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AUTHOR – AUTEUR

Full Name of Author – Nom complet de l'auteur: THOMAS GENTZIS

Date of Birth – Date de naissance: AUGUST 11, 1958

Canadian Citizen – Citoyen canadien: ☐ Yes Oui ☑ No Non

Country of Birth – Lieu de naissance: GREECE

Permanent Address – Résidence fixe:
12 Willow [illegible]
Calgary, Alberta
T3C [illegible]

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ORGANIC PETROLOGY AND DEPOSITIONAL ENVIRONMENT OF THE HAT CREEK No. 2 COAL DEPOSIT, BRITISH COLUMBIA, CANADA

by

ⓒ THOMAS GENTZIS

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND
RESEARCH IN PARTIAL FULFULLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE

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Supervisor

Frances J. Hein

F. GOODARZI

External Examiner

Date 1985-10-10

ABSTRACT

The Hat Creek No. 2 coal deposit occurs within folded and faulted Tertiary (Eocene) strata of the Kamloops Group, which comprises shales, siltstones and conglomerates underlying the floor and lower flanks of upper Hat Creek valley.

The deposit was divided into four main zones: A, B, C, and D. Macrosopically, the coal zones A and D appear bright and rich in huminite. These zones also have the thickest 'clean' uninterrupted coal measures. Zones B and C contain fewer and thinner coals seams, are rich in humodetrinite and, macroscopically, consist mainly of carbominerite and carbonaceous shale.

The coals are very low in inertinite, indicating low levels of peat (forest) fire and/or oxidation in accordance with the climatic conditions during mid-Eocene. Sub-tropical and humid forest-moor swamp environments were dominant in the Hat Creek swamps, characterized by *Metasequoia* and *Glyptostrobus*. A transitional reed marsh, dominated by *Equisetum* and minor *Typha*(?) was the co-dominant moor environment.

The coal deposit is of lacustrine origin and the coal formed in a graben structure in an isolated intermontane basin. The coal is autochthonous (*in situ*) in origin for zones A and D with increasing hypautochthonous (semi-drifted) influence in zones B and C. A very delicate balance among the rate of subsidence, run-off and vegetation growth existed for a very long period of time before the swamp finally drowned.

Thick coal seams formed under a stable environment, whereas thin seams, interbedded with sediment, formed under unstable water conditions.

A high proportion of humotelinite and humocollinite indicates 'dry' conditions, whereas a high proportion of humodetrinite and inertinite (Sclerotinite) indicates 'wet' conditions in the peat swamp.

Eu-ulminite reflectance was used for rank determination and results appear to be suitable for determining the coalification trend of low-rank coals. The reflectance of eu-ulminite varied slightly depending on whether it was enclosed in coal, shale or carbonate matrix, and the coalification gradient was very small.

The rank of the Hat Creek No. 2 coal deposit is lignite (0.35% R_{oil}) to subbituminous B (0.45% R_{oil}).

PURPOSE OF THE STUDY

General aims

The study has two general aims:

1. To determine the petrographic characteristics of the Hat Creek coals and of the dispersed organic matter (kerogen) found in the interbedded sediment using both reflected (white) and fluorescent (ultra-violet/blue) light microscopy.
2. To examine the nature and vertical variation of the coal and associated clastics in borehole cores and to establish the depositional environment of the deposit.

Specific aims

1. To determine the suitability of huminite reflectance as a rank parameter in these low-rank (lignite to subbituminous) coals; and if suitable, to use this parameter as the basis of determination of the coalification gradient.
2. To compare the reflectance of huminite (eu-ulminite) in coal with the reflectance of dispersed organic matter (kerogen) in interbedded clastics and carbonates.
3. To establish and correlate the associations of the various macerals and define the depositional environment in the ancient peat swamp.
4. To examine the various types of the maceral resinite using fluorescence microscopy.

ACKNOWLEDGMENTS

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1.0 INTRODUCTION

1.1 History of the coal deposits

The Hat Creek coal deposits were first reported by G.M. Dawson of the Geological Survey of Canada in 1877. The coal exposures were limited to a small area along the bank of Hat Creek, where erosion had removed the cover of glacial till. By 1925, three shallow shafts and two adits had been driven into the coal and seven holes had been bored into it, but no further work was done until 1933. From 1933 until 1942, a few hundred tons of coal were mined each year and sold locally, but this activity ceased during World War II and was never resumed (Campbell *et al.*, 1977).

In 1957, Western Development and Power Ltd., a subsidiary of British Columbia Electric Co. Ltd., optioned the property as a possible future fuel source for a major thermal-electric generating plant. The area of the exposed portion of the Hat Creek coal deposits was explored by reconnaissance diamond drilling and trenching during 1957 and 1959. The property was subsequently bought by B.C. Electric (Campbell *et al.*, 1977).

Following expropriation of B.C. Electric by the Provincial Government, the ownership of the coal property passed to the B.C. Hydro and Power Authority and no future work was done on it until 1974. Since that year, 55,750 m of diamond drilling, 1394 m of rotary drilling and 273 m of bucket auger drilling were completed for the Hat Creek coal deposits. In addition, 5273 m have been drilled for engineering purposes (Campbell *et al.*, 1977).

The upper Hat Creek valley is located at 50°45'N and 121°35'W, (Fig. 1-1) within the Interior Dry Belt of British Columbia. The floor of the valley ranges in elevation from 850 m ASL at the north end to about 1200 m ASL at the south end.

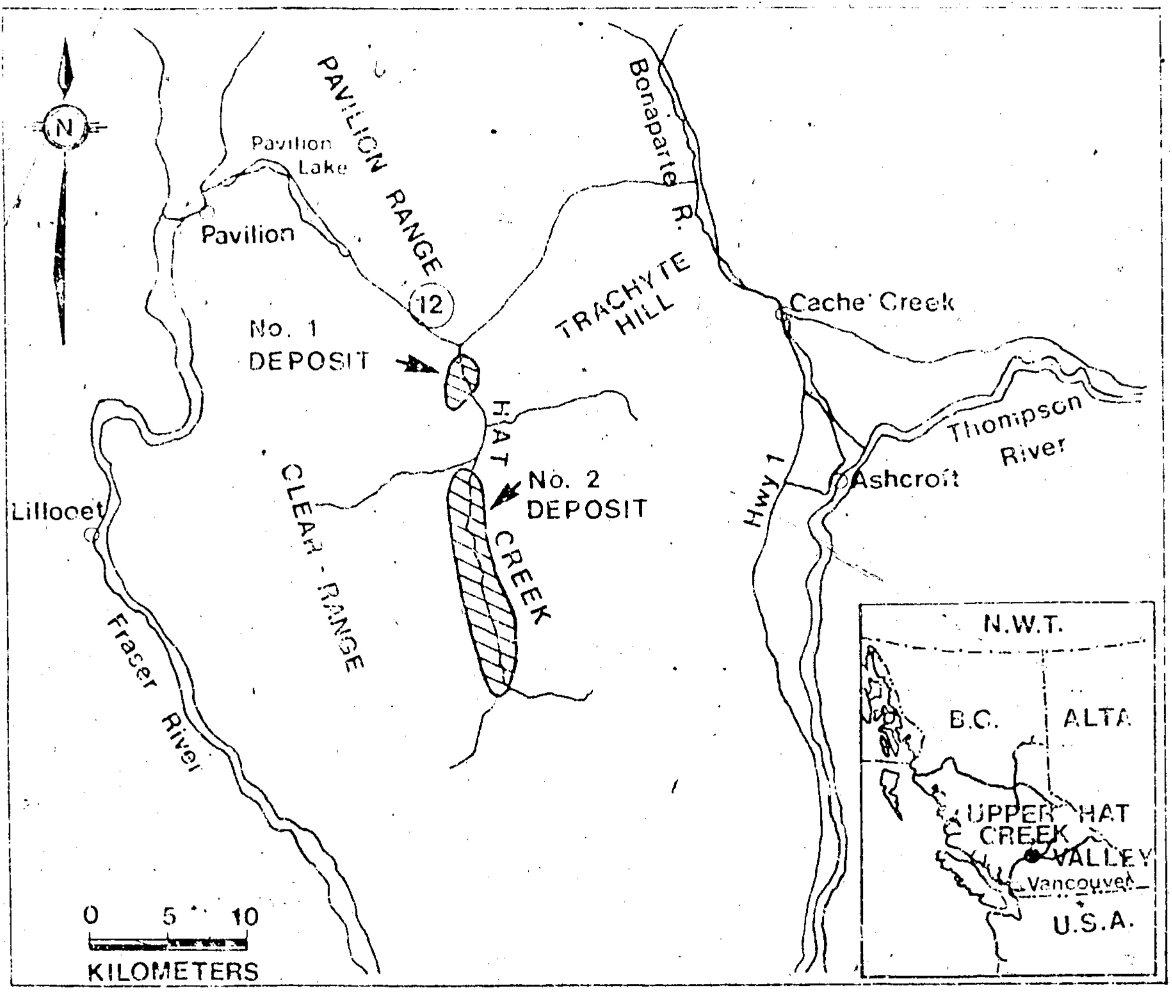


Figure 1-1. Map location of the upper Hat Creek valley (inset) and the relative position of the Hat Creek No. 1 and No. 2 coal deposits (adapted from British Columbia Hydro and Power Authority, 1980).

2.0 PREVIOUS WORK

Church (1975) and Campbell *et al.* (1977), studied the geology of the Hat Creek valley and Kim (1979) investigated the stratigraphy and depositional history of the deposits. Hopkins (1980) studied the palynology of the Hat Creek deposits and Blackburn (1982) described the paleobotany of the deposits.

Two separate coal deposits, the No. 1 and No. 2, are present in the Hat Creek valley (Fig. 1-1). Almost all previous work has been done on the No. 1 deposit.

2.1 Organic Petrology

The organic petrology and reflectance studies of the Hat Creek No. 1 coal deposit were initially carried out by Marchioni (in prep.). Marchioni was mainly interested in the maceral composition of the coal microlithotypes and used only selected coal samples from a 9 m interval taken from the basal zone of the coal deposit.

Goodarzi (1985) studied the Hat Creek No. 1 coal deposit in detail, in terms of its organic petrology, environment of coal deposition and the characteristics of its liptinite macerals under fluorescence (blue and ultra-violet) light. He arrived at the following conclusions:

a) The Hat Creek coal is lignitic at the top and becomes subbituminous at the base.

b) The low inertinite content of the coals is unique and indicates a relatively humid coal-forming environment.

c) The reflectance of huminite particles contained in interbedded sediment is less for shales, similar for siltstones and equal or slightly higher for carbonates in comparison to the reflectance of huminite in coals.

d) The high proportion of liptinite in coal may result in the lowering of the reflectance of coal in comparison with similar coal containing less liptinite.

e) The relationships among the huminite group of macerals are good indicators of the paleoenvironment. A high proportion of humotelinite indicates dry conditions whereas a high proportion of humodetrinite indicates wet conditions.

f) Coals formed in an unstable environment contain thin seams and more interbedded sediment, whereas coals formed in a stable environment contain thicker seams and very little interbedded sediment.

2.2 Palynology

No palynological work has been done on the Hat Creek No. 2 coal deposit. Most of the information regarding palynomorph assemblages of the upper Hat Creek valley comes from Hopkins (1980) and Blackburn (1982).

Additional work by Rouse (1977) on the palynomorphs of the interior of British Columbia helped in trying to establish the paleoclimatic conditions that prevailed in this area during the Middle and Late Eocene.

Blackburn (1982) studied 18 samples taken from a trench of the Hat Creek No. 1 coal deposit. He sampled both coal-bearing and interbedded clastic sequences of the Hat Creek Coal Formation, and found that the coal-bearing strata are dominated by the fossil remains of *Glyptostrobus* and *Metasequoia*. *Metasequoia* appeared to dominate the more massive coals with lower inorganic content, whereas *Glyptostrobus* was more dominant in the more clayey coals. *Equisetum* was locally abundant in transitional carbonaceous clays and was associated with the gymnosperms mentioned above, whereas the more massive clay and carbonaceous shale units were dominated by ferns and angiosperms. The angiosperm families Betulaceae and Tiliaceae were observed based on their leaf remains.

Rouse (1977) also identified several palynomorph assemblages from a borehole (77-44) of the Hat Creek No. 1 deposit. He concluded that the genera *Taxodium*, *Glyptostrobus*, *Pinus*, *Juglans* and *Carya* were the dominant ones whereas *Tilia*, *Quercus*, *Liquidambar*, *Engelhardtia* and *Alnus* were the subdominant genera present.

Hopkins (1980) studied 49 samples taken from borehole 75-106 in the center of the Hat Creek No. 1 deposit. He treated coal and clastics independently in order to determine if significant variation in microfloral content existed in the two lithologies.

He arbitrarily categorized all palynomorphs into four main groups: *Pinaceae*, *Cupressaceae-Taxodiaceae*, ferns and angiosperms. He observed that a gradual decrease of the conifers *Pinaceae* and *Cupressaceae-Taxodiaceae* down the hole was replaced by an increase in the relative abundance in the angiosperms.

The coal fraction showed a higher proportion of *Alnus* and a reduced *Cupressaceae-Taxodiaceae* content as compared to the clastics.

Hopkins (1980) states that the depositional environment, the climate, and the taxa he identified from the borehole remained remarkably constant throughout the deposition of the Hat Creek Coal Formation. An increase in *Pinaceae* and a decrease in virtually everything else in the upper 130 m of the coal deposit could have been the result of a major climatic deterioration, or most likely, a change in the local environment which accompanied the termination of the deposition in the basin.

Hopkins also estimated that it probably took 1.3 to 2.1 million years for the No. 1 deposit (300 m thick) to accumulate at a rate of accumulation of 1 m per 4500 to 7500 years. He agrees with Rouse (in Kim, 1979) that an Upper Eocene age is the most likely but does not completely rule out a Lower to Middle Oligocene age based on some of his data. Additional evidence based on potassium-argon (K/Ar) dating (Hills and Baadsgaard, 1967; Wilson, 1979) gives a Middle Eocene age (45 Ma to about 53 Ma with an average 48 Ma) for rocks of the Kamloops Group.

3.0 REGIONAL GEOLOGY

3.1 Geology during the Late Cretaceous

During Late Cretaceous time, the portion of western Canada presently occupied approximately by the interior system was predominantly a mountainous land area, flanked to the east by a broad epeiric sea and to the west by open ocean. Upper Cretaceous strata found in the interior system thus are a product of continental sedimentation in intermontane basins. Coarse continental clastics, including coal, and interbedded volcanic rocks, characterize Upper Cretaceous strata of the interior system (Williams and Burk, 1964).

3.2 Geology during the Paleocene

Continental sedimentation continued without interruption through uppermost Cretaceous into Paleocene time in most of western Canada. The bulk of these sediments are clastics, coarsest nearest the source area.

Plant debris accumulated to considerable thicknesses in the west and in lesser amounts in the east and north, in swamp and deltaic environments associated with slow-moving rivers and shallow lakes (Taylor *et al.*, 1964).

3.3 Geology during the Eocene-Oligocene

The Eocene time was the time of major uplift and profound deformation of strata resulting in the formation of the Rocky Mountains. The particular time of the culmination of Laramide Orogeny within the Eocene has not been determined. Hypotheses have been advanced supporting intervals from Early Eocene to Late Eocene in age (Taylor *et al.*, 1964).

Numerous occurrences of volcanic rocks in the southern interior of British Columbia are in isolated structural basins and fault troughs surrounded by older and stratigraphically higher rocks. The great thicknesses, in excess of 1500 m in some of the basins, are almost certainly local (Taylor *et al.*, 1964). Apart from the conglomerates of fluviatile origin, the associated sedimentary rocks (particularly the lacustrine beds and coal) are essentially restricted to the basins. It appears that the accumulation of sediments and of abnormally thick volcanic successions took place during subsidence of the individual basins. Six potassium-argon dates (45-49 Ma) from five separate occurrences as well as vertebrate remains from one locality all indicate a common Middle Eocene age (Rouse and Matthews, 1961).

3.4 Tectonics

Widespread Late Mesozoic and Early Cenozoic sedimentary sections in western North America are associated with a continental margin arc-trench system (Dickinson, 1976). The Hat Creek basin which is located in the Intermontane Belt of the Canadian Cordillera lay within the magmatic arc. After a period of magmatic cessation during the Late Cretaceous and Early Tertiary, arc magmatism resumed during the Eocene 55 to 50 million years ago (Davis, 1977; Snyder *et al.*, 1976).

Eocene geology of the Intermontane Belt in south-central British Columbia is characterized by concomitant volcanism and sedimentation. Regional north-south block faulting was prevalent and thick successions of volcanic and sedimentary rocks were deposited in lakes and valleys associated with north-south trending block faults (Okulitch *et al.*, 1977). Block faulting along with volcanism provided possible mechanisms for the formation of poorly drained areas suitable for coal deposition (Taylor *et al.*, 1964).

The region surrounding the Hat Creek area forms the westernmost part of the Intermontane Belt. It is bounded on the west by the north and northwest striking Fraser fault system, west of which again is the predominantly granitic Coast Plutonic Complex. Steeply dipping faults, parallel and subparallel with those of the Fraser fault system, are the dominant features (Monger, 1981). These normal faults are at least in part contemporaneous with extrusion of Eocene continental volcanics (Ewing, 1981) and may be linked genetically with the right lateral, strike-slip Fraser fault system (Price, 1979).

3.5 Palynology of Central British Columbia during the Eocene

Palynomorph assemblages from Interior British Columbia imply a warm to subtropical continental climate during Middle and Late Eocene time (Rouse, 1977). Conifers, such as *Metasequoia* and *Glyptostrobus* (Blackburn, 1982) and other plants found in Hat Creek coals probably grew near the water table. The genera *Alnus*, *Pinus*, *Betula*, *Carya* and *Juglans*, present in the Hat Creek coal deposits, are all characteristic of a subtropical to warm temperate climate (Leopold, 1969). Rouse (1977) states that the interior Eocene assemblages reflect a slightly cooler climate than coastal Eocene assemblages, and suggests that the present Coast and Cascade Mountain Ranges were much lower during the Eocene than at present. He identified coniferous pollen represented by the *Pinaceae* and deciduous pollen represented by the *Juglandaceae* in coals from the Princeton coalfield.

Other evidence (Wolfe and Barghoorn, 1960) confirms the existence of humid, to partly subtropical forests in the northwestern U.S. and southwestern Canada during Eocene time. *Glyptostrobus* probably indicates a forest swamp in a warm temperate or subtropical climate (Barghoorn and Spackman, 1950).

3.6 *Relation between the Hat Creek and adjacent basins*

Surrounding the Hat Creek area in the south central interior of British Columbia (Fig. 3 1) are a large number of irregularly shaped areas of Tertiary formations. Most of these areas expose Tertiary volcanic rocks at the surface, and are probably underlain by pre-Miocene sedimentary and volcanic rocks. Their present location, along with the fact that numerous faults are present in the area, suggests that the patches are remnants of one or more Tertiary basins (Campbell *et al.*, 1977).

All of the known Tertiary coal deposits in the Hat Creek basin as well as in the adjacent basins of Tulameen, Princeton and Merritt in south central British Columbia, occur within Eocene sedimentary strata (Williams and Ross, 1979). Correlations of these sedimentary basins are hampered by the scarcity or absence of diagnostic fossils, facies changes and poor exposures (Hills, 1965), although Wilson (1979) correlated Tertiary rocks from the above basins based on freshwater fish remains. At the present time they are isolated from one another but may have been originally interconnected; all are Eocene in age and the sedimentary strata that underlie or incorporate the coal seams are of fluvial-lacustrine origin (Rice, 1947; Cockfield, 1948).

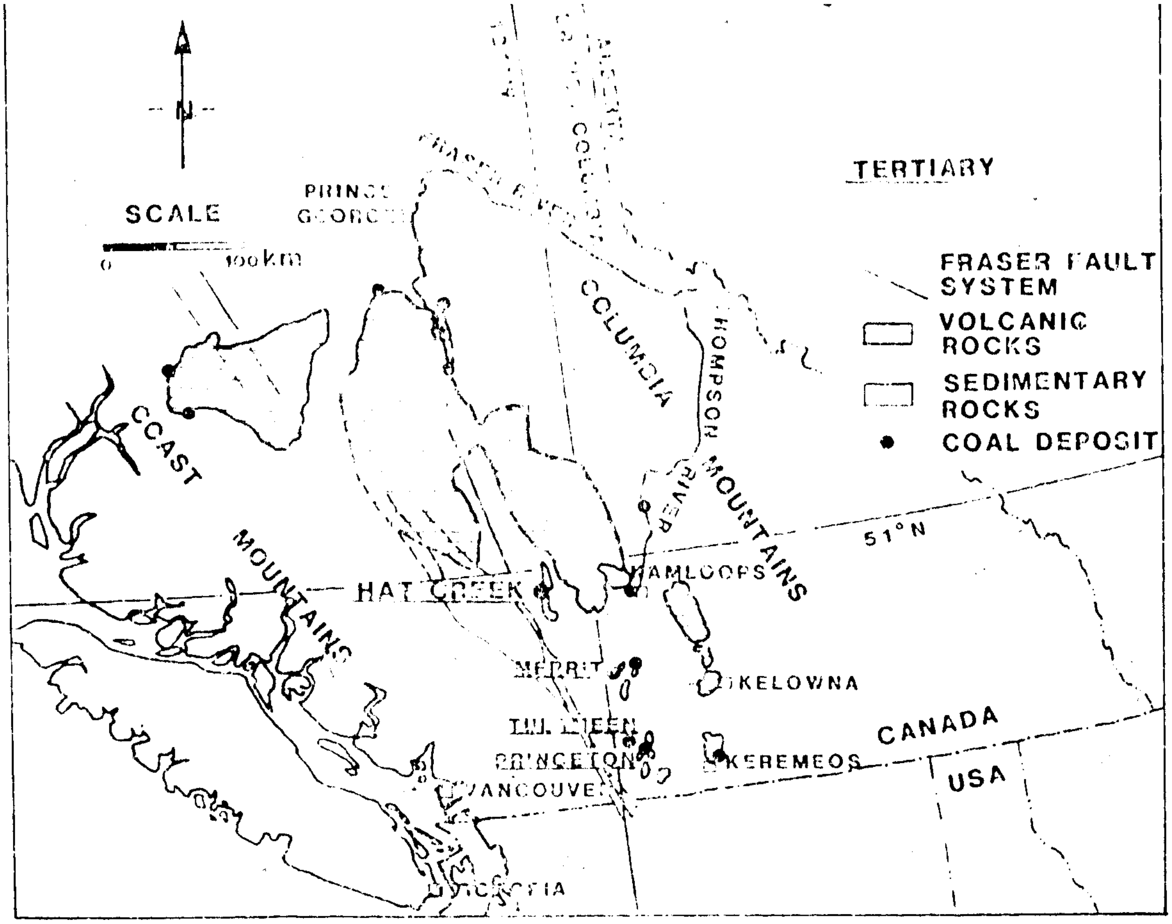


Figure 3-1. Tertiary remnants in south-central British Columbia (adapted from Campbell et al., 1977).

4.0 GEOLOGY OF THE HAT CREEK AREA

4.1 General geology

The geology of the Hat Creek area was described originally by Dawson (1877) and was later amplified by MacKay (1926) and Duffell and McTaggart (1952). Recent studies include a number of investigations by Campbell et al. (1977) for the British Columbia Hydro and Power Authority and by Hoy (1975). MacKay (1926, p. 166A, 167A) provides a good geological summary:

> "The oldest rock formation exposed near upper Hat Creek and the one which apparently underlies all the coal basin is a thick series of compact, grey limestones and argillites of Carboniferous age. These beds, termed by Dawson the Cache Creek group, have been folded and faulted and three miles west of upper Hat Creek are intruded by several large stocks of granite, granodiorite and diorite, so that much of the limestone has been converted into marble, hence the name Marble Canyon. The age of the instrusives is not definitely known, but they are thought to be late Jurassic, the period of the Coast Range batholith intrusion.
>
> Lying unconformably upon the limestone is a series of early Tertiary deposits, several thousand feet thick, consisting of a basal conglomerate overlain by brown to purplish-weathering, semi-indurated sandstone, shales, and clay, which in the upper part of the series carry thick seams of lignite. The outcrops of these sediments which have been designated by Dawson the Coldwater Group, are confined to the lower slopes of Hat Creek valley, and it may be that the coal basin is very limited in extent.
>
> From divergence of dip observed in the tunnel section and the volcanic outcrop 1000 feet distant the Tertiary sediments appear to be unconformably overlain by Miocene volcanics consisting of basalt, breccias and tuffs, the latter being in places fine-grained and showing distinct stratification, as if laid down under water. These have been subjected to folding and faulting parallel to the general axis of the valley, so that they now dip at angles up 45 degrees. The volcanics have their greater development to the west of Hat Creek, covering all of Clear Mountain range, where the events were apparently located. Late Tertiary erosion has largely removed the volcanics from the valley area, but remnants of the extensive flows still occur on the east slope of the valley and on the west of Hat Creek to the coal outcrop."

The volcanic rocks, considered by Dawson to be entirely of Tertiary age, are now known to comprise a broader assemblage of both Cretaceous and Tertiary lavas and breccias referred to as the Spences Bridge Group and Kamloops Group, respectively (Duffell and McTaggart, 1952).

4.2 Regional stratigraphy

The oldest rocks of the Hat Creek coal basin are Pennsylvanian to Permian in age or perhaps older, and the youngest are Quaternary (Campbell *et al.*, 1977). Therefore, the stratigraphic column covers a time span of over 250–300 million years of sedimentation and igneous activity in the vicinity of the upper Hat Creek valley. Some of the ages have been established by palynology and plant fossils studies (Duffell and McTaggart, 1952; Rouse, 1977).

4.2.1 Paleozoic and Mesozoic stratigraphy

The oldest stratigraphic unit in the region is the Cache Creek Group (Fig. 4–1), which has been divided into the Marble Canyon Formation, consisting of limestone and marble and the Greenstone Formation, consisting mainly of chert, limestone, argillite, chlorite, schist and quartz–mica schist (B.C. Hydro and Power Authority, 1980).

The Cache Creek Group has been intruded by granodiorites and tonalites of the Mount Martley Stock, which is probably of Jurassic age (B.C. Hydro and Power Authority, 1980). The stock is unconformably overlain by the andesites, basalts, dacites and rhyolites of the Cretaceous Spences Bridge Group (B.C. Hydro and Power Authority, 1980).

4.2.2 Cenozoic stratigraphy

The Kamloops Group which is divided into numerous formations, unconformably overlies the Spences Bridge Group. The Kamloops Group, of Middle Eocene age, consists of rhyolites, dacites, andesites, basalts and pyroclastics. These volcanics are overlain by sedimentary rocks of the Coldwater Formation which consists of sandstone, siltstone, conglomerate and coal. Lying conformably over the Coldwater strata is the Hat Creek Coal Formation, composed mainly of coal with interbedded sandstone, siltstone and claystone.

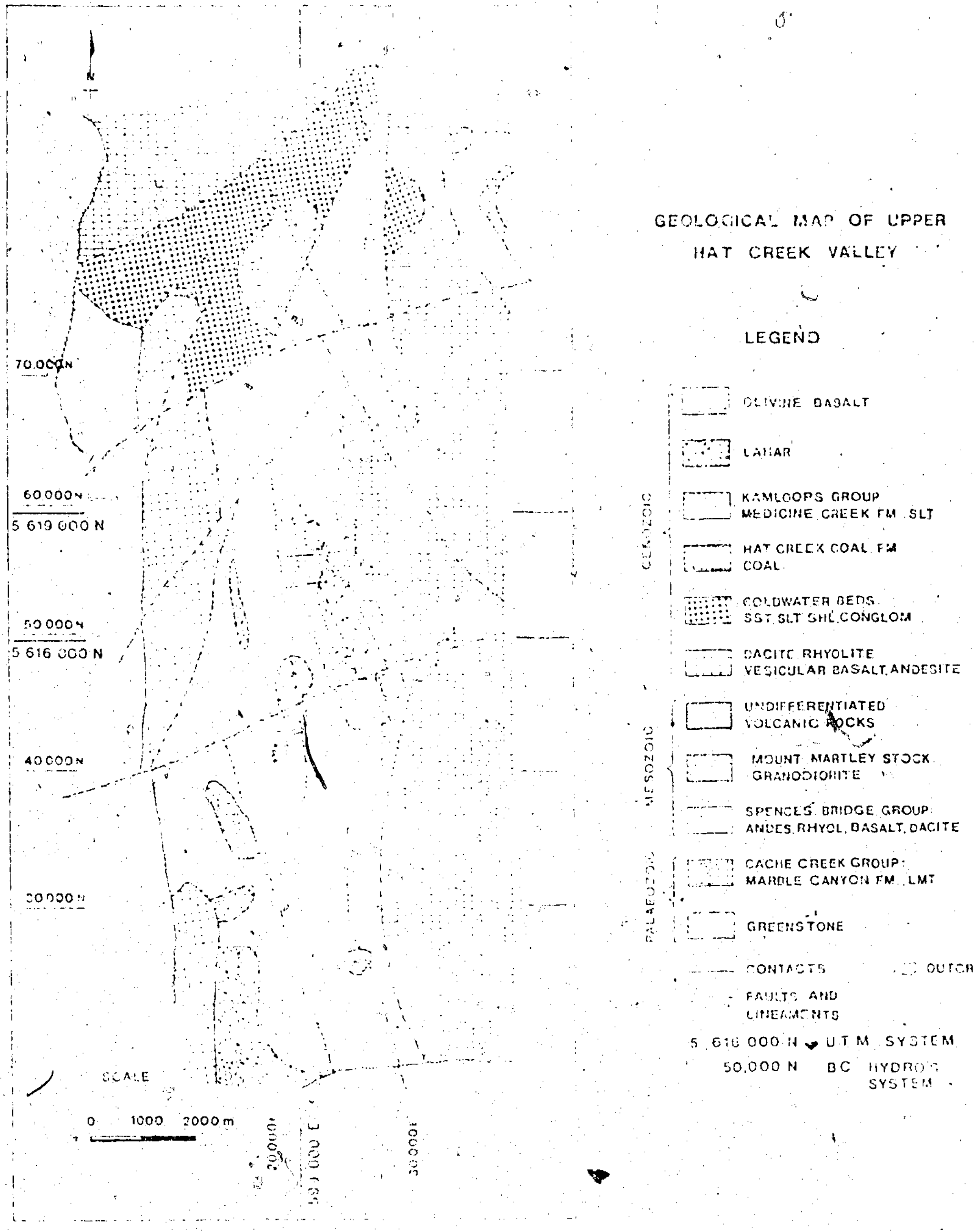


Figure 4-1. Geological map of upper Hat Creek valley (adapted from British Columbia Hydro and Power Authority, 1980).

Overlying the Hat Creek Coal Formation paraconformably is the Medicine Creek Formation which consists of approximately 600 m of monotonous lacustrine sediments.

The uppermost stratigraphic units of the Kamloops Group is represented by the sandstone and conglomerate of the Finney Lake Formation.

Miocene plateau basalts overlie the Finney Lake Formation. These consist of olivine basalts, andesites and vesicular basalts that have been dated at 13.2 Ma, and are the youngest volcanic rocks in the area (B.C. Hydro and Power Authority, 1980).

The generalized stratigraphic succession of the Tertiary of the Hat Creek coalfield and its correlation to the Tertiary succession of the three other major coalfields in south-central British Columbia are given in Figure 4-2.

4.2.3 Quaternary stratigraphy

During the Quaternary the entire Hat Creek area, along with a large part of the Interior Plateau was extensively glaciated. As a result, up to 150 m of till, glacio-fluvial and glacio-lacustrine sediments, with associated alluvium and colluvium were deposited (B.C. Hydro and Power Authority, 1980).

4.3 Regional structure

The structure of the upper Hat Creek basin is relatively simple. With the exception of the volcanics at the south end of the valley, most of the Tertiary rocks, which contain the coal, occur along the lower slopes of the valley.

The central zone of the valley is a graben (Fig. 4-3) formed by downward movement on a series of north-south tension faults trending subparallel to the direction of regional maximum stress (Church, 1975). Locally, the walls of the

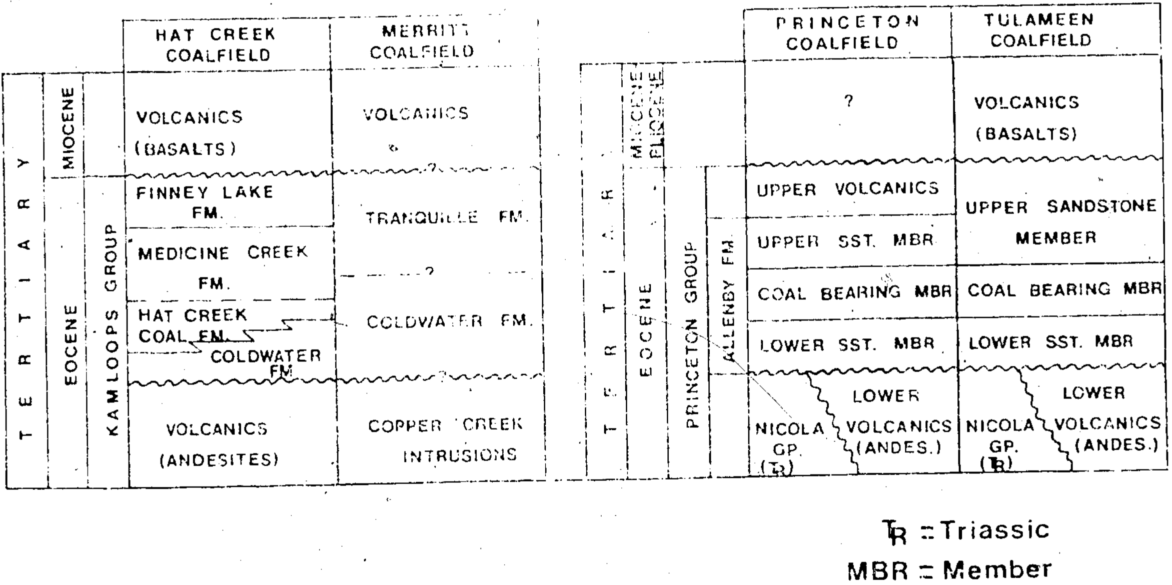


Figure 4-2. Generalized stratigraphic succession (not to scale) of the Hat Creek and adjacent coalfields (modified after Williams and Ross, 1979).

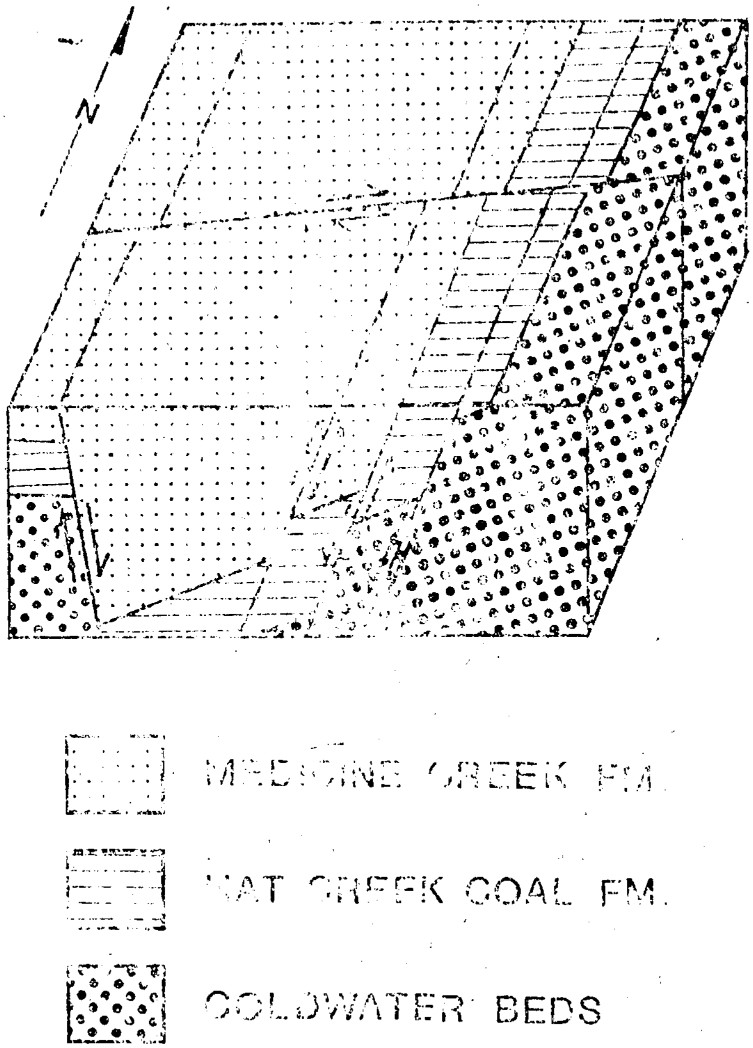


Figure 4-3. Simplified structural diagram of the Hat Creek basin (modified after Church, 1975).

graben have been offset somewhat by a series of northwest- and northeast-striking conjugate shear faults. Also, an important system of easterly-trending gravity faults cuts across the basin and superimposes its effects upon the main graben structures. Two bounding regional faults (the West and East Boundary Faults) confine the Tertiary strata of the upper Hat Creek valley. Dominant structures in this area are 140°-150° trending and due north-trending steep faults that involve rocks probably as young as Early Oligocene. That rocks apparently as young as Early Oligocene are involved in strong deformation along the Fraser River fault zone is regionally significant, as it shows that there were very late, strong movements on this fault zone (Monger, 1981).

According to the literature, normal faults appear to have been active in the Hat Creek valley during Eocene time. The latest known occurrence of north-northwest trending thrust and (?) strike-slip faults took place in mid-Cretaceous time in the eastern margin of the Coast Mountains (Monger, 1982).

Due to limited and scattered surface outcrops, most of the stratigraphy and the structure of Tertiary formations of the basin is known only from diamond drill cores.

4.4 Detrital sedimentation in the Hat Creek Basin

The Late-Middle Eocene Coldwater Formation consists of conglomerates, sandstones, siltstones and coal, deposited in a narrow, intermontane lake basin (Kim, 1979).

Kim (1979) prepared a lithofacies map of sediment influx for the Hat Creek basin, which shows carbonaceous claystone, silt and organic muds (gyttjae) occupying the central position of the basin. The centre of the basin is flanked by areas of siltstone, which in turn, are surrounded by areas of coarser clastics, mainly sandstones and conglomerates.

Because coarser material is more abundant in the southwestern part of the basin, it seems that the transport direction was from the southwest with clastics carried into the basin by surrounding streams. Due to the uplift in the west, during the Tertiary, the streams had higher flow velocity and transport capacity in the western part of the Hat Creek basin. The position of the fine clastics in the central part of the basin coincides with the main area of coal deposition of the Hat Creek No. 1 and No. 2 coal deposits.

The narrow and elongate shape of the basin, along with the presence of steeply dipping normal faults bounding the basin, indicate that the coal seams were laid down in a narrow, intermontane lake basin. Thick coal seams may originate in such basins if very little fluctuation in the water table was taking place and the water level was maintained at a moderate position (Falini, 1965).

The Coldwater Formation, which underlies the coal-bearing strata at Hat Creek consists of conglomerate, sandstone and siltstone, probably derived from a nearby source, deposited rapidly and represents a high energy fluvial regime. The thick sequences of coal-bearing and interbedded sandstones, siltstones, shales and claystones of the Hat Creek Coal Formation indicate lower energy environments.

