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Recent Mediterranean Sea Sediments - An Analogue to Lower Cretaceous Petroleum Source Rocks in Lower Indus Basin, Pakistan

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ABSTRACT

The Recent Mediterranean Sea sediments from Cilician Basin show low total organic carbon (TOC) contents (0.3-0.6%) with a higher value of 0.8-1.52% being observed in the sapropelic layers. Similarly TOC contents of Cretaceous Lower Goru and Sembar Formations occur in the range of 0.25-1.79 and 0.93-2.53%, respectively. TOC varies normally with grain size and environmental conditions. Non Sapropelic Mediterranean Sea sediments predominantly contain degraded amorphous organic matter (AOM) with a little concentration of terrestrial organic matter (TOM), while sapropelic layers contain of degraded AOM with increased amount of TOM (pollen, spores and plant fragments). The sediments in close proximity of Goksu River have high concentration of dark brownish woody vitrinite type of organic matter (terrestrial plant material) with recognizable rectangular woody structure and little coaly (inertinite) recycled type of organic matter (OM). Similarly, sediments of Lower Goru and Sembar Formations reveal the dominant occurrence of Type III (OM) but the presence of Type II was also observed in Almani-1 and Bhadmi-1. The geochemical and petrographic studies reveal that Recent Mediterranean Sea sediments, particularly sapropelic layers and sediments of the Goksu Delta predicted to be oil/gas prone on maturity.

INTRODUCTION

The concentration and distribution of OM in Recent marine sediments has been investigated for various purposes: some researchers have been interested in identifying modern analogues of petroleum source rocks while others have investigated the role of OM and its degradation in providing the energy for diagenetic chemical reactions in marine sediments (Calvert and Pederson, 1991). Some have studied the carbon cycle in the ocean, which involved studies of the settling and burial fluxes of carbon and associated biogenic elements in oceanic sediments. More recently research has focused on the study of OM in Recent marine sediments to investigate the origin of organic rich horizons thought to have accumulated as a result of stagnant conditions (Calvert, 1987).

The purpose of this paper is to delineate the nature and source of OM in the Recent sediments of Cilician Basin and to evaluate its potentiality based on organic geochemical investigation and compare it to Lower Cretaceous petroleum source (Lower Goru and Sembar Formation) in Lower Indus Basin of Pakistan.

The Cilician Basin is relatively shallow sedimentary basin bordered by Southern Turkish coastal area towards north and Cyprus Coast towards south (Figure 1). The Indus basin is located on the north western margin of the Precambrian Indian shield. The Lower Indus basin is a sub basin of the larger Indus basin. It is one of the major hydrocarbon producing basin in southern part of Pakistan (Figure 2). The stratigraphy and petroleum geology of the Lower Indus basin has been described by many authors including Williams (1959), Rahman (1973), Shah (1977), Quadri and Shuaib (1986), Malik et al.(1988) and Raza et al. (1990).

METHODOLOGY

Piston and gravity cores, used in this study (Figure 1), were collected from Cilician Basin, northeastern Mediterranean in 1972, 1974 and 1977 on "RSS" Shackleton supported by NERC under the supervision of Geologists from Imperial College, London. Samples for analysis were provided by the Department of Geology, Imperial College, London.

Total Organic Carbon (TOC) and petrographic analyses of kerogen on representative samples were performed. TOC was determined using Perkin-Elmer 240 CHN analyzer, while petrographic study of kerogen was carried out using reflected light microscope. Three-five mg frozen, dried and crushed powdered samples were first acidified with 16% HCl to remove inorganic carbon. Then samples were dried in oven at 38±2^{o}C overnight and run for CHN analysis on Perkin-Elmer 240 organic carbon analyzer. Replicate analyses of all samples were performed to check the accuracy and precision. Kerogen extraction using 10% HCl and 60% HF were performed for detailed petrographic study.

Organic geochemical data of Lower Goru and Sembar Formations were obtained by the investigation of core and flush cutting sediments from various exploratory wells (Almani-1, Sakrand-1, Pasaki-1, Dhamraki-1 and Bhadmi-1) drilled by Oil and Gas Development Corporation (OGDC) in Lower Indus Basin of Pakistan.

