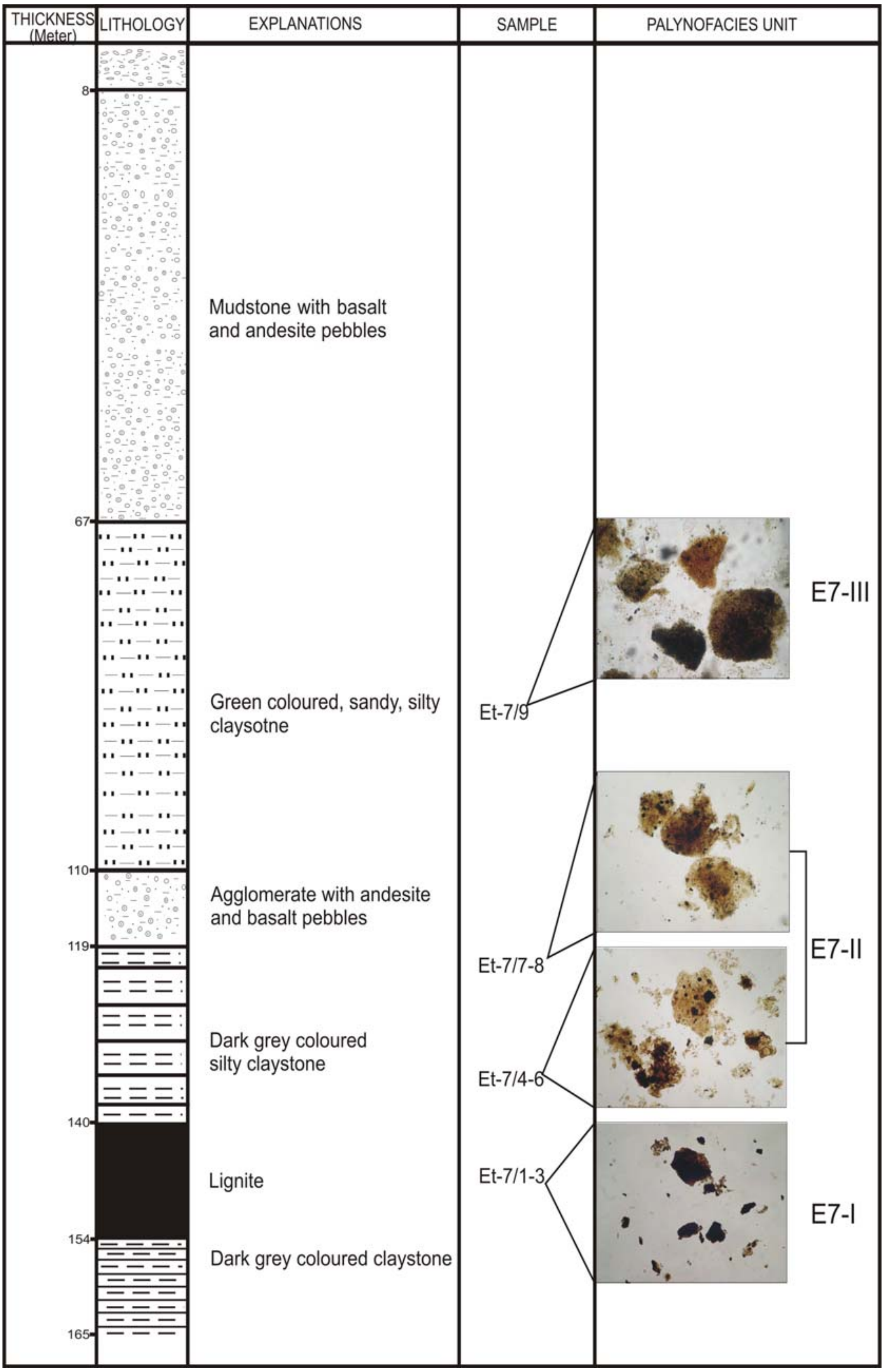


Figure 5.8 Stratigraphic profile of ET-7 borehole.