No marine fossils have been found to date, indicating that the environment of coal deposition in the Hat Creek basin was not marine or coastal-paralic (Kim, 1979). The lithology of the sediments underlying and overlying the coal measures (conglomerates, siltstones and sandstones) indicates that the material was transported into the basin from the surrounding areas. During peat accumulation the Hat Creek basin was probably a marsh with little circulating water (Kim, 1979).

5.0 GEOLOGY OF COAL

5.1 Peat swamp environments

Coal is a sedimentary rock (Pettijohn, 1957), and hence its composition can be expected to reflect its depositional environment and origin as peat (Hacquebard *et al.*, 1967).

The prerequisites for the formation of a thick peat deposit are:

1. A slowly subsiding basin with poor drainage and sufficient inflow of water to permit peat formation, and
2. A low-relief hinterland and, therefore, a restricted supply of fluviatile sediments which otherwise would interrupt peat formation (Teichmüller and Teichmüller, 1975).

If the water level rises too high, generally because of rapid subsidence, the swamp will drown and inorganic sediment will be deposited; if subsidence is too slow, the plant material on the surface will decompose and any peat which has formed will be oxidized and eroded. The type of basin, therefore, controls the nature of the peat and ultimately the character of the coal (Hacquebard *et al.*, 1967).

Generally, the maceral composition of any coal can be related to the coal facies which are the expression of their depositional environment (Tasch, 1960). Swamp environments can be identified by their predominant type of vegetation (Spackman, 1958; Cohen, 1968).

Three main swamp types can be distinguished on the basis of plant vegetation and its relation to high and low water levels (Teichmüller, 1975):

1. Forest moor and bush swamps with an arborescent vegetation and relatively unstable fluctuating water table, partially in a telmatic zone; these are rich

in wood and are characterized by high amounts of xylite and structured huminite (textinite), associated with sporinite, cutinite and resinite (Table 1).

2. Reed marsh swamp, with sedges and herbaceous vegetation, generally characterized by a decrease of xylite and structured huminite and an increase in the amount of humodetrinite compared to the forest moor.
3. Areas of open water where peats and organic deposits (gyttjae) are formed from partly subaquatic water plants or from allochthonous material. The peats forming in this latter environment would be rich in the macerals alginite (boghead coals) and sporinite (cannel coals), as well as humodetrinite (desmocollinite) and clay minerals. Usually, the spores are transported and the cuticles washed into the swamp.

Peat formation takes place relatively quickly in forest moor swamps provided that the water table remains at moderate levels. Commonly wood-rich peats are transformed into xylitic-rich brown coals with coalification.

Reed (marsh) swamps with grasses, sedges, etc., in general, have a higher water table than forest swamps since they are transitional between environments 1 and 3.

Depending on their original geographical location, coal deposits are distinguished into two main types (Teichmüller and Teichmüller, 1975):

1. Paralic (coastal marine), and
2. Limnic (mainly lacustrine).

Limnic coal basins form inland, sometimes at a considerable distance from the coast. They include true lacustrine basins in which eustatic sea level fluctuations play no part in controlling the groundwater level.

TABLE 1

Origin and petrological characteristics of macerals
(after Cameron et al., 1984)

Huminite group	
Textinite	ungelified plant tissue with open cell lumens
Texto-ulminite	partially gelified plant tissue, open lumens partially closed
Eu-ulminite	completely gelified tissue with no open lumens but with strongly swollen cell walls, cell structure still recognizable
Attrinite	mixture of finely comminuted humic particles with variable amounts of humic gel; in texture presents a loose, porous, cloudy appearance
Densinite	same composition as attrinite but more compact
Porigelinite	granular, porous material believed to be of colloidal origin; often fills cell cavities
Levigelinite	massive, structureless material also believed to be of colloidal origin; often shows characteristic cracks believed due to shrinkage [illegible]
Corpohuminite	rounded, oblong or tabular bodies with a reflectivity equal to or greater than the associated huminite; in this study two varieties were distinguished: (a) *phlobaphinite* occurring within cells of plant tissue; (b) other *corpohuminite* similar in shape and reflectivity to *phlobaphinite* but not occurring in clearly defined cell structure
Liptinite group	
Sporinite	- coalified exines of spores and pollen grains
Cutinite	- coalified remains of leaf and stem cuticle
Resinite	- bodies of varying morphology derived from resins and waxes with reflectivities lower than associated huminite
Suberinite	- often occurs as a low reflecting mesh or network enclosing the cells of [illegible], derived from the protective material [illegible] at the surface of stems and roots
Alginite	- coalified algal remains often with distinctive internal morphology
Bituminite	- an amorphous or finely structured material with relatively weak fluorescence, [illegible] as a matrix for other macerals
Liptodetrinite	detritus formed from other liptinite macerals, individual fragments too small to be assigned to these other macerals
Inertinite group	
Semifusinite and Fusinite	- although normally classified separately, these two macerals form a continuum; both are characterized by the preservation of cell structure; fusinite has higher reflectance, better cell structure and higher relief than semifusinite which is intermediate in this regard between fusinite and the [illegible] macerals of the huminite group
Macrinite	- material occurring in masses of indefinite shape with no internal structure, possibly derived from highly gelified parent material
Inertodetrinite	- rounded to angular fragments (usually <30 microns) of detrital origin formed by the mechanical disaggregation of other inertinite macerals
Sclerotinite	- bodies of varied shape and size always with some cellular or porous structure, usually displays high relief, derived from fungal remains or oxidized resins

Limnic coals are often associated with fault bounded basins in intermontane regions and are generally characterized by thick coal seams with limited lateral continuity. Coal measures of limnic origin are characterized by both coarse and very fine fluvio-lacustrine sediments (Hacquebard *et al.*, 1967).

Limnic basins may originate wherever a hydrologically closed depression occurs. The depression may be the result of different geological causes, among which are tectonic activity and erosive or glacial activity. The position of the water level is closely related to the shape of the basin and controls the type of vegetation, the mode of peat preservation and ultimately the type of coal (Falini, 1965).

The nature of the clastic sediments and associated thick coal seams is an important aspect of lacustrine sedimentation. Coals generally grade vertically and laterally into shaly coals and shales; the presence of fine clastic sediments and 'clean' coal near the centre of the structural basin has been regarded (Hacquebard *et al.*, 1967) as evidence to support the view that the basin was tectonically active during peat formation and deposition.

Limnic coals are usually humic coals having a rather uniform composition (Hacquebard *et al.*, 1967). The coals appear bright (due to the presence of xylite) to semi-dull (due to the presence of interbedded, thick dull bands of carbargilite or shale).

6.0 ANALYTICAL METHODS

6.1 General aspects

6.1.1 *Systems of coal classification*

The classification of coal has never been a simple task. Because of the complexity of its chemical and physical properties and its varied uses, a multitude of classification schemes has been proposed over the years using a variety of parameters as terms of reference (Bustin *et al.*, 1983).

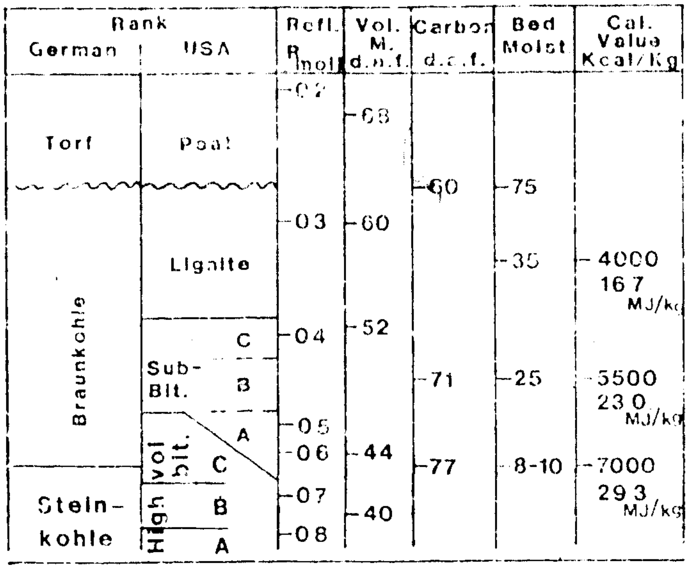
The standardization of nomenclature for coal petrography was rendered difficult by the existence of two different systems, the American and European. The European (German-DIN) evolved from the Stopes-Heerlen System, whereas, in North America, the ASTM system (American Society of Testing and Materials, 1979) (Table 2) is used as the standard rank system for classification of coal. The coal series begins with peat at the low end of the scale, and progresses with increasing metamorphism through meta-anthracite to graphite at the high end. With its emphasis on volatile matter, ash, and moisture, the ASTM system relies heavily on proximate analysis. It has weaknesses, including the fact that volatile matter may be affected by the presence of carbonate minerals or abnormal amounts of either of the maceral groups liptinite or inertinite. Nevertheless, over the years it has served the coal industry and the coal scientific community reasonably well and it will be used in this study.

6.1.2 *Terminology*

Coal is not a homogeneous substance but consists of various basic components analogous to the minerals of inorganic rocks. In coal these components are called macerals. Particularly in low rank coals, they can be further divided into maceral types and macerals varieties. The macerals are

TABLE 2

The German and North American schemes
for classification of brown coals and lignites



LEGEND

Vol M VOLATILE MATTER
d.a.f. DRY ASH FREE
Cal Value CALORIFIC VALUE

classified into three groups: vitrinite, liptinite, and inertinite either because of similar origin (liptinite) or because of differences in preservation (macerals of vitrinite and inertinite groups). In low rank coals the term huminite is used instead of vitrinite, along with a greater variety of distinguishable macerals, submacerals, and maceral varieties within this group (Table 3). Macerals of liptinite and inertinite groups are used under the same names in low and high rank coals (Table 4).

The origin and petrological characteristics of the three maceral groups are summarized, in a simplifed manner, in Table 1. The classification of the maceral groups for brown coals-lignites used throughout the study has been established by the International Committee for Coal Petrology (I.C.C.P., 1971).

6.1.3 *Types of organic matter-kerogen*

Dispersed solid organic matter occurs as a minor constituent in most sedimentary rocks. It consists of diverse material that is similar to coal and its maturation follows a similar physical and chemical pattern to coalification (Bostick, 1979). Reflected-light microscopy enables one to recognize the different organic grains and to select the best type for optical measurement to indicate the indigenous level of metamorphism of the organic matter in the rock.

The term kerogen originally referred to the insoluble organic matter in sedimentary rocks that yields oil on heating. In recent years, it has been defined as all the disseminated organic matter of sedimentary rocks which is insoluble in non-oxidizing acids, bases, and organic solvents (Hunt, 1979). Kerogen, which is the precursor of most oil and gas, may be either marine or terrestrial. Terrestrial kerogen has components similar to coal (Hunt, 1979).

Kerogen can be classified as sapropelic and humic. Sapropelic kerogen includes the algal (Type I) and the amorphous and herbaceous (Type II) categories

TABLE 3

Classification of the huminite macerals of brown coals and lignites

BROWN COAL-LIGNITE

MACERAL GROUP	MACERAL SUBGROUP	MACERAL	MACERAL TYPE	MACERAL VARIETY
HUMINITE	HUMOTELINITE	TEXTINITE		A (dark)
				B (light)
		ULMINITE	TEXTO-ULMINITE	A (dark)
				B (light)
			EU-ULMINITE	A (dark)
				B (light)
	HUMODETRINITE	ATTRINITE		
		DENSINITE		
	HUMOCOLLINITE	GELINITE	LEVIGELINITE	
			PORIGELINITE	
		CORPOHUMINITE	PHLOBAPHINITE	
			PSEUDO-PHLOBAPH	

TABLE 4

Classification of the liptinite and inertinite macerals of coals

MACERAL GROUP	MACERALS	MACERAL TYPE	MACERAL VARIETY
LIPTINITE	SPORINITE		TENUISPORINITE CRASSISPORINITE
	CUTINITE		
	RESINITE		
	ALGINITE		
	LIPTODETRINITE		
	FLUORINITE		
	BITUMINITE		
	EXSUDATINITE		
	SUBERINITE		
INERTINITE	MICRINITE		
	MACRINITE		
	SEMIFUSINITE		
	FUSINITE	PYROFUSINITE DEGRADO-FUSINITE	
	SCLEROTINITE	FUNGO-SCLEROTINITE	PLECTENCHYMINITE
	INERTODETRINITE		

(Fig. 6-1). The corresponding coal macerals in the liptinite group are alginite (Type I) and resinite, sporinite, and cutinite (Type II). Humic kerogen includes the woody (Type III) and coaly (Type IV) categories. The corresponding coal macerals are huminite/vitrinite (Type III) and inertinite (Type IV).

The above classification of kerogen and its relation to coal macerals was established by Hunt (1979) and will be used throughout the study.

6.1.4. *Reflectance of coals*

The reflectance of the coal macerals and the various kerogen types was used to determine the rank or the level of organic metamorphism of the Hat Creek No. 2 coals. It is, therefore, appropriate to explain what reflectance is and of what use is it to a coal petrologist studying low-rank coals in particular.

Introduction

The rank of coal, small coal lenses, or grains of kerogen dispersed in clastic sedimentary rocks is a valuable indicator of catagenesis or low-temperature metamorphism (Hacquebard and Donaldson, 1970; Alpern *et al.*, 1972).

Since the early 1930's, attention was drawn to the fact that the reflectance of vitrinite increased progressively with increasing rank. It has also been observed however, that the reflectance values of vitrinite/huminite from rocks of different lithology or different depositional environments may be quite variable (Bostick and Foster, 1975), and this must be taken into account when using reflectance measurements as indicators of rank.

Previous work

Teichmüller (1958) described the use of vitrinite reflectance as a technique for determining the level of organic metamorphism of argillaceous and calcareous

	SAPROPELIC			HUMIC	
KEROGEN (by transmitted light)	Algal	Amorphous	Herbaceous	Woody	Coaly (Inertinite)
COAL MACERALS (by reflected light)		Liptinite		Vitrinite	Inertinite
	Alginite	Amorphous	Sporinite Cutinite Resinite	Telinite Collinite	Fusinite Micrinite Sclerotinite
KEROGEN (by evolutionary pathway)		Types I, II	Type II	Type III	Type IV

Figure 6-1. Classification of kerogen (adapted from Hunt, 1979).

rocks. She observed that where coals were not readily available, it was possible to measure the reflectance of the small vitrinite inclusions that commonly occur in shales and carbonates.

The quantitative determination of the rank of coal by making reflectance measurements on vitrinite has become a common practice in coal petrography, because this method has the advantage of being independent of the varying maceral composition (Bostick and Foster, 1975).

Timofeev and Bogolyubova (1970) described the rank of coal and coaly inclusions in clastic rocks, and they consistently found that coaly inclusions in argillite, siltstone and sandstone have lower rank than coal in the same strata. They also noted that the reflectance of vitrinite in carbonates was higher than that of corresponding vitrinite in coal. Bostick and Foster (1975) measured the reflectance of vitrinite phytoclasts from sandstones, shales and limestones as well as vitrinite from coals. They found that the reflectances were mostly lower for vitrinite from sandstones (0.5% R_{oil}) and somewhat higher for vitrinite from adjacent shales, limestones and coals in the same part of the section (0.65% R_{oil}). (R_{oil} is the reflectance of an organic particle, such as vitrinite, when oil is used as the immersion medium). They also concluded that the range of values was too great to provide any general and consistent correlation factor. Jones *et al.* (1972) found that vitrinite reflectance values of coals roofed with sandstone were lower than those of coals roofed with shale.

The reflectance of vitrinite and the rank of coals and kerogen depends on the termal conductivity of the host rocks, permeability of the sediment, the underground water circulation pattern and the heat flow from the crust. Sandstones, for example, allow the volatile matter formed due to coalification to escape and water to circulate through the sediment. This process influences the oxidation-reduction potential of the water and affects the reflectance of vitrinite (Goodarzi, 1985).

6.1.5 *Fluorescence microscopy*

Schochardt (1936) was the first to note and take advantage of the auto-fluorescence properties of coal macerals but it was not until recently that fluorescence has been used routinely in coal microscopy. The fluorescence properties of coal macerals and dispersed organic matter (kerogen) in sediments have been studied by van Gijzel (1975, 1981), Ottenjann *et al.* (1975), Teichmüller and Wolf (1977), and Goodarzi (1985) among others.

In low-rank coals (lignite to subbituminous), macerals of the liptinite group are very dark and sometimes indistinguishable from minerals such as quartz or clays in reflected white light. In order to solve this problem, high intensity light is used, which causes the liptinite group macerals to show auto-fluorescence. In this way, the presence or absence of liptinite macerals (kerogen Types I, II) is highlighted and their morphology more clearly delineated. The different intensity and colour of fluorescence of various macerals aid in their identification (I.C.C.P., 1971; Stach, 1975b).

Fluorescence microscopy is frequently used in coal and hydrocarbon source-rock studies to indicate the presence of hydrogen-rich (liptinite) macerals (van Gijzel, 1971; Ottenjann *et al.*, 1975) and it has been the main tool used to define new liptinite macerals (Teichmüller and Wolf, 1977). Both fluorescence colours and intensities are different for the liptinite macerals and change continuously with increasing rank (Table 5).

TABLE 5

Fluorescence colours of the lignite macerals

MACERAL GROUP	SOFT BROWN COAL (LIGNITE)	HARD BROWN COAL (LIGNITE)
LIPTINITE	STRONG, GREEN, YELLOW ORANGE AND BROWN	STRONG – MODERATE; GREENISH – YELLOW, YELLOW – ORANGE & BROWN
HUMINITE	STRONG TO WEAK, YELLOW & BROWN OR NONE	VERY WEAK, BROWN, OR NONE
INERTINITE	NONE	NONE

Huminite may also fluoresce weakly with dark brown colour in the lignite to sub-bituminous range (Stach, 1975b). Colour and intensity may be related to the hydrogen atoms in the unsaturated bonds of the chemical structure of the maceral (Goodarzi, 1985).

According to Goodarzi (1985), three advantages are derived from using fluorescence microscopy:

1. Both the shape and internal structure of the liptinite macerals become more clearly visible.
2. The fluorescence colours are not influenced by the thickness of the thin section (when transmitted light is used); differences in fluorescence colours indicate a different origin or a different rank.
3. Polishing does not affect the fluorescence properties of liptinite macerals.

6.2. Materials and methods

6.2.1 *Sampling*

Coal and interbedded sediment samples were taken from the cores of boreholes 75-77 and 75-62 (Fig. 6-2). Borehole 75-77 is situated near the centre of Hat Creek No. 2 coal deposit and intersects a total of 533 m of coal and interbedded sediment. Borehole 75-62 is situated approximately 1 km SSE of borehole 75-77 and intersects 467 m of coal and sediment.

Borehole 75-62 penetrated the lower part of the coal deposit, whereas 75-77 did not. Neither of the two boreholes nor any of the boreholes drilled into the Hat Creek No. 2 coal deposit penetrated the entire coal interval.

A total of 459 samples was obtained from both boreholes, but only 312 were actually used for petrographic analysis and fluorescence studies. Sampling was done on a regular-interval basis, with each sample representing approximately 1.5 m of core.

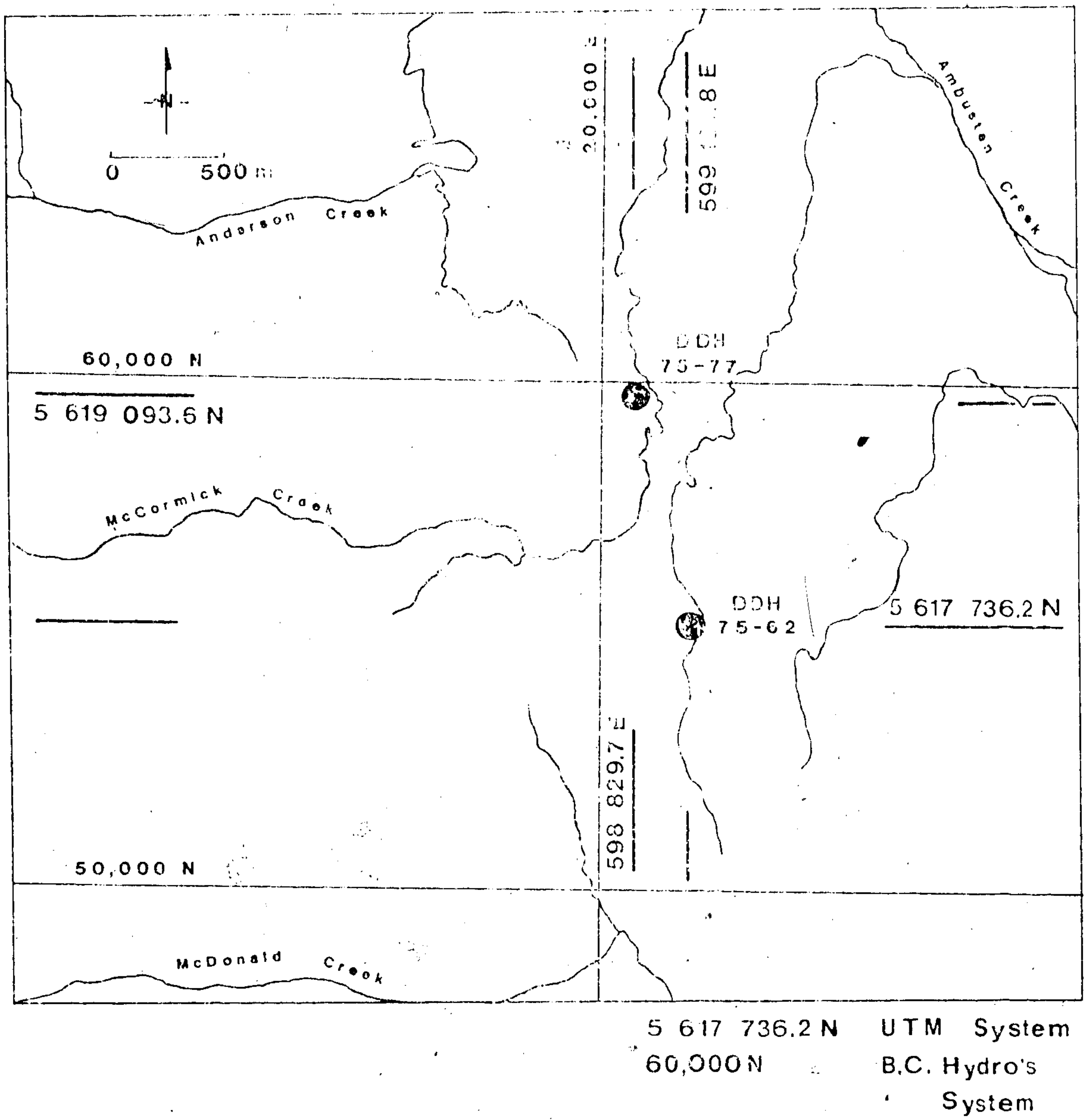


Figure 6-2. Location map of the two boreholes used in this study (modified from British Columbia Hydro and Power Authority, 1980).

Since the samples were approximately eight to ten years old, there was a possibility that they may have been oxidized. As a precaution, in all cases, samples were taken from the central part of the core. It is believed that the freshest available specimens were obtained for crushing and that the results obtained below are characteristic of the coal deposit in the study area.

6.2.2 *Sample preparation*

Samples were washed in distilled water to get rid of loose dirt and were left to dry overnight. Each sample was split into three portions. The first was used for preparing the polished block (pellet), for reflectivity and maceral analyses, the second was used for proximate analysis and the third was stored for future use.

Samples were then crushed and passed through a 20 mesh (850 µm) screen. The crushed samples were mixed with an appropriate amount of epoxy and hardener to form a fairly thick paste and were allowed to harden. The pellets were then mounted in a Buehler Automet specimen holder to ensure that the surfaces to be polished were all level, then they were ground on 240 and 600 grit papers. Between each stage, the pellets were placed in an ultrasonic cleaner, washed and rinsed with distilled water.

The pellets were further polished using a 'Texmet' paper and water. The paper was covered with a slurry of 0.3 micron Alpha alumina powder, and the Automet was turned on for about 3-4 minutes during which time periodic applications of the alumina mixture were made. During the final 30 seconds to 1 minute of this stage, the lap was flushed with distilled water to 'buff' the surface of the pellet.

Finally, the pellets were polished on a lap on which two layers of silk had been attached. This stage required 1/2 to 2 minutes and included the application of 0.05 micron Alpha alumina powder mixed with water in the same fashion as the preceding stage. The pellets were cleaned in the ultrasonic cleaner and finally polished on a clean silk lap with no alumina using a good supply of distilled water.

Problems

No difficulties were encountered during polishing; in some cases, a few scratches remained after the final step, and polishing was repeated giving special attention to the time parameter. Detergents were not used for washing the pellets, because they created a multi-coloured thin film which affected reflectance measurements.

6.2.3. *Equipment and method employed for rank determination*

Reflectance measurements on the polished blocks were carried out using a Zeiss MPM II microscope (Plate 1, Fig. 1A) fitted with white (halogen) and fluorescence (HBO) light sources and using an Epiplan-Neofluar oil immersion (N_{oil} = 1.5180 at 23°C) objective (N.A. 0.90 x 40).

A 'ZONAX' microcomputer (Plate 1, Fig. 1B) was used to calculate the mean, standard deviation and coeffiecent of variation of fifty (50) reflectance measurements made on each pellet. The microcomputer was connected to an EPSON printer (Plate 1, Fig. 1C), for tabulation of reflectance data.

Before taking reflectance measurements, the various components of the apparatus were carefully aligned, to compensate for variations in electrical current, deviations in the optical path, and instability due to change in humidity. The photomultiplier was calibrated using glass standards of known reflectance at the start and after each series of six (6) pellets. The glass standard used throughout the study had a refractive index of 1.7477, a calculated reflectance of 0.4958 and a corrected reflectance of 0.506 at 546 nm at room temperature. The glass standard was chosen to have a reflectance slightly higher than the reflectance values of the coal particles.

After calibrating the photomultiplier reading to be exactly the same as the reflectance of the glass standard, 50 reflectance measurements were carried out on each pellet.

Periodic replications were performed on randomly selected samples using the same microscope to check the precision of the results. The mean reflectance values, in most cases, were within the ±0.02% limit recommended by Mackowsky (1975).

Reflectance measurements were taken on the maceral eu-ulminite, variety B (Table 3); on rare occasions, due to the absence of eu-ulminite B, measurements were taken on eu-ulminite A (dark) and/or texto-ulminite. Random reflectance, the reflectance of a grain in the orientation at which it is encountered, was measured at all times. For low-rank coals, random reflectance is used routinely because their bireflectance (R_{max}-R_{min}) is almost negligible.

6.2.4 *Point counting*

The maceral composition of coal and kerogen was examined under reflected light using a Zeiss microscope (Plate 1, Fig. 2A) with an Antiflex-Epiplan oil immersion (N_{oil} = 1.5180 at 23°C) objective (N.A. 0.40 x 16). Point counting was performed using a Swift Model E automatic point counter (Plate 1, Fig. 2B) on the same pellet which was used for reflectivity studies. Five hundred points, including mineral matter were counted on each pellet and the volume percentage of the three main maceral groups and mineral matter was calculated (Appendix I). Organic constituents (macerals) were identified only to the subgroup level; if the cross hairs fell at the boundary between two macerals or if the particle was too small, the point was disregarded (Mackowsky, 1975). Counts were made over the whole surface area of the pellet, along traverses about 0.5 mm apart.

Although the maceral analysis was performed in one plane, the values can be looked upon as percentages by volume. With 500 points measured, the error should be approximately ±1.5% (Mackowsky, 1975).

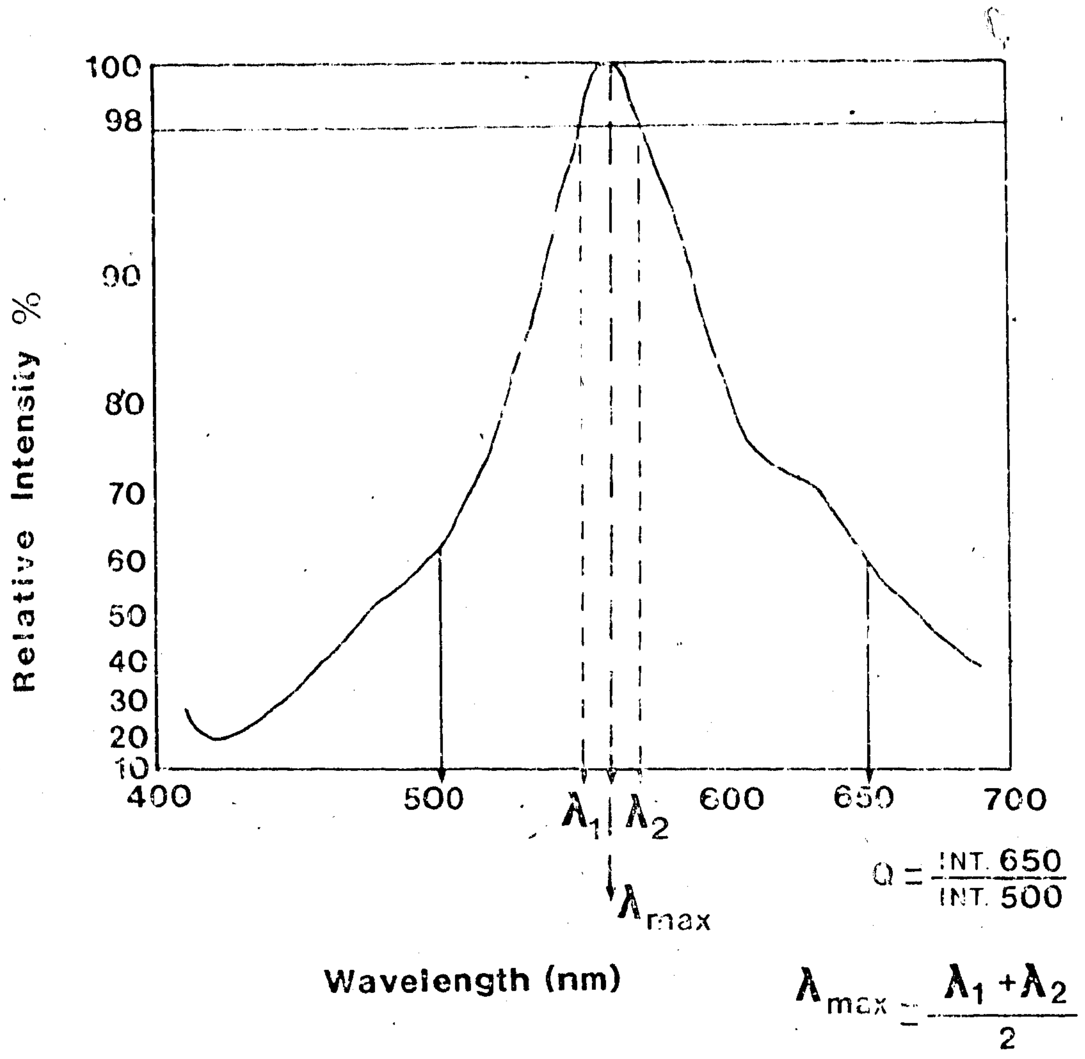
6.2.5 *Equipment and method used for fluorescence studies*

Equipment used for the measurement of fluorescence spectra is shown in Plate 1, Figure 1A, D; fluorescence photometry was combined with reflectance photometry in a single operation. For measurement of fluorescence an excitation filter of 365 nm and a barrier filter of 395 nm were used, whereas for visual observation, an excitation filter of 450-490 nm and a barrier filter of 510 nm were used.

Based on the ability of liptinite macerals to fluoresce, a quantitative measurement of fluorescence colours may be diagnostic of the macerals and their rank.

After excitation at a wavelength of 365 nm, the emission spectrum from the maceral is recorded between 400 and 700 nm (Fig. 6-3). Average spectra built up from a number of individual spectra from single points on the same liptinite maceral are used to determine the wavelength of the maximum peak (λmax) and the so called red/green quotient (Q), which is the ratio between the relative intensities at 650 nm and 500 nm.

The position of λmax of the maceral changes because changes take place in both the intensity and the colour of fluorescence during irradiation. These changes can be diagnostic of individual liptinite macerals and may be of significance in coal rank studies (Teichmüller and Wolf, 1977). As the hydrogen



$$Q = \frac{\text{INT. } 650}{\text{INT. } 500}$$

$$\lambda_{max} = \frac{\lambda_1 + \lambda_2}{2}$$

λ_1 = Intensity 98% short wavelength

λ_2 = Intensity 98% long wavelength

Figure 6-3. Determination of peak wavelength (λmax) and red/green quotient (Q) from a spectral curve (adapted from Ottenjann et al., 1975).

content of the macerals decreases, the fluorescence intensity falls, accompanied by a colour shift to longer wavelengths.

The emission spectrum of an individual liptinite maceral was recorded over a period of 30 seconds, because irradiation periods tend to alter the 'true' fluorescence colour, resulting in a shift of the wavelength and erroneous intensities.

7.0 RESULTS

The Hat Creek No. 2 coal deposit was divided into four main zones of coal and interbedded sediment; they are zones A, B, C, and D (Fig. 7-1 to 7-4). Zone A (top) has a total thickness of 185 m; Zone B 100 m; Zone C 150 m, and Zone D 80 m. The division was arbitrary although log characteristics (γ-ray and density logs) as well as macroscopic and microscopic properties were used as guidelines.

7.1 Organic petrology

Introduction

Organic petrology is the science dealing with the study of the organic matter in sediments. The organic matter may consist of coalified or charred woody tissues, resin, plant spores and pollen (Bostick, 1973). The above material can either be dispersed in the form of grains or plant fragments within the sedimentary rocks, in which case it is referred to as kerogen, or it can be concentrated as in coal.

As a result, macroscopic and microscopic examination of the coal and interbedded sediment was necessary. The results have as follows.

7.1.1 Macroscopic description

Based on the macroscopic description of the core, the following observations were made for each of the four main zones.

Zone A

Zone A is the thickest zone of the coal deposit, approximately 185 m (Fig. 7-1). It contains numerous zones of clastic sediments ranging in thickness from 60 cm to 5 m and consisting of carbonaceous to coaly claystone, shale and organic mudstone. A few iron carbonate-rich (carbo-ankerite) intervals as well as a thin band (~14 cm) of bentonite are present. The latter indicates volcanic activity during peat accumulation.

The thickest coal seam of the zone is approximately 20 m and coal is present throughout the entire zone except at its very base. The basal 20-25 m of the zone contain coal of secondary quality (based on calorific value and density) and clastic sedim[illegible] including marl and carbonaceous shale.

The coals are relatively clean and generally contain great quantities of xylite indicating the origin of the coal from the coalified tree trunks of conifer wood. The coal also appears dark brown to black in colour and its lustre ranges from bright to dull. The most common sedimentary structures observed in the coal and interbedded sediment include laminations (even-parallel, wavy-parallel, discontinuous wavy-parallel and wavy-nonparallel), carbonaceous debris (plant remains), rootlets and carbonaceous laminae.

Zone B

This zone contains fewer coal seams than zone A (Fig. 7-2) with the thickest approximately 6 m. Zone B contains numerous clastic beds (the thickest being approximately 7 m) composed of marls, carbonaceous shale and thin carbo-ankerite layers. Coals are not concentrated in any particular part of the zone but it appears that most of the good quality coal is located near the top of the zone.

The sedimentary structures observed include carbonaceous laminae, plant remains and laminations (even-parallel, discontinuous wavy-parallel and curved-parallel). The colour and lustre of the coal is similar to those of zone A.

Zone C

The thick, clean coal seams are situated at the lower half of the zone (Fig. 7-3). The thickest seam is 11 m and the thinnest about 1 m. The clastic intervals consist of carbonaceous shale to claystone, siltstone and marlstone, the thickest being approximately 5 m. The coals are dark brown to black, bright to dull and rich in xylite. The common sedimentary features are carbonaceous laminae, plant remains, clay intraclasts, wavy-parallel and inclined even-parallel laminations.

Zone D

This zone consists almost entirely of coal (Fig. 7-4). The thickest seam is 24 m and the thinnest 1.5 m. There are only a few interbedded clastic intervals (the thickest being ~1.5 m composed of carbonaceous to coaly claystone or shale. Almost all of the coal is good quality, has a dark brown to black colour and is rich in xylite with a bright lustre. Sedimentary structures include inclined even-parallel laminations, discontinuous wavy-parallel and wavy-nonparallel laminations. Carbonaceous debris and carbonaceous laminae are also present.

7.1.2 Microscopic description

Microscopically, the Hat Creek coals have the following characteristics:

Zone A

The coals are relatively clean and contain greater quantities of humotelinite (xylitic) than humodetrinite (detritus) (Fig. 7-5). Humotelinite averages 57%, humocollinite 10% and humodetrinite 15% throughout the sequence. Coals in the middle part of the zone are richer in humocollinite than in other parts. In the same way, the basal part of the zone contains high quantities of mineral matter

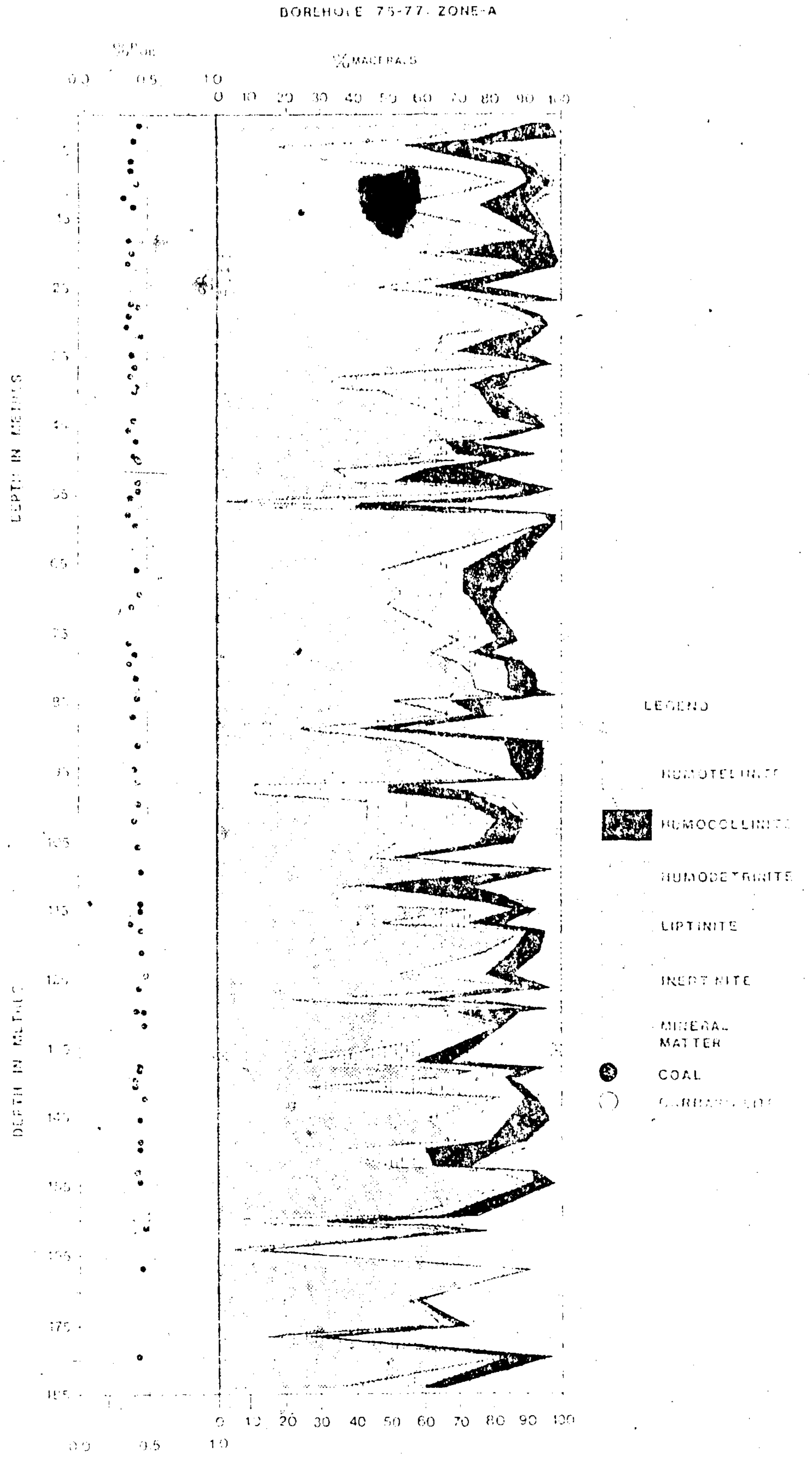


Figure 7-5. Reflectance and maceral analyses for Zone A.

and very little humocollinite or humodetrinite. The percentage of humotelinite, except for a few cases, remains constant and the organic matter content in the interbedded clastics ranges from 38 to about 66 per cent. The average mineral matter content is 14 per cent.