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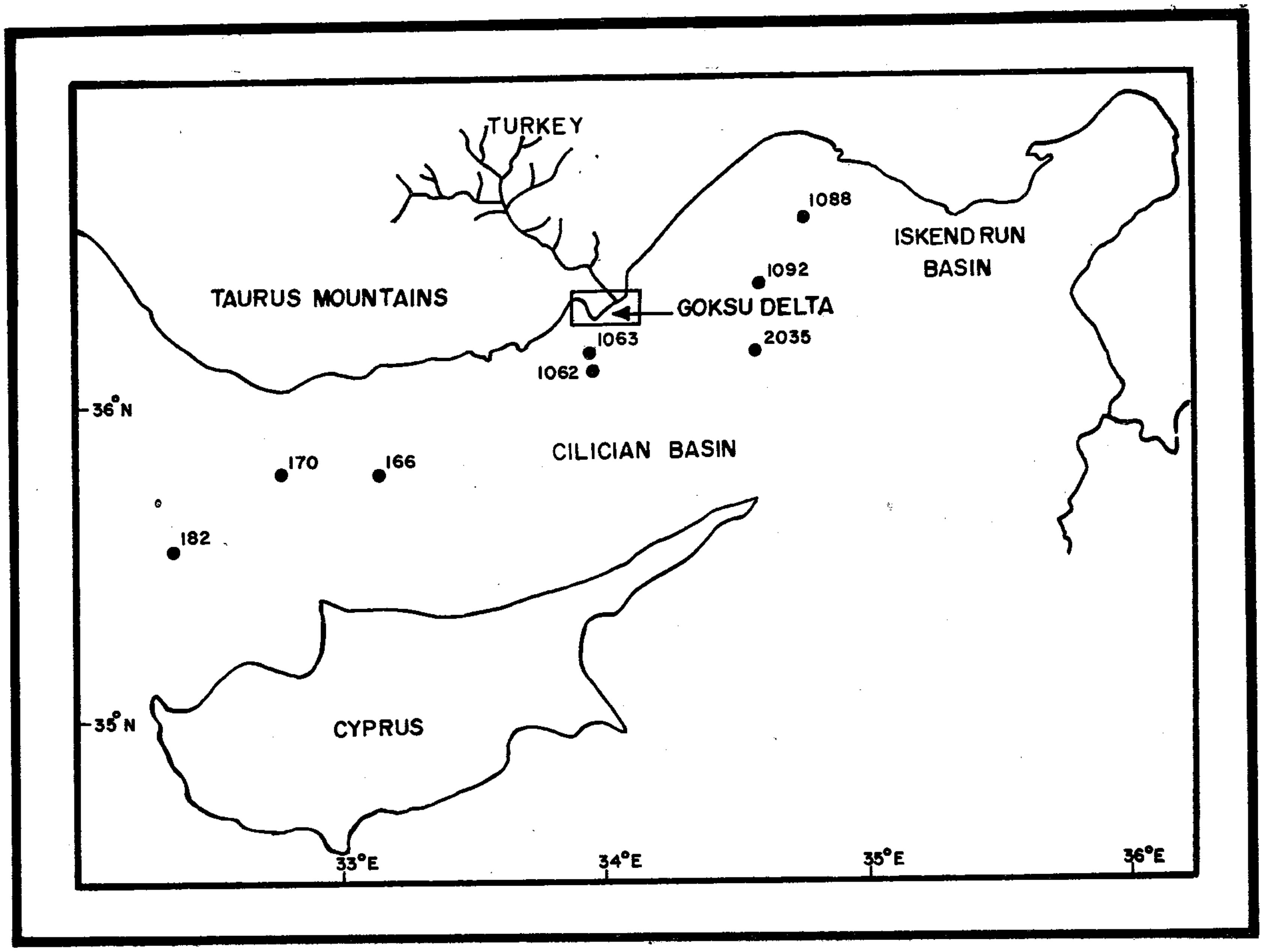


Figure 1- Location map of piston and gravity cores from Cilician Basin northeastern Mediterranean.

TOC contents of the samples from Lower Goru and Sembar Formations were determined using LECO DC-12 carbon analyzer. Selected samples were subjected to the assay of pyrolysis for the evaluation of quality and types of organic matter present in the sediments. In this paper, priority is given to the type of organic matter evaluated based on hydrogen index (HI) and oxygen index (OI). Petrographic study of extracted kerogen here is not possible due to the lack of facilities. However, efforts are made for the identification of geopolymers by visual observations and petrographic/binocular microscopic studies of the rock samples from Lower Goru and Sembar shales.