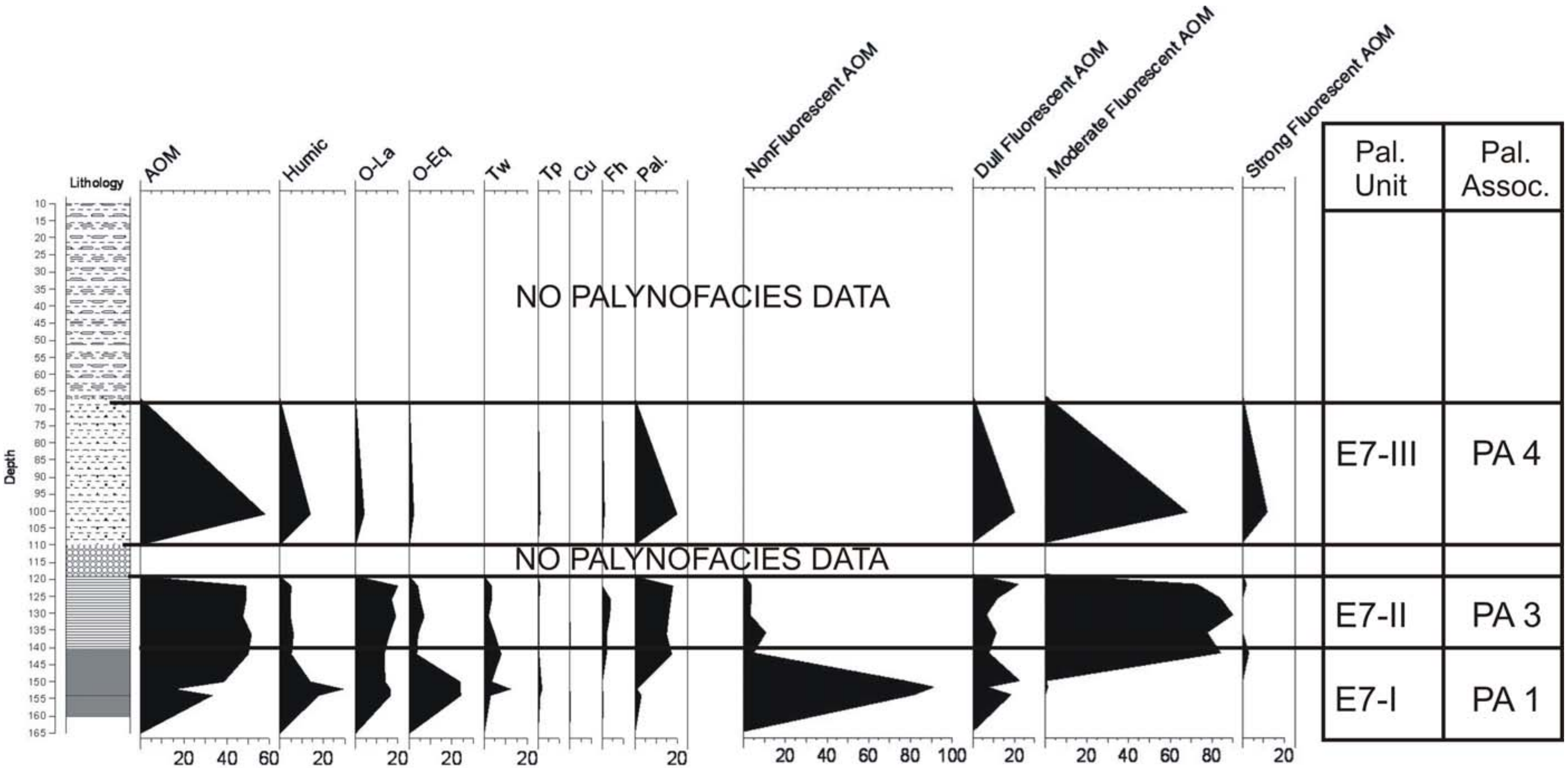


Figure 5.9. Stratigraphic distrubution of palynological kerogen categories in ET-7 borehole

.5.5.2 Palynofacies Unit E7-II

This unit is dominated by the AOM group with an abundance of opaque phytoclast. Opaque lat phytoclast particles are the most abundant particle in the phytoclast group (Table 5.11). Abundance trendline of the AOM group is increase toward top. The AOM group consists of heterogeneous, yellowish to dark brown coloured AOM particles which are smothered to pollen grains and phytoclast. These particles show heterogeneous moderate fluorescence (Qualitative preservation scale 4). Non fluorescence brown coloured humic gels are rare in this group. Unit is observed in grey coloured silty claysotne samples.

Table 5.11 Palynofacies distribution of unit E7-II

Sample No	Palynological Kerogen Groups			Phytoclast Group						AOM Group	
				Opaque		Translucent				AOM	Humic
	AOM	Phyt	Pal	O-La	O-Eq	Tw	Tp	Cu	Fh		
ET-7/N-4	55,36	27,39	17,2	13,6	3,64	7,66	0,57	0	1,92	50,19	5,17
ET-7/N-6	52,46	31,43	16,1	18,66	6,87	1,96	0,59	0	3,34	47,54	4,91
ET-7/N-5	57,43	27,72	14,9	15,84	3,96	4,95	0,59	0,2	2,18	51,49	5,94
ET-7/N-7	54,03	28,29	17,7	19,65	3,93	3,54	0,98	0	0,2	49,12	4,91
ET-7/N-8	53,85	29,39	16,8	16,77	4,93	3,55	0,39	0	3,75	49,11	4,73

5.5.3 Palynofacies Unit E7-III

The relatively high amount of the AOM group with an abundance of palynomorph group, which shows the highest AOM value of whole studied bore holes, is characteristic for Unit E7-III. In addition, the phytoclast group shows the lowest abundance (Table 5.12). Humic gels and AOM particles are composed the AOM group. AOM particles are consisting of dark to grey brown coloured and heterogeneous particles. Pyrite crystals are dominant inclusions in these particles.