Zone B

Humotelinite is more abundant (41%) than both humocollinite (9%) and humodetrinite (11.5%) (Fig. 7-6). Humodetrinite appears to be more common near the top and base of the zone. Mineral matter content is high (average is 36%), with clastic sediments having total kerogen content of 16 to 78 per cent. The changes in maceral composition for zone B are more erratic compared to those in zone A.

Zone C

Humotelinite averages 36%, the lowest in all zones (Fig. 7-7). In the middle and lower part of the zone humotelinite content decreases in the expense of high mineral matter and humodetrinite contents. Humocollinite averages 12% whereas humodetrinite 16%. The interbedded clastic sediments have a total kerogen content of 33 to 82% and the maceral changes are as erratic as those of zone B.

Zone D

The coals of zone D are rich in humotelinite (50%) (Fig. 7-8). Humocollinite content is at 10%, whereas humodetrinite averages 18%, higher than in zone A. The mineral matter content is 20% and the interbedded clastics are, generally more organic-rich (34-81%) than those of zones B and C. The maceral changes occur more frequently than those of zone A.

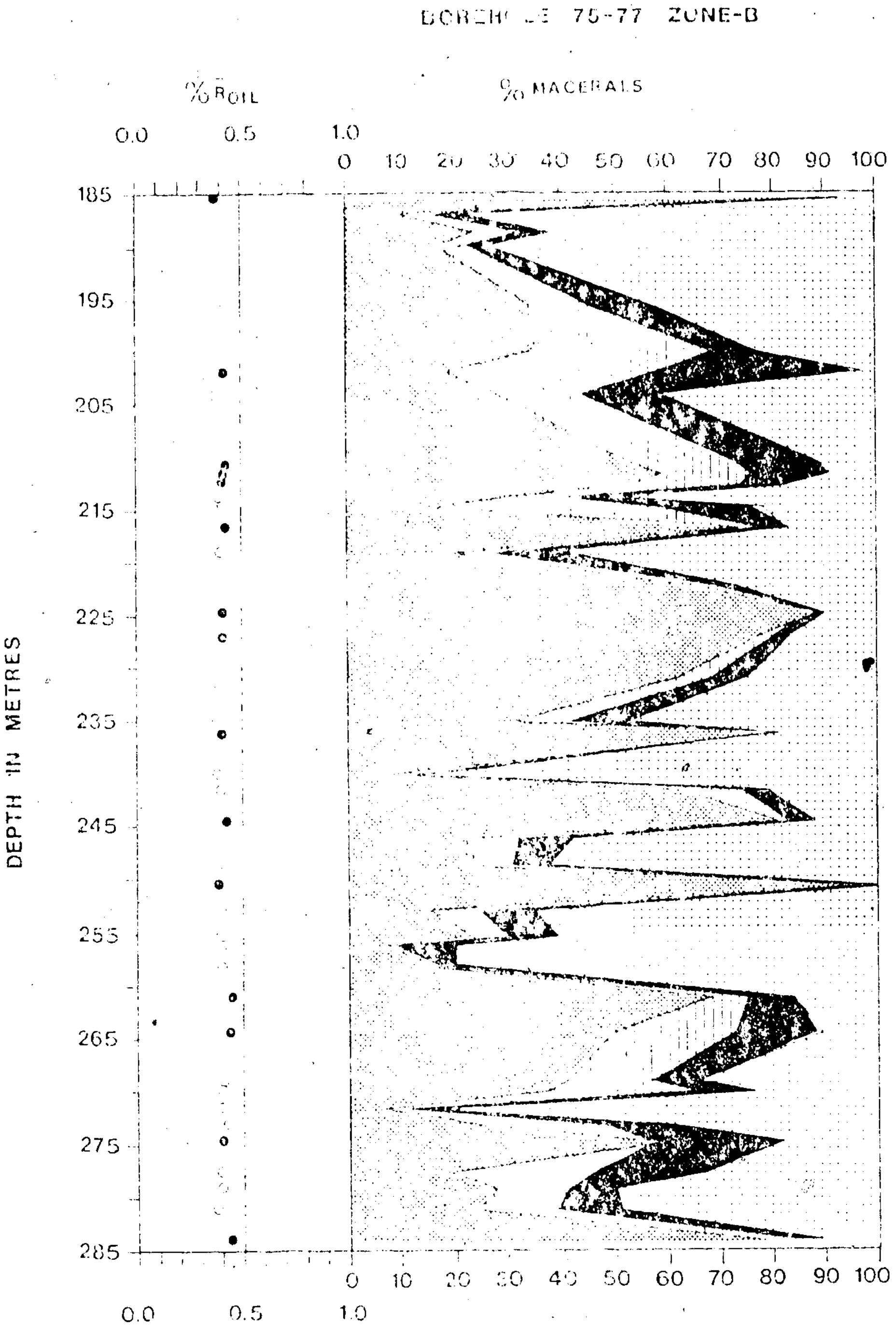


Figure 7-6. Reflectance and maceral analyses for Zone B.

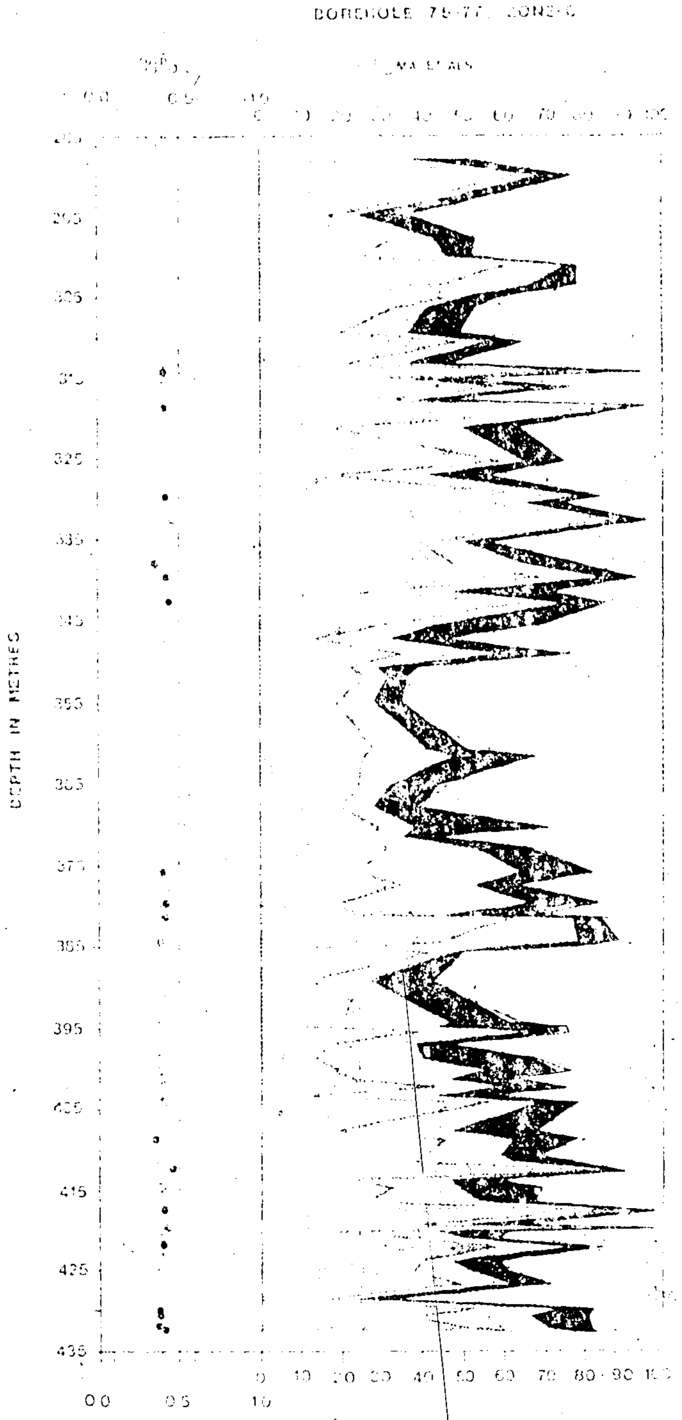


Figure 7-7. Reflectance and maceral analyses for Zone C.

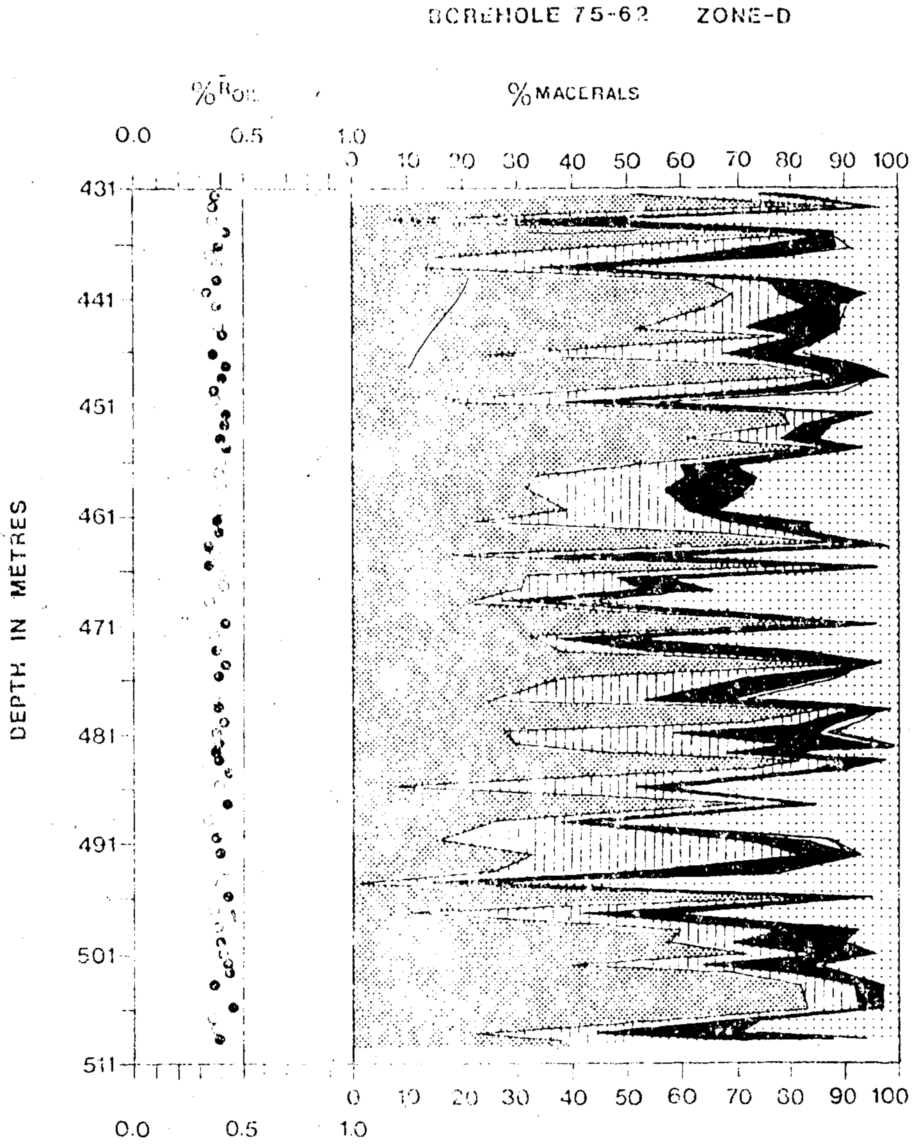


Figure 7-8. Reflectance and maceral analyses for Zone D.

7.1.3 Maceral groups

Huminite group

The huminite macerals are the most abundant of the three maceral groups which are present in the Hat Creek No. 2 coal deposit.

Humotelinite

This subgroup consists of both textinite and ulminite (Plates 2, 3). Textinite (Plate 2, Figs 1-3) is more abundant in coals of zone A with the transitional texto-ulminite (Plate 3, Figs. 1-4) present throughout the entire succession (zones A to D). The open cell lumens of textinite were often filled, either with resinite or porigelinite (Plate 2, Fig. 2). Two varieties of eu-ulminite were observed, the low reflecting variety A (Plate 3, Fig. 5) and the high reflecting variety B (Plate 3, Figs. 5, 6). The entities classed as humotelinite show a variety of structure, reflecting their different plant tissue origins, and a range in the degree of gelification and compaction. At one extreme eu-ulminites grade into texto-ulminites and on the other become almost structureless and closely resemble the telocollinite of bituminous coals. These gradations, observed within the same sample, demonstrate the influence of local factors on the degree of compaction and preservation of huminitic tissue.

Humocollinite

The humocollinite subgroup comprises corpohuminite and gelinite (Plates 4, 5). Corpohuminite was mainly associated with textinite and ulminite, whereas gelinite occurred with humodetrinite. The association of corpohuminite with textinite and texto-ulminite cell lumens is evident in Plate 4, Figs. 1-3. Gelinite also occurred in association with carbonate-rich sediments (carbo-ankerite) (Plate 6, Fig. 6). Gelinite was present as both levigelinite (telogelinite)

(Plate 5, Fig. 2) and as eu-gelinite (Plate 5, Fig. 1). In some instances, gelinite, in the form of porigelinite, infilled cell lumens of humotelinite, mainly textinite (Plate 2, Fig. 2). The porigelinitic particles, which commonly occurred in aggregates, were approximately spherical with a variable size (Plate 5, Fig. 4).

Phlobaphinite occurred as globular to elongate bodies associated with plant tissues. High- and low-reflectance varieties of phlobaphinite were seen; high-reflectance phlobaphinite (Plate 4, Fig. 1) exhibited a rounded to elongate shape and was associated mainly with humotelinite whereas the low-reflectance varieties (Plate 4, Fig. 2), with a rounded shape were associated with humodetrinite. Phlobaphinites, particularly the elongate ones, contained devolatilization vacuoles (Plate 4, Fig. 4) indicating that they have undergone structure changes which produced an increase in reflectance. Apart from small cavities (Plate 4, Fig. 3), phlobaphinite occupies the whole of the available volume, is remarkably uniform and terminates sharply without a transition zone at the interfaces with the cell walls.

Humodetrinite

This subgroup is represented by the presence of densinite (Plate 5, Fig. 5). No attrinite was observed. Humodetrinite appeared as a mixture of humic detritus with a fine humic gel resulting from the strongly decomposed plant material. In densinite the individual components were cemented tightly together along with spores and mineral matter. Some of the particles were of the same general character as in porigelinite although much larger. The fragments that had an elongate shape were probably of huminitic character (Plate 5, Fig. 2) but some were of liptinitic affinity (Plate 5, Fig.3).

Inertinite group

Hat Creek No. 2 coals are characterized by extremely small amounts of inertinite. Sclerotinite exhibiting one-, two-, three- and multiple-cellular structure (Plate 6, Figs. 1-3) was the most abundant maceral of the group. The variety Plectenchyminite (Plate 6, Fig. 4) was also observed, but in lesser amounts. The maximum inertinite value recorded was 3 per cent in a dull coal. Inertinite shows a slight increase from bright to dull coals.

No fusinite, semifusinite or inertodetrinite were observed in the samples.

Liptinite group

The liptinite group in the samples is represented mainly by the macerals resinite and sporinite and by lesser amounts of cutinite, suberinite, bituminite and fluorinite. Liptinite made up less than 3 per cent by volume of the average maceral composition of most samples of all four main zones of the coal deposit. A minor increase in the liptinite component from bright to dull coal and variation in the proportions of individual macerals of this group were observed.

Resinite and other macerals

Resinite is the most abundant maceral of the group, concentrated mainly in certain beds in zones A and D. Its spectral characteristics are briefly summarized in Table 6.

The following types of resinite were recognized:

1. Massive resinite, one of the most abundant types (Plate 7, Fig. 1), occurs mainly as large irregular bodies (~300 µm). In fluorescent light this material appears as a clear to translucent solid occasionally with fractures. The clear and 'fresh' surface may occasionally show a cloudy (mottled)

TABLE 6

Spectral characteristics and brief description of Hat Creek resinite types

$\bar{R}_{oil}$	λ_{max}(nm)	R/G Q	COLOUR (in fluor)
0.02	440	0.02	Light blue
0.04	450	0.07	Off white
0.06	460	0.27	Bright yellow
0.09	500	0.29	Yellow, int. refl.
0.1	520	0.33	Yellow
0.2	590	1.08	V.dk.yellow - lt. brown

int. refl.=internal reflections

TABLE C

Spectral characteristics and brief description
of Hat Creek resinite types

$\bar{R}_{oil}$	λ_{max}(nm)	R/G Q	COLOUR (in fluor)
0.02	440	0.02	Light blue
0.04	450	0.07	Off white
0.06	460	0.27	Bright yellow
0.09	500	0.29	Yellow, int. refl.
0.1	520	0.33	Yellow
0.2	590	1.08	V.dk. yellow -lt. brown

int. refl.=internal reflections

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0.06	460	0.27	Bright yellow
0.09	500	0.29	Yellow int. ref

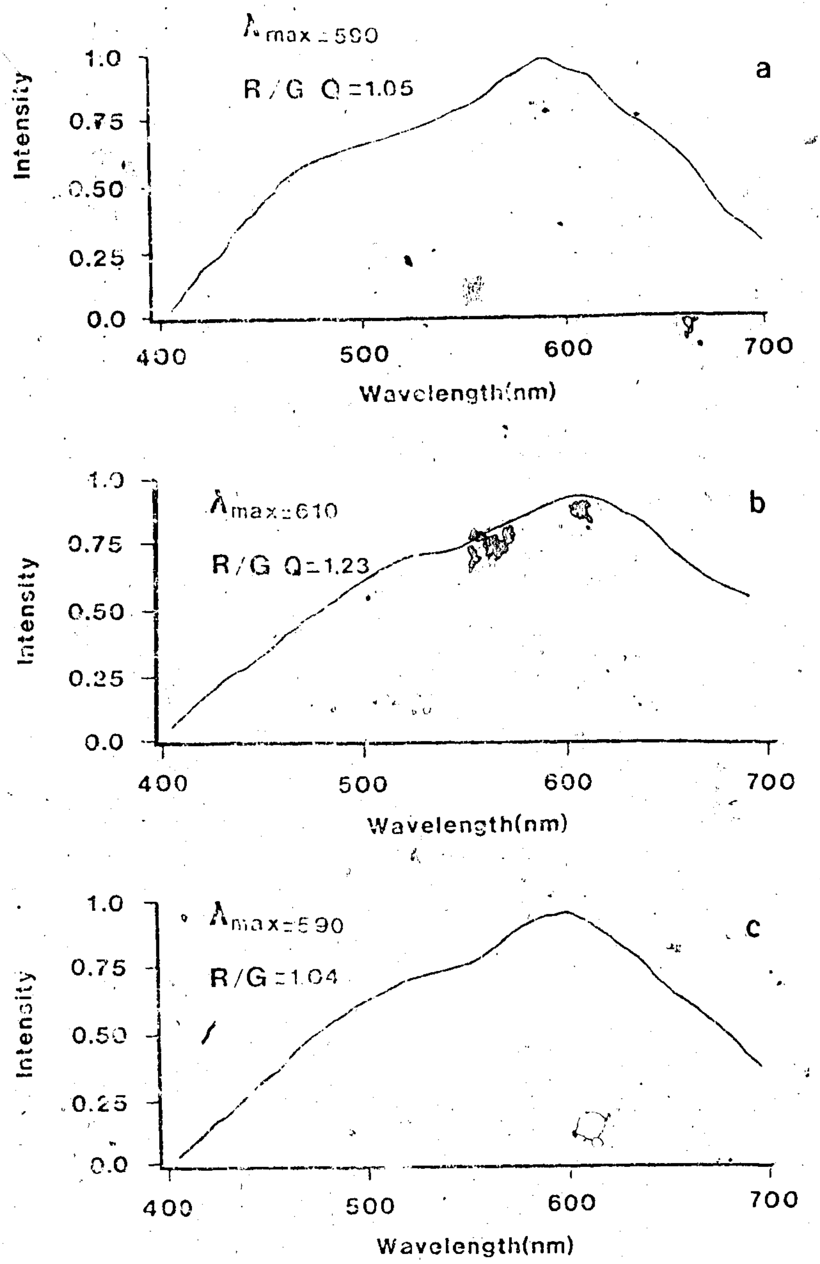


Figure 7-10. Fluorescence spectra of bituminite (a), cutinite (b), and sporinite (c).

Sporinite, mainly miospores (tenuisporinite) was observed either as individual grains or in large masses (Plate 8, Fig. 4) which were light to dark grey in white light and a very light yellow-orange fluorescent colour under UV light. It showed a spectral maximum at 590 nm and a red/green quotient of 1.04 (Fig. 7-10c).

Fluorinite (Plate 8, Fig. 5) appeared black in normal reflected light and displayed unusually strong fluorescence.

7.1.4 Types of kerogen

The following types of kerogen were found in the interbedded sediment of the coal deposit:

1. Type II kerogen (Plate 8, Figs. 1-6) represented by the macerals of the liptinite group (excluding alginite).
2. Type III kerogen (Plates 2-5), very abundant and consisting mainly of the macerals humotelinite, humocollinite and humodetrinite.
3. Type IV kerogen (Plate 6, Figs. 1-4) represented by the inertinite macerals, and only sporadically present.

Type II kerogen (cutinite, sporinite) was mainly associated with carbonaceous shales and marls.

Resinite and Type III kerogen were present in carbominerites, carbonaceous shales and shales.

The carbonates (carbo-ankerite) contained Type III kerogen, in particularly humocollinite (gelinite).

7.1.5 *Ternary composition diagrams*

On the ternary comp[illegible]al diagrams (Figs. 7-11 to 7-14) the boundary between clean coal and [illegible]inerite was set at 20 per cent mineral matter content (Goodarzi, 1985), whereas sediment that has more than 60 per cent mineral matter content by volume was classified as carbonaceous shale (Stach, 1975a). A coal with more than an 80 per cent content by volume of humotelinite plus humocollinite was considered to be bright (Marchioni, 1980); coals having a humotelinite plus humocollinite content between 60 and 80 per cent were classified as banded bright, and with less than 60 per cent were considered to be dull coals.

The lower right-hand apex of the triangle represents relatively dry conditions, whereas the lower left-hand apex of the same triangle represents relatively wet conditions.

Zone A

Figure 7-11 shows the composition of zone A, in terms of its macerals. The coals of this zone are generally very rich in humotelinite and humocollinite and poor in humodetrinite. The majority of the coal samples studied from Zone A were bright and banded-bright.

Zone B

Among the total number of samples analyzed from this zone, there is approximately an equal number of samples classified as carbonaceous shales and samples classified as carbominerites (Fig. 7-12). The zone contained a limited number of coal seams and the coals were not 'clean'.

Zone C

Zone C is microscopically similar to zone B. The zone contained a small number of coals seams and the majority of the samples analyzed were classified as carbominerites (Fig. 7-13).

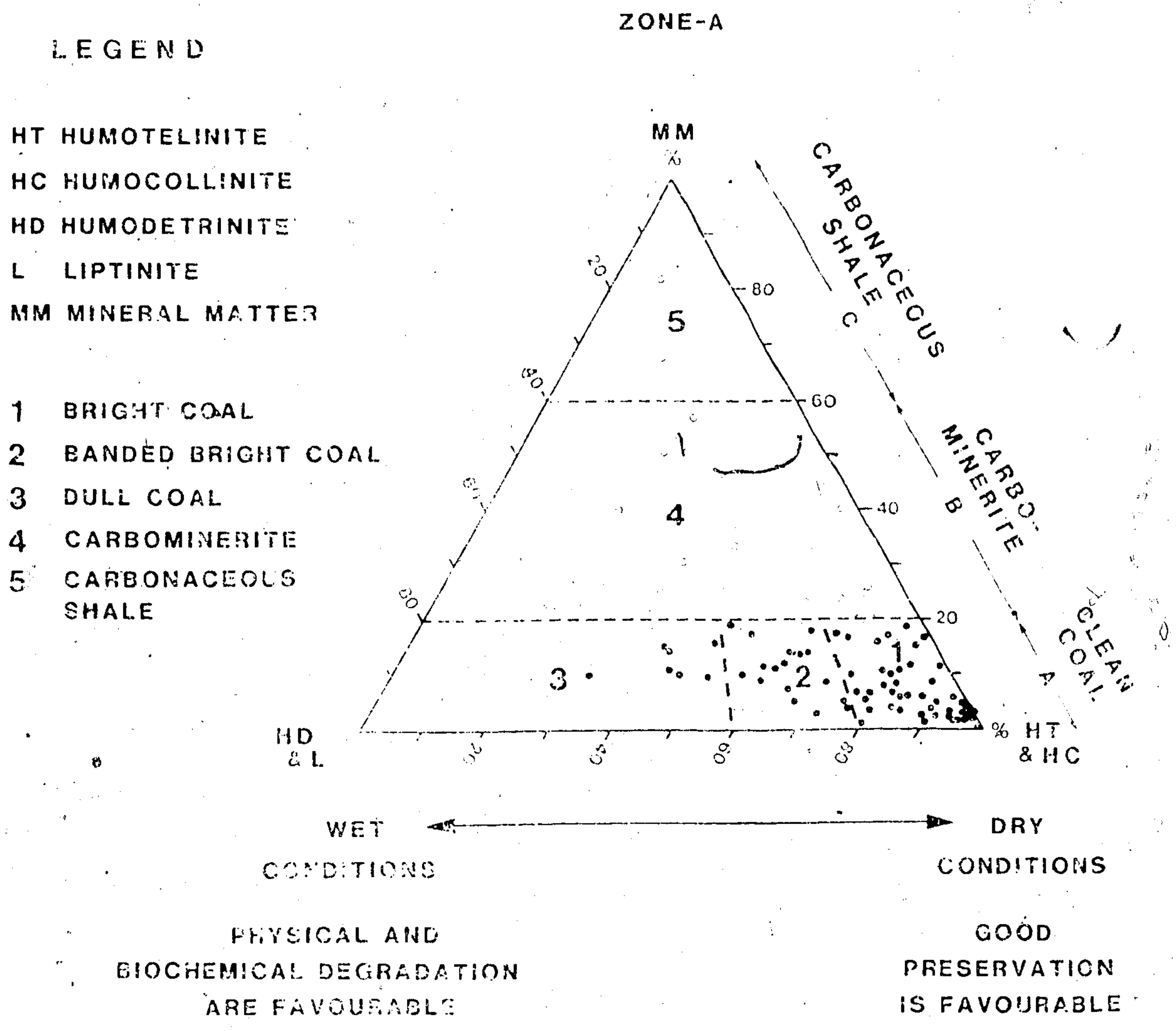


Figure 7-11. Ternary compositional diagram for Zone A.

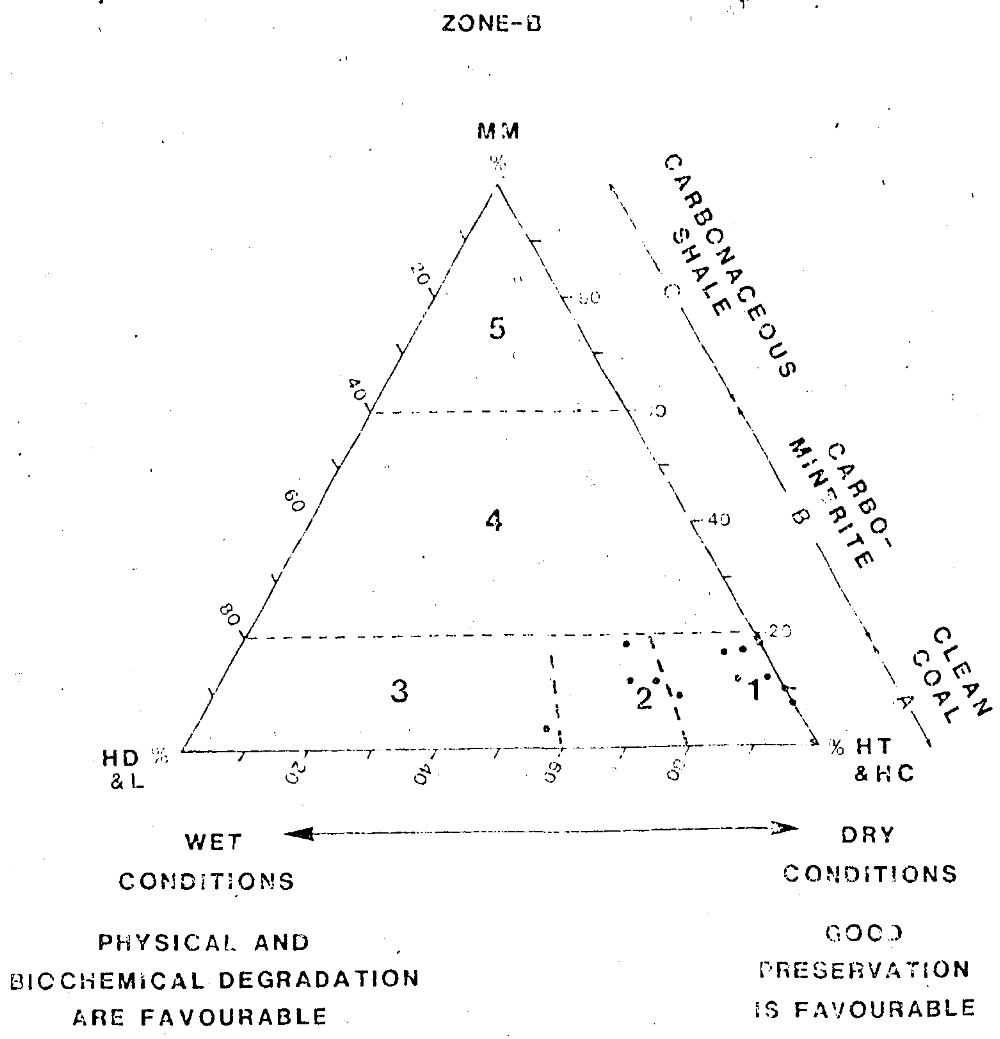


Figure 7-12. Ternary compositional diagram for Zone B.

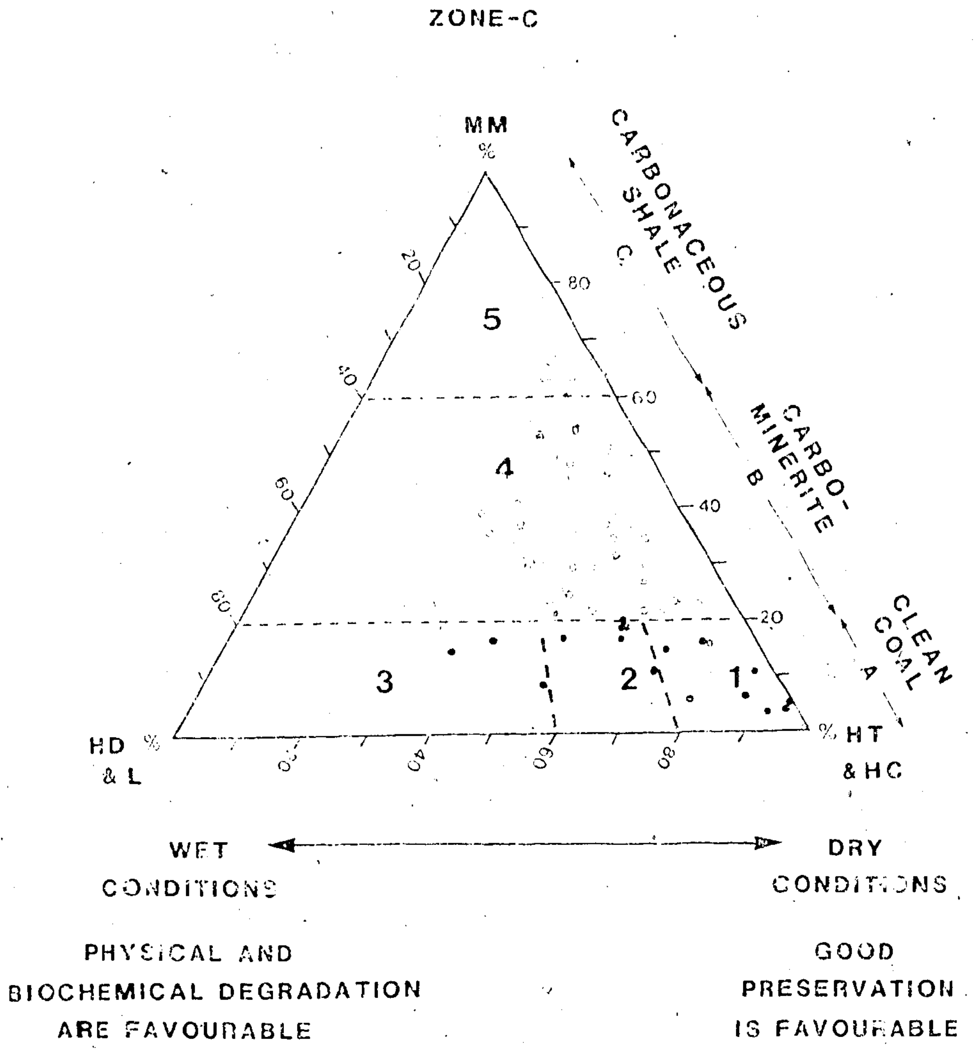


Figure 7-13. Ternary compositional diagram for Zone C.

Zone D

Zone D is similar to zone A (Fig. 7-14) although the coals appear to be more dull than the coals of zone A. Most of the non-coal samples were classified as carbominerite.

General statement

The microscopic analysis was based on the fact that 'coal' could not contain more than 20% by volume clays or other minerals (Stach, 1975a). The macrocopic description, on the other hand, based mainly on log interpretation and core description, did not use the 20 per cent threshold. Therefore, material with up to 50 per cent mineral matter content was probably considered and described as 'coal' and the difference between the two descriptions is due to the above reason.

7.1.6 Selected samples

The macerals: resinite, sporinite, texto-ulminite, eu-ulminite A and B, low and high reflectance phlobaphinite and gelinite, were studied from selected coal and interbedded sediment samples. The selection was done for each zone individually in such a way that each sample contained as many of the named macerals as possible.

The objective was to study how the reflectance of all these macerals changes with depth and with increasing rank. It should be noted that, changes in reflectance reflect changes in the chemical structure of the maceral, therefore, any information on relative reflectance behavior with increasing depth may give a clue as to the way coalification affects the physical chemistry of a maceral.

Resinite types 1, 2, and 3 had a range of reflectance from 0.02 to 0.1% R_{oil}, the lowest of all macerals (Figs. 7-15 to 7-18). Next was sporinite (R_{oil} 0.06 to

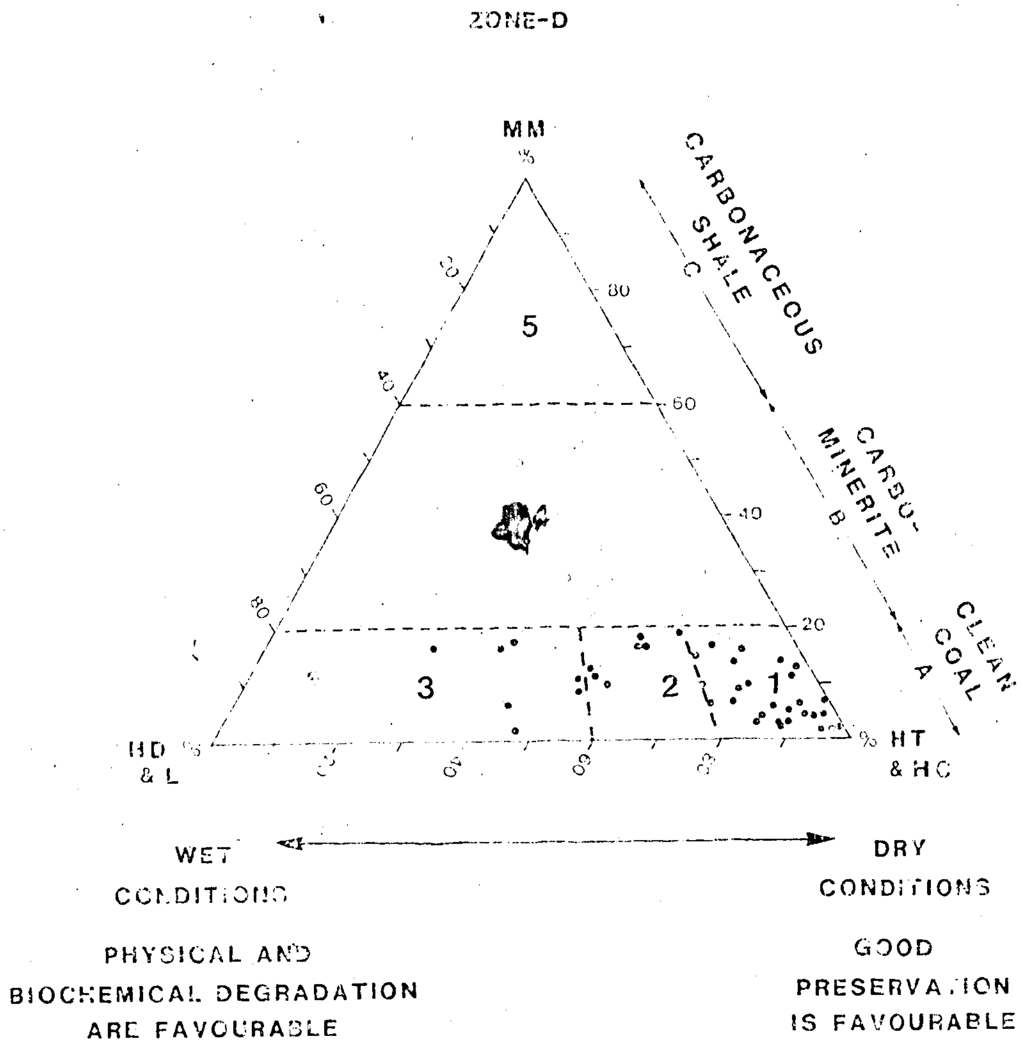


Figure 7-14. Ternary compositional diagram for Zone D.