RESULTS AND DISCUSSION

TOC concentration occurs in the range of 0.3-1.52% with a higher value of 0.8-1.52% being observed in the sapropelic layers (Figures 3,4). The TOC content varies widely and is related to the lithology and grain size of the sediments (Ali, 1992). The data show that TOC content increases in concentration as the fine fraction of the sediments increases. This is evident from the TOC contents of the surface sediments of the cores SH/1088, SH/1062 and SH/1063 which show significantly low TOC concentration (Figure 3). This low TOC corresponds well with the decrease in fine clay size fraction material and increase in coarse size fraction material. Similarly, high TOC concentration of the sapropelic horizon also indicates the effect of high input of clay size fraction material as evident from the grain size data of cores bearing sapropelic horizons (Ali, 1992). Another possibility of the increase of TOC in fine fraction is better preservation of the organic matter (Welte, 1984; Ali, 1993).

The TOC in the sediments of Cilician Basin is observed to be low as compared to the other marine basins such as Atlantic Ocean, Baltic, Azove, Black Sea and many other Mediterranean Sea sediments (Emelyanove and Shimkus, 1986). Relatively high TOC contents, in the range of 0.8-1.52%, are present in the sapropelic horizons. This TOC content is also generally lower than that of the other Mediterranean Sea sapropel or sapropelic layers, which indicates that the conditions of sapropel formation in the Cilician Basin were probably less favourable than elsewhere (Shaw and Evans, 1984). These organic rich