Matrix of AOM particles show heterogeneous and moderate to strong fluorescence intensity (Qualitative preservation scale 4-5). This unit is observed in green coloured sandy-silty claystone samples.

Table 5.12 Palynofacies distribution of unit E7-III

Sample No	Palynological Kerogen Groups			Phytoclast Group						AOM Group	
				Opaque		Translucent				AOM	Humic
	AOM	Phyt	Pal	O-La	O-Eq	Tw	Tp	Cu	Fh		
ET-7/N-9	72	8	20	4	2	0	1	0	1	58	14

CHAPTER SIX
PALEOENVIRONMENTAL INTEREPRETATION

Palynofacies association 1 consists of palynofacies units H-II, H- III, E12-I and E7-I. Phytoclast particles in this associtaton are variable and large sized (particularly cuticle fragments. Large sized and high proportion of phytoclast (33-45%) is characteristic for proximal facies (Tyson, 1995). The palynomorphs vary is 1 to 9%, notwithstanding palynomorph species are variable. The high proportion of *Alnus*, presence of swamp element palynomorphs' (Sparganiaceae, Nymphaeaceae, Polypodiaceae), and dense palynomorphs such as Osmundaceae are related with proximal facies, because these pollen grains are generally deposited in near producing plant (Tyson, 1988; Davis, 2000; Martin- Closas et al., 2005; Barron and Rengifo, 2007).

The AOM group is consisting of humic gels and AOM particles. Occurrences of non fluorescent AOM particles (Qualitative Preservation scale 2a-b) indicated oxic-proximal conditions (Follows & Tyson, 1998; Del Papa et al., 2002). Though the presence of weak to moderate fluorescent membranaceous AOM and pyrite crystals is indicate anoxic bottom conditions during deposition. In AOM-phytoclast-palynomorph ternary plot (APP) samples from this association plotted in suboxic-anoxic area (Figure 6.1). Palynofacies associtation 1 corresponds to proximal suboxic-anoxic conditions and probably deposited in shore of lake or swamp depositional environment (Figure 6.2).

Palynofacies association 2 contains palynofacies unit H-IV. This association is only observed in the Hs-2 borehole. The AOM group varies from 72%. It consists of dispersed AOM, that is, heterogeneous particles. These particles show dull to moderate fluorescence intensity and orange fluorescing colours (Qualitative Preservation scale 3-4). That intensity and abundance of AOM group is characterising low energy, oxygen depleted conditions which related to distal anoxic reducing environment (Staplin, 1969; Tyson, 1995; Pitten&Gorrin, 1997).