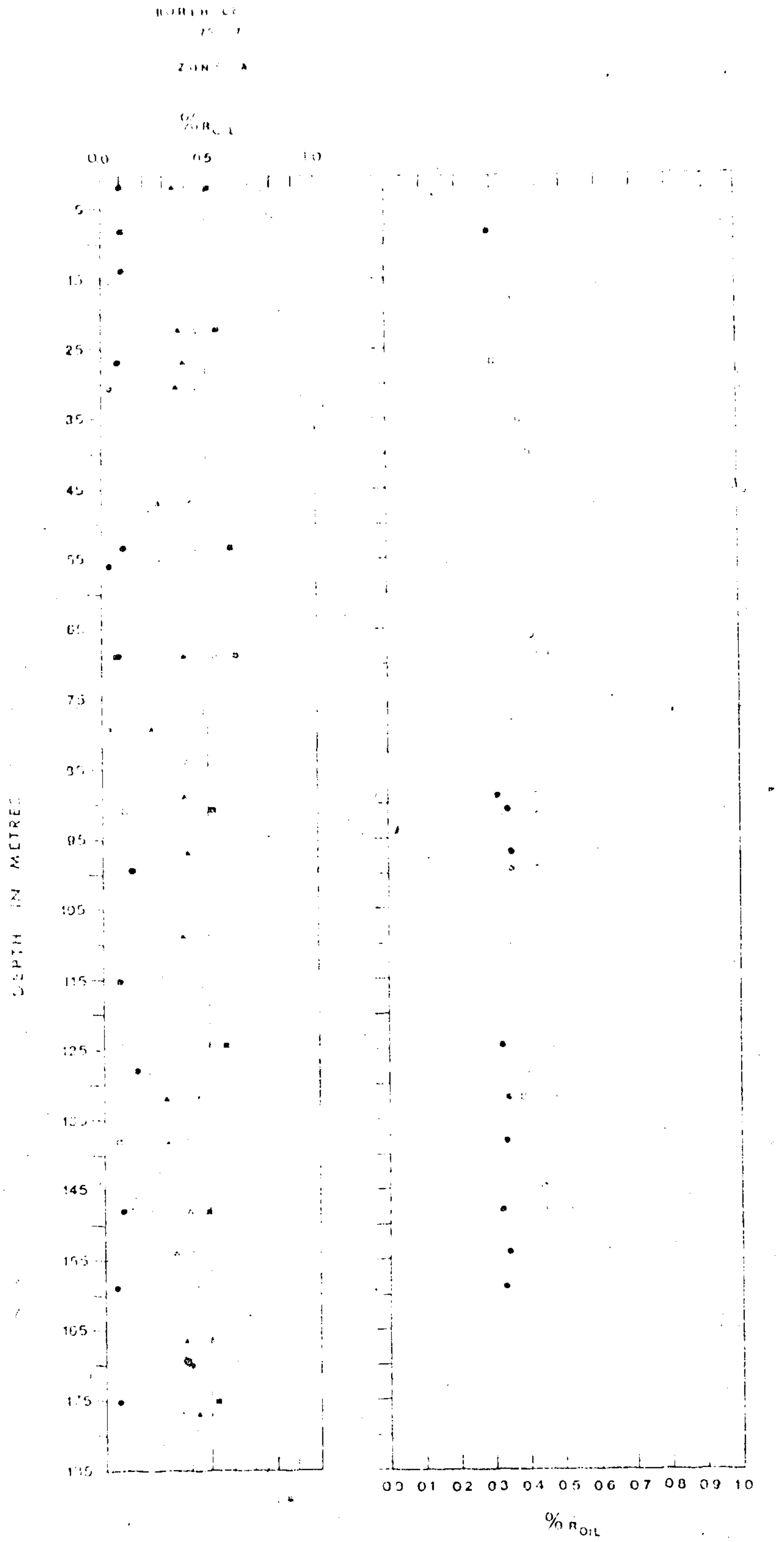


Figure 7-15. Reflectance of huminite and liptinite macerals in coal and interbedded sediment (Zone A).

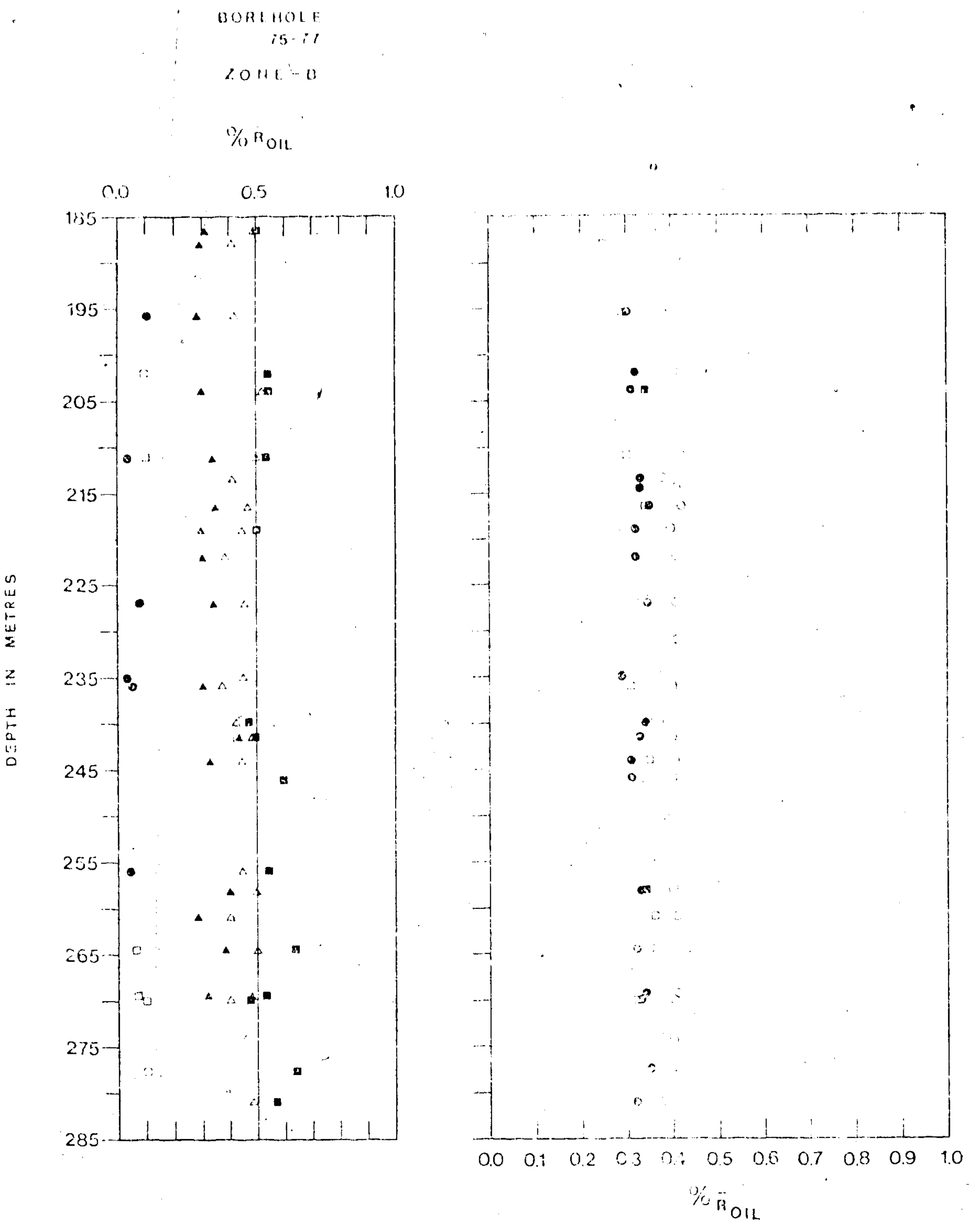


Figure 7-16. Reflectance of huminite and liptinite macerals in coal and interbedded sediment (Zone B).

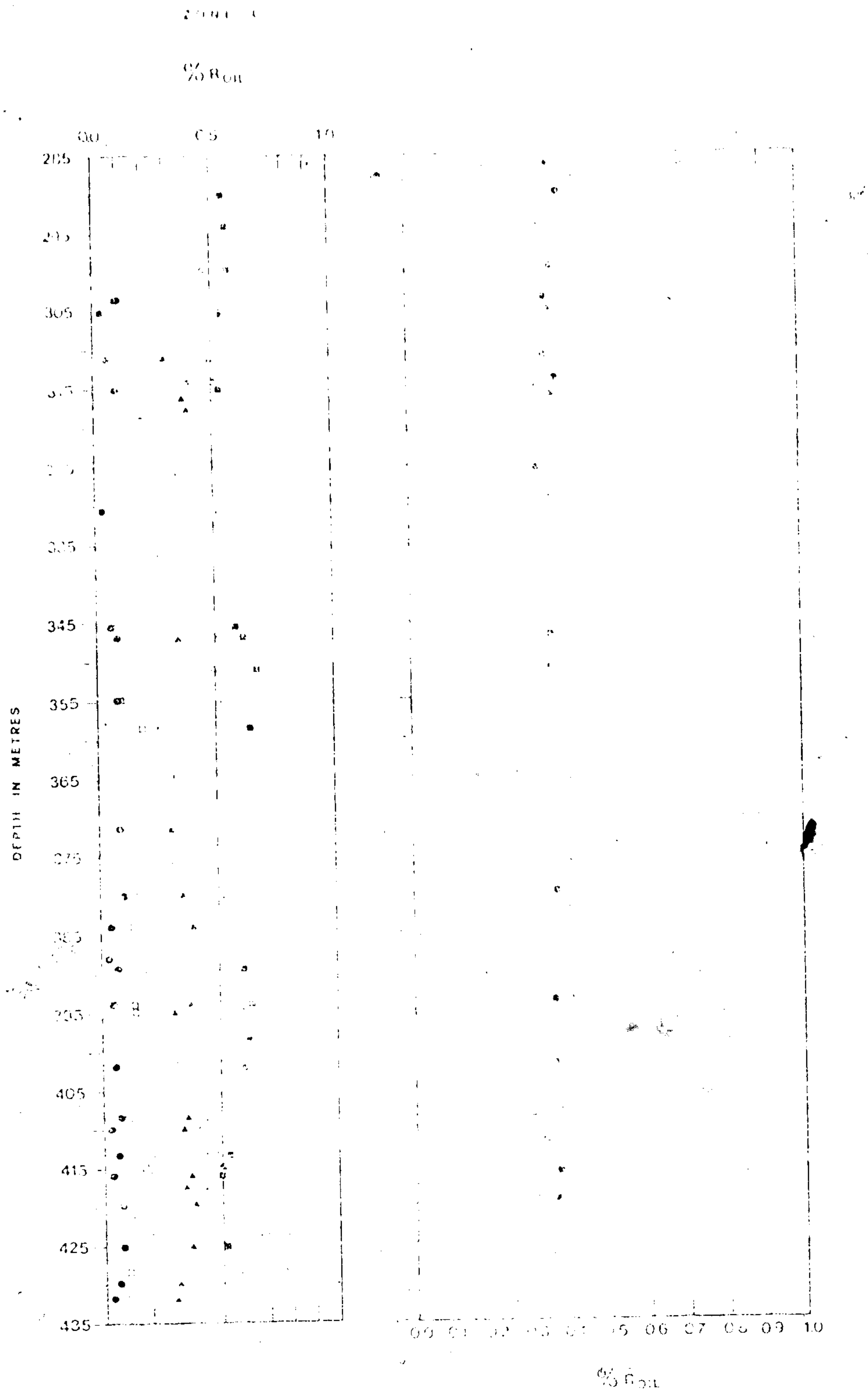


Figure 7-17. Reflectance of huminite and liptinite macerals in coal and interbedded sediment (Zone C).

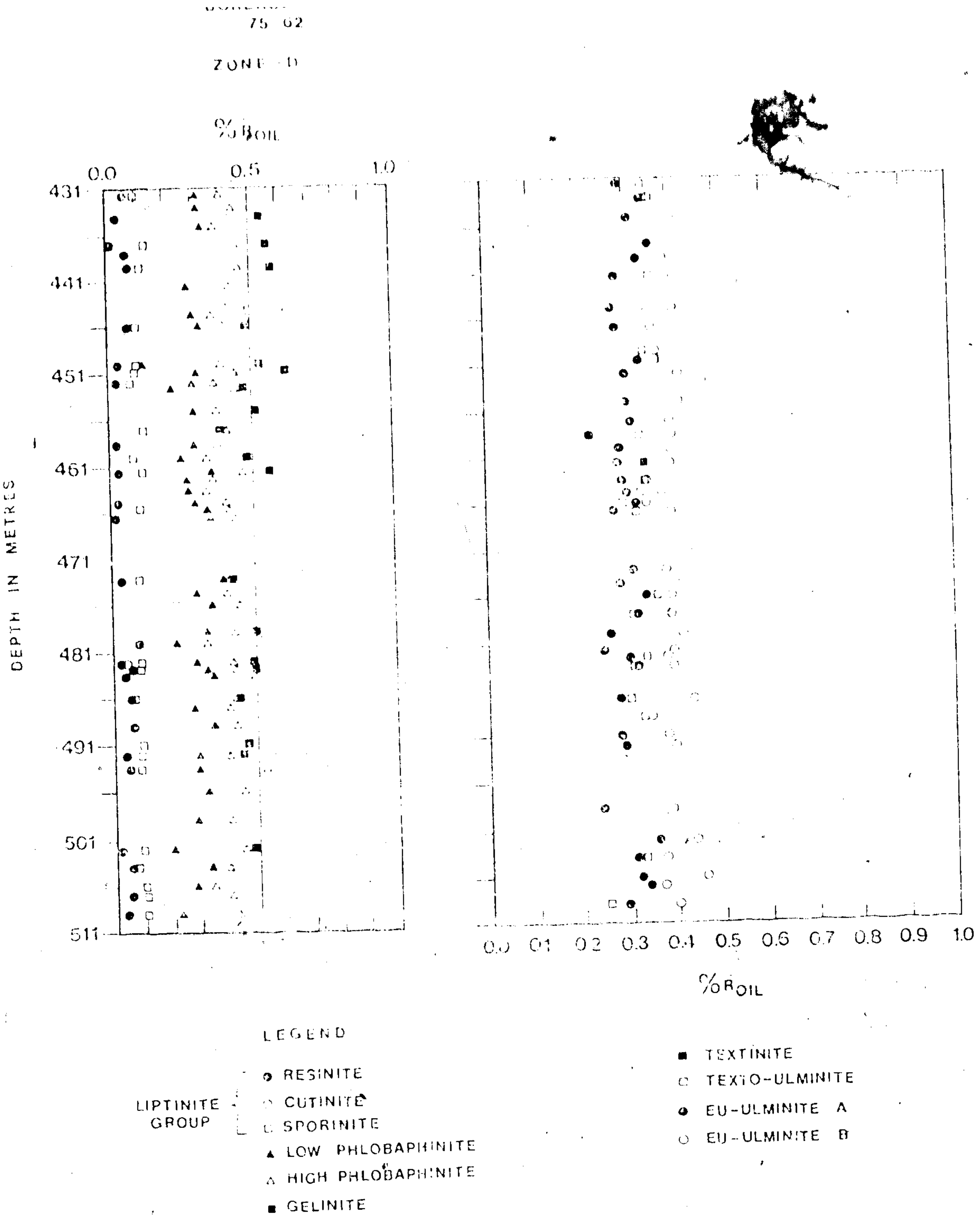


Figure 7-18. Reflectance of huminite and liptinite macerals in coal and interbedded sediment (Zone D).

0.2%). Low phlobaphinite (Plate 3, Fig. 4) with reflectance range of 0.25-0.4% R_{oil} and high phlobaphinite (Plate 3, Fig. 3) (0.4-0.55% R_{oil}) had higher reflectances.

Gelinite (eugelinite, Plate 5, Fig. 1) had the highest reflectance of all the macerals studied with a range between 0.45-0.65% R_{oil}. Gelinite has high reflectance because it has a high carbon content, less volatile matter and considerably less hydrogen in its structure. A distinct relationship exists between the reflectance of a maceral and its carbon or volatile-matter content. Reflectance generally increases with a decrease in volatile matter and an increase in carbon content. The same pattern in the order of reflectance increase with depth was observed in all zones.

Among the macerals of the humotelinite group, eu-ulminite A had the lowest reflectance increase with increasing depth. Eu-ulminite B showed the highest reflectance increase with increasing depth. The above relationship was observed in all zones. Due to the narrow ranges of eu-ulminite reflectance change with depth, it is very hard to obtain an accurate coalification gradient.

It was noted that the high reflectance phlobaphinite was similar in reflectance to eu-ulminite B. The relationship is clear and shows that in the absence of eu-ulminite B, high phlobaphinite may be used to estimate the rank of coal. Eu-ulminite A and low reflectance phlobaphinite also showed similarities in their reflectance behaviour.

7.1.7 Individual macerals and their alteration

Huminite group

Textinite

Textinite present in zone A exhibited a characteristic cellular structure (Plate 2, Fig. 3). It was also observed in zone D where it had high reflectance

(R_{oil} 0.43–0.48%), and was completely gelified, representing petrified wood associated with carbonate-rich sediments (carbo ankerite) (Plate 2, Fig. 2). These features reflect the moderate degree of compaction and gelification of the coals.

Texto-ulminite and eu-ulminite

Through the process of gelification textinite altered to ulminite. The macerals texto-ulminite (partially gelified) and eu-ulminite [both A and B varieties (Plate 3, Fig. 5)] were found through the succession. Ting (1976) believes that secondary xylem of conifers is giving rise to dark huminite whereas cortical tissues give rise to light huminite. Eu-ulminite was completely gelified and had a similar appearance to vitrinite (telinite) of bituminous coals. Gelification is probably the chief factor in the loss of botanical detail in huminite. Presumably the gelification, which was responsible for the effects observed here, was mainly biochemical and occurred at, or very soon after, the time of peat deposition.

Densinite

Densinite, found in Hat Creek coals, consisted of detrital particles cemented together as a result of gelification. The detritus was intimately mixed with finely divided gel (resulting mainly from strongly decomposed plant material). The material was clearly heterogeneous on the basis of both morphological and material differences. Some particles appeared with an angular outline and may be the residuals after the removal of surrounding material during partial gelification.

Gelinite

Material precipitated from colloidal solutions which migrate through existing cavities within the coals is termed gelinite (Teichmüller, 1975). Levigelinite (Plate 5, Fig. 3) was dense and massive with characteristic desiccation cracks, due to shrinkage from a fully hydrated gel, whereas porigelinite (Plate 5, Fig. 4) was very finely porous to granular, intruding into cell lumens of textinite.

Corpohuminite

The coals are rich in corpohuminite which appeared to be cell infillings with equal or greater reflectance than the surrounding huminite. The type phlobaphinite was found to be associated in large numbers with the plant tissues of conifers and material rich in wood (Cohen, 1968).

Significance

The entire change from textinite to eu-ulminite can be observed in the Hat Creek coals. There is a very insignificant change in the petrological features of the humotelinite group macerals which, along with the small increase in the reflectance of eu-ulminite B from the top to the bottom of the deposit (Tables 7-10), suggest a very small coalification gradient.

Humic materials, in general, respond relatively uniformly during the individual stages of coalification, irrespective of the fact that they are the most abundant constituents of the Hat Creek coals. This is the reason why only the huminites were used for rank estimation.

Liptinite group

Sporinite

Sporinite originates from the outer cell walls of spores and pollen (Teichmüller, 1975), and its content may be influenced by climate (Teichmüller, 1975).

In the Hat Creek coals, sporinite was mainly associated with interbedded sediments rich in humodetrinite, and was rarely observed in clean coals.

Cutinite

Cutinite forms from the cuticular layers and cuticles of the epidermis of leaves (Teichmüller, 1975).

Cutinite was less abundant than sporinite in the Hat Creek coals, possible because the cuticular layers have been destroyed mechanically (Teichmüller, 1975). Cutinite is rare in many autochthonous peats and coals suggesting that the Hat Creek coals are mainly autochthonous.

Resinite

Resinite (Plate 7) can have many origins, but its principal precursors are resins and waxes, although oils and fats are also considered to be source materials (Teichmüller, 1975). The different precursors explain the varying microscopic properties (form, colour, reflectivity, fluorescence) of resinites in the same coal (Teichmüller, 1975).

Resinite has high concentrations of hydrogen compared to the inertinite or huminite macerals (Stach, 1975a). Depending on filter combination, the colour variation may range from blue to light brown, a function of the amount of hydrogen present and/or the manner in which hydrogen is bound to other elements in the structure (Stach, 1975a).

Dobell *et al.* (1984) recognized four types of resinite in the Hat Creek No. 1 coals. These types were identified as type 1a and 1b (crystalline), type 2 (yellow), type 3 (orange or mustard), and type 4 (brown). Crelling *et al.* (1982) also obtained similar results from studies on resinites in western United States coals of Cretaceous and Tertiary ag[illegible]

The Hat Creek coals are rich in resin because of the abundance of conifers in the Tertiary flora of central British Columbia. Isolated resinite bodies are particularly common in the coals at Hat Creek (Plate 7, Fig. 1). They are probably original cell excretions, which, when the tissues are destroyed, remain as individual entities (Teichmüller, 1975). Resinite appeared darker than huminite in reflected light and fluoresced with different colours and intensities.

Each resinite type is characterized by maximum intensity at a different wavelength, with type 1 at the lowest and type 4 at the highest. As the peak of maximum intensity shifts to longer wavelengths, the shape of the curves also changes. With type 1 resinite the curve appears to be less flat and the peak of maximum intensity less diffuse than in other types (compare Fig. 7-9a to 7-9f) in agreement with the results of Dobell *et al.* (1984). The spectral shift to longer wavelengths was accompanied by a rise in reflectivity and a fall in fluroescence intensity; all the above changes with coalification are typical of resinite.

Suberinite

This maceral (Plate 8, Fig. 6) in the Hat Creek coals consists of suberin, a substance found in cork cell walls, mainly in bark, but also at the surface of roots and on stems (Teichmüller, 1975). In the typical cork tissues the suberin layer of the cell walls is usually preserved.

Significance

It goes without saying that the resin and wax content of coals originates from the peat-forming plants. Conifers contain more resin and less wax than angiosperms (Stach, 1975a). Therefore, the resinite types appear to have had different physical and chemical properties from the beginning, probably because they originated from different precursors and are oxidized since resinites of different types are found in coexistence in the same coal interval. Generally, their carbon content rises at the expense of oxygen and hydrogen with increasing coalification (Teichmüller, 1975). In addition to differences in origin, the various types may have followed somewhat different paths during the conversion of peat to subbituminous coal, responding to alterations in varying ways.

Fluorescence microscopic studies indicate that the coalification stage of the Hat Creek coals lies below the first coalification 'jump', therefore, no petroleum-like substances are expected to be produced by the kerogen of the coals at this stage.

Inertinite group

Sclerotinite

Sclerotinite was the only maceral of this group present in relatively large quantities. Sclerotia, from which the term sclerotinite is derived (Teichmüller, 1975), are the winter spores of fungi which survive in unfavourable toxic conditions.

Significance

High sclerotinite content in coal indicates dry periods (Cohen, 1968), and therefore the small amount of sclerotinite (Plate 6, Figs. 1-4) in the Hat Creek coals indicates moist conditions in the peat swamp. This is in agreement with the conclusions from other aspects of this study.

7.2 Use of analysis of variance (ANOVA) and linear regression analysis

Introduction

In order to compare the variation of huminite (eu-ulminite) reflectance versus depth, a formalized procedure for analysis of the variance (ANOVA) was used. Reflectance is the dependent variable and depth is the independent one. Analysis of variance was applied for coaly particles occurring in three different matrices, namely shaly matrix, carbonate matrix and coaly matrix. Coaly matrix was further subdivided into A and B, A corresponding to the good quality coal and B to the secondary quality coal. All four zones were combined.

Linear regression analysis was performed along with ANOVA. This type of analysis will infer the presence of any trends in the vertical sequence for each of the three matrices. It will also aid in the interpretation of the coalification history of the zones, particularly if combined with the Markov analysis.

7.2.1 Variation in reflectance with depth

Zone A

The reflectance, measured on ulminite, has a range from 0.35 to 0.47% R_{oil} with a mean value of 0.41% for most of the coal seams. Reflectance increases gradually from the top to the base of the zone, at a very small rate.

Generally the reflectance of ulminite in coal was higher (in the order of 0.03% R_{oil}) than the reflectance of ulminite in the interbedded carbonaceous shales, shaly coals and marls.

Zone B

The ulminite reflectance ranges from 0.36 to 0.45% R_{oil} with a mean value approximately 0.40%. Ulminite reflectance increases very slightly with depth. Three samples (166A, 190 and 219) containing huminite in carbonates, exhibited higher reflectance values (0.44-0.45% R_{oil}) than the associated coals.

Zone C

Ulminite reflectance ranges from 0.36 to 0.49% R_{oil} with a mean of 0.40%, showing a negligible increase with depth. Seven carbo-ankerite samples (245, 256, 274, 279, 332, 330) exhibited reflectance values (0.45–0.49% R_{oil}) much higher than the associated coals, and the interbedded sediments show a greater range in reflectance than coals.

Zone D

The range in ulminite reflectance is 0.36 to 0.44 R_{oil} with a mean around 0.40% and a very small rate of increment. Ulminite in coal has higher reflectance and a wider range of values than kerogen in interbedded sediment. In general, reflectance of kerogen in carbonates > reflectance of ulminite in coal > reflectance of kerogen in shaly coal > reflectance of kerogen in carbonaceous shale.

This appears to agree with [illegible] obtained by Timofeev and Bogolyubova (1970) and Goodarzi (1985). No comparison can be made with Bostick and Foster (1975) or Jones *et al.* (1972) because they were dealing with bituminous coals.

7.2.2 Variation of reflectance of kerogen in different matrices with depth

Shaly matrix

The reflectance, measured on ulminite, has a slightly negative slope (Fig. 7-19), meaning that the reflectance does not increase with depth.

The variance is large in zone A (top 185 m) and much smaller in zones C and D (280 m to bottom). The points in zones C and D are clustered closer to the computed fit line despite the fact that there are more points observed as compared to zone A.

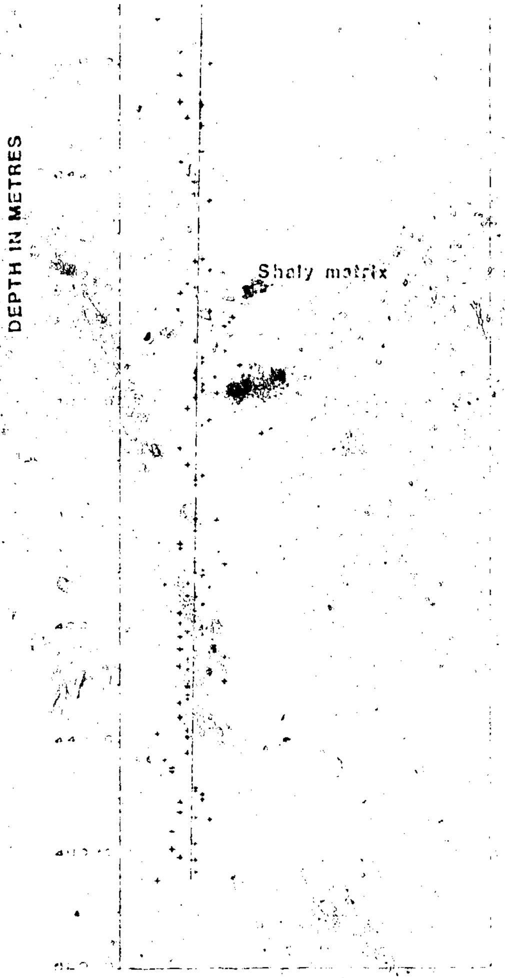


Figure 7-19. Reflectance of kerogen in shaly matrix versus depth.

The variation of reflectance versus depth in this case is not useful in interpreting the coalification of the coal because it does not appear to be susceptible to changes within a limited depth range. This indicates a problem with the uniformity of variance with depth. Unfortunately 'ANOVA' assumes (Davis, 1973) a uniformity of variance.

Carbonate matrix

The reflectance of coaly particles associated with carbo-ankerite was higher than that of particles occurring in shaly or coaly matrix (Fig. 7-20). Although there is an increase of reflectance versus depth and a small variance, due to the small number of observations it is not known how the regression line would behave in zone A and D because of the lack of points for these zones.

Coaly matrix A and B

Only in zones A and D the slope of the best-fit line is positive (Figs. 7-21 and 7-22). There are also more points observed for these zones. For zones B and C, not only the points are very few, but also the slope for matrix B in zones B and C is slightly negative. The same is true for matrix A in zone B. The above characteristics show how little the coaly particles change in reflectance throughout the entire 500 m sequence and also how little they are susceptible to changes with increasing depth. The interval is rather small to observe any major changes in reflectance and the rate of increment is almost negligible.

It is also worth mentioning that the zones where the reflectance of kerogen in coaly matrix has a positive slope are the ones containing most of the coal seams of the deposit. In these zones A and D, it appears that kerogen in coaly matrix responds to depth changes and, therefore, to coalification better than kerogen in shaly matrix.

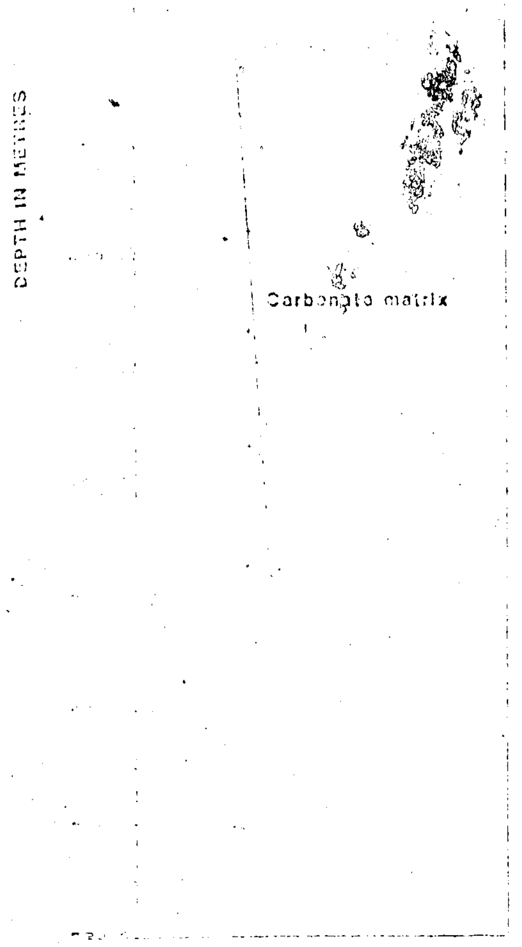


Figure 7-20. Reflectance of kerogen in carbonate matrix versus depth.

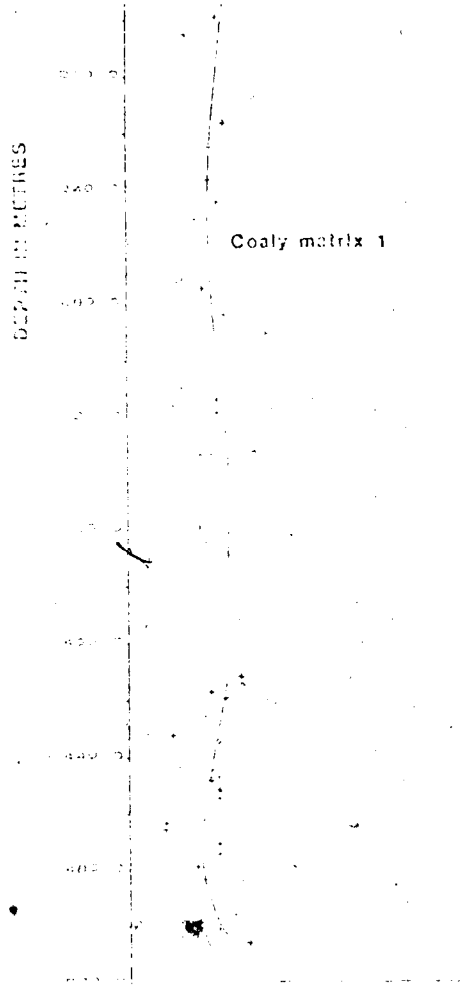


Figure 7-21. Reflectance of kerogen in coaly matrix A versus depth.

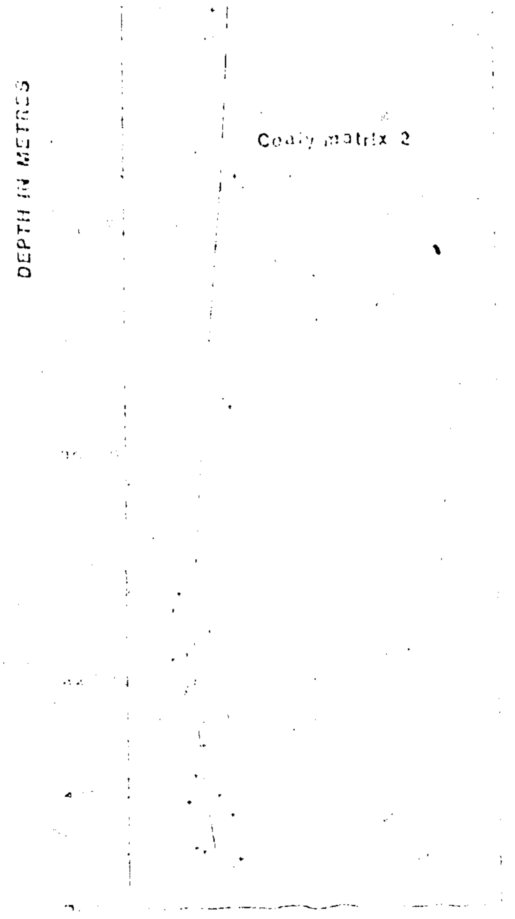


Figure 7-22. Reflectance of kerogen in coal matrix B versus depth.

7.3 Use of Markov chains in sedimentary succession analysis

Introduction

A vertical sequence of rock types is the product of a series of sedimentation events, ordered in time. Time sequence structures are members of a continuous spectrum bounded by the conditions of independent events and determinism and subdivided on the basis of behaviour pattern. They are realized as stochastic models in which predictions of behaviour must be made in terms of probability (Doveton and Skipper, 1973).

Such a model that is readily applicable to geological successions is provided by Markov chains. The rationale of Markov chain analysis and its use in geological sequence studies are described in explanatory texts such as Davis (1973) and Harbough and Bonham-Carter (1970). Some of the basic ideas are briefly reviewed and will be clarified in their application to the data of this study. The simplest Markov model is one of first order, characterized by a partial sequential dependency between immediately successive events, and independence related to all other preceding events (Doveton and Skipper, 1973). Potential Markovian properties are analyzed through the summation of an event succession in terms of transition matrices. A first order Markov model is found appropriate if a null hypothesis of independent events is statistically rejected at a selected level of significance. Statistical testing procedures normally utilize the Chi-square test in the form of a contingency table.

7.3.1. Markov analysis as applicable to the Hat Creek sequence

The data in Appendix 3 represent a stratigraphically measured core section, where each lithologic unit has been classified into the following mutually exclusive states – coal 1, coal 2, carbonaceous to coaly claystone or shale, siltstone, petrified wood, ironstone or siderite and carbonate or marl. Since Markov chain analysis was applied to each of the four main zones of the deposit, not all seven of the above states occurred in each zone. The seven states were arbitrarily designated as A, B, C, D, E, F, and G, respectively.

The analytical results for each zone of the deposit have as follows:

Zone A

State A (C_1) Coal 18.0 m J/Kg and > 23.2 API was the thickest, approximately 108 m followed by State B (C_2 Coal 18.0-9.3 m J/Kg and 23.2-38 API.

The matrix of proportion of transitional pairs indicates that the transitions from state A to state B and vice-versa are the two with the highest values. The transition probability matrix on the other hand, upon which the transition scheme was based, shows that the transitions from A to B and C to A are the most common with the transition from state B to state A coming in third place. This means that almost 75 per cent out of 100, good quality coal is always followed by secondary quality coal and that carbonaceous claystone is followed by good quality coal.

The Chi-square value for zone A is 43.7 with 9 degrees of freedom at a level of significance of 5%. Since the value is much higher than 16.92, which is the critical value of x^2 with 9 degrees of freedom at the 5% level of significance, there was a rejection of independent events in favour of a first order Markov property.

Zone B

State A (C_1) - good quality coal, was the thickest one, approximately 39 m, followed by C_2 (~30 m). Carbonaceous claystone and shale amounted to 27 m.

The matrix of proportion of transitional pairs indicates that the transition from state B to State A has the highest value followed by the transitions from A to B and C to B. The transition probability matrix shows that almost 78 times out of 100 secondary quality coal is followed by good quality coal, and almost 72% of the times carbonaceous claystone is followed by coal.

With 9 degrees of freedom the critical x^2 value is 28.95 at the 5% significance level, higher than the 16.92 value of the table. Therefore, there is a rejection of independent events in favour of a first order Markov property.

Zone C

State A (C_1) has a maximum thickness of 70m, whereas state B (C_2) comes second with almost 44m.

The matrix of proportion of transitional pairs indicates that the transition from state B to state A is the most common followed by the transition from A to B. The transition probability matrix reflects that and shows that this transition (B to A) has the highest value.. Transition E to A was disregarded, despite the high value, because it occurs only once.

The total Chi-square test value is 50.53 with 36 degrees of freedom at the 5% significance level. The table value is very close to 50.0, indicating that an acceptance of the null hypothesis is possible. This, in turn, would mean that there is no dependency between adjacent points and that zone C may not have a Markov property. Because the table does not show the exact value of x^2 for 36 degrees of freedom at 5%, it is very hard to decide exactly on whether the null hypothesis should be accepted or rejected.

Zone D

No Markov chain analysis was performed for this zone because there were only three states present and would not have served any purpose.

Substitutability analysis and discussion

The upward (left) substitutability matrix for zone A indicates that states B and C tend to be followed by a common state, A. The downward (right) substitutability matrix shows that states B, C and A, C have the highest value indicating that they are preceded by a common state. The mutual substitutability matrix shows that states B and C appear in a common context and are enclosed between similar states. The other high transition values (i.e. between zone C, B, A, and D) were disregarded.

The upward substitutability matrix on zone B shows that states A and C have a high value meaning that they are followed by a common state, B. The downward substitutability matrix indicates that states B and C as well as A and C tend to be preceded by a common state. The mutual substitutability matrix indicates that states A and C are enclosed between similar states and may substitute for each other. The remaining high substitutabilities with zone D were disregarded.

The upward substitutability matrix of zone C indicates that states A and C have a high value with C and B having the second highest. The downward substitutability matrix shows again that states A and C have the highest value. The above means that states A and C are preceded and succeeded by a common state. The mutual substitutability matrix reflects this and shows that states A and C appear betwen similar states and can be substituted by one another. The other values were disregarded because of very small number or no transition values among the states.

The qualitative interpretation of the model transition schemes in the light of the transition matrices on which they are based, shows a strong parallelism in its inference of sequential pattern. It appears that the most frequent transition is that of a secondary quality coal (state B) to a good quality coal (state A) followed by the transition of A to B and carbonaceous claystone or shale (state C) to secondary quality coal (state B).

Substitutability analysis largely reinforces conclusions derived from the Markov transition schemes.