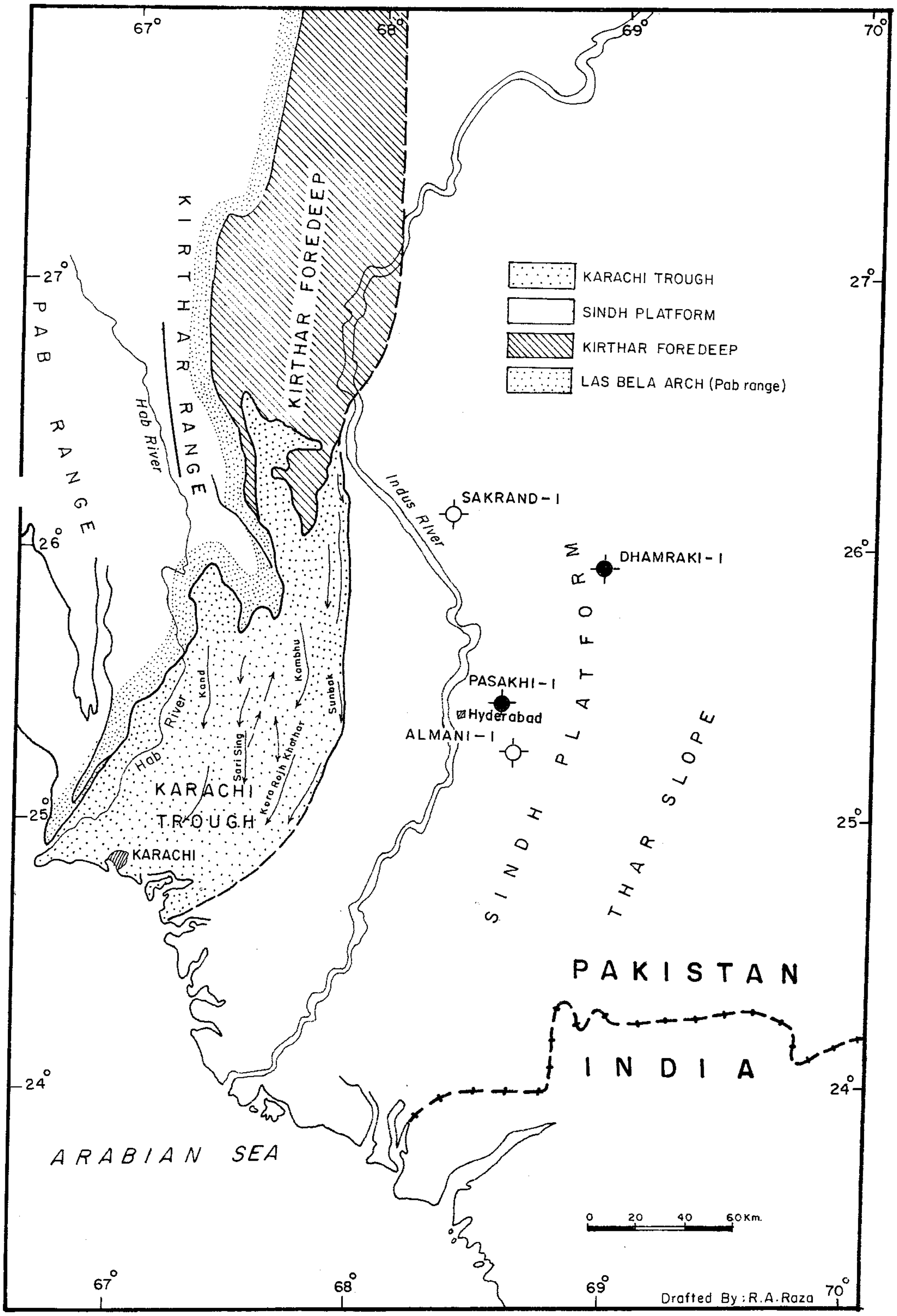


Figure 2- Location map of Lower Indus Basin.