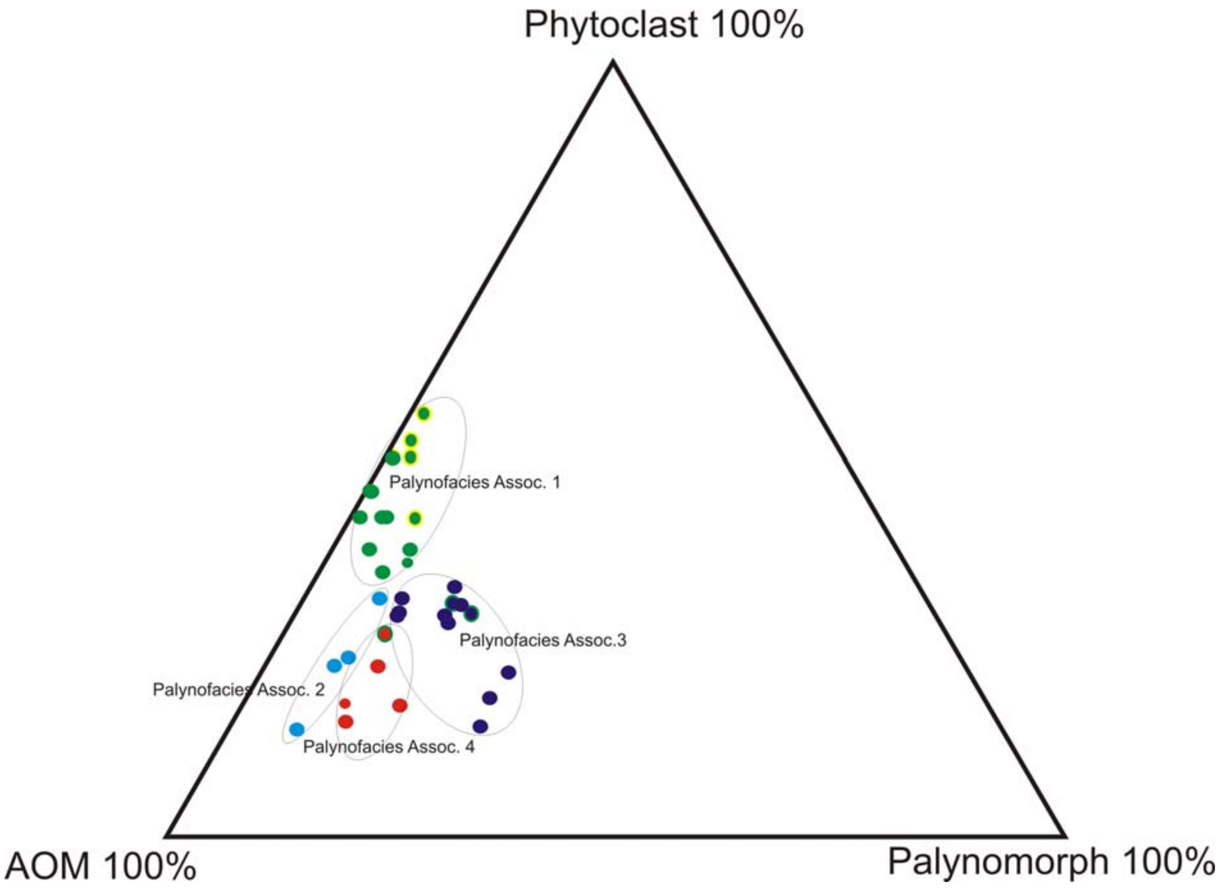


Figure 6.1 Ternary APP diagram (Tyson, 1995) summarising the varying proportions of amorphous organic matter, phytoclasts and palynomorphs in samples from Hs 2and Et-12 bore hole.

Samples from this association are plotted in AOM dominated fields in APP ternary diagram. These fields are usually associated with distal suboxic-anoxic facies (Tyson, 1995). Crystals of pyrite and gypsum in the samples also indicate anoxic conditions. The high propotion of opaque lath particles in phytoclast group is related with distance from fluvial source and low energy conditions (Cope, 1981; Steffen & Gorrin, 1993 b). This association corresponds to distal suboxic-anoxic environments (Fgure 6.2).