8.0 DISCUSSION

The Hat Creek No. 2 coals are characterized by the dominance of huminite group macerals (humotelinite, humocollinite, humodetrinite) and lesser amounts of macerals of the liptinite group (resinite, sporinite, cutinite, and bituminite). Although these coals contain no fusinite, semifusinite or inertodetrinite, sclerotinite is present in very small amounts reflecting the nature of the vegetation. The near absence of inertinite in Hat Creek indicates that the swamp was very rarely sub-aerially exposed, and that conditions for the formation of inertinitic macerals (oxidation, forest fires, etc.) were not common in the peat swamp, possibly due to the humid climate of the swamp. The above characteristics set the Hat Creek coals apart from many coals of the world. They are, however, petrographically similar to other thick, low-rank Tertiary deposits such as those in the Rhine district of Germany and the Latrobe Valley of southeastern Australia.

Environments of deposition in peat bogs have been the subject of numerous investigations (Marchioni, 1980; Smyth and Cameron, 1982; Goodarzi, 1985). A detailed study of the maceral composition of the coals, combine with a macroscopic analysis of the coal and interbedded sediment can usually delineate the petrographic characteristics of the coals and highlight the petrologic features typical of individual peat-forming environments.

During the deposition of the Coldwater Formation, which underlies the coal beds, the total percentage of organic matter was too low and the influx of sediment too high for peat to accumulate (Goodarzi, 1985). As soon as a balance among the supply of vegetal matter, influx of sediment, rate of subsidence and water level fluctuations was achieved, the Hat Creek swamp began to develop. Zones D and A contain mainly bright and banded bright coal which represents vegetation growth in a forest swamp environment. The limited number of dull coals are thought to have developed in response to rising water inundating the peat swamp. The dull coals have high proportions of detrital material (humodetrinite) and are associated with clastic zones (Goodarzi, 1985), implying 'wet' conditions where physical and biochemical degradation are favourable.

Zone D coals, although bright and banded bright, appear to be duller than coals of zone A. The zone contains numerous coal seams which appear to be uninterrupted.

The peat is wood-rich (xylitic) indicating that the water table in the coal-forming peat for zone D was probably at a moderate level. The dominance of humotelinite and humocollinite as well as the relatively high percentage of humodetrinite indicate a peat containing mainly trees and shrubs. Coals from zones A and D are quite similar, based on their macroscopic and microscopic characteristics. In a relatively stable environment, deposition of peat is accompanied by a succession of plant communities, with the initial stage assumed to have taken place under a shallow to moderate covering of stagnant water.

In zone C seams are more abundant in the lower part, and thickest one is 11 m. The inorganic sediment consists mainly of carbominerite, and the maceral versus depth profile indicates a dominance of mineral matter in the upper and middle part of the zone. The paleoenvironment appears to have been similar to that of zone B, with unstable water conditions and frequent inundations of the peat swamp by inorganic sediments being the major characteristics of zone C.

Zone B consists mainly of clastic sediments. Coal seams are evenly distributed throughout the zone with the thickest one being approximately 6 m. The mineral matter content of the sediments of this zone increases indicating an environment with clastic sediment interbedding the coal seams frequently.

The clastic horizons containing clays, carbonaceous shales and coaly matter represent introduction of inorganic material into the peat swamp, interrupting periods of deposition of coal. In order to introduce some inorganic material into the swamp, however, it seems necessary to invoke an air-fall mechanism (Teichmüller, 1975). The bentonitic beds (sample 225) and perhaps some other clastic intervals may represent air-fall deposition.

The ternary compositional diagram of Zone A indicates that the coals of this zone are mainly bright and banded-bright in nature. The maceral composition versus depth profile for zone A shows that the coals consist of humotelinite and humocollinite. Zone A contains numerous, very thick (up to 20 m) clean coal intervals. The humotelinite dominance over humodetrinite for most of zone A suggests a high input of woody material to the coal-forming peat (Goodarzi, 1985). The plant communities of this zone consist of *Glyptostrobus* and *Metasequoia* based on studies by Blackburn (1982) on paleobotany which suggest a forest-moor swamp environment (Fig. 8-1a).

Coal in zone A was deposited in a very stable depositional environment where the rate of accumulation of plant material was closely regulated by a rather slow rate of subsidence. The result is a very thick, uninterrupted coal deposit indicating a quiet coal-forming environment with very little flooding taking place and minor clastic introduction in the swamp.

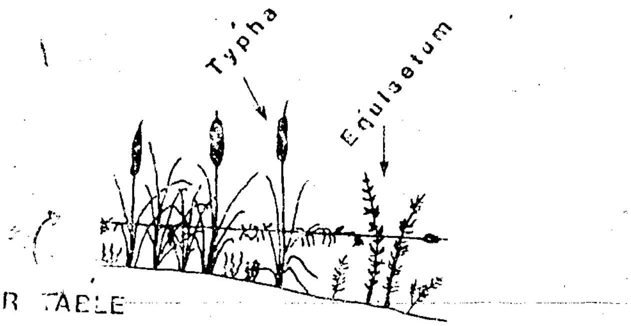
The clastic interval near the base of zone A has a thickness of approximately 15 m and possibly indicates a period of more active erosion in the surrounding terrain -perhaps due to tectonic uplift. The presence of marl containing pollen grains indicates possibly a fresh water environment similar to the reed marsh of Teichmüller (1975). The other clastic interval of zone A represent periods during which the swamp was inundated with sediments.

MOOR TYPE : METASEQUOIA -GLYPTOSTROBUS-ANGIOSPERM
FOREST MOOR SWAMP ENVIRONMENT

RESULTING COAL :

MEGASCOPIC : COAL WITH COALIFIED TREE STEMS (XYLITIC)

MICROSCOPIC : MUCH HUMOTELINITE,WELL PRESERVED TISSUES(TEXTINITE)



MOOR TYPE : EQUISETUM-TYPHA REED MARSH ENVIRONMENT

RESULTING COAL :

MEGASCOPIC : COAL WITHOUT TREE STEMS (DETRITAL)

MICROSCOPIC : MUCH HUMODETRINITE,VERY FEW TISSUES

Figure 8-1. Forest moor swamp environment (a): the dominant environment of the Hat Creek peat swamp. Reed marsh environment (b): the sub-dominant environment of the Hat Creek peat swamp.

The rate of subsidence of zone D was regular and there was a balance among the water level fluctuation, rate of subsidence and accumulation of vegetal matter during coal formation producing uninterrupted, thick and 'clean' coal with only minor quantities of mineral matter. The rate of subsidence increased during deposition of zone C (especially the middle and upper parts), resulting in the formation of a thick sedimentary section with low organic content. These carbonaceous clastic units, dominated by *Equisetum* and minor *Typha*(?) (Blackburn, 1982) indicate a reed marsh environment, where humodetrinite is relatively abundant compared to humotelinite (Fig. 8-1b).

The balance between the accumulation of plant material and the rate of subsidence for zone B was still not good enough to allow the development of thick, 'clean' coal seams. The rate of subsidence must have been constant throughout the entire zone and the environment appears to have been mainly reed marsh mixed with forest swamp.

During deposition of zone A, the rate of basin subsidence was very regular, except during deposition of the thick, clastic interval near its base. This interval indicates that the balance between vegetal accumulation and subsidence was disrupted in favour of greater subsidence. The environment was probably a forest-moor swamp.

The peat of zones A and D is autochthonous. Root horizons (samples 59, 65, 70 and 149), well preserved remains of coalified tree stems (xylite), excellent preservation of cell structure, stratification, definite roof and floor boundaries of the coals and the thickness and continuity of the coal seams all tend to indicate a high degree of autochthony. A small degree of hypautochthony (semi-drifting) is suggested by significant proportions of humodetrinite and mineral matter in the coals of zones A, B and D.

Figures 8-2 and 8-3 illustrate schematically how vegetation in the Hat Creek basin was growing. The interval between high and low water levels (Fig. 8-2) has been called the telmatic zone (Teichmüller, 1975) and has been equally divided between the forest-moor and the reed marsh environments. The Hat Creek coal probably represents peat that formed in a telmatic zone; and the absence of large quantites of organic mud (gyttjae) interbedding the coal as well as large spore and algal quantities probably indicates that the open water-moor environments is not represented in Hat Creek. No alginite was observed microscopically, suggesting that the limnotelmatic (subaquatic) zone was probably not attained.

Although pollen grains were observed in a few samples, their percentage is too small to indicate a dominance of open water conditions. The bright nature of the Hat Creek coal therefore, particularly in zones A and D most likely indicates an environment dominated mainly by a forest swamp with reed marsh environment being subordinate. Such forest swamps rarely dry-out and this coupled with a humid climate may account for the petrographic characteristics of the coals.

Figure 8-3 is a three dimensional representation of the Hat Creek basin, showing the forest moor swamp as it may have appeared during peat accumulation. The alteration of plant material to huminite requires anaerobic, reducing conditions (Francis, 1961) which are maintained when the swamp is covered by stagnant water (Teichmüller and Teichmüller, 1975). With time, biological and physico-chemical processes altered the peat into coal. Because forest moor environments promote relatively continuous and rapid accumulation of peat, the groundwater level must steadily rise to keep abreast of peat formation (Williams, 1978) if huminite is to accumulate.

Seam thicknesses and the uniform composition (humotelinite>humocollinite plus humodetrinite) of the Hat Creek coals in zones D and A along with thin

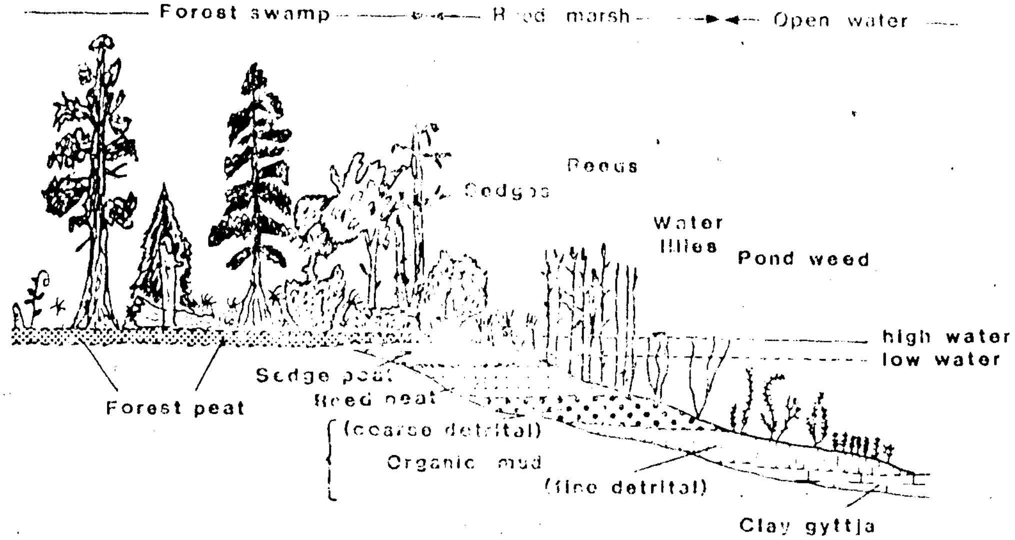


Figure 8-2. *Filling of the Hat Creek lake basin with the resulting sequence of peat.*

Figure 8.3 [illegible]

clastic zones indicate a relatively stable rate of subsidence in relation to the accumulation of plant material at the surface (Shibaoka and Smyth, 1975). It has been recognized that tectonism played an important role in Hat Creek coals attaining their great thicknesses but the water level must have been responding (i.e. rising) during every stage of swamp evolution.

At the end, the water level probably rose rapidly due to a sudden increase of the rate of subsidence that initiated inorganic sedimentation, and the swamp simply drowned. The Medicine Creek Formation, overlying the coal deposits, consists of approximately 600 m of lacustrine sediments.

Metasequoia and *Glyptostrobus* (Blackburn, 1982) were probably constituents of the autochthonous peat swamp itself, whereas the transitional reed marsh comprising carbonaceous claystone and shaly coal lithofacies, was probably hypautochthonous and characterized by *Equisetum* and ferns as dominants, with some *Typha*(?), and in the more coaly samples by *Glyptostrobus*, *Equisetum* or *Metasequoia* (Blackburn, 1982). The open water assemblages, present in the carbonaceous clay lithologies were probably stream or lake vegetation. Root horizons were absent in the massive clays and support the suggestion that the assemblages were transported (Blackburn, 1982).

The autochthony of the vegetable matter of the Hat Creek No. 2 coal deposit and the considerable compaction (>2:1) necessary for the transformation from peat to lignite (Teichmüller and Teichmüller, 1975) suggest that the deposit developed from bogs that grew *in situ*. Vegetal residues are not preserved unless they are submerged under partially stagnant water (Teichmüller, 1975) and it appears that most of the coal originated from residues of rooted vegetation which do not live under great water depths.

The rate of vegetation growth and subsequent peat accumulation must be controlled by the rise of the water level in order to form a coal deposit (Falini, 1965). The amount of vegetable matter that can accumulate in a year in a peat bog is limited however, and depends on environmental conditions (i.e. climate); it is clear, therefore, that there must be an upper limit to the growth rate.

The petrographic composition of the Hat Creek coals illustrates the significant increase in humotelinite and decrease in humodetrinite and liptinite from dull to bright coals. The transition from bright to dull coals is apparently a response to rising water levels and increased circulation within the swamp as well as an accompanying increase in the detritic component of organic influx. This may be due to some changes in the vegetation community.

Due to the lack of the major variable inertinite, petrographic variation among the Hat Creek coals is limited. It would be difficult to compare the Hat Creek coals with the Kootenay coals in southeastern British Columbia because the latter generally contain more inertinite and have been deposited in a deltaic, coastal swamp environment. The Carboniferous coals of Pennsylvania and Illinois, on the other hand, are generally bright and contain much more sulphur indicating the influence of marine waters on the coals. The environment of deposition for these coals is a series of prograding deltas interfingering with marine sediments (A.R. Cameron, pers. comm., 1985).

9.0 CONCLUSIONS

The organic petrology (coal and kerogen) of the Hat Creek No. 2 coal deposit was examined in detail. Petrography was related to the depositional environments of the ancient peat swamp in an attempt to reconstruct the paleoenvironment during peat accumulation.

The following conclusions can be made:

1. The Hat Creek No. 2 coal deposit is of lacustrine origin. Sedimentation and peat accumulation were probably controlled by regional north-south block faulting. The coal basin developed as a swamp in a poorly drained, low-lying area adjacent to eroding uplands. Relatively high water levels in the swamp and continual subsidence resulted in favourable conditions for thick peat accumulation. Repeated flooding and volcanic activity resulted in an inorganic material including ash falls being introduced into the swamp.
2. The coal is mainly bright in zones D and A and composed primarily of huminite with only minor liptinite. The near absence of inertinite indicates a relatively humid coal forming environment.
3. In zones C and B the coal is interbedded with sediments which include carbonaceous shales, marls and shaly coals.
4. Eu-ulminite reflectance measurements show an increase in coal rank from lignite (0.35% R_{oil}) at the top to subbituminous B (0.45% R_{oil} at the base of the deposit. This represents a very small increase in rank for a 600 m thick deposit, indicating that the coalification gradient was very small.
5. The reflectance of huminite particles contained in carbonaceous shales is less than the reflectance of huminite in coals, whereas the reflectance of huminite in carbonates is higher than that in coal.

6. Four different types of the liptinite maceral resinite were identified, based on morphology and fluorescence properties. They indicate different origins and/or different coalification histories.

7. The very thick coal seams with little interbedded sediment were formed under a stable environment whereas thin coal seams with numerous and thick interbedded sediments were formed under unstable conditions.

8. The supply of vegetation, rate of subsidence and water level fluctuations must have been delicately balanced for most of the life span of the ancient peat swamp. The balance was finally destroyed; the swamp drowned and was covered by lacustrine sedimentation.

9. The coal deposit was derived from vegetation which grew in fresh water marshes in an intermontane basin. The origin of the coal is autochthonous (*in situ*) for zones D and A and possibly hypautochthonous (semi-drifted) for zones C and B.

10. A warm, subtropical climate prevailed during the Middle-Late Eocene in south-central British Columbia and contributed to the formation of a forest-moor swamp environment in the basin. The forest swamp, dominated by *Metasequoia* and *Glyptostrobus*, produced coals containing high proportions of humotelinite, indicative of relatively 'dry' conditions. Coals rich in humodetrinite indicate 'wetter' conditions in which *Equisetum* and minor *Typha*(?) thrived in the reed marsh environment.

LITERATURE CITED

Alpern, B., Durand, B., Espitalié, J. and Tissot, B., 1972. Localisation, caractèrisation et classification pètrographique des substances organiques sedimentaires fossiles: Advances in Organic Geochemistry, 1971, 1-28 Pergamon Press: Oxford-Brawnschweig.

ASTM, 1979. Gaseous fuels, Coal and Coke: Annual Book of ASTM Standards, Pt. 26, p. 222-224, Philadelphia, Pa.

Barghoorn, E.S. and Spackman, W., 1950. Geological and botanical study of the Brandon lignite and its significane in coal petrology: Economic Geology, v. 45, no. 4, p. 344-357.

Blackburn, D.T., 1982. Paleobotany of coal-bearing strata from the Cretaceous and Tertiary of western Canada and Ellesmere Islands: unpublished report to the Geological Survey of Canada Calgary Alberta.

Bostick, N.H., 1970. Thermal alteration of clastic organic particles as an indicator of contact and burial metamorphism in sedimentary rocks: Geoscience and Man, v. 3, p. 83-92.

Bostick, N.H., 1973. Time as a factor in thermal metamorphism of phytoclasts (coaly particles): 7th Congr. Internat. Stratigraphie et Geologie Carbonifere, Krefeld, 1971, Compte Rendu, v. 2, p. 183-193.

Bostick, N.H., 1979. Microscopic measurement of the level of catagenesis of solid organic matter in sedimentary rocks to aid exploration for petroleum and to determine formal burial temperatures - A review: The Society of Economic Paleontologists and Mineralogists, Special Publication No. 26, p. 17-43.

Bostick, N.H. and Foster, J.N., 1975. Comparison of vitrinite reflectance in coal and in kerogen of sandstones, shales and limestones in the same part of a sedimentary section; Colloque International, Petrographie de la matiere organique des sediments, Alpern B., ed.: Centre National de la Reserche Scientifique, Paris, p. 13-25.

British Columbia Hydro and Power Authority, 1980. Hat Creek Project - Preliminary Geological Report, No. 2 Deposit: Mining Department, Hat Creek Thermal Projects Group (Unpublished).

Bustin, R.M., Cameron, A.R. Grieve, D.A. and Kalkreuth, W.D., 1983. Coal Petrology -Its Principles, Methods, and Applications: Geological Association of Canada Short Course Notes, v. 3, p. 119.

Cameron, A.R., Kalkreuth, W.D., and Koukouzas, C., 1984. The petrology of Greek brown coals: International Journal of Coal Geology, v. 4, no. 3, p. 173-207.

Campbell, D.D., Jory, L.T. and Saunders, C.R., 1977. Geology of the Hat Creek coal deposits: Canadian Institute of Mining and Metallurgy, v. 7, no. 782, p. 99-108.

Church, B.N., 1975. Geology of the Hat Creek Basin: Summary of Field Activities, B.C. Dept. of Mines, p. 104-108.

Church, B.N., 1977. Geology of the Hat Creek Coal Basin, *in* Geology in British Columbia: British Columbia Ministry of Mines and Petroleum Resources, p. G99-G118.

Cockfield, W.E., 1948. Geology and mineral deposits of Nikola map area, British Columbia: Geological Survey of Canada, Memoir 249, 164 p.

Cohen, A.D., 1968. The petrology of some peats of southern Florida (with special reference to the origin of coal): Unpublished Thesis, Pennsylvania State Univ., Dept. Geol. Geophys., 352 p.

Crelling, J.C., Dutcher, R.P. and Lange, R.V., 1982. Petrographic and fluorescence properties of resinite macerals from western U.S. coals: Utah Geological and Mineral Survey, Bulletin 118, p. 187-191.

Davis, J.C., 1973. Statistics and data analysis in geology: John Wiley, New York, p. 278-295.

Davis, G.A., 1977. Tectonic evolution of the Pacific Northwest from Precambrian to present: WNP-114, PSAR, Amendment 23, Subappendix 2RC (report to the Nuclear Regulatory Commission by Washington Public Supply systems), 46 p.

Dawson, G.M., 1877. Map of a portion of the Southern Interior of British Columbia, Canada, Map No. 363.

Dickinson, W.R., 1976. Sedimentary basins developed during evolution of Mesozoic-Cenozoic arc-trench system in Western North America: Canadian Journal of Earth Sciences, v. 13, p. 1268-1287.

Dobell, P., Cameron, A.R. and Kalkreuth, W.D., 1984. Petrographic examination of low-rank coals from Saskatchewan and British Columbia, Canada, including reflected and fluorescent light microscopy, SEM, and laboratory oxidation procedures: Canadian Journal of Earth Sciences, v. 21, p. 1209-1228.

Doveton, J.H. and Skipper, K., 1974. Markov chain and substitutability analysis of a turbidite succession, Claridorme Formation (Middle Ordovician), Gaspé, Quebec: Canadian Journal of Earth Sciences, v. 11, p. 472-488.

Duffell, S. and McTaggart, K.C., 1952. Ashcroft Map-area, British Columbia: Geological Survey of Canada, Memoir 262.

Ewing, T., 1981. Geology and tectonic setting of the Kamloops Group, south-central British Columbia: Unpublished Ph.D. thesis, University of British Columbia, 225 p.

Falini, F., 1965. On the formation of coal deposits of lacustrine origin: Geological Society of America Bulletin, v. 76, p. 1317-1346.

Francis, W., 1961. Coal, its formation and composition: Edward Arnold Ltd., London, 860 p.

Goodarzi, F., 1985. Organic petrology of Hat Creek Coal Deposit No. 1, British Columbia; International Journal of Coal Geology, in press.

Harbaugh, J.W. and Bonham-Carter, G., 1970. Computer simulation in geology: John Wiley, New York, 575 p.

Hacquebard, P.A. and Donaldson, J.R., 1970. Coal metamorphism and hydrocarbon potential in the Upper Paleozoic of the Atlantic provinces, Canada: Canadian Journal of Earth Sciences, v. 7, p. 1139-1163.

Hacquebard, P.A., Birmingham, T.F. and Donaldson, J.R., 1967. Petrography of Canadian coals in relation to environment of deposition, *in* Symposium on the Science and Technology of coal: Department of Energy, Mines and Resources, Ottawa, Canada, p. 84-97.

Hills, L.V., 1965. Palynology and age of early Tertiary basins, interior British Columbia: Unpublished Ph.D. thesis, University of Alberta, 188 p.

Hills, L.V. and Baadsgaard, H., 1967. Potassium-argon dating of some lower Tertiary strata in British Columbia: Bulletin of Canadian Petroleum Geology, v. 15, no. 2, p. 138-149.

Hopkins, W.S., 1980. Palynology of the 75-106 corehole, Hat Creek Coal Basin, British Columbia: Geological Survey of Canada, Open File Report 547.

Höy, T., 1975. Depositional Environment and Stratigraphic subdivision of the Hat Creek No. 1 Deposit: Canadian Institute of Mining and Metallurgy Paper, B.C. Hydro Mining Department.

Hunt, J.M., 1979. Petroleum geochemistry and geology: W.H. Freeman and Company, San Francisco, 617 p.

International Committee for Coal Petrology, 1971. International handbook of coal petrology, 2nd edition 1963, supplement to 2nd edition 1971: Centre Nationale de la Reserche Scientifique, Paris.

Jones, J., Murchison, D.G. and Saleh, S., 1972. Variation of vitrinite reflectivity in relation to lithology, *in* Gaertner, H.W. and Wehner, H., eds.: Advances in Organic Geochemistry, Pergamon Press, p. 601-612.

Kim, H., 1979. Depositional environment and stratigraphic subdivision, Hat Creek No. 1 deposit, British Columbia: Proceedings, 4th Annual Meeting Canadian Institute of Mining and Metallurgy, Vancouver, British Columbia, p. 1-20.

Leopold, E., 1969. Late Cenozoic palynology, *in* Tschudy, R.H. and Scott, R.A., eds.: Aspects of Palynology, Wiley-Interscience, p. 377-438.

MacKay, B.R., 1926. Hat Creek Coal Deposit, Kamloops District, British Columbia: Geological Survey of Canada, Sum. Rept. Pt. A, p. 164-181.

Mackowsky, M-Th, 1975. Methods of examination of coal, *in* Stach, E. Mackowsky, M-Th, Teichmüller, M., Teichmüller, R., Taylor, G.H. and Chandra, D., eds.: Stach's Textbook of Coal Petrology, Gebruder Borntraeger, Berlin-Stuttgart, p. 244-255.

Marchioni, D.L., 1980. Petrography and depositional environment of the Liddel Seam, Upper Hunter valley, New South Wales: International Journal of Coal Geology, v. 1, no. 1, p. 35-61.

Marchioni, D.L., in prep. The petrography of lithotypes in the Hat Creek lignites, British Columbia.

Monger, J.W.H., 1981. Geology of parts of western Ashcroft map area, southwestern British Columbia, *in* Current Research, Pt. A: Geological Survey of Canada, Paper 81-1A, p. 185-189.

Monger, J.W.H., 1982. Geology of Ashcroft map area, southwestern British Columbia, *in* Current Research, Pt. A: Geological Survey of Canada, Paper 82-1A, p. 293-297.

Okulitch, A.V., Price, R.A. and Richards, T.A., 1977. A guide to the geology of the southern Canadian Cordillera; Geological Association of Canada - Mineralogical Association of Canada - Society of Exploration Geophysicists Field Trip Guidebook 8, 135 p.

Ottenjann, K., Teichmüller, M. and Wolf, M., 1975. Spectral fluorescence measurements of sporinite in reflected light and their applicability for coalification studies, *in* Alpern, B., ed., Petrographic organique et potentiel pétrolier - 49-65: Centre Nationale Recherche Scientifque, Paris.

Pettijohn, F.J., 1957. Sedimentary rocks: Harper and Row, New York, 718 p.

Price, R.A., 1979. Intracontinental ductile crustal spreading linking Fraser River and northern Rocky Mountains trench transform fault zones, south-central British Columbia and northwest Washington: Geological Society of America, Abstracts with Programs, v. 11, no. 7, p. 499.

Rice, H.M.A., 1947. Geology and mineral deposits of the Princeton map-area, British Columbia: Geological Survey of Canada Memoir, 243, 136 p.

Rouse, G.E., 1977. Paleogene palynomorph ranges of western and northern Canada; *in* Elsik, W.C., ed., Contributions to Stratigraphic Palynology, v. 1: American Association of Stratigraphic Palynologists, Contr. Ser. 5A, p. 48-65.

Rouse, G.E. and Mathews, W.H., 1961. Radioactive dating of Tertiary plant-bearing deposits: Science, v. 133, p. 1079-1080.

Schochardt, M., 1936. Zur Praxis der Lumineszenz-Mikroscopie mit dem Epi-Kondensor W.: Zeiss - Nachrichten 2, 16.

Shibaoka, M. and Smyth, M., 1975. Coal petrology and the formation of coal seams in some Australian sedimentary basins: Economic Geology, v. 70, p. 1463-1473.

Smyth, M. and Cameron, M., 1982. Organic petrology and source rock potential of sediments in the Eromanga Basin, South Australia: International Journal of Coal Geology, v. 1, no. 4, p. 263-281.

Snyder, W.S., Dickinson, W.R. and Silberman, M.L., 1976. Tectonic implications of space-time patterns of Cenozoic magmatism in the western United States: Earth and Planetary Science Letters, v. 32, p. 91-106.

Spackman, W., 1958. The maceral concept and the study of modern environments as a means of understanding the nature of coal: Trans. New York Acad. Sci. Ser. II, 20, No. 5, p. 411-423.

Stach, E., 1975a. The microscopically recognizable constituents of coal, *in* Stach, E., Mackowsky, M.-Th., Teichmüller, M., Teichmüller, R., Taylor, G.H. and Chandra, D., eds., Stach's Textbook of Coal Petrology: Gebruder Borntraeger, Berlin-Stuttgart, p. 54-106.

Stach, E., 1975b. Fluorescence microscopy, *in* Stach, E., Mackowsky, M.-Th., Teichmüller, M., Teichmüller, R., Taylor, G.H. and Chandra, D., eds., Stach's Textbook of Coal Petrology: Gebruder Borntraeger, Berlin-Stuttgart, p. 292-302.

Tasch, K.H., 1960. Die Möglichkeiten der Flözgleichstellung unter Zuhilfenahme von Flözbildungs diagrammen: Bergbau-Redschr 12, p. 153-157.

Taylor, R.S., Mathews, W.H., and Kupsch, W.O., 1964. Tertiary, *in* Geological History of Western Canada, McCrossan, R.G. and Glaister, R.P., eds., Ch. 13, p. 190-194.

Teichmüller, M., 1958. Métamorphisme du carbon et prospection du pétrole: Rev. Industr. minér. spéc. Paris, p. 99-113.

Teichmüller, M. 1975. Origin of the petrographic constitutents of coal, *in* Stach, E., Mackowsky, M.-Th., Teichmüller, M., Teichmüller, R., Taylor, G.H. and Chandra, D., eds., Stach's Textbook of Coal Petrology: Gebruder Borntraeger, Berlin-Stuttgart, p. 176-238.

Teichmüller, M., and Teichmüller, R., 1969. Geological aspects of coal metamorphism, *in* Murchison, D. and Westoll, T.S., eds., Coal and coal-bearing strata: Oliver and Boyd, Edinburg and London, p. 233-263.

Teichmüller, M. and Teichmüller, R., 1975. Fundamentals of coal petrology, *in* Stach, E., Mackowsky, M.-Th., Teichmüller, M., Teichmüller, R., Taylor, G.H. and Chandra, D., eds., Stach's Textbook of Coal Petrology: Gebruder Borntraeger, Berlin-Stuttgart, p. 5-53.

Teichmüller, M. and Wolf, M., 1977. Applications of fluorescence microscopy in coal petrology and oil exploration: Journal of Microscopy, v. 109, Pt. 1, p. 49-73.

Timofeev, P.P. and Bogolyubova, L.I., 1970. Postsedimentasionnyye izmeneniya organicheskogo veshchestva v zanisimosti ot litoyicheeskikh tipov porod; fatsialnykh usloviy ikh nakopleniuya (post sedimentational changes of organic matter in relation to lithology and deposition facies), *in* Vassoyevich, N.B., ed., organichskoy veshchestro sovremennykh i iskopayemykjh osadkov: Nauka Press, Moscow, p. 169-190.

Ting, F.T.C., 1976. Microscopical investigation of the transformation (diagenesis) from peat to lignite: Journal of Microscopy, v. 109, Pt. 1, p. 75-83.

Van Gijzel, P., 1971. Review of the UV-fluorescence microphotometry of fresh and fossil exines and exosporia, *in* Brooks, J., Grant, P.R., Muir, M.D., van Gijzel, P. and Shaw, G., eds., Sporopollenin: Academic Press, London, p. 659.

Van Gijzel, P., 1975. Polychromatic UV-fluorescence microphotometry of fresh and fossil plant substance with special reference to the location and identification of dispersed organic material in rocks, *in* Alpern, B., ed., Pétrographie organique et Potentiel Pétrolier: Centre Nationale de la Researche Scientifique, Paris, p. 67.

Van Gijzel, P., 1981. Applications of the geomicrophotometry of kerogen, solid hydrocarbons and crude oils to petroleum exploration, *in* Brooks, J., ed., Organic Maturation Studies and Fossil fuel Exploration: Academic Press, p. 352-379.

Williams, G.D. and Burk, C.F., Jr., 1964. Upper Cretaceous, *in* Geological History of Western Canada, McCrossan, R.G. and Glaister, R.P., eds.: Ch. 12, p. 168-189.

Williams, V.E., 1978. Coal petrology of the Tulameen coalfiled, south-central British Columbia: Unpublished M.Sc. thesis, Western Washington University, Bellingham, Washington, 77 p.

Williams, V.E. and Ross, C.A., 1979. Depositional setting and coal petrology of Tulameen coalfield, south-central British Columbia: The American Association of Petroleum Geologists Bulletin, v. 63, no. 11, p. 2058-2069.

Wilson, M.V.H., 1979. Middle Eocene freshwater fishes from British Columbia: Royal Ontario Museum, Contribution no. 113, p. 1-61.

Wolfe, J.A. and Barghoorn, E.S., 1960. Genetic change in Tertiary floras in relation to age: American Journal of Science, Bradley Volume, v. 258A, p. 388-399.

Plate 1 Reflectance and Fluorescence Equipment

Fig. 1 Equipment used for coal reflectance measurements and fluorescence analysis of coal macerals (see text for detailed description).

Fig. 2 Equipment used for coal maceral identification and point counting (see text for detailed description).

PLATE 1

1

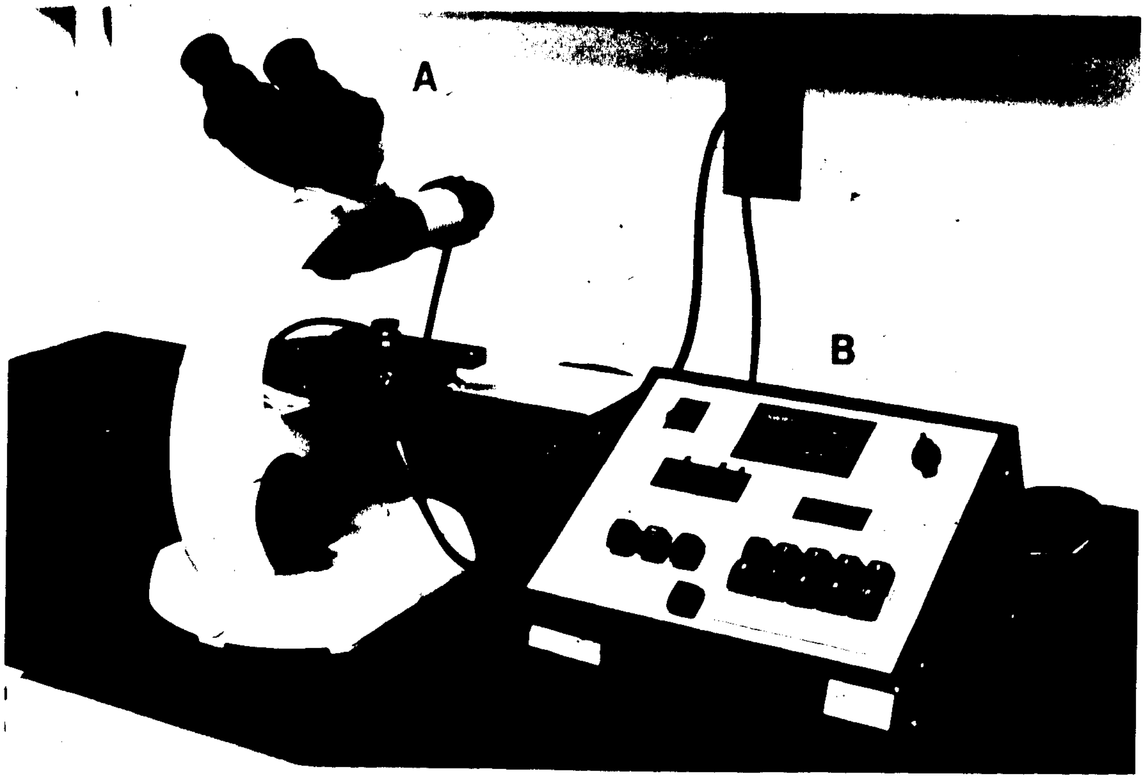


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Plate 2 Macerals of the huminite group (all photographs in black and white, reflected light, oil immersion).

Fig. 1 Textinite (TX) characterized with open cell lumina. Resinite (R) occurs as dark cell fillings.

Fig. 2 Textinite with gelified cell walls. Resinite (R) and poriegelinite (PG) fill the open cell lumina.

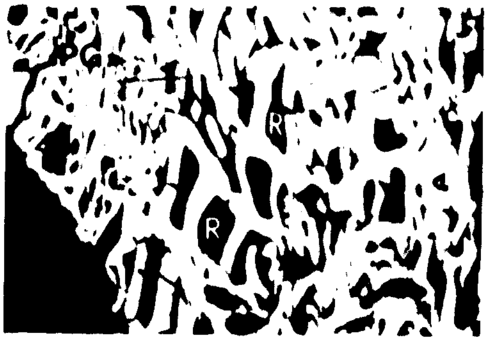
Fig. 3 Textinite showing cell wall layering (white arrow). Cell lumina filled with humodetrinite (HD).

Fig. 4 Transition of textinite (TX) on the left to texto-ulminite (TU) on the right.

Fig. 5 Texto-ulminite B (TU_B) (bright variety) in the Hat Creek coals.

PLATE 2

1



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0 microns 100

Plate 3	Macerals of the huminite group (all photographs in black and white, reflected light, oil immersion).
Fig. 1	Texto-ulminite with most of the cell lumina compressed due to compaction.
Fig. 2	Texto-ulminite A (dark) and texto-ulminite B (light) occurring in bands.
Fig. 3	Rounded and oval corpohuminite (C) bodies enclosed in texto-ulminite A.
Fig. 4	Corpohuminite (C) associated with texto-ulminite B.
Fig. 5	Alternating bands of eu-ulminite B (light) and eu-ulminite A (dark). Phlobaphinite (Pl) also present.
Fig. 6	Eu-ulminite B, Hat Creek coals. Note the much higher compaction of the cellular tissue when compared with Plate 2, Figs. 3, 4, and 5.

PLATE 3


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Plate 4 Macerals of the huminite group (all photographs in black and white, reflected light, oil immersion).

Fig. 1 High reflectance phlobaphinite (Pl) associated with texto-ulminite.

Fig. 2 Lower reflectance phlobaphinite (Pl) in texto-ulminite.

Fig. 3 Collapsed phlobaphinite (arrow) in texto-ulminite.

Fig. 4 Multi-vaculated (V) phlobaphinite showing a granular texture.

Fig. 5 Dense phlobaphinite (Pl) and porigelinite (PG) in texto-ulminite.

PLATE 4

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0 microns 100

Plate 5	Macerals of the huminite group (all photographs in black and white, reflected light, oil immersion).
Fig. 1	Gelinite (G) showing desiccation cracks (arrows).
Fig. 2	Levigelinite (LG), as telogelinite, between texto-ulminite (TU) and humodetrinite (HD). Arrows point to characteristics desiccation cracks.
Fig. 3.	Levigelinite (LG), as eugelinite, surrounded by oval resinite (R) in a densinite (D) matrix.
Fig. 4	Finely granular porigelinite (PG) associated with corpohuminite (C).
Fig. 5	Densinite (D) associated with corpohuminite (C). Note the highly compacted nature of the material.

PLATE 5

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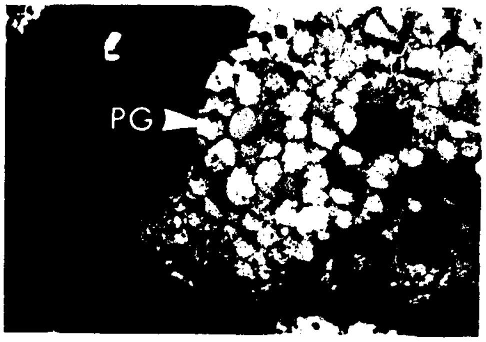

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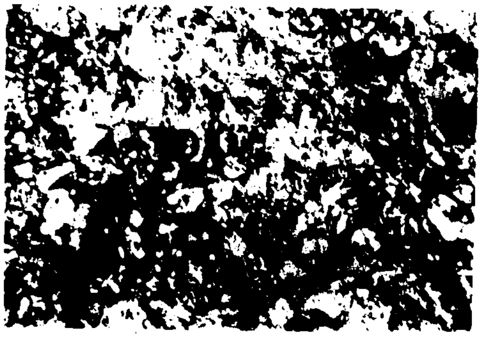
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0 microns 100

Plate 6 Macerals of the inertinite group-mineral matter (all photographs in black and white, reflected light, oil immersion).