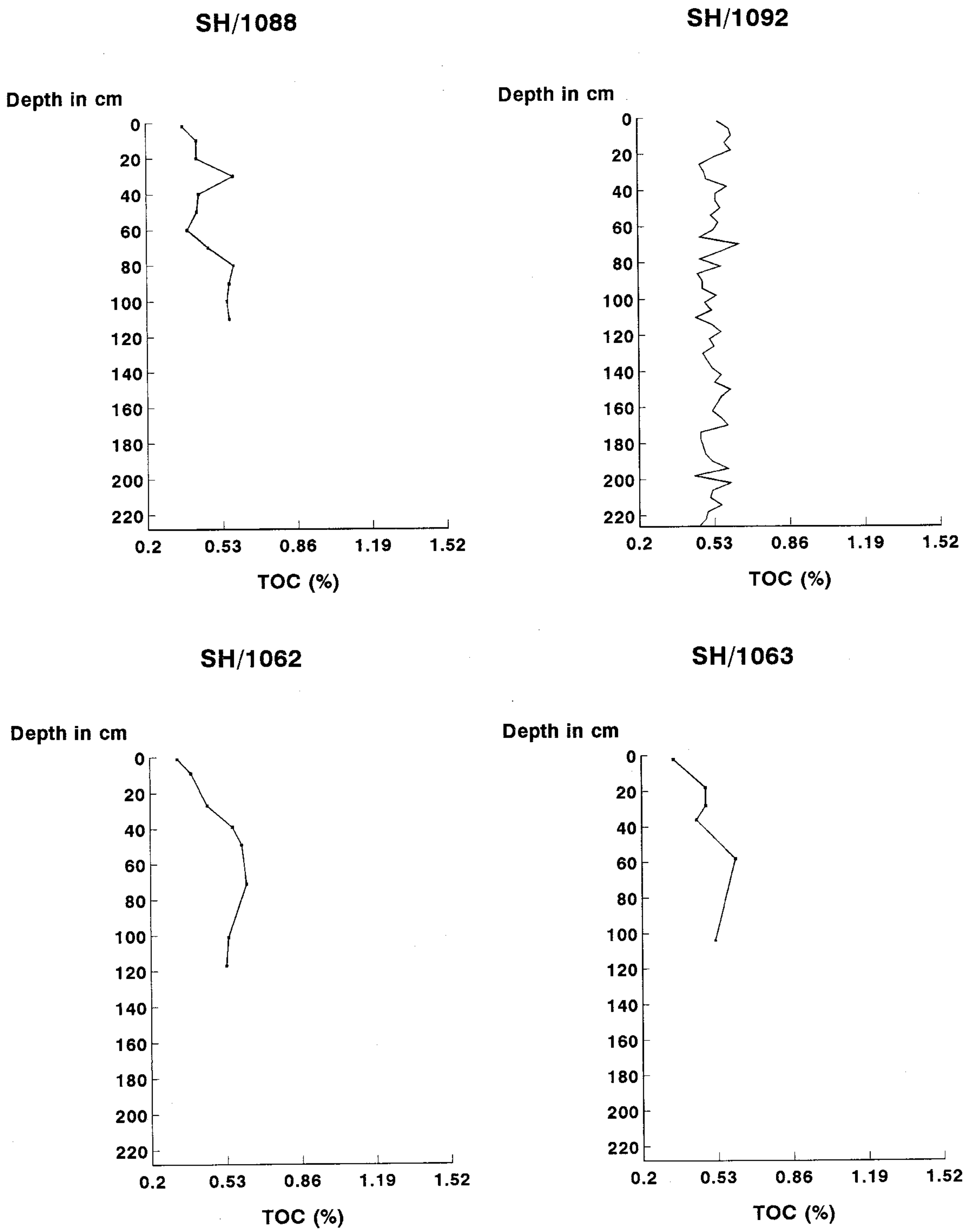


Figure 3- Distribution of TOC concentration in cores bearing sapropelic horizon.

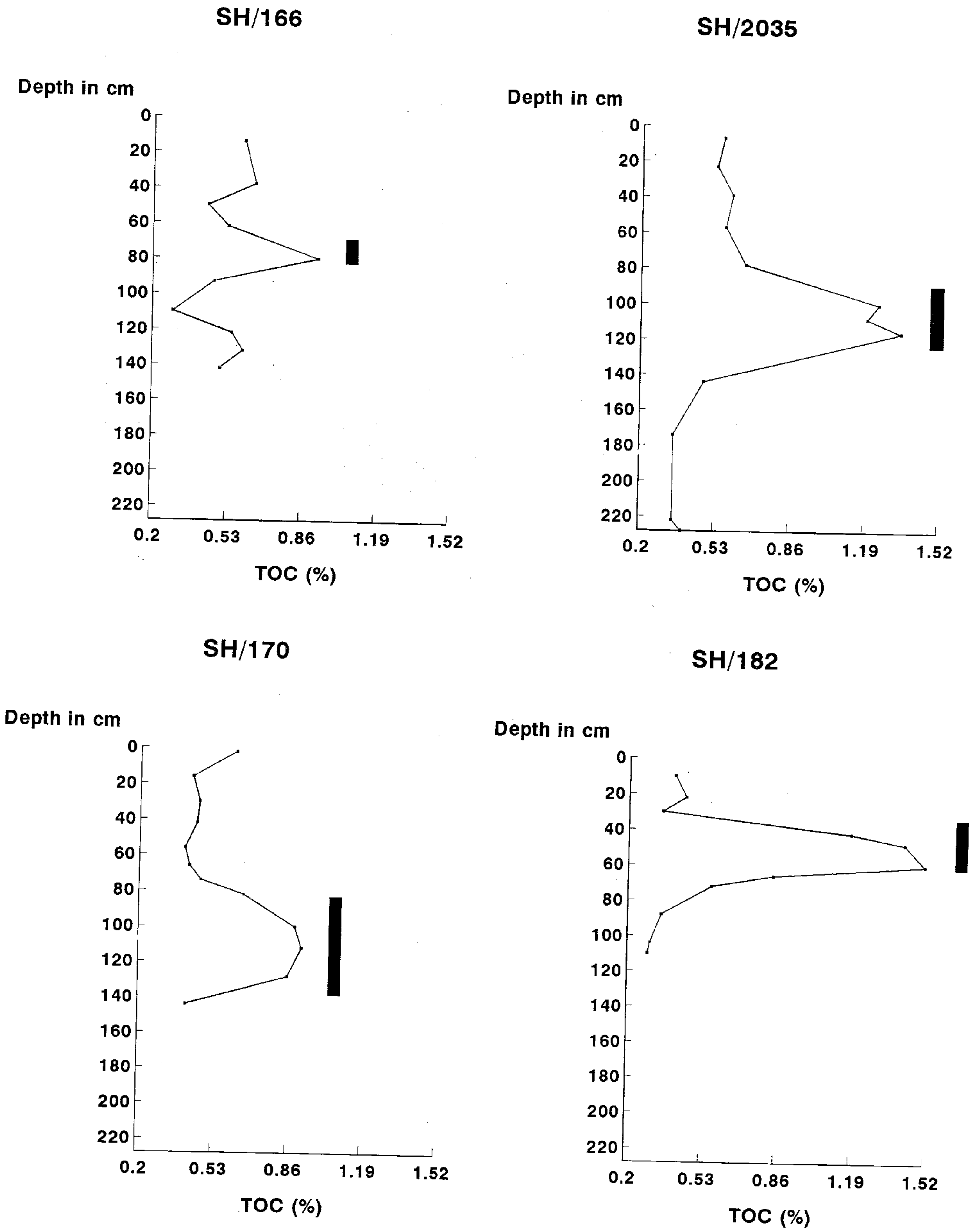


Figure 4- Distribution of TOC concentration in cores without sapropelic horizon.

horizons should be classified as sapropelic layers rather than sapropel according to definition of Kidd et al. (1978).