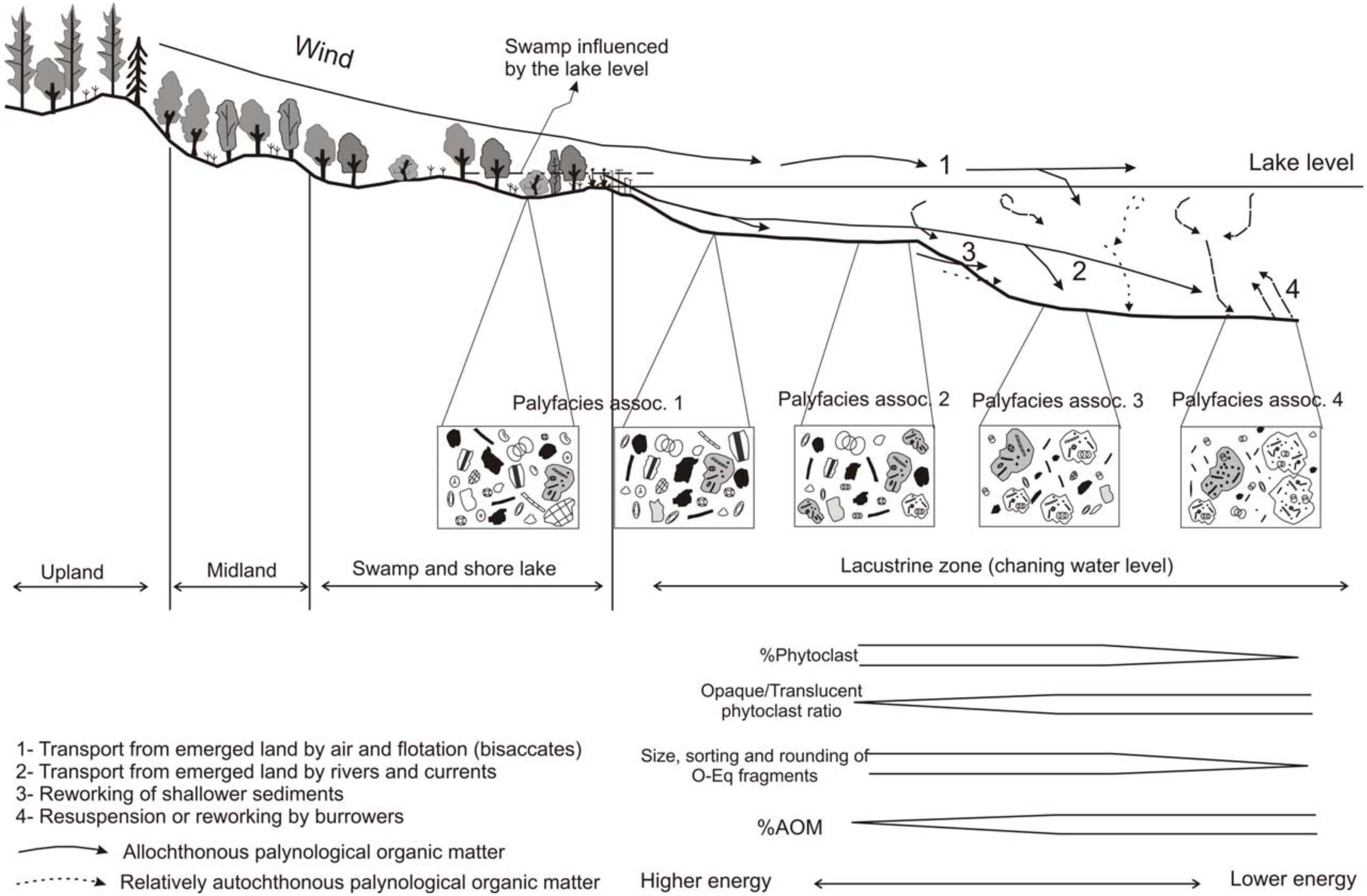


Figure 6.2 Depositional pathways and distribution of palynologocial kerogen (modified from Steffen & Gorrin, 1993 b)

Palynofacies association 3 includes palynofacies unit H-I, HV, E12-II and E7-II. The palynomorph group show highest palynomorph value. AOM group is dominated by large sized heteregenous particles (with pollen grains, phtyoclast and pyrite inclusions). They show moderate fluorescence, orange to brownish yellow colour (Qualitative Preservation scale 4). That fluorescent intensity is characteristic of dysoxic reducing environment. Additionally humic gels are present. Opaque particles show abundance in phytoclast group, however poorly preserved translucent wood fragments and cuticle fragements common. Those particles are small sized.

The high amount of opaque lath particles and fluorescence property indicate distal low energy conditions (Steffen & Gorrin, 1993 b; Tyson, 1993; Waterhouse, 1995). Undetermined dinocysts and acritarchs were found only this association (Ertuğ, 2007 pers. com; Ligouis, 2008 pres. com.). The presence of those are pointed out relatively higher water level than other associations (Ertuğ, 2007 pres. com.) or an increase of salinity in water body (Quattrocchio & Del Pappa, 2000). For all that occurrence of small sized translucent particles and non fluorescent humic gels are related with supply from shallower sediments or reworking of shallower sediments (Steffen & Gorrin, 1993 a; Waterhouse, 1995). In APP ternary diagram this association samples are plotted in distal dysoxic-anoxic fields (Tyson, 1995) (Fgure 6.1). Palynofacies association 3 corresponds distal dysoxic-anoxic depositional setting and relatively high water level (Figure 6.2).

Palynofaceis association 4 consists of palynofaceis unit HVI, E12-III, and E7-III. The AOM is vary up to 72%, consists of abundant granulated, well preserved coherent particles, and humic gels are present. Pyrite crystals are dominant inclusions in well preserved AOM particles. These particles provide strong greenish yellow-yellowish orange fluorsence colour (Qualitative Preservation scale 4-5). That fluorescence intensity and high abundance of AOM represents low energy, stagnant, oxygen depleted paleoenvironments (Boultar & Riddick, 1986; van der Zwan et al., 1990; Tyson, 1995). Such environments are related to distal reducing enviroments (Hart, 1986; Batten, 1996).

Small sized opaque lath particles are dominant compenent in phytoclast group. Those show that distal and low energy environment. In this association bisaccetes are abundant in palynomorph group and most of them were broken. Such pollen grains are generally found in the deep lacustrine conditions (Hopkins, 1950; Davids, 2000; Martin-Closas et al., 2005; Barron&Rengifo, 2007). In APP ternary plot, this association plotted in distal dysoxic-anoxic flied (Figure 6.1). This association indicates distal dysoxic-anoxic environments and deposited in lacustrine facies (Figure 6.2).

CHAPTER SEVEN
CONCLUSIONS

Palynofacies analyses on the coal bearing sediment in Çanakkale-Çan basin have yielded following conclusions.

1. For the palynofacies analyses palynological kerogen categories were counted and five types of palynological kerogen were identified for analyses. These kerogens are; amorphous organic matter (AOM), opaque equidimensional phytoclast, opaque lath phytoclast, translucent phytoclast and palynomorphs.
2. The cluster analysis is based on distribution and abundance of palynological kerogen types which are used for the definition palynofacies units.
3. In borehole Hs-2 two superclusters were revealed. Supercluster A is mainly consists of phytoclast group. The AOM group is mainly included in supercluster B. For bore ET-12, two superclusters were revealed as supercluster A and B. Opaque equidimensional phytoclast particles are mainly included in supercluster A. Supercluster B is characterized by a moderate abundance of AOM group. Two super clusters were revealed in bore hole ET-7. Supercluster A characterized by a proportion of equidimensional phytocalst particles. The AOM group shows high proportion in supercluster B.
4. Based on the cluster analysis three palynofacies units are defined in boreholes Et-12 and Et-7, and six palynofacies units in the borehole Hs-2.
5. The succession studied in boreholes Hs-2, ET-7 and ET-12 in the basin showed a rich palynological kerogen content.
6. The phytoclast group shows a moderate abundance in lower parts of sedimentary successions in boreholes. In upper successions, the AOM group shows a moderate abundance and the abundance trend increases toward the top, there is a clear increase in the palynomorph group.