Fig. 1 Twin-celled sclerotinite (Sc), partly deformed. This is a teleutospore (winter spore of fungi).

Fig. 2 Multi-celled sclerotinite associated with eu-ulminite A.

Fig. 3 Sclerotinite and corpohuminite in a humodetrinite and clay matrix (C).

Fig. 4 Another variety of sclerotinite (Plectenchyminite).

Fig. 5 Framboidal concentrations of pyrite crystals (P) in humodetrinite.

Fig. 6 Eugelinite (EG) in carbonate mineral matter (carboankerite).

PLATE 6

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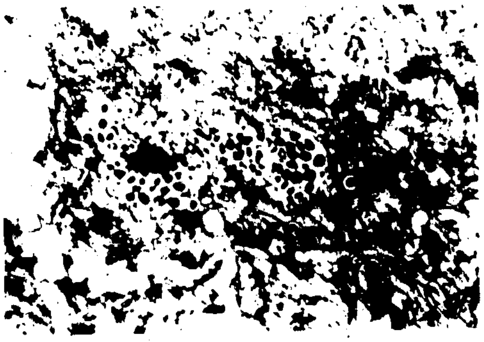

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0 microns 100

Plate 7 Macerals of the liptinite group (all photographs in black and white, reflected light, oil immersion).

Fig. 1 Massive resinite (Type 1); note is characteristic 'mottled' surface.

Fig. 2 Resinite cell fillings (Type 4) of various reflectivities surrounded by texto-ulminite cell walls.

Fig. 3 Elliptical resin body with internal reflections (Type 3) associated with eu-ulminite.

Fig. 4 Concentration of elongated resin bodies, some of which are characterized by zonation rims (arrow) and vacuoles (V).

Fig. 5 Thin-walled cuticles (tenuicutinite) characterized by serrated edges.

Fig. 6 Dark suberinite (Su) bodies associated with light phlobaphinite (Pl) bodies.

PLATE 7

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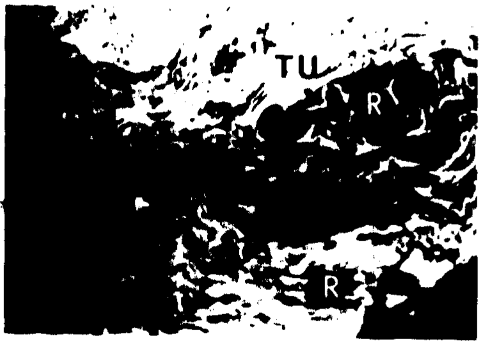

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0 microns 100

Plate 8 <u>Macerals of the liptinite group</u> (all photographs in colour, blue light irradiation, oil immersion).

Fig. 1 Angular resinite body (R) showing a bright yellow colour when under blue light irradiation.

Fig. 2 Cell filling resinite (R) with texto-ulminite (TU). Resinite displays yellowish fluorescent colour, while texto-ulminite appears olive-brown.

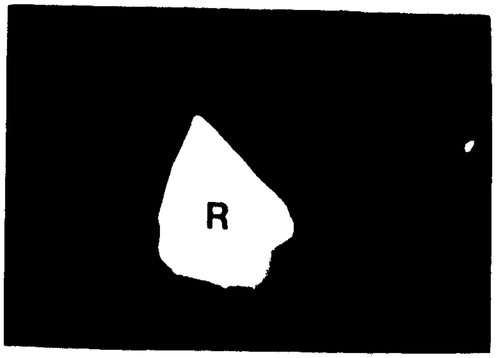
Fig. 3 Large resinite body (R) under blue light irradiation. It is associated with the cell structure of plant material.

Fig. 4 Thin-walled cutinite (CU) and sporinite (SP) during blue light irradiation. Both fluoresce with a yellowish-orange colour.

Fig. 5 Thin-walled cutinite (CU) displaying a yellowish fluorescent colour. The yellowish fluorescing globular bodies possibly represent fluorinite.

Fig. 6 Suberinite (Su) and Phlobaphinite (Pl) bodies. Suberinite displays greenish-yellowish fluorescence colours. Phlobaphinite does not fluoresce.

PLATE 8



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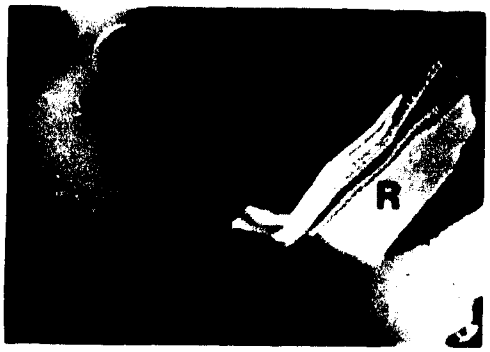

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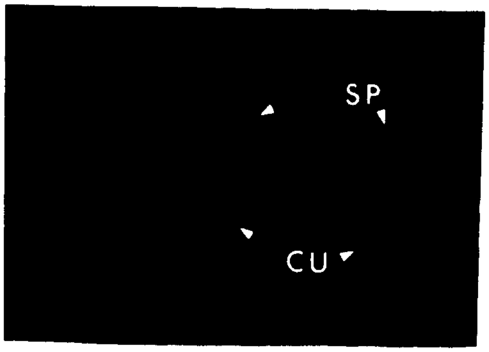

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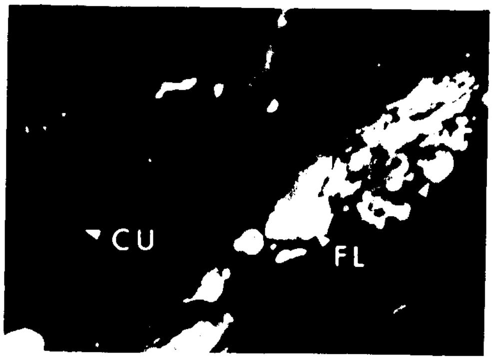

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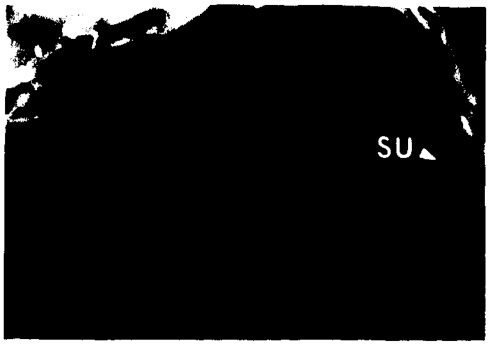

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0 microns 100

APPENDIX I

Reflectance, maceral composition and other statistical parameters of the Hat Creek samples

BBH [illegible]
[illegible] A

SAMPLE	DEPTH (m)	RANDOM REFLECTANCE (%) MEAN	S.D.	C.V.	MACERALS (VOL%) HT	HC	HD	LIPT	INER	MM
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4	[illegible]	[illegible]	1	[illegible]
3	3.6	0.4[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1	[illegible]
4	4.6	0.36	[illegible]	[illegible]	37	[illegible]	[illegible]	[illegible]		
5	6.5	0.38	[illegible]	3.5	81	5	4	1	3	[illegible]
6	8.0	0.36	0.0[illegible]	4.7	[illegible]	[illegible]	[illegible]	3	1	[illegible]
8	9.9	0.31	[illegible]	1.4	[illegible]				1	
9	11.8	0.32	[illegible]	[illegible]	[illegible]	10	12	2	1	1
10	13.4	0.40	[illegible]	4.7	83	13	[illegible]	1	1	[illegible]
12	18.[illegible]	0.[illegible]5	[illegible]	[illegible]	95					4
14	21.0	0.33	0.02	[illegible]	[illegible]	[illegible]	7	[illegible]	[illegible]	1
15	21.6	0.35	0.02	1.6	77	13	[illegible]	[illegible]		2
16	22.4	0.42	0.01	[illegible]	95	[illegible]	4	[illegible]	[illegible]	
19	25.2	0.41	[illegible]	3.1	4[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
21	27.2	0.38	0.02	5.7	90	[illegible]	[illegible]	1		3
22	27.7	0.42	0.0[illegible]	[illegible]	7[illegible]	[illegible]	3	[illegible]		[illegible]
23	29.8	0.36	0.02	5.[illegible]	86	4	4	[illegible]	[illegible]	[illegible]
24	31.6	0.35	0.02	5.1	91	2	[illegible]	[illegible]	[illegible]	3
25	32.1	0.45	[illegible]	3.3	65	[illegible]	12	[illegible]	[illegible]	2
26	34.5	0.38	0.02	6.[illegible]	63	13	[illegible]	2	[illegible]	[illegible]
27	35.4	0.31	[illegible]	6.3	9[illegible]	3	4	[illegible]	[illegible]	[illegible]
30	37.8	0.36	[illegible]	2.5	77	[illegible]	23	[illegible]	[illegible]	4
32	39.3	0.42	0.02	4.8	[illegible]	[illegible]	42	1	1	[illegible]
33	40.[illegible]	0.40	0.02	4.7	47	5	2[illegible]	1	1	[illegible]
34	44.[illegible]	0.40	0.02	6.0	65	12	15	[illegible]	1	16
36	46.7	0.36	0.02	5.5	92	[illegible]	[illegible]	[illegible]		5
37	47.2	0.43	0.02	5.6	59	[illegible]	[illegible]	[illegible]		17
38	47.3	0.45	0.02	5.4	60	7	[illegible]	[illegible]	[illegible]	26
39	49.3	0.40	0.02	5.5	67	23	[illegible]	[illegible]	[illegible]	[illegible]
40	49.7	0.42	0.03	7.9	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
41	50.1	0.41	0.01	[illegible]	[illegible]	6	3			[illegible]
43	51.5	0.36	0.03	9.7	24	[illegible]	[illegible]	1	[illegible]	[illegible]
44	[illegible]	0.43	0.02	4.2	4[illegible]	[illegible]	[illegible]			11
46	51.4	0.43	0.01	3.2	[illegible]	3	3	[illegible]	[illegible]	2
47	55.4	0.37	0.03	7.2	6[illegible]	5	2[illegible]	0	[illegible]	8
49	56.[illegible]	0.39	[illegible]	7.[illegible]	3	17	[illegible]	1	4	[illegible]
50	56.5	0.45	0.02	5.5	[illegible]	[illegible]	1		1	[illegible]
51	56.8	0.45	0.03	[illegible]	[illegible]	[illegible]	[illegible]	4	[illegible]	1
54	58.0	0.36	0.01	[illegible]	[illegible]	2	[illegible]	1		[illegible]
56	59.4	0.42	0.01	[illegible]	16	[illegible]	[illegible]			1
58	65.9	0.41	0.03	8.[illegible]	47	11	24	1	1	[illegible]
59	69.[illegible]	0.44	[illegible]	6.6	53	1	13	[illegible]		[illegible]
61	71.1	0.39	0.03	6.9	49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
63	76.2	0.39	0.02	4.1	7[illegible]	6	11	[illegible]		[illegible]
64	77.8	0.43	0.01	3.7	62	6	[illegible]	[illegible]	4	18
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2		[illegible]
67	8[illegible].2	0.42	[illegible]	[illegible]	71	6	[illegible]			[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	75	9			1	[illegible]
71	84.2	[illegible]	[illegible]	[illegible]	92	1	6	[illegible]	[illegible]	
[illegible]	[illegible]	0.44	[illegible]	4	51	8	15	[illegible]	1	[illegible]
[illegible]	[illegible]	[illegible]	0.02	4.[illegible]	67	3	8	1	[illegible]	17
76	[illegible]	0.42	0.02	6.4	24	[illegible]	17		1	47
[illegible]	[illegible]	[illegible]	[illegible]	7.6	56	11	27		1	[illegible]
[illegible]	[illegible]	0.4[illegible]	[illegible]	6.1	7[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
[illegible]	[illegible]	0.4[illegible]	[illegible]	7.4	64	4	4	1		8
[illegible]	[illegible]7.6	0.42	[illegible]	[illegible]	11	[illegible]	28	[illegible]	1	4
[illegible]	[illegible]	[illegible]	[illegible]	6.5	11	2[illegible]	[illegible]		1	25
[illegible]	9[illegible]	[illegible]	0.02	4.2	43	[illegible]	2[illegible]	2	4	[illegible]
[illegible]	[illegible]2	[illegible]	0.02	5.7	43	8	33		1	[illegible]
[illegible]	[illegible]	0.41	[illegible]	4.2	51	11	24	[illegible]	[illegible]	14
[illegible]	[illegible]	0.4[illegible]	[illegible]	6.5	41	[illegible]	4	[illegible]		44
[illegible]	[illegible]	0.4[illegible]	[illegible]	[illegible]	93	2		[illegible]	1	[illegible]
[illegible]	[illegible]	0.43	[illegible]	4.0	56	32	7	0	0	[illegible]
[illegible]	[illegible]	0.41	[illegible]	5.4	34	[illegible]	44	0	1	11
100	[illegible]2	[illegible]	0.02	4.4	72	6	14	0	1	7
102	[illegible]	0.36	[illegible]	7.7	47	11	26	[illegible]	3	12
103	115.9	0.45	[illegible]	2.7	89	6	1	0	0	4
104	[illegible].9	0.45	0.02	5.[illegible]	78	9	7	0	0	5
[illegible]	121.6	0.47	0.02	4.9	52	5	26	[illegible]	1	12
[illegible]	125	0.44	0.02	4.[illegible]	[illegible]	7			[illegible]	
[illegible]	[illegible]	0.4[illegible]	[illegible]	6.7	72	2	10	12	3	23
[illegible]	[illegible]	[illegible]	[illegible]	4	89	6	2	0	3	[illegible]
111	[illegible]	0.46	0.02	4.5	66	21	1	0	0	[illegible]
[illegible]	[illegible]	0.47	0.02	5.5	80	2	1	0	0	17
[illegible]	[illegible]	0.4[illegible]	0.02	6.[illegible]	2[illegible]	11	32	0	1	31
[illegible]	137.6	0.41	0.02	5.6	56	19	2[illegible]	0	0	5
[illegible]	135.3	0.43	0.02	4.2	[illegible]	5	12	0	1	7
113	139.2	0.4[illegible]	0.02	5.5	63	2	[illegible]	0	1	14
119	14[illegible].5	0.41	0.02	5.1	25	4	59	0	[illegible]	[illegible]
[illegible]	[illegible].2	0.47	[illegible]	[illegible]4	81	4	8	1	[illegible]	[illegible]
[illegible]	[illegible].3	0.44	0.02	4.6	60	12	24	0	1	4
[illegible]	[illegible].3	[illegible]	[illegible]	6.[illegible]	60	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	149.4	0.44	0.02	[illegible]6	23	2[illegible]	27	6	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.02	4.8	59	11	12	3	7	26
[illegible]	[illegible]2.7	0.42	0.02	4.9	60	2	31	0	[illegible]	7
[illegible]	154.2	0.43	0.03	8.0	39	6	[illegible]	[illegible]	[illegible]	2
[illegible]	[illegible]9.0	0.40	0.02	5.5	55	1[illegible]	[illegible]	1	0	23
[illegible]	159.4	0.41	[illegible]	[illegible]	8	[illegible]	24	0	2	[illegible]
[illegible]	[illegible]	0.42	0.03	7.[illegible]	14	11	[illegible]			[illegible]
[illegible]	[illegible].7	0.4[illegible]	0.02	4.[illegible]	71	7	3	[illegible]	[illegible]	10
[illegible]	[illegible]6.6	0.45	0.02	4.[illegible]	31	52	[illegible]		[illegible]	12
[illegible]	174.5	0.45	0.02	5.[illegible]	64	4	5	0	0	26
[illegible]	176.2	0.43	0.02	5.4	11	7	[illegible]	0	0	[illegible]
[illegible]	179.1	0.41	[illegible]	[illegible]	94	12	1	0	1	2
[illegible]	185.3	0.35	[illegible]	[illegible]	[illegible]	7	23	[illegible]	[illegible]	34

LEGEND

S.D. STANDARD DEVIATION
C.V. COEFFICIENT OF VARIATION
HT HUMOTELINITE
HC HUMOCOLLINITE
HD HUMODETRINITE
LIPT LIPTINITE
INER INERTINITE
MM MINERAL MATTER

B3H [illegible]
ZONE B

SAMPLE	DEPTH	RANDOM REFLECTANCE MEAN	S.D.	[illegible]	MACERALS [illegible]		[illegible]	[illegible]	[illegible]	M.M.
151	185.[illegible]	[illegible]	[illegible]	[illegible]						
152	186.7	[illegible]	[illegible]	[illegible]						
153	188.3	0.39	[illegible]	[illegible]						
154	189.9	0.43	[illegible]	[illegible]	17					
160	195.[illegible]	0.35	[illegible]	[illegible]	34		11			4
162	200.0	0.42	[illegible]	[illegible]	31		4			
164	202.0	0.42	[illegible]	.72			39			
166	204.1	0.38	.02	[illegible]						
172	212.6	0.43	[illegible]	.47						
173	211.3	0.42	.02	.55			12			
174	212.1	0.41	[illegible]	.63	64		2	1		
176	213.6	0.38	[illegible]	.63						
178	214.6	0.41	.03	.77			[illegible]	2		21
180	216.5	0.43	.01	.33						
181	219.2	0.39	[illegible]	.56	[illegible]					
183	222.0	0.41	.02	.30						
186	224.8	0.41	[illegible]	[illegible]						10
189	227.0	0.41	.02	[illegible]	77					
192	231.[illegible]	0.41	.02	[illegible]						25
194	234.3	0.38	.02	.66			11			46
195	236.4	0.41	0.02	.51	51					
198	240.1	0.39	.03	.67	8		5			4
201	241.8	0.40	.03	.75	61	5				
202	244.4	0.42	[illegible]	.45	81		2			
203	246.1	0.4	.03	[illegible]						
204	248.[illegible]	[illegible]	.02	[illegible]	24					
205	[illegible]	0.39	.02	[illegible]	39					
207	252.8	0.44	.02	.57						
208	255.2	[illegible]	[illegible]	.76			7			
209	256.0	0.42	.02	.61		14	2			
211	258.3	0.40	.02	[illegible]		2				
213	261.2	0.45	.03	.6						
214	[illegible]	0.43	.02	.51			2			11
217	[illegible]	0.41	[illegible]	[illegible]						
218	269.7	0.40	.02	.58		11				
220	271.6	0.41	[illegible]	.24		5				
221	273.0	0.42	.02	.33						
223	271.5	[illegible]	.02	.52						
226	277.5	0.39	.02	.64	19	[illegible]				
227	279.0	0.40	.03	.68	29		13			
228	281.[illegible]	[illegible]	.02	[illegible]	24					
230	284.[illegible]	0.43	[illegible]	[illegible]	77					

Reflectance, maceral composition and other statistical parameters of Zone B samples

BCH 75-77
ZONE C

		RANDOM REFLECTANCE % OIL			MACERALS (% VOL)					
SAMPLE	DEPTH m	MEAN	S.D.	C.V.	HT	HC	HD	LPT	INER	MM
[illegible]	2876	0.42	[illegible]	4.1	24	12	[illegible]	[illegible]	[illegible]	[illegible]
233	2896	0.45	.002	5.0	62	[illegible]	6	[illegible]	[illegible]	[illegible]
235	2927	0.44	.002	5.5	41	9	5	8	0	44
[illegible]	2942	0.40	.004	9.2	10	12	[illegible]	[illegible]	[illegible]	64
239	2978	0.40	.003	7.8	22	15	11	[illegible]	0	47
240	2996	0.43	[illegible]	5.1	[illegible]	7	[illegible]	[illegible]	[illegible]	[illegible]
242	3014	0.44	.002	[illegible]	60	3	15	0	0	22
[illegible]	3036	0.41	.003	6.4	48	[illegible]	[illegible]	0	0	[illegible]
245	3050	0.41	.003	7.6	45	10	4	8	0	[illegible]
247	3062	0.46	.003	5.9	33	12	8	0	0	[illegible]
[illegible]	3089	0.40	.003	7.9	20	13	16	0	0	[illegible]
[illegible]	3107	0.40	.003	7.0	48	9	8	0	0	[illegible]
[illegible]	3129	0.41	.002	5.8	21	[illegible]	15	0	0	[illegible]
[illegible]	3141	0.42	.004	3.5	76	11	7	[illegible]	0	[illegible]
[illegible]	3150	0.41	.003	6.8	23	16	5	0	0	47
254	3161	0.43	.003	8.1	58	11	[illegible]	[illegible]	0	[illegible]
[illegible]	3175	0.40	.002	5.0	30	2	7	[illegible]	0	[illegible]
258	3187	0.42	.002	5.5	93	1	[illegible]	[illegible]	0	5
[illegible]	3213	0.39	.002	5.1	13	14	23	0	0	26
264	3257	0.42	.003	7.3	59	15	5	[illegible]	0	[illegible]
265	3272	0.41	.003	6.6	13	15	[illegible]	[illegible]	0	42
267	3295	0.42	.003	[illegible]	70	6	3	0	0	16
268	3306	0.40	.003	5.2	57	10	8	1	0	[illegible]
269	3328	0.47	.003	5.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4
271	3395	0.38	.002	5.3	40	7	17	0	1	4
273	3370	0.37	[illegible]	8.0	47	15	[illegible]	[illegible]	0	[illegible]
[illegible]	3395	0.43	.003	8.2	59	3	15	0	0	6
276	3416	0.39	.004	9.1	24	25	23	1	[illegible]	29
277	3427	0.44	.002	[illegible]	64	12	9	0	[illegible]	15
[illegible]	3455	0.41	.003	7.5	30	27	13	0	[illegible]	30
[illegible]	3472	0.40	.002	5.8	14	14	19	0	0	54
282	3488	0.40	.003	7.0	34	16	24	1	0	[illegible]
284	3509	0.40	.003	7.0	22	10	7	0	0	61
[illegible]	3514	0.37	.004	[illegible]	26	5	5	0	[illegible]	[illegible]
[illegible]	3552	0.35	.002	5.1	19	7	[illegible]	0	0	[illegible]
294	3609	0.40	.003	6.8	23	10	13	5	0	[illegible]
296	3616	0.43	.003	8.0	[illegible]	[illegible]	[illegible]	0	0	[illegible]
[illegible]	3652	0.40	.003	6.5	24	[illegible]	8	[illegible]	0	[illegible]
[illegible]	3678	0.38	.002	[illegible]	20	12	[illegible]	0	0	60
302	3699	0.38	.002	5.5	29	33	9	0	[illegible]	23
304	3714	0.38	.002	5.0	23	[illegible]	7	0	0	15
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31	13	22	1	1	[illegible]
[illegible]	[illegible]	0.40	[illegible]	4.5	24	17	40	0	[illegible]	17
312	[illegible]	0.44	.003	6.4	34	[illegible]	20	[illegible]	[illegible]	[illegible]
314	3795	0.41	[illegible]	[illegible]	[illegible]	15	45	1	[illegible]	15
[illegible]	[illegible]	0.40	.003	[illegible]	20	[illegible]	47	4	[illegible]	24
[illegible]	[illegible]	0.41	.003	7.8	24	24	22	0	0	[illegible]
[illegible]	[illegible]	0.41	.002	[illegible]	[illegible]	[illegible]	14	1	0	[illegible]
[illegible]	[illegible]	0.39	[illegible]	[illegible]	43	11	35	2	[illegible]	9
[illegible]	[illegible]	0.36	[illegible]	[illegible]	18	[illegible]	45	[illegible]	1	[illegible]
323	[illegible]	0.42	[illegible]	[illegible]	42	1	6	0	0	51
[illegible]	[illegible]	0.35	.002	6.4	7	14	13	1	0	64
[illegible]	[illegible]	0.40	[illegible]	4.4	12	[illegible]	14	1	[illegible]	55
[illegible]	[illegible]	0.41	.002	[illegible]	[illegible]	16	13	1	[illegible]	46
335	[illegible]	0.40	.003	[illegible]	[illegible]	15	25	2	1	35
336	3948	[illegible]	.003	[illegible]	11	[illegible]	[illegible]	[illegible]	1	24
[illegible]	3953	0.40	.003	[illegible]	[illegible]	8	27	1	1	25
[illegible]	[illegible]	0.33	.004	[illegible]	[illegible]	9	21	[illegible]	0	53
[illegible]	[illegible]	0.39	.002	[illegible]	[illegible]	[illegible]	[illegible]	1	0	[illegible]
[illegible]	4007	[illegible]	.002	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	24
343	[illegible]	[illegible]	.002	4.9	31	[illegible]	25	1	[illegible]	[illegible]
[illegible]	[illegible]	0.41	.003	[illegible]	43	[illegible]	[illegible]	1	[illegible]	[illegible]
[illegible]	[illegible]	0.39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	0	40
[illegible]	[illegible]	0.42	[illegible]	[illegible]	56	[illegible]	12	[illegible]	[illegible]	21
[illegible]	[illegible]	0.38	.003	8.2	19	21	29	0	1	[illegible]
[illegible]	[illegible]	[illegible]	.002	6.6	48	[illegible]	17	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.44	.003	[illegible]	41	10	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.39	.003	8.7	38	15	14	0	[illegible]	[illegible]
357	[illegible]	0.45	.002	5.5	84	[illegible]	[illegible]	0	[illegible]	11
[illegible]	[illegible]	[illegible]	.003	8.4	[illegible]	13	23	3	[illegible]	[illegible]
[illegible]	[illegible]	0.39	[illegible]	5.1	32	13	17	1	1	[illegible]
[illegible]	[illegible]	0.42	[illegible]	6.5	38	16	14	[illegible]	0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	7.0	27	14	27	1	0	[illegible]
364	[illegible]	0.41	.003	5.8	37	5	5	0	0	3
366	[illegible]	0.44	.004	8.1	39	[illegible]	13	0	0	35
[illegible]	[illegible]	0.43	.003	7.4	37	[illegible]	0	0	0	1
[illegible]	[illegible]	0.39	.003	[illegible]	[illegible]	17	25	0	1	[illegible]
[illegible]	[illegible]	[illegible]	.003	7.4	[illegible]	[illegible]	[illegible]	[illegible]	0	40
[illegible]	[illegible]	0.41	.003	[illegible]	[illegible]	[illegible]	17	0	0	16
[illegible]	[illegible]	[illegible]	.003	6.6	40	12	7	[illegible]	[illegible]	40
[illegible]	[illegible]	0.39	[illegible]	7.7	[illegible]	[illegible]	13	1	0	[illegible]
[illegible]	4265	[illegible]	.002	6.6	[illegible]	11	12	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	6.4	17	[illegible]	[illegible]	[illegible]	[illegible]	67
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50	[illegible]	21	[illegible]	[illegible]	19
[illegible]	[illegible]	[illegible]	.003	[illegible]	35	15	28	2	[illegible]	17
[illegible]	4315	0.36	.002	[illegible]	51	11	22	1	[illegible]	17
[illegible]	[illegible]	0.40	.003	7.6	64	5	13	6	0	11

Reflectance, maceral composition and other statistical parameters of Zone C samples

CBH 76 62
ZONE D

		RANDOM REFLECTANCE %			MACERALS (% VOL)					
SAMPLE	DEPTH (m)	MEAN	S.D.	C.V.	HS	HC	HD	LIPT	INER	M.M
5	4315	0.38	0.03	8.4	51	[illegible]	23	1	[illegible]	16
6	4325	0.36	0.04	10.2	83	3	5	0	[illegible]	4
7	4339	0.37	0.03	8.2	7	8	21	0	[illegible]	64
8	4350	0.42	0.02	4.7	84	1	2	0	[illegible]	12
9	4360	0.39	0.03	7.4	43	14	38	2	[illegible]	[illegible]
10	4372	0.35	0.03	[illegible]	15	17	44	1	[illegible]	23
11	4382	[illegible]	0.04	11.6	14	10	20	0	0	56
12	4396	0.30	0.02	6.2	65	10	11	0	0	14
13	4407	0.30	0.03	7.1	60	16	9	[illegible]	0	[illegible]
14	4417	0.38	0.02	5.5	66	6	17	0	1	10
15	4446	0.39	[illegible]	6.9	52	17	20	0	0	49
17	4453	0.41	0.02	4.6	77	5	4	0	0	14
18	4464	0.56	[illegible]	9.4	25	13	42	1	0	18
19	4473	0.42	0.02	4.7	75	12	5	0	0	[illegible]
20	4485	0.41	0.03	7.4	66	11	[illegible]	[illegible]	0	2
21	4494	0.37	[illegible]	9.7	40	12	35	2	0	11
22	4506	0.37	0.04	[illegible]	14	9	23	2	0	52
23	[illegible]	0.42	[illegible]	3.5	76	6	11	0	1	3
24	4525	0.42	0.02	[illegible]	80	5	2	0	0	12
25	4540	0.40	0.02	5.7	61	7	17	0	0	15
26	4546	0.42	0.03	6.4	[illegible]	7	1	0	[illegible]	[illegible]
28	4563	0.40	0.02	5.7	52	10	8	0	0	30
29	4574	0.40	0.04	[illegible]	24	13	27	0	1	25
30	4585	0.41	0.05	8.1	32	15	25	1	0	28
31	4602	0.41	0.03	8.4	37	6	22	0	0	35
32	4614	0.38	0.03	8.9	[illegible]	14	45	1	0	16
33	4622	0.40	0.03	5.7	64	6	13	0	0	17
35	4636	0.35	0.02	6.1	88	8	2	0	[illegible]	2
36	4649	0.38	0.04	3.5	19	18	23	1	0	40
37	4657	0.35	0.03	[illegible]	82	6	7	0	0	5
38	4666	0.40	0.03	[illegible]	32	9	17	0	1	41
39	4675	0.42	0.03	6.4	31	13	22	0	0	34
41	4690	0.35	0.02	5.4	21	7	6	0	0	64
42	4710	0.42	0.02	5.9	87	6	2	0	0	4
43	4718	0.37	0.02	6.2	33	10	4	0	0	53
44	4733	0.33	0.02	6.2	38	26	17	0	0	19
46	4746	0.42	0.02	[illegible]	91	1	4	0	0	4
47	[illegible]	0.40	0.02	5.3	39	14	33	1	0	13
48	[illegible]	0.37	[illegible]	[illegible]	[illegible]	15	28	1	[illegible]	[illegible]
49	[illegible]	0.39	[illegible]	11.4	86	8	4	0	0	[illegible]
50	4800	0.42	[illegible]	6.9	72	6	13	[illegible]	0	7
51	4808	0.38	0.02	[illegible]	[illegible]	29	31	1	1	[illegible]
52	4818	0.40	0.04	[illegible]	30	16	49	2	1	2
53	4826	0.38	0.03	7.3	46	14	22	0	1	[illegible]
54	4835	0.40	0.03	7.8	81	7	8	1	0	3
55	[illegible]	0.45	0.03	[illegible]	73	6	11	0	[illegible]	10
57	4860	0.40	0.03	7.2	8	7	44	1	0	[illegible]
58	4875	0.44	[illegible]	[illegible]	72	3	9	0	0	16
59	4890	0.35	0.02	[illegible]	27	4	11	0	0	[illegible]
61	4908	0.38	0.02	[illegible]	16	10	57	4	1	12
62	4920	0.40	0.02	[illegible]	33	10	49	0	1	7
63	4926	0.42	0.03	7.3	26	23	27	0	1	[illegible]
64	4947	0.36	0.02	6.1	1	3	14	0	0	[illegible]
65	4950	0.44	0.02	5.2	84	8	3	1	0	4
66	4972	0.37	0.03	7.2	11	18	31	1	[illegible]	37
67	4988	0.39	0.03	6.6	60	15	18	0	0	[illegible]
68	[illegible]	0.40	0.03	7.4	58	21	11	0	0	10
69	5010	0.42	0.03	7.2	[illegible]	12	12	0	0	4
70	5020	0.44	0.02	5.5	40	19	24	0	[illegible]	17
71	5027	0.45	0.02	4.9	68	10	12	1	0	9
72	5040	0.37	0.03	9.3	82	5	10	0	0	2
73	5060	0.46	0.02	3.7	83	4	10	0	0	3
74	[illegible]	0.37	0.03	8.2	56	4	15	1	1	22
75	5083	0.39	0.04	10.3	22	26	23	0	0	29
76	[illegible]	0.41	0.03	[illegible]	38	15	34	3	1	9

Reflectance, maceral composition and other statistical parameters of Zone D samples

APPENDIX II

Transition Matrices - Substitutability Analysis

The total thickness of the states in each zone as well as a matrix showing the number of times a given state is succeeded by another for each zone were constructed. A matrix of this type is called a transition frequency matrix (App. III).

A matrix expressing the tendency of one state to follow another regardless of the total abundance of the initial state, the so-called matrix of proportion of transitional pairs was also constructed for each zone (App. III). It was constructed by dividing each element in the ith row by the total of the ith row. The rows sum to one. The above matrix tells us how often state A is followed by state B regardless of the total number of times that state A occurs.

Transitional probability matrices were also constructed (App. III), by means of which we can study the nature of sequences that range from purely deterministic to purely random (Davis, 1973). The transition probability matrix is regarded as an estimate of the probabilities that certain states follow other states. Diagrams of the predominant order of succession are shown in Appendix IV; heavy lines denote highest transition probabilities, lighter lines denote the next highest transitional probability.

The more common tests for a Markov property are against a null hypothesis of independence of successive events. A x^2 test for the Markov property can be developed from the transition frequency and the transition probability matrix. The null hypothesis of this test is that states observed at successive points are independent of states at adjacent points. The alternative is that a dependency exists between adjacent points, or the sequence has the Markov property (Davis, 1973).

The computed chi-square values for each zone led to rejection of the null hypothesis and the alternative hypothesis that the sequence can be represented by a first order Markov model was therefore accepted as statistically viable. This means that a state occurring at point i in a sequence is dependent, in a probabilistic manner, on the immediately preceding states only. In other words, at some point, the probability of occurrence of a state is independent of the initial state in the sequence. This is a manifestation of 'memory' in a Markov process, which 'remembers' a preceding event, but the event's influence diminishes with distance or time until it is 'forgotten' (Davis, 1973).

The theory of Markov chains is assuming increasing importance in attempts to simulate or model geologic processes.

An alternative treatment of the observed transition matrices is provided by substitutability analysis. The tendency of two or more states to occur in a common context is called substitutability, and the investigation of this phenomenon may reveal groupings of states that are not apparent otherwise (Davis, 1973). The methodology appears to be applicable to geologic data.

From the transition probability matrix, we can develop two quantities the first-order left (upward) substitutability (App. V, Eq. 1) and the first-order right (downward) substitutability. The method is based on the observation that if two states tend to be succeeded by a third common state, then these states can be termed to have a high left substitutability; if preceded by a third common state, a high right substitutability; and if preceded and followed by equivalent states, a high mutual substitutability (App. V, Eq. 2) (Doveton and Skipper, 1973). The matrix of left substitutability is obtained from the upward transition probability matrix by computing a cross-product ratio between rows of the matrix. The matrix of right substitutability is found by computing the cross-product ratios between columns of the downward transition probability matrix (Davis, 1973).

Finally, one can define a matrix of mutual substitutability by forming the products of all pairs of right and left substitutabilities.

Substitutability analysis is a viable ancillary procedure to conventional first order Markovian analysis for the following reasons. Markovian analysis has the advantages of a structured statistical hypothesis testing strategy. Raw variation is trimmed to elements of demonstrated significance that can be interpreted in discrete model terms. Substitutability analysis remains a manipulative recasting of the information contained in a transition probability matrix into a comparative transition behaviour mode that describes the system. While no formal statistical hypothesis testing procedure is invoked, the resulting matrices retain the full information contained in transition matrices.

Regression analysis

In many types of problems, we are concerned not only with changes along a sequence, but also in where these changes occur. In order to examine these problems, we must have a collection of measurements of a variable, and we must also know the locations of the measurement points. We are interested in the general tendency of the data and this tendency will be used to interpolate between data points and infer the presence of trends. If certain assumptions can be made about the distribution of the populations, then, statistical tests called regression analyses can be performed (Davis, 1973).

We must define some terms. The variable being examined is the dependent or regressed variable, designated Yi. Deviations of Yi form the fitted line will be minimized. The other variable is the independent or regressor variable and is denoted Xi. The fitted line will cross the Y axis at a point b_0 (the intercept) and will have a slope b_1 (App. V, Eq. 3).

In the case of the Hat Creek coals, reflectance of ulminite Y, is the random variable, and depth X, is fixed. Therefore, the problem is to predict Y from X.

Analysis of variance (ANOVA)

If we want to compare the variation of huminite reflectance occurring in different lithologies (coaly matrix, shaly matrix and carbonate matrix) versus depth, we have to use a formalized procedure for analysis of variance called ANOVA.

We can define three terms which express variation of the dependent variable (reflectance). The first of these is measured by the total sum of squares (SST) of Y (App. V, Eq. 4).

The second measure of variation is the sum of squares due to regression (SS_R) (App. V, Eq. 5) and the third is the sum of squares due to deviation about regression (App. V, Eq. 6). Equation 5 provides a measure of the variation of the regression line around the mean, whereas Equation 6 is measure of the failure of the least-squares line to fit the data points.

The number of degrees of freedom for variance in the total data set is N-1. Degrees of freedom for variance due to regression is m-1, because we are estimating this variance from the means. The difference between the two is the degrees of freedom attributable to deviation about regression.

Assuming that the distribution of the points is normal, the first step would be to test the equality of variance. In order to do this, we must do the 'F' test (App. 5, Eq. 7), to obtain a critical value. The 'F' test involves the ratio of two variances each having its respective degrees of freedom. A table allows the localisation of a value for the 'F' value. Obviously, a ratio equal to 1 is not determinable. Having chosen a critical region based on our selection of the desired level of significance and the degrees of freedom, we can either accept or reject the hypothesis that the variance about the regression line is or is not different from the variance in the observations. If the computed test value falls well in the critical region, then the null hypothesis is rejected meaning that the two variances are different.