The petrographic data (Table 1) indicates that the organic material in the sediments of the Cilician Basin is dominated by highly degraded amorphous organic matter (AOM) with eminent recognizable land derived organic matter (Figure 5), while in sapropelic layer besides the degraded AOM there is large amount of terrestrial land derived plant material dominantly pollen, spores and plant fragments all of which are well preserved (Figure 6). However, very few examples of degraded pollen (Figure 7), have been noticed which may have been caused by the effect of transportation from land to sea. Similarly, Bates (1982) and Ali, (1992) also noticed the increase of pollen and spores in the sapropelic sediment of the Cilician Basin. According to them throughout the period ca. 10,000 to ca. 5000 B.P high fluvial sediment input has led to the high terrestrial organic input.

The non-sapropelic sediments and shallow shelf sediments off the Seyhan Delta give low TOC contents and degraded AOM (Figure 8) with little or no woody or herbaceous organic matter. In contrast, the sample from the SH/1063 which was the only core collected in close proximity of Goksu River that was analyzed, have high concentration of dark brownish woody vitrinite-type organic matter which mostly consists of terrestrial plant material with recognizable rectangular woody structure and a little coaly (inertinite) recycled type organic material (Figure 9), which show the high fluvial sediments influx from the Goksu River as described by Bates, (1982) and Ali, (1992). This woody and coaly material contributed towards the high concentration of kerogen carbon, but the TOC is low. However, according to Tissot et al. (1984) TOC does not give true representation of the kerogen carbon. The only major difference between the OM in the normal sediments i.e. non-sapropelic and sediments off the Seyhan Delta and that found in the sapropelic layer is the high contents of plant material, pollen and spores as reported previously by Sigl et al. (1978), Bates (1982), Shaw and Evans (1984) and Ali (1992), is at least part of the explanation of the higher TOC content.

The sediments of the sapropelic horizons are like those of the non-sapropelic horizons found to be dominated by degraded AOM but also contain a relatively high concentration of well preserved herbaceous organic matter (plant fragments, pollen and spores). However, there is very little evidence of preserved amorphous type of kerogen i.e. AOM in the sapropelic layer from core SH/2035 (Figure 10), which may have been due to high rate of sedimentation relatively to the other sapropelic horizon (Ali, 1993). The sapropelic sediments based on dominant occurrence of TOM and little concentration of marine AOM reveal Type III accompanied by small amount of Type II as evident from

Table 1. Petrography of extracted organic matter.

Sample No Depth [cm]	Algal [AOM] Pres	Algal [AOM] Deg	Marine Structure	Humic: Pollens	Humic: Spores	Humic: Woody organic	Recy.
SH/1092							
0-10	Absent	Dominant	Traces	Traces	Absent	Traces	-
270-290	Absent	Dominant	Absent	Traces	Absent	Traces	-
470-490	Absent	Dominant	Minor	Traces	Absent	Traces	-
SH/1063							
0-4	Absent	Very Common	Traces	Common	Absent	Abundant	Traces
102-105	Absent	Very Common	Absent	Common	Absent	Abundant	Absent
SH/2035							
0-10	Absent	Dominant	Traces	Absent	Absent	Traces	-
69-74	Absent	Dominant	Absent	Traces	Absent	Traces	-
114-120[sp]	Common	Dominant	Absent	Common	Minor	Minor	-
169-174	Absent	Dominant	Traces	Traces	Absent	Traces	-
222-224	Absent	Dominant	Traces	Traces	Absent	Minor	-
SH/166							
65-70	Absent	Dominant	Traces	Traces	Absent	Traces	-
74-78[sp]	Traces	Dominant	Absent	Minor	Traces	Common	-
169-174	Absent	Dominant	Absent	Traces	Absent	Minor	-
SH/182							
30-37	Absent	Dominant	Traces	Traces	Absent	Absent	-
56-60[sp]	Traces	Dominant	Absent	Common	Minor	Minor	-
69-74	Absent	Dominant	Traces	Traces	Absent	Traces	-