7. Based on composition, distribution and abundance of palynolgoical kerogen types, and clusters, four palynofacies associations were recognized.
8. Palynofacies association 1 is characterized by predominance of phytoclast group combined with a moderate of the AOM group. The palynomorph group has low value, however palynomorph species are variable. Humic gels are common in AOM group.
9. The AOM group dominated in kerogen assemblage in palynofacies association 2. The phytoclast group is dominated by opaque lath particles.
10. In palynofacies association 3 AOM and palynomorphs are dominated kerogen assemblage. The AOM group is mainly consists of well preserved AOM particles with inclusions. Humic gels and small sized translucent particles are preserved. The palynomrophs group shows the highest palynomorph group.
11. Palynofacies association 4 shows the highest AOM value in the studied succession.
12. The palynofacies analysis allowed environmental reconstruction of the studied succession.
13. In palynofacies association 1; the high proportion of phytoclast, swamp element palynomorphs, and non fluorescent AOM particles are indicated proximal oxic conditions. Therefore this association deposited in shore of lake or swamp environment.
14. Due to the dominance of dull to moderate fluorescent AOM particles, high proportion of lath particles in phytoclast group, palynofaceis association 2 corresponded distal, low energy and low oxygen conditions.
15. The palynofacies association 3 occurred in relatively higher water level, distal dysoxic-anoxic botton conditions because of moderate heterogeneous fluorescent AOM particles and undetermined dinocysts and acritarchs. However occurrences of non fluorescent humic gels and small sized translucent phytoclast particles are pointed out supply or reworking from shallower sediments.

16. The palynofacies association 4 indicates deep lacustrine facies with dysoxic-anoxic bottom conditions owing to dominance of strong fluorescent well preserved algal AOM, minimal sized equidimensional particles; and fragmented bisaccete pollen grains.

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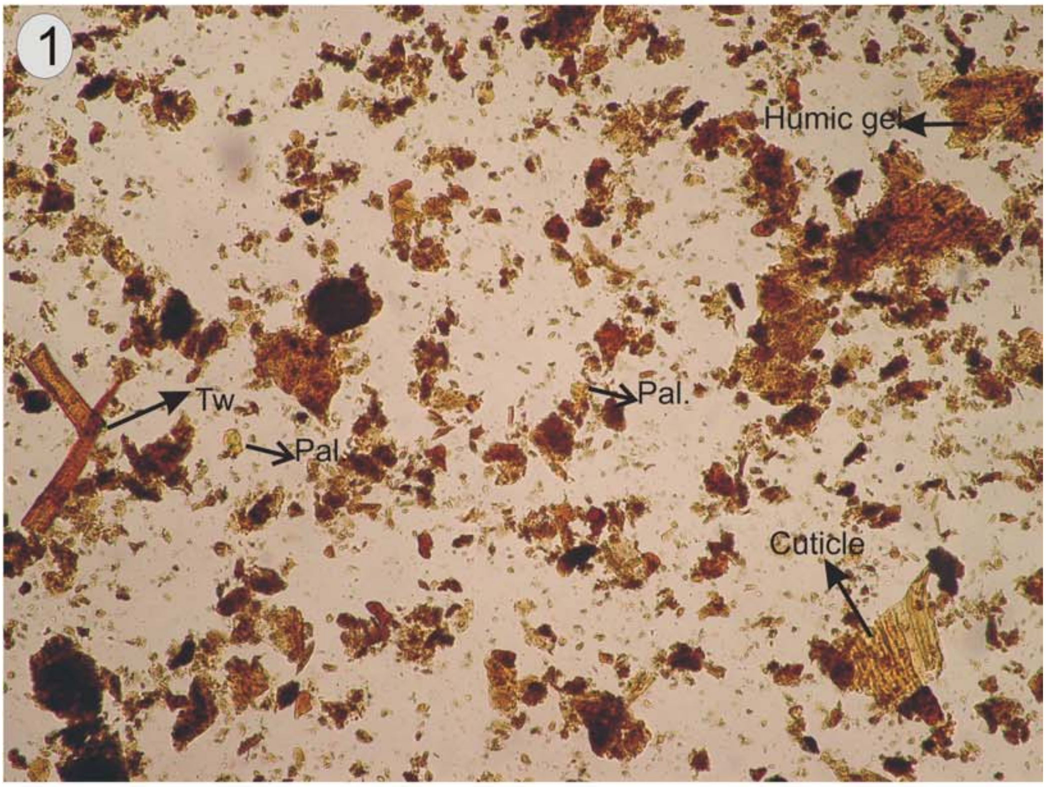
PLATE-II

Palyological kreogen types Palynofacies 1

Figure 1. Humic gels, Translucent phytoclast well preserved (Tw), Opaque equidimensional phytoclast (O-eq), Cuticle, Amourphous organic matter (AOM), Pollen grains (Pal.) - Hs-2 borehole, 133 m. (Claystone sample).