APPENDIX III

Zone A

Thickness of states

A	108.20 m
B	48.60 m
C	14.30 m
D	1.30 m

where

A is coal 1
B is coal 2
C is carbonaceous claystone or shale
D is carbonate, marl

Number of states = 4

Original transition frequency matrix

		TO				
		A	B	C	D	Row Totals
FROM	A	0	14	4	1	19
	B	12	0	4	1	17
	C	6	2	0	0	8
	D	1	1	0	0	2
Column totals		19	17	8	2	46 Grand total

Matrix of proportion of transitional pairs

		TO			
		A	B	C	D
FROM	A	.0000	.3043	.0870	.0217
	B	.2609	.0000	.0870	.0217
	C	.1304	.0435	.0000	.0000
	D	.0217	.0217	.0000	.0000

Transition probability matrix

	A	B	C	D
A	.0000	.7368	.2105	.0526
B	.7059	.0000	.2353	.0588
C	.7500	.2500	.0000	.0000
D	.5000	.5000	.0000	.0000

Chi-square = 43.69 with 9 degrees of freedom

Upward subsitutability matrix

		TO			
		A	B	C	D
	A	1.0000	.0918	.3033	.6783
	B	.09181	1.0000	.8972	.6687
FROM	C	.3033	.8972	1.0000	.8944
	D	.6783	.6687	.8944	1.0000

Downward substitutability matrix

	A	B	C	D
A	1.0000	.0682	.6307	.6307
B	.06821	1.0000	.6983	.6983
C	.6307	.6983	1.0000	1.0000
D	.6307	.6983	1.0000	1.0000

Mutual substitutability matrix

	A	B	C	D
A	1.0000	.0063	.1913	.4278
B	.0063	1.0000	.6265	.4669
C	.1913	.6265	1.0000	.8944
D	.4278	.4669	.8944	1.0000

Zone B

Thickness of states

A	39.00 m	where	A is coal 1
B	29.80 m		B is coal 2
C	27.00 m		C is carbonaceous claystone or shale
D	2.40 m		D is petrified wood

Number of states : 4

Original transition frequency matrix

		TO				
		A	B	C	D	Row Totals
FROM	A	0	5	3	2	10
	B	7	0	2	0	9
	C	2	5	0	0	7
	D	1	0	1	0	2
Column totals		10	10	6	2	28 Grand total

Matrix of proportion of transitional pairs

		TO			
		A	B	C	D
FROM	A	.0000	.1786	.1071	.0714
	B	.2500	.0000	.0714	.0000
	C	.0714	.1786	.0000	.0000
	D	.0357	.0000	.0357	.0000

Transition probability matrix

	A	B	C	D
A	.0000	.5000	.3000	.2000
B	.7778	.0000	.2222	.0000
C	.2857	.7143	.0000	.0000
D	.5000	.0000	.5000	.0000

Chi-square = 28.95 with 9 degrees of freedom

Upward subsitutability matrix

	A	B	C	D
A	1.0000	.1337	.7531	.3441
B	.1337	1.0000	.3571	.8742
C	.7531	.3571	1.0000	.2626
D	.3441	.8742	.2626	1.0000

Downward substitutability matrix

	A	B	C	D
A	1.0000	.1925	.5455	.0000
B	.1925	1.0000	.5669	.7071
C	.5455	.5669	1.0000	.8013
D	.0000	.7071	.8013	1.0000

Mutual substitutability matrix

	A	B	C	D
A	1.0000	.0257	.4108	.0000
B	.02571	1.0000	.2025	.6181
C	.4108	.2025	1.0000	.2106
D	.0000	.6181	.2106	1.0000

Zone C

Thickness of states

A	69.80 m		A is coal 1
B	43.70 m		B is coal 2
C	14.90 m		C is carbonaceous claystone or shale
D	3.30 m	where	D is siltstone
E	3.00 m		E is petrified wood
F	3.00 m		F is ironstone, siderite
G	1.00 m		G is carbonate, marl

Number of states = 7

Original transition frequency matrix

TO

		A	B	C	D	E	F	G	Row totals
	A	0	6	1	1	0	4	1	13
	B	8	0	2	0	0	1	0	11
	C	2	2	0	0	1	1	0	6
FROM	D	0	0	1	0	0	0	1	2
	E	1	0	0	0	0	0	0	1
	F	2	2	2	0	0	0	0	6
	G	1	0	0	1	0	0	0	2
Column totals		14	10	6	2	1	6	2	41 Grand Total

Matrix of proportion of transitional pairs

TO

		A	B	C	D	E	F	G
	A	.0000	.1463	.0244	.0244	.0000	.0976	.0244
	B	.1951	.0000	.0488	.0000	.0000	.0244	.0000
	C	.0488	.0488	.0000	.0000	.0244	.0244	.0000
FROM	D	.0000	.0000	.0244	.0000	.0000	.0000	.0244
	E	.0244	.0000	.0000	.0000	.0000	.0000	.0000
	F	.0488	.0488	.0488	.0000	.0000	.0000	.0000
	G	.0244	.0000	.0000	.0244	.0000	.0000	.0000

Transition probability matrix

	A	B	C	D	E	F	G
A	.0000	.4615	.0769	.0769	.0000	.3077	.0769
B	.7273	.0000	.1818	.0000	.0000	.0909	.0000
C	.3333	.3333	.0000	.0000	.1667	.1667	.0000
D	.0000	.0000	.5000	.0000	.0000	.0000	.5000
E	1.0000	.0000	.0000	.0000	.0000	.0000	.0000
F	.3333	.3333	.3333	.0000	.0000	.0000	.0000
G	.5000	.0000	.0000	.5000	.0000	.0000	.0000

Chi-square = 50.53 with 36 degrees of freedom

Upward substitutability matrix

	A	B	C	D	E	F	G
A	1.0000	.0974	.6822	.1907	.0000	.5449	.0953
B	.0974	1.0000	.6472	.1703	.9631	.6950	.6810
C	.6822	.6472	1.0000	.0000	.6325	.7303	.4472
D	.1907	.1703	.0000	1.0000	.0000	.4082	.0000
E	.0000	.9631	.6325	.0000	1.0000	.5774	.7041
F	.5449	.6950	.7303	.4082	.5774	1.0000	.4082
G	.0953	.6810	.4472	.0000	.7071	.4082	1.0000

Downward substitutability matrix

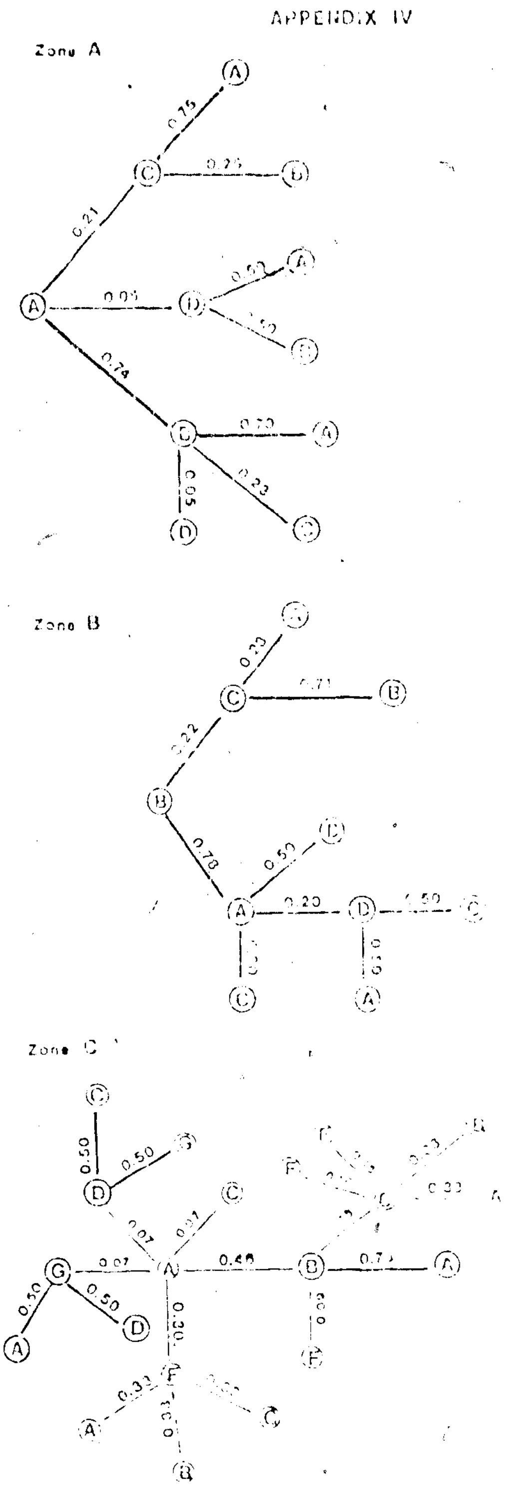
	A	B	C	D	E	F	G
A	1.0000	.1402	.7352	.0822	.2325	.2725	.0000
B	.1402	1.0000	.4767	.6396	.3015	.9239	.6396
C	.7352	.4767	1.0000	.2236	.0000	.4472	.4472
D	.0822	.6396	.2236	1.0000	.0000	.6667	.5000
E	.2325	.3015	.0000	.0000	1.0000	.2357	.0000
F	.2740	.9239	.4472	.6667	.2357	1.0000	.6667
G	.0000	.6396	.4472	.5000	.0000	.6667	1.0000

Mutual substitutability matrix

	A	B	C	D	E	F	G
A	1.0000	.0137	.5016	.0157	.0000	.1493	.0000
B	.0137	1.0000	.3085	.1089	.2904	.6421	.4356
C	.5016	.3085	1.0000	.0000	.0000	.3266	.2000
D	.0157	.1089	.0000	1.0000	.0000	.2722	.0000
E	.0000	.2904	.0000	.0000	1.0000	.1361	.0000
F	.1493	.6421	.3266	.2722	.1361	1.0000	.2722
G	.0000	.4356	.2000	.0000	.0000	.2722	1.0000

APPENDIX IV

Markov analysis transition schemes of the four zones of the deposit



APPENDIX V

Equations used in the Study

Left substitutability matrix

$$S_{ab} = \frac{\sum_{i=1}^{m} Pai\ Pbi}{\sum_{i=1}^{m} Pai^{2}\ \Sigma Pbi^{2}} \tag{1}$$

where S_{ab} = substitutability of states a and b,

Pai = transition probability to the ith state, given state a,
m = number of states in the system

$$Cij = Lij\ Rij(2)$$

It is the product of all pairs of right and left substitutability

Linear regression

$$Yi = b + b^{1}\ Xi \tag{3}$$

where Yi is the estimated value of Yi at specified values of Xi

Total Sum of Squares

$$SS_{T} = \sum_{i=1}^{n} Yi^{2} - \frac{(\sum_{i=1}^{n} Yi)^{2}}{n} = \sum_{i=1}^{n} (Yi - \hat{Y})^{2} \tag{4}$$

where Y is the estimated value at the sample point

Sum of Squares due to Regression

$$SS_{R} = \sum_{i=1}^{n} Yi^{2} - \frac{(\sum_{i=1}^{n} Yi)^{2}}{n} = \sum_{i=1}^{n} (Yi - \hat{Y})^{2} \tag{5}$$

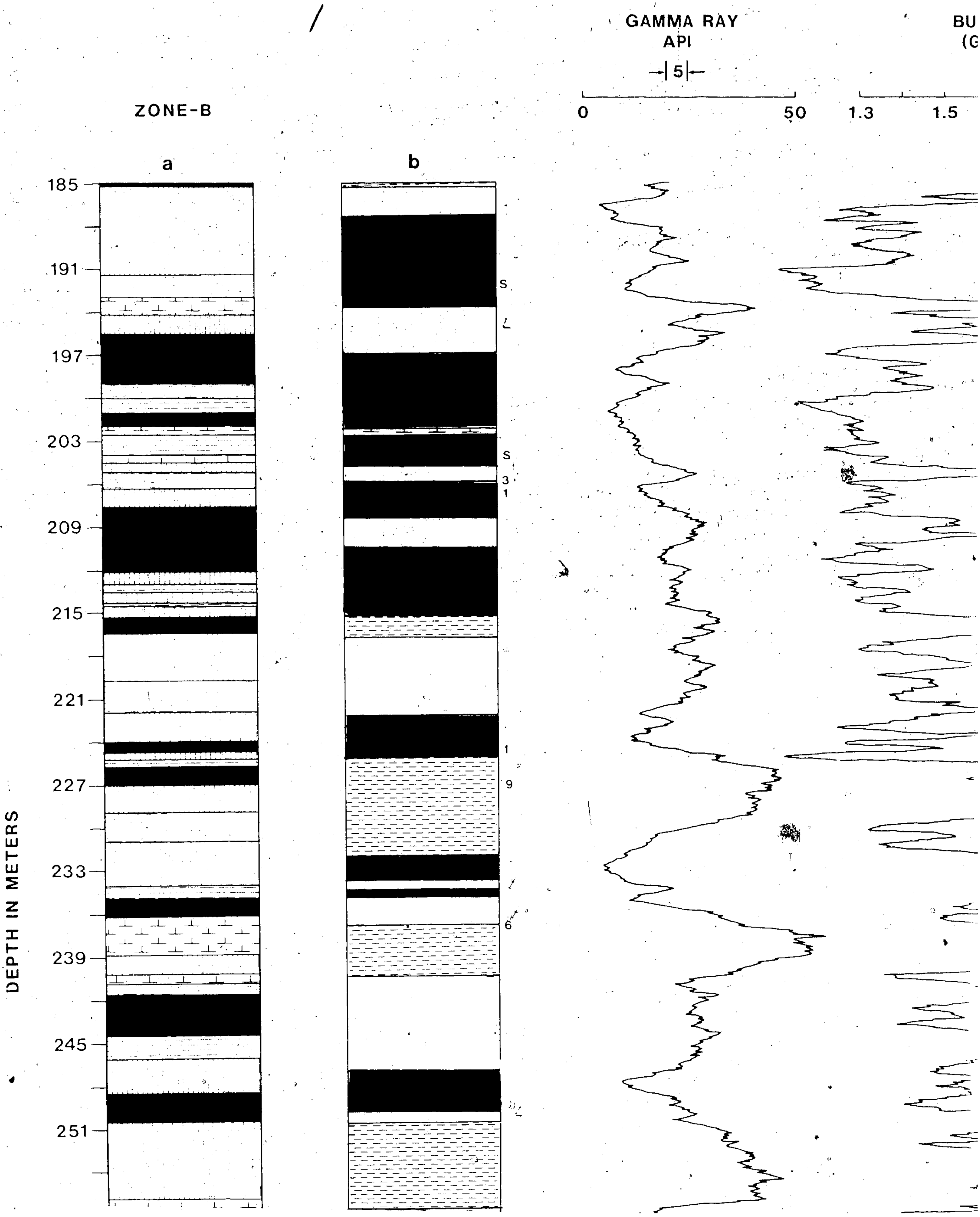
Sum of Squares due to Deviations

$$SS_{D} = \sum_{i=1}^{n} (Yi - Yi)^{2} \tag{6}$$

F test

$$F = MS_{R}/MS_{D} \text{ where } MS = \text{mean square} \tag{7}$$

$$SS_{T} = SS_{R} + SS_{D} \tag{8}$$


ZONE-B
a
b
GAMMA RAY
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50
BU
(G
1.3
1.5
DEPTH IN METERS
185
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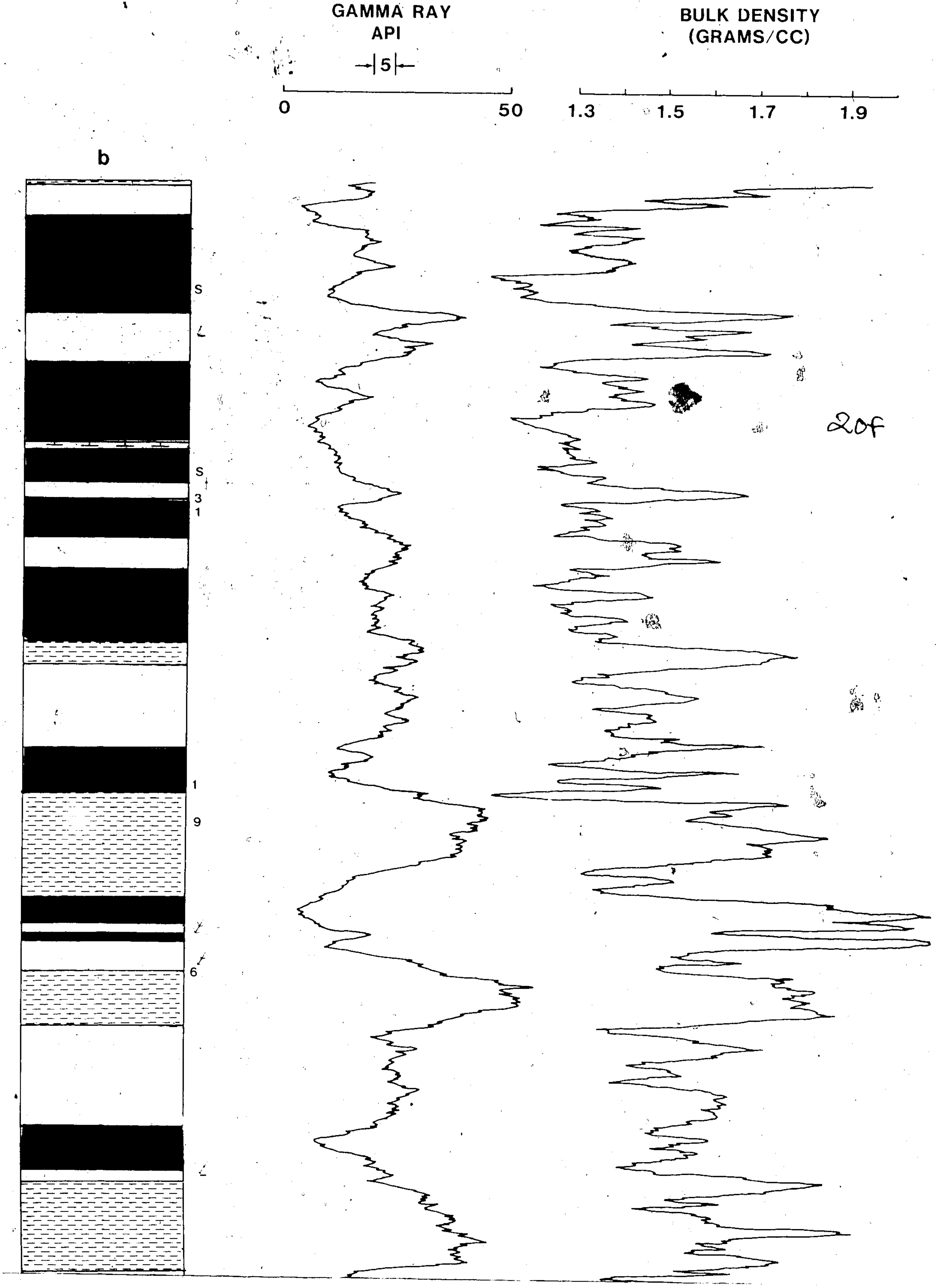

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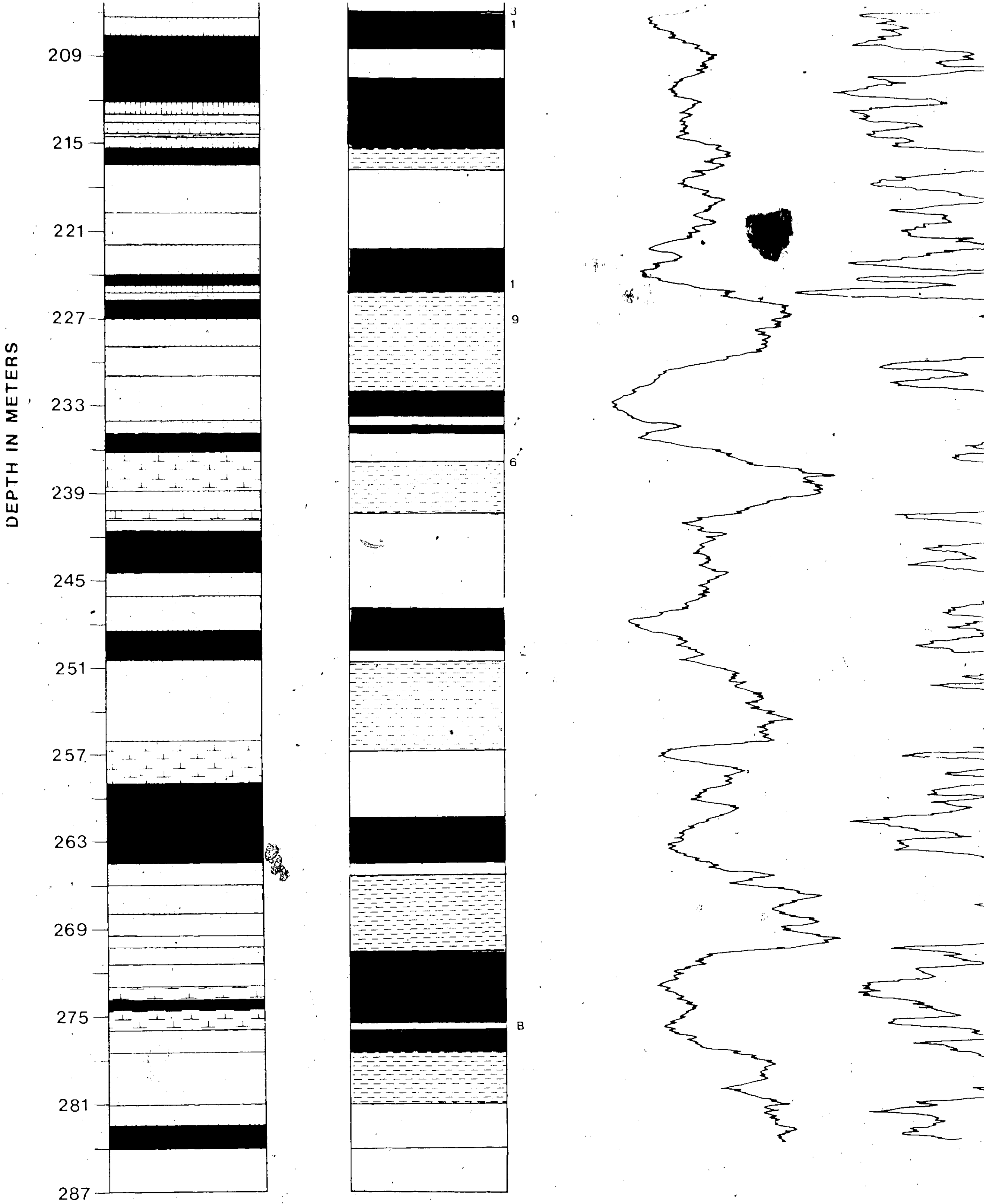
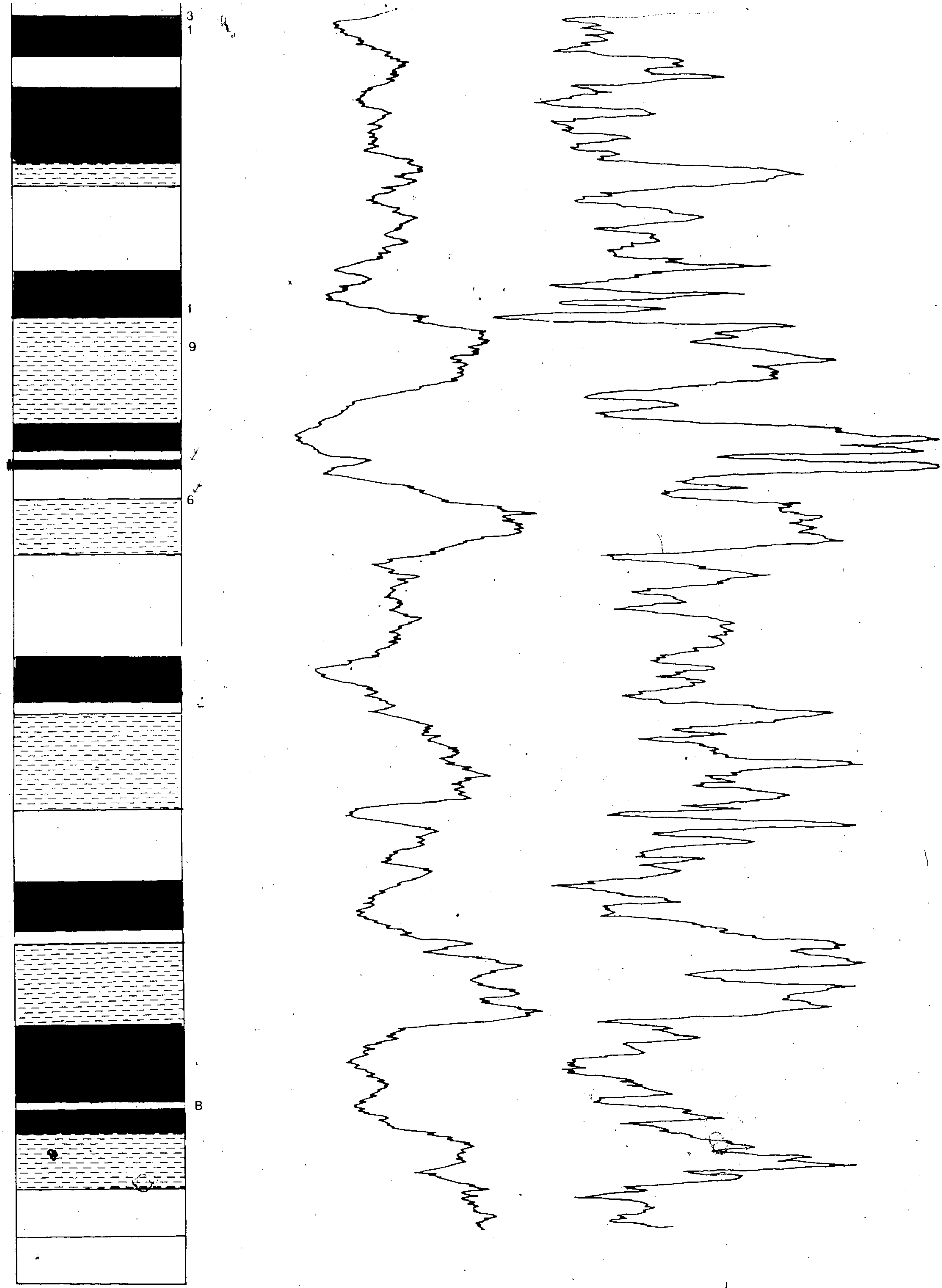
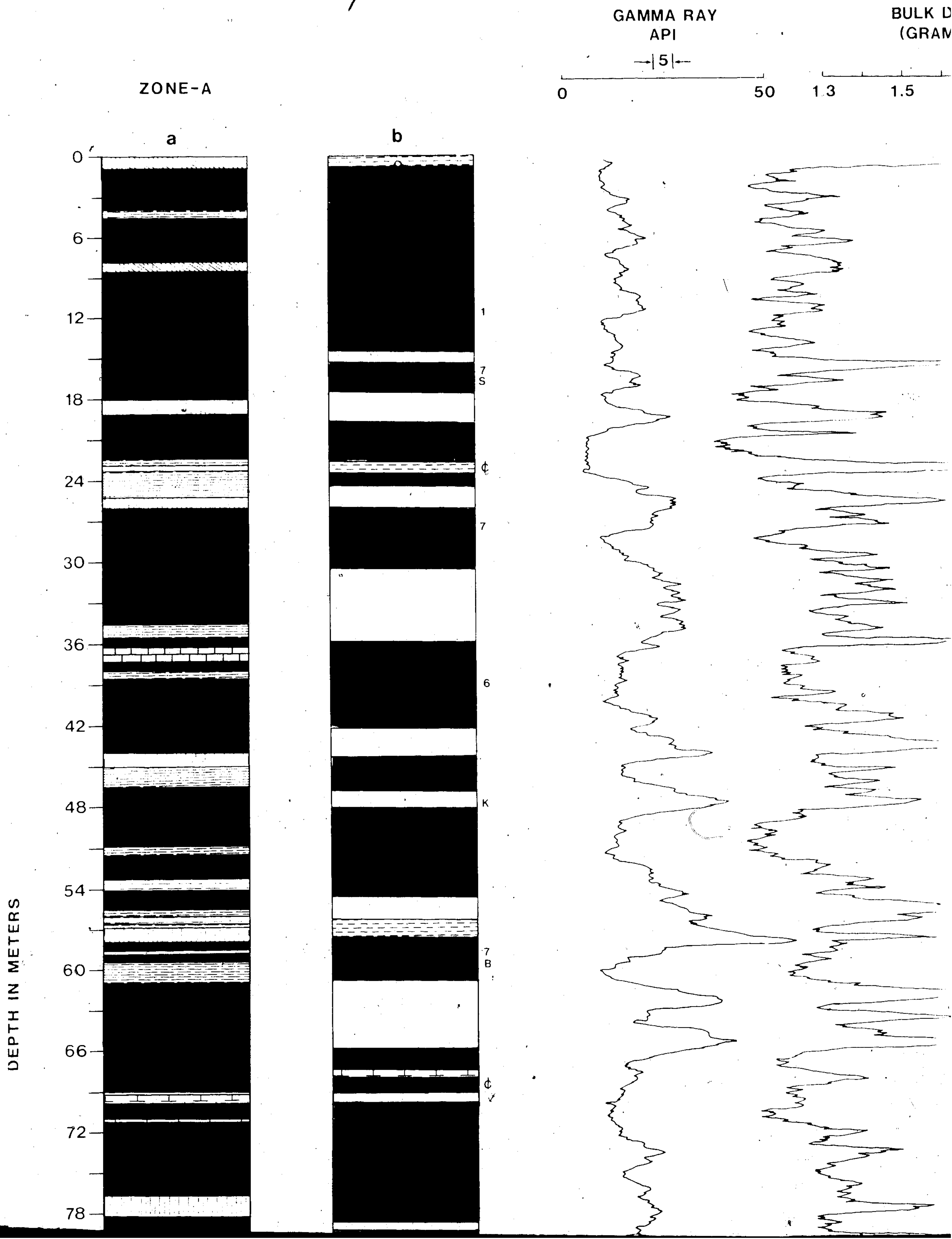


Figure 7-2. Stratigraphic columns of Zone B.



gure 7-2. Stratigraphic columns of Zone B.

4of4


ZONE-A
a
b
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BULK D
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DEPTH IN METERS
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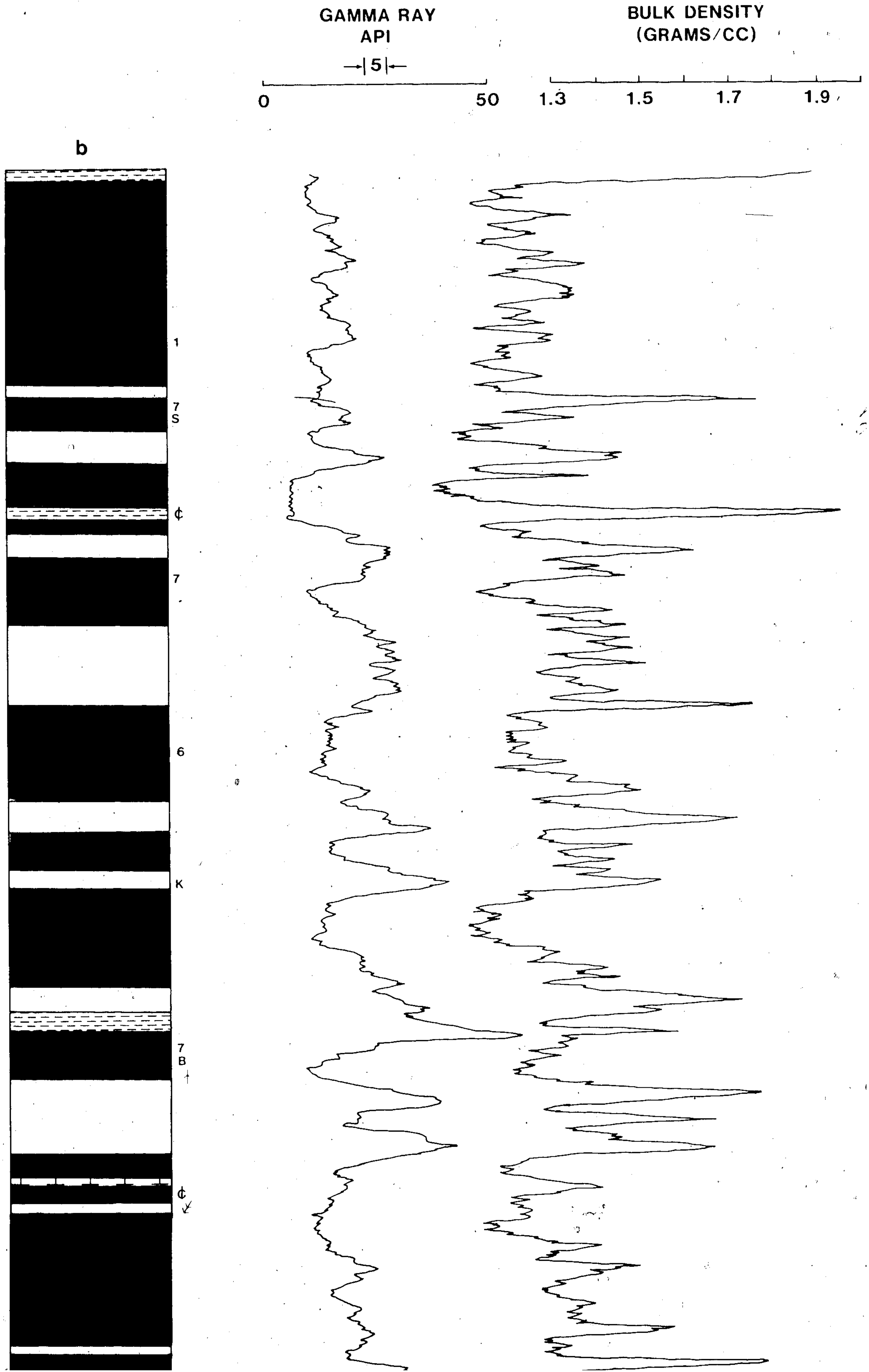
GAMMA RAY
API
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BULK DENSITY
(GRAMS/CC)
1.3
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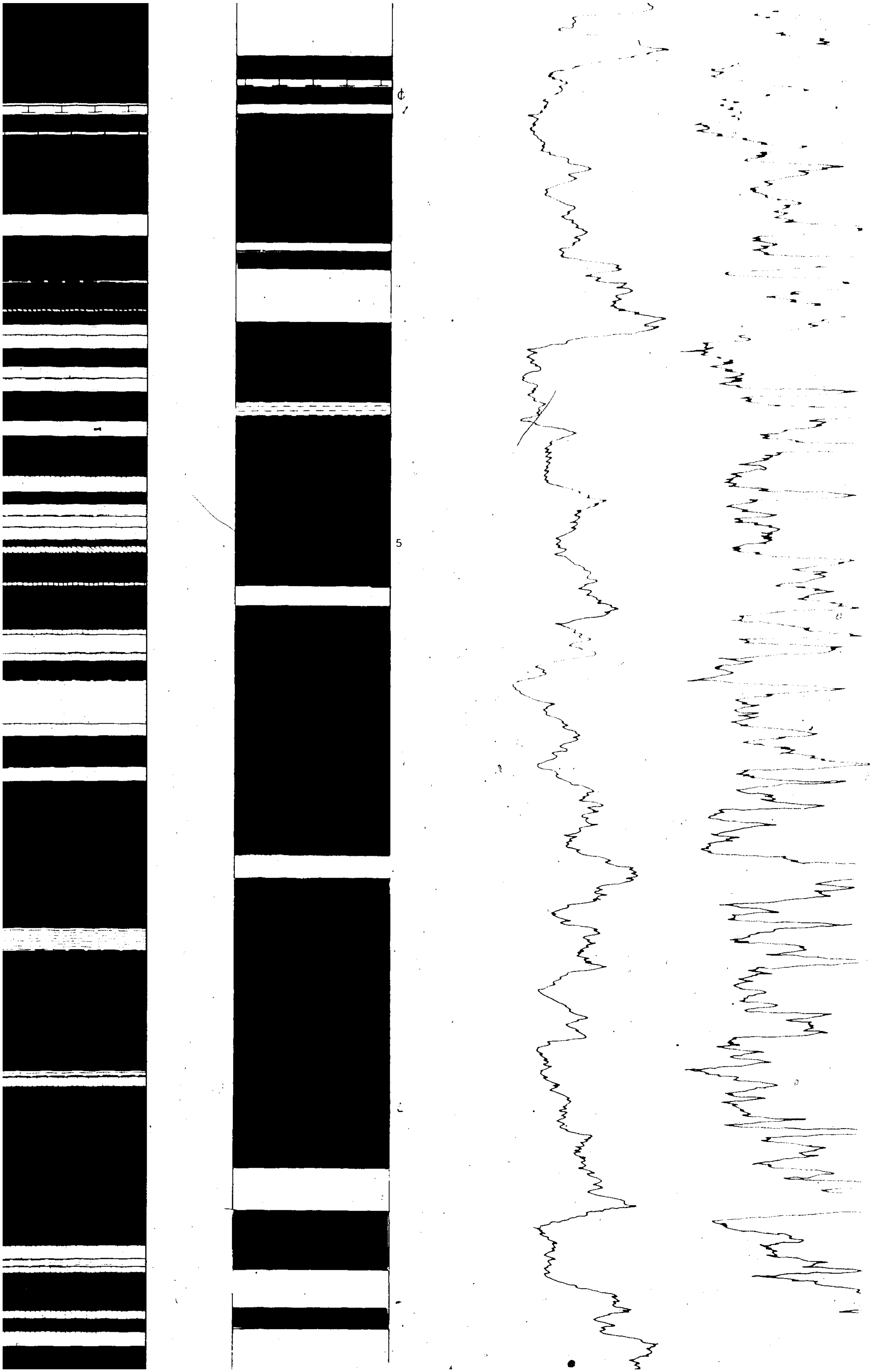
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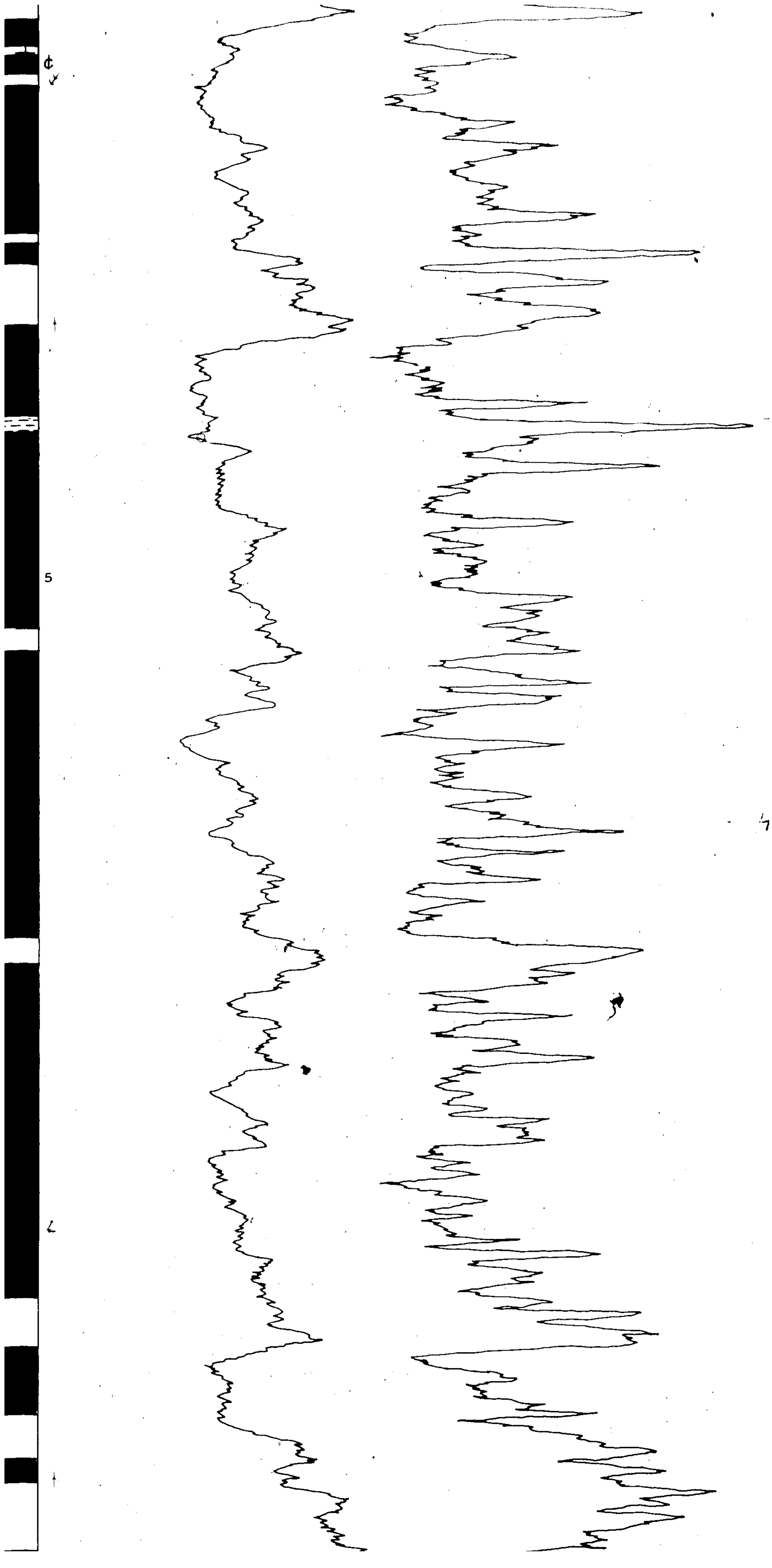
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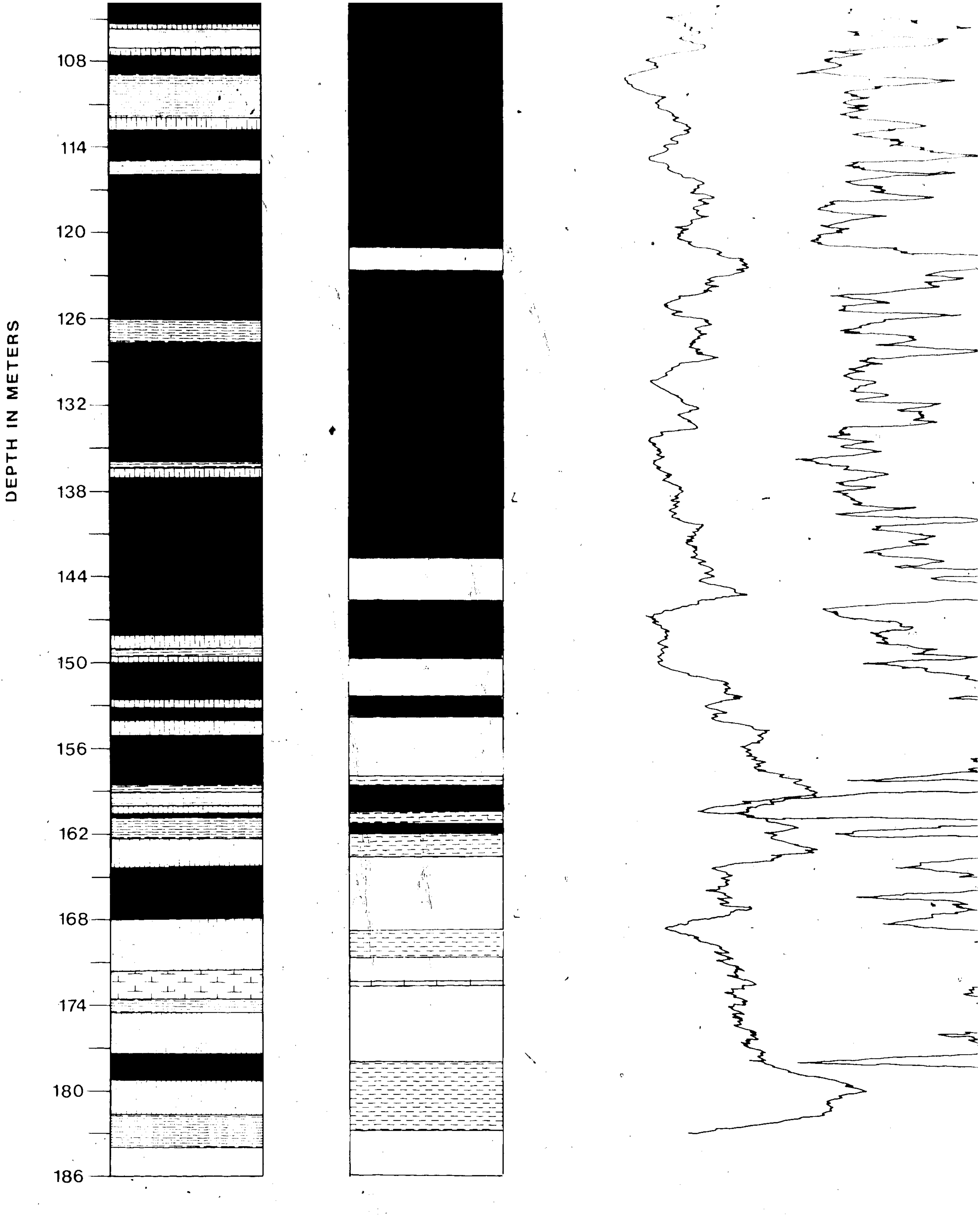
DEPTH IN METERS
108
114
120
126
132
138
144
150
156
162
168
174
180
186