Figure 2. Amourphous organic matter (AOM), Opaque equidimensional phytoclast (O-eq), Cuticle, Opaque Lath phytoclast (O-La) - Hs-2 borehole, Hs-2 borehole, 128 m. (Lignite sample).

Plate-I



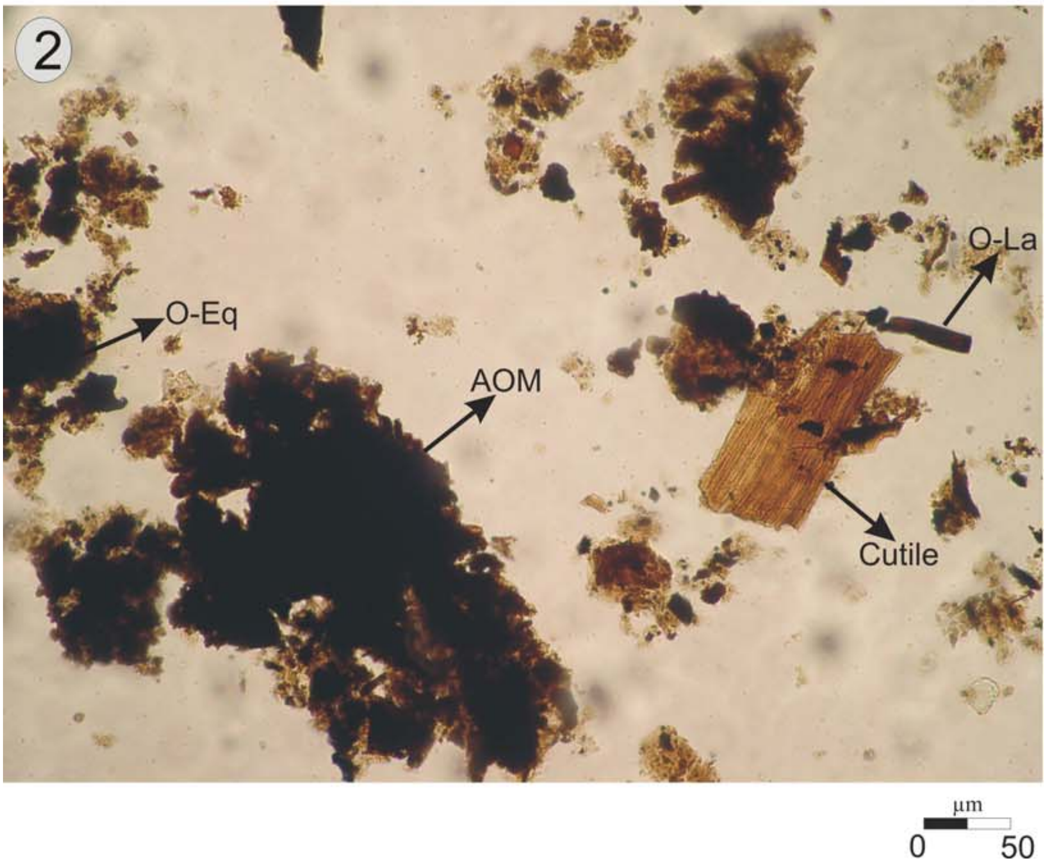


PLATE-II

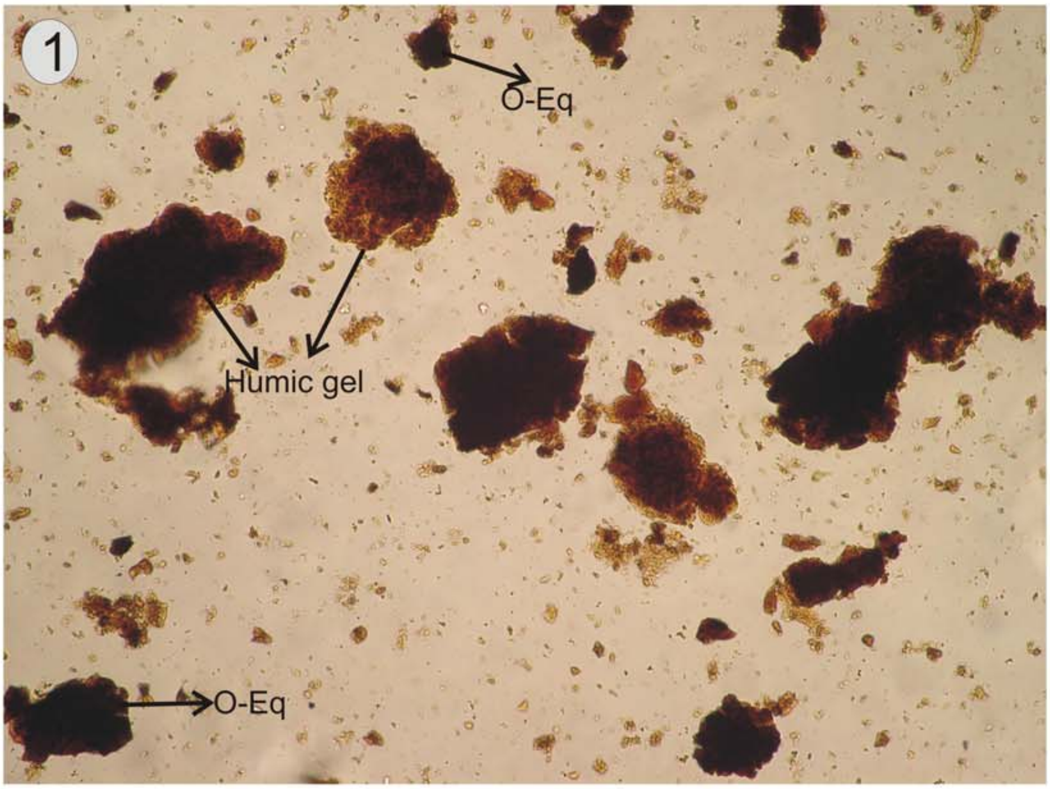
Palyological kreogen types Palynofacies 1

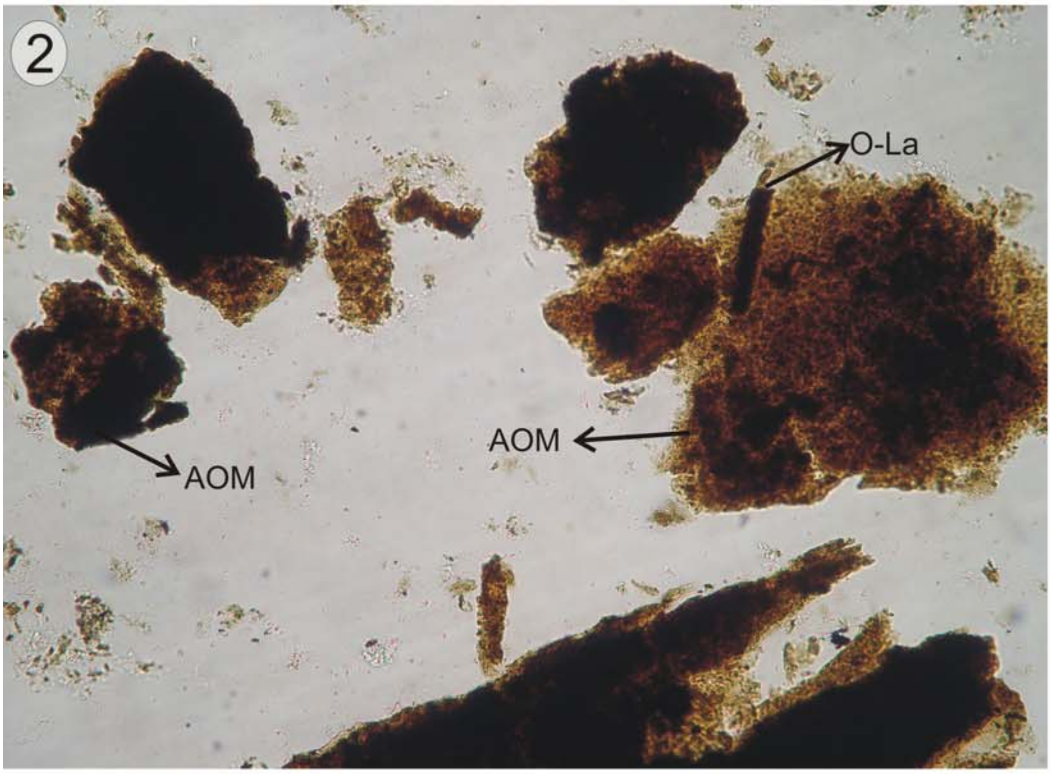
Figure 1. Humic gels, Opaque equidimensional phytoclast (O-eq), Amourphous organic matter (AOM) - Hs-2 borehole, 120 m. (Lignite sample)

Palyological kreogen types Palynofacies 2

Figure 2. Amourphous organic matter (AOM), Opaque Lath phytoclast (O-La) Opaque equidimensional phytoclast (O-eq) – Hs-2 borehole, 112 m. (Claystone sample).

Plate-II





µm
0 50

PLATE-III

Palyological kreogen types Palynofacies 3

Figure 1. Amourphous organic matter (AOM), Pollen grains (Pal.), Opaque equidimensional phytoclast (O-eq), Fungal hypae – ET-7 borehole, 136m. (Silty claystone sample)

Palyological kreogen types Palynofacies 4

Figure 2. Amourphous organic matter (AOM), Opaque Lath phytoclast (O-La), Pollen grains (Pal.) – ET-12 borehole, 115 m. (Organic claystone sample).

Plate-III