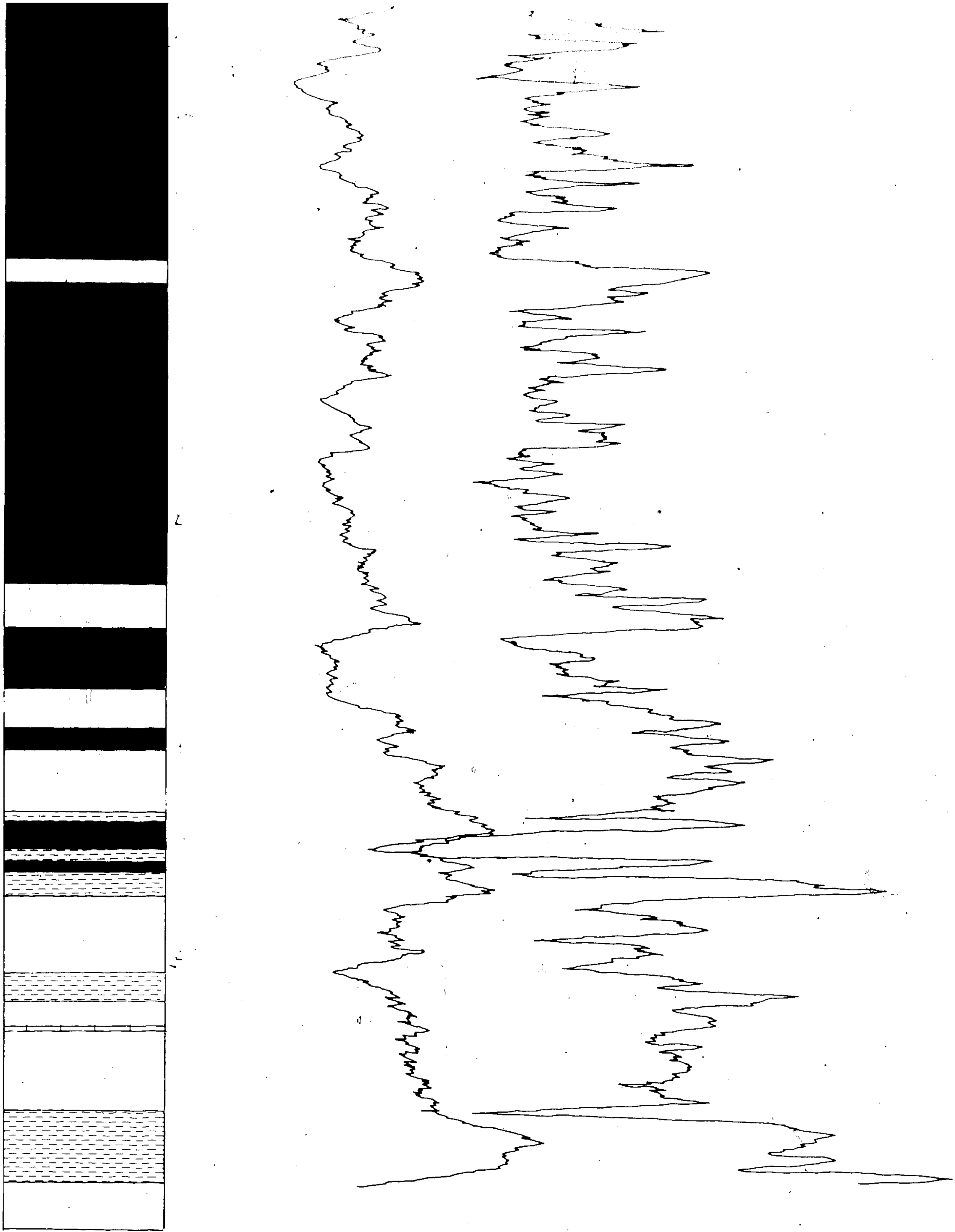

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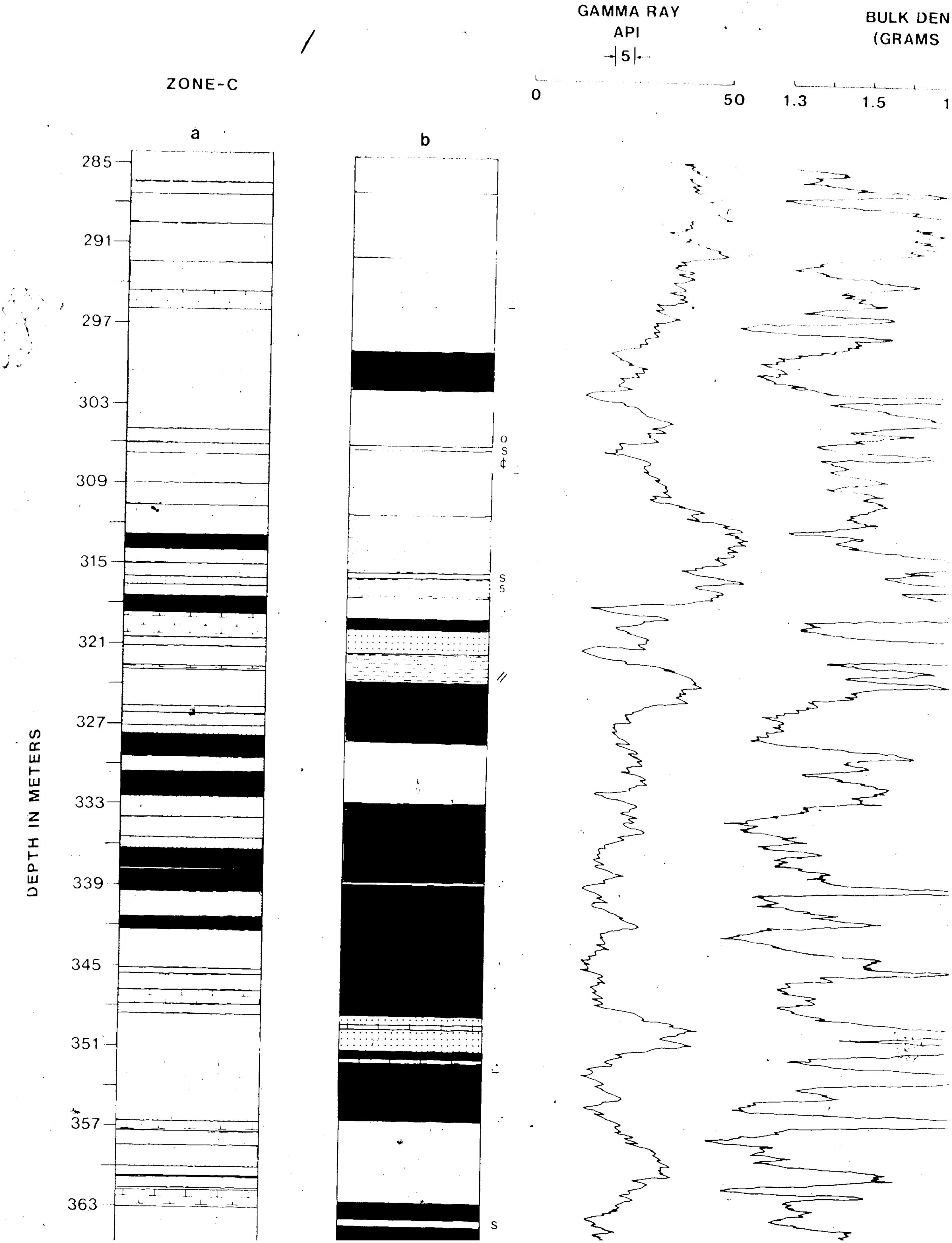
Figure 7-1. Stratigraphic columns of Zone A.



GAMMA RAY
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ZONE-C
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DEPTH IN METERS
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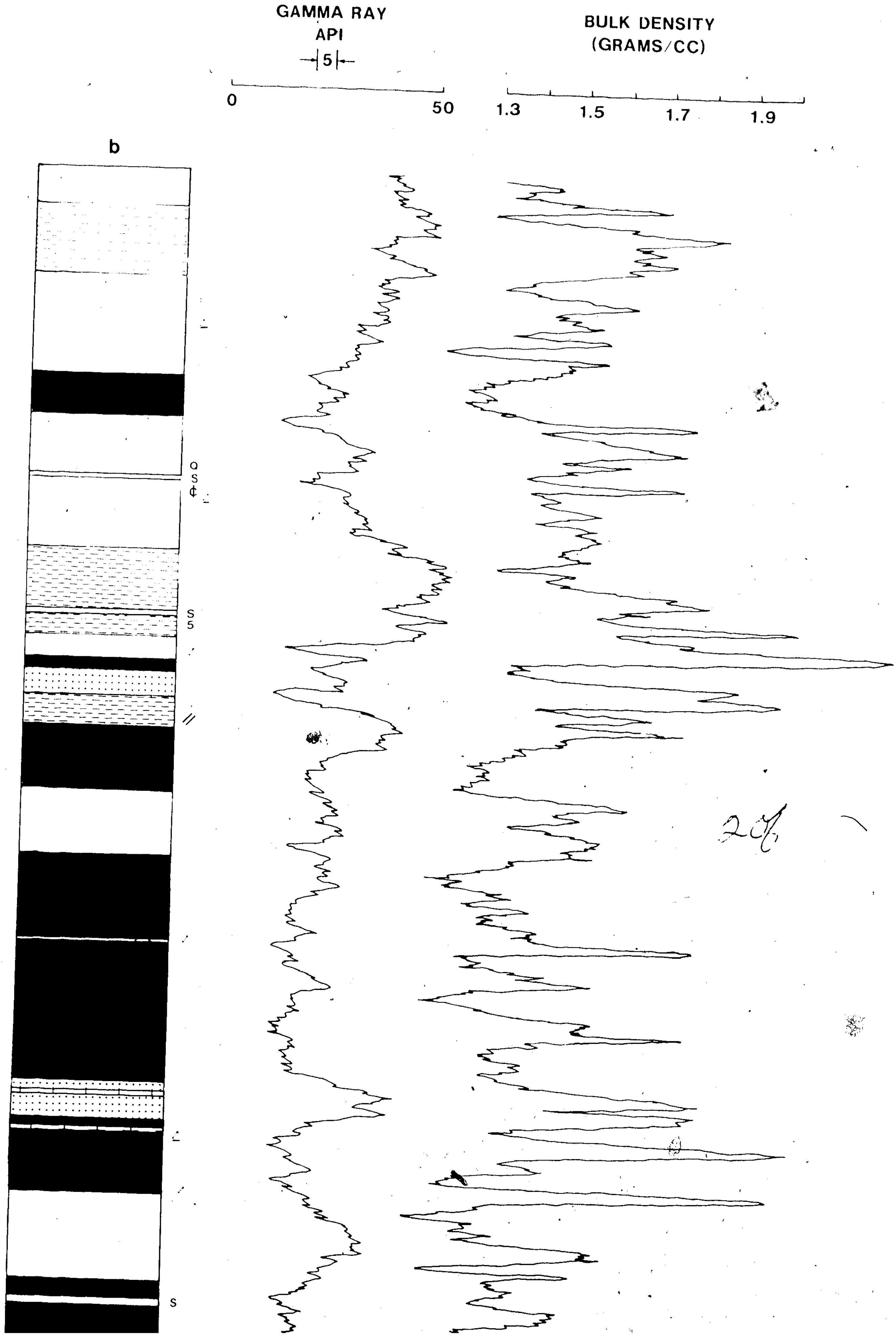
S



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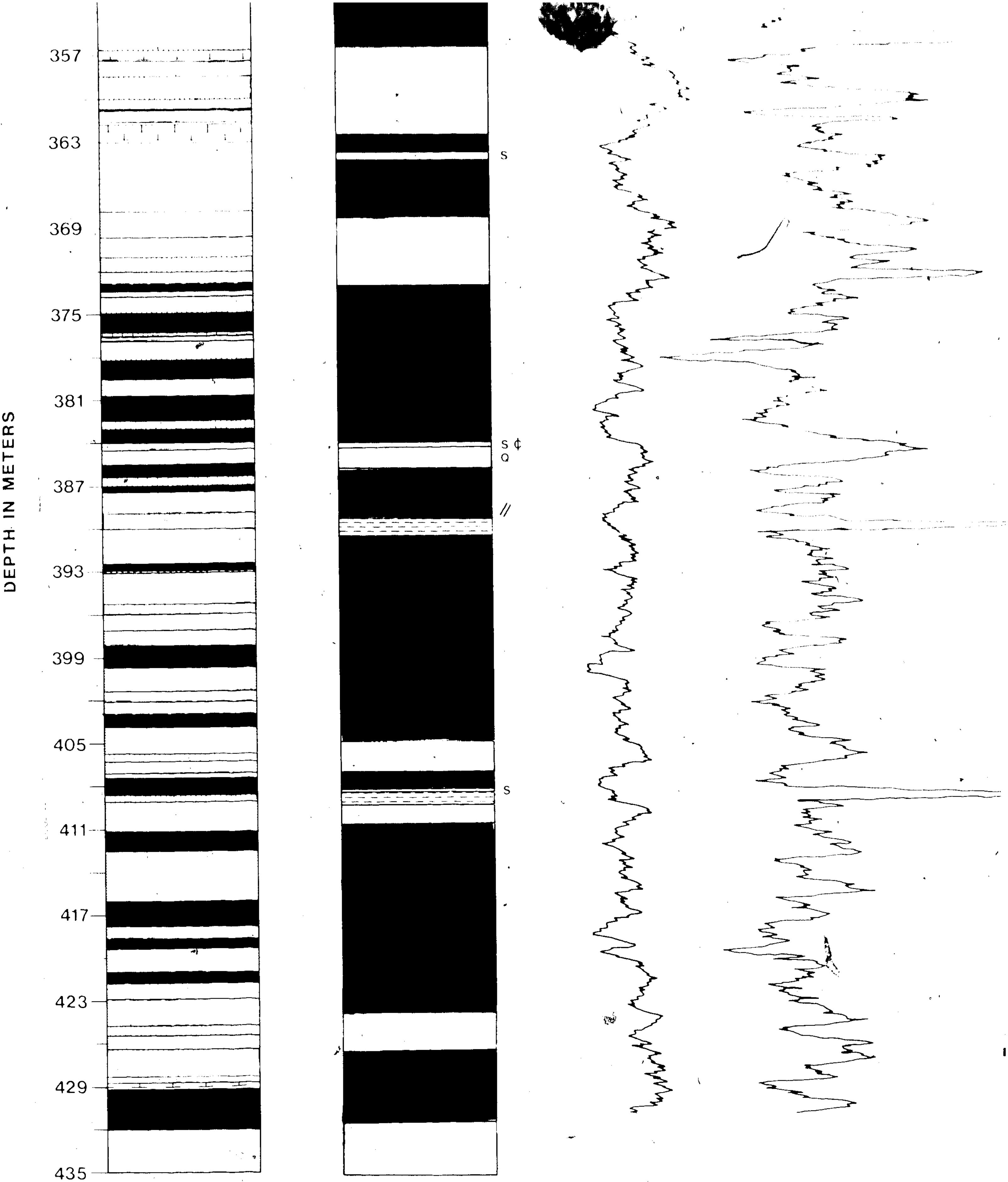

Figure 7-3. Stratigraphic columns of Zone [illegible].

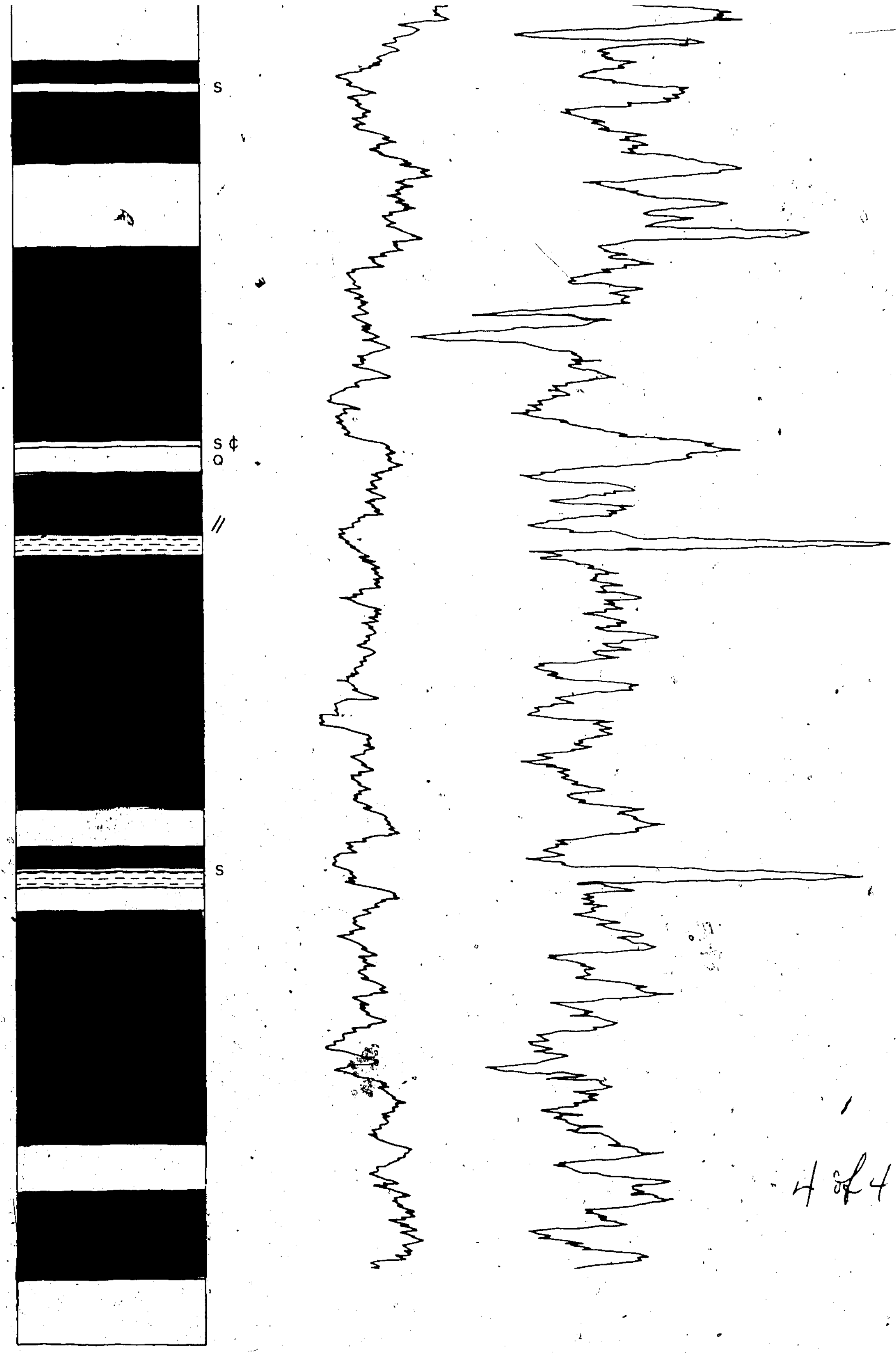

Figure 7-3. Stratigraphic columns of Zone C.

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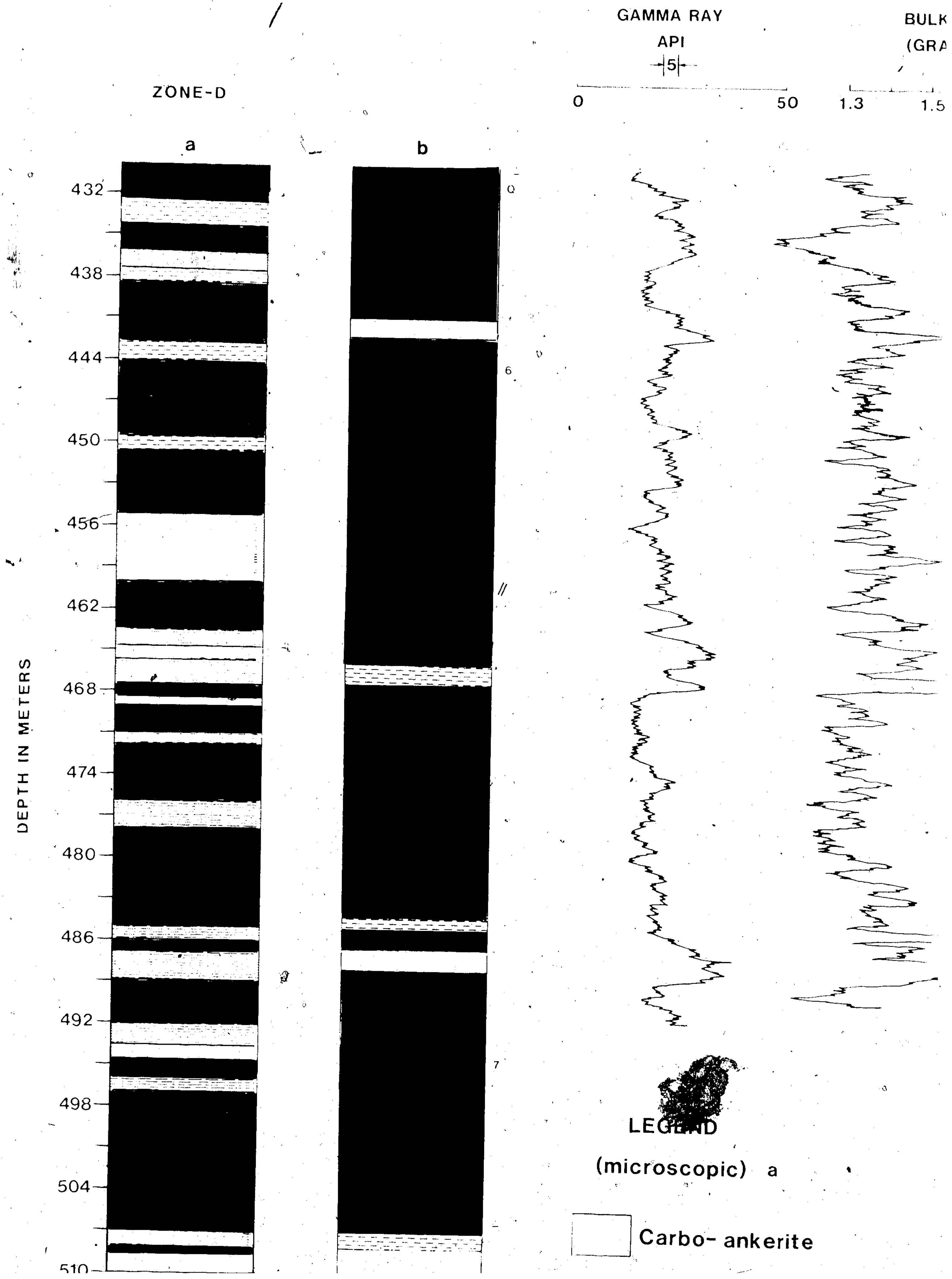
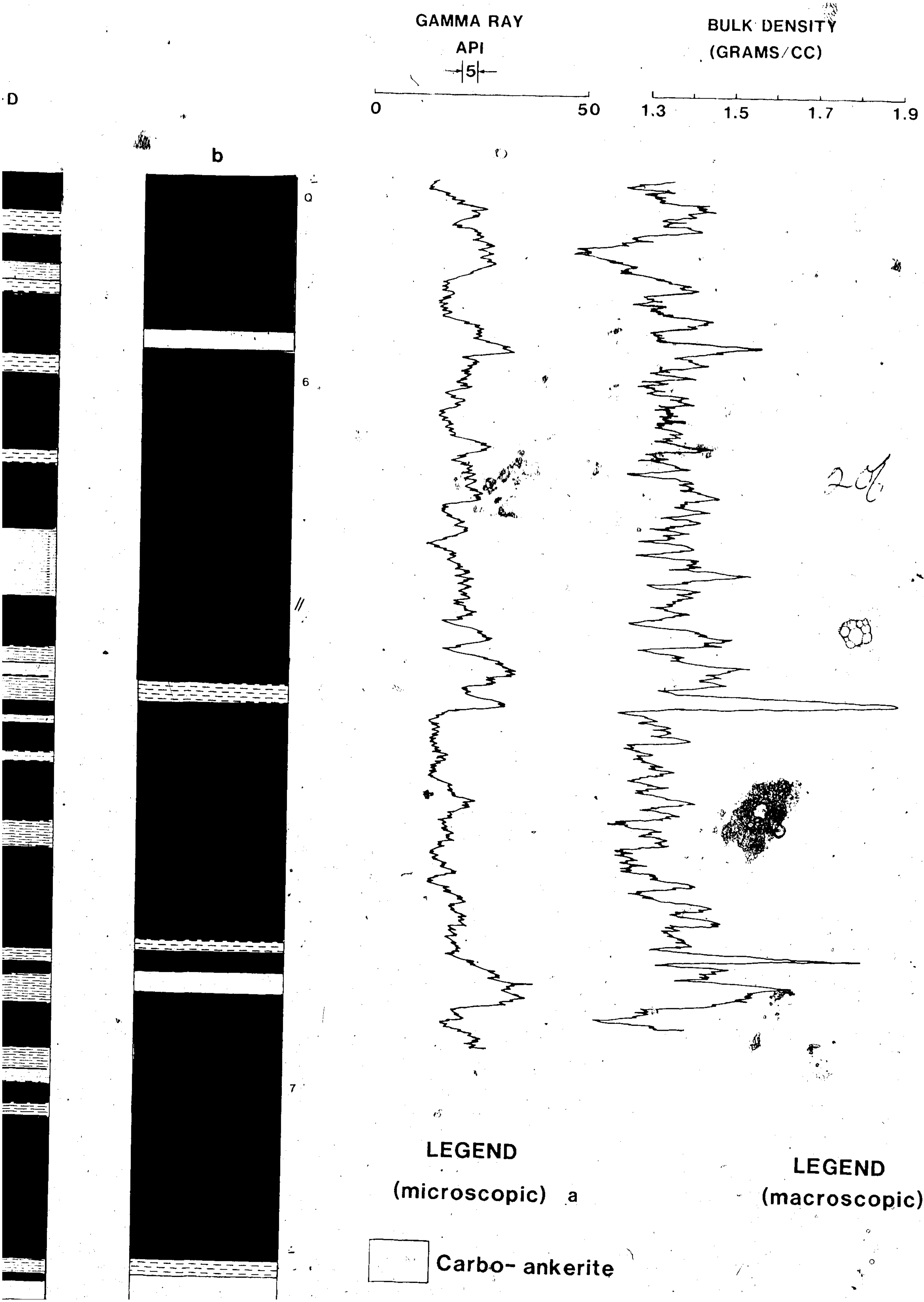

ZONE-D
a
b
GAMMA RAY
API
5
0
50
BULK
(GRA
1.3
1.5
DEPTH IN METERS
432
438
444
450
456
462
468
474
480
486
492
498
504
510
0
6
//
7
LEGEND
(microscopic) a
Carbo- ankerite



20

LEGEND

(microscopic) a

LEGEND

(macroscopic) b

☐ Carbo- ankerite

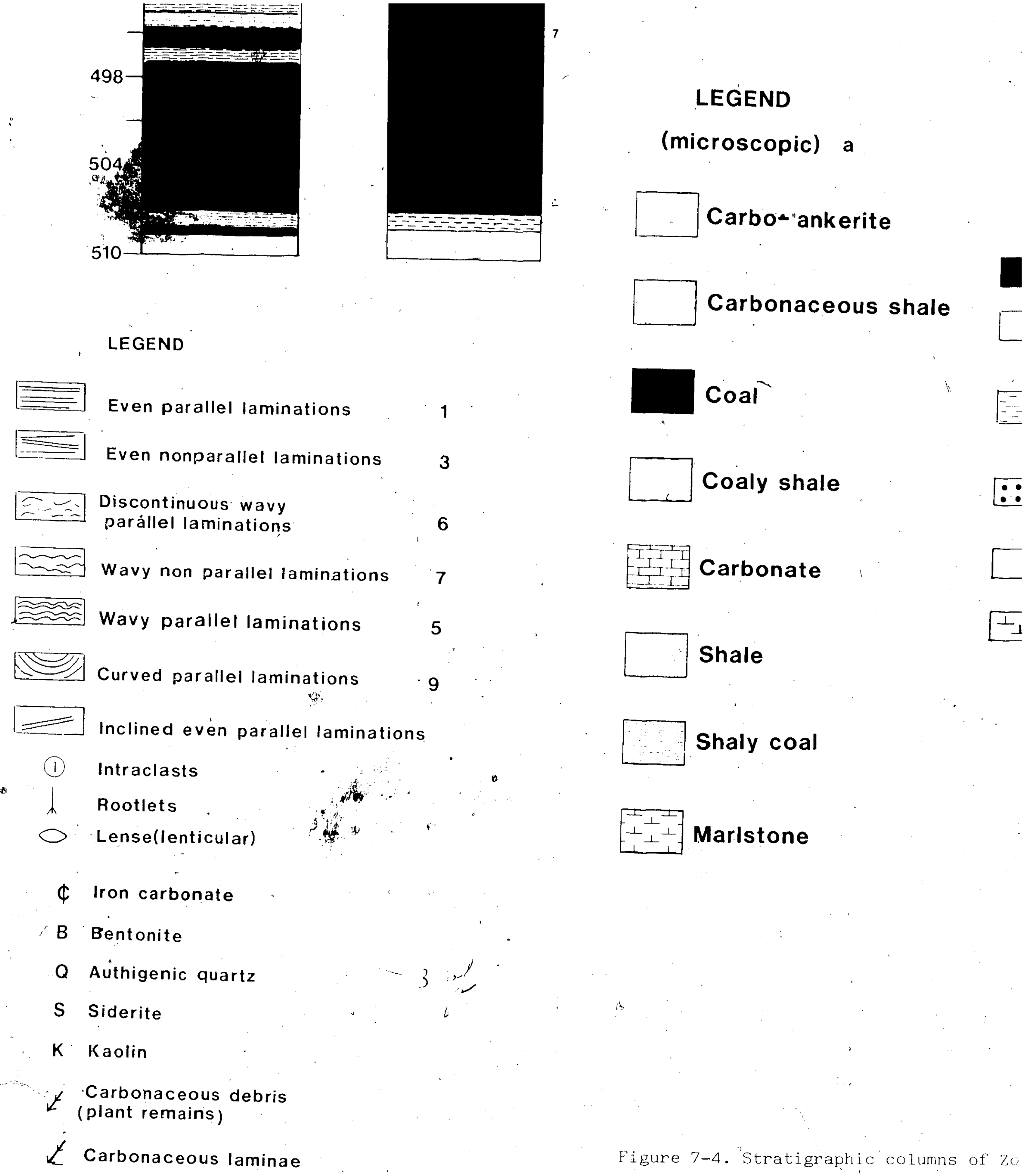


Figure 7-4. Stratigraphic columns of Zo

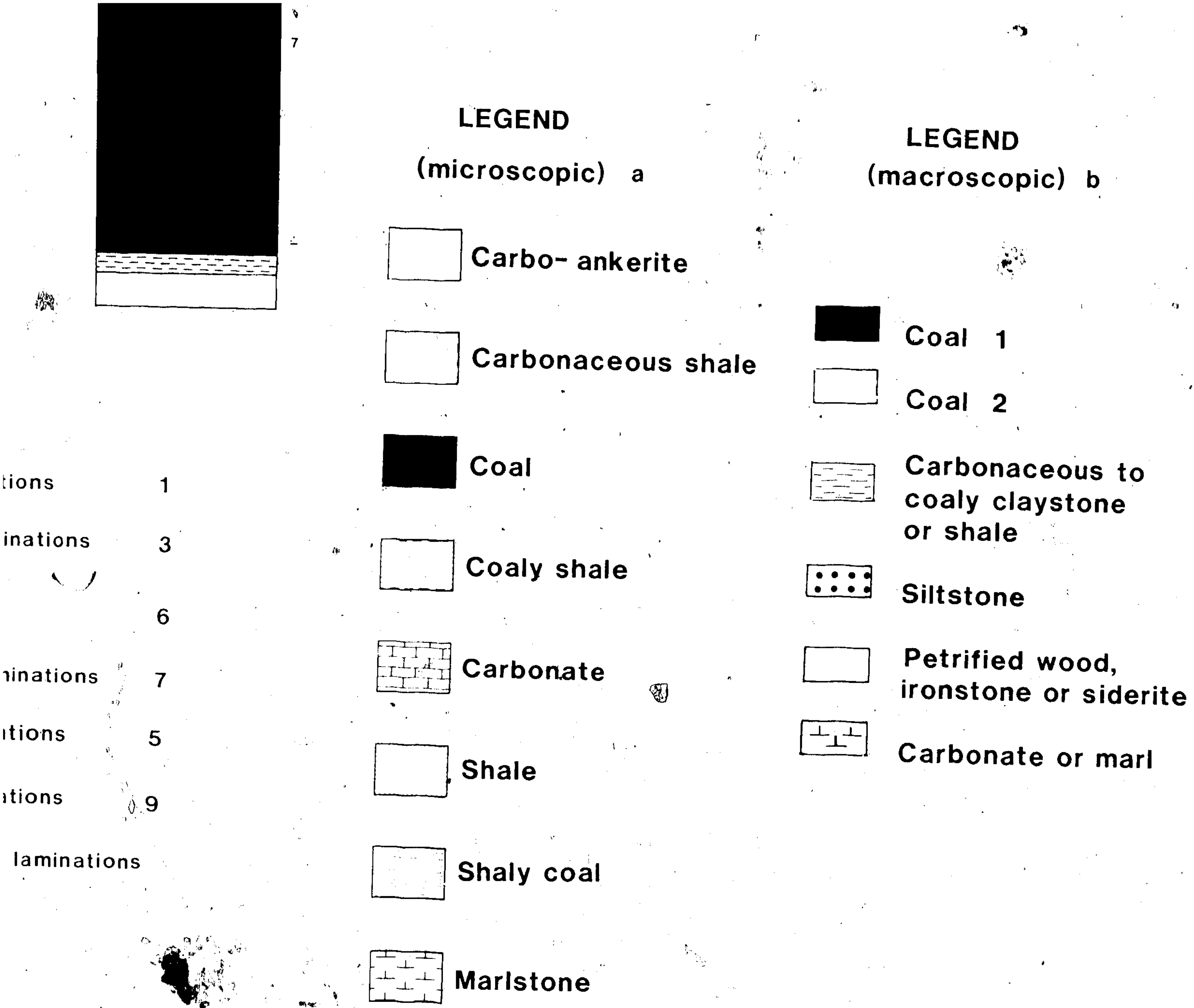


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Figure 7-4. Stratigraphic columns of Zone D.