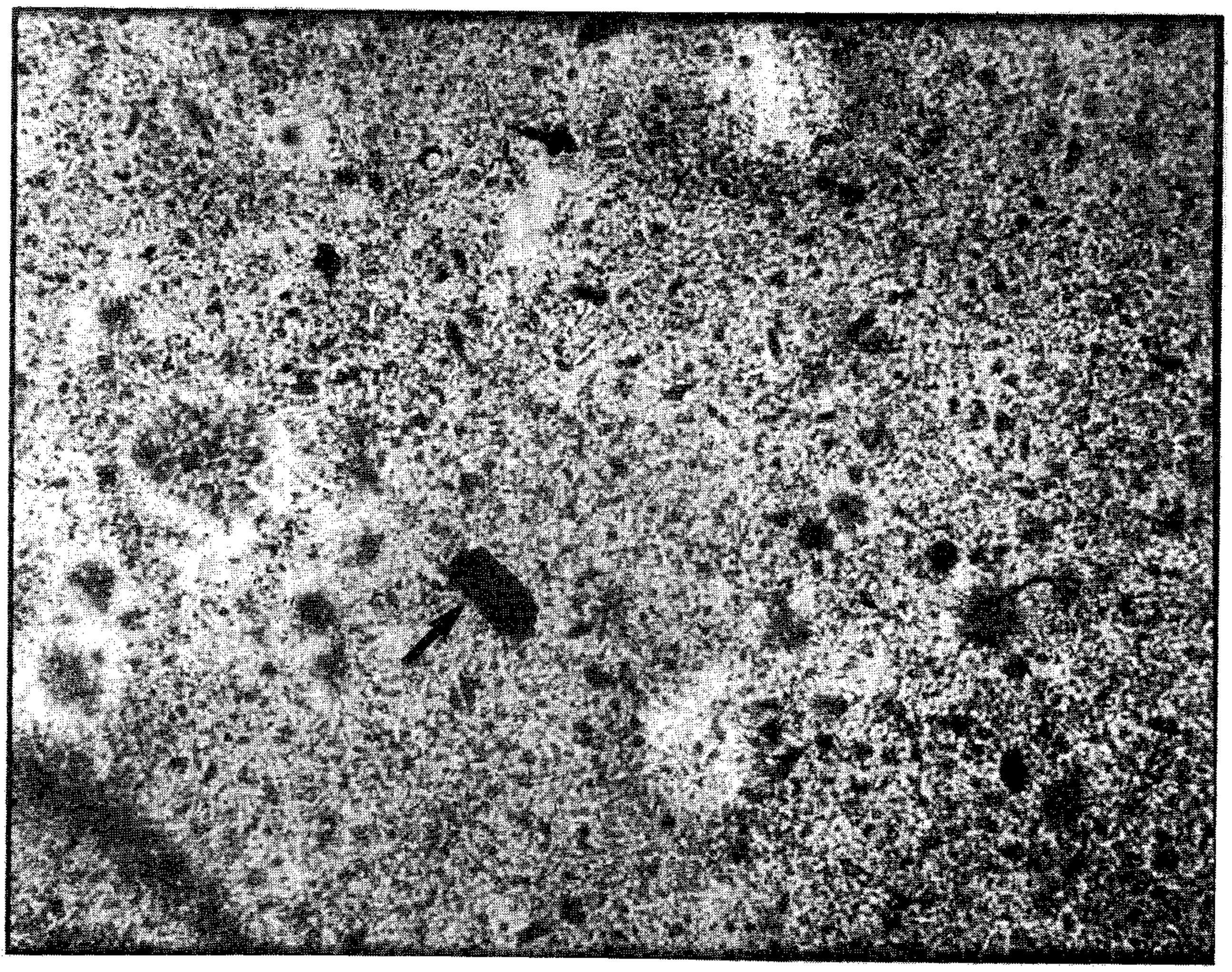


Figure 5- Photomicrograph showing degraded AOM and plant fragments as indicated by an arrow head. Magnification: 20x10x3.2.

the observation in present study. The change in the influx of OM reflects the high river run off during the period 9000-6800 yrs B.P of S1 sapropel deposition. The occurrence of these layers in the Cilician Basin sediments which are very similar to that of other Mediterranean sediments points towards different environmental conditions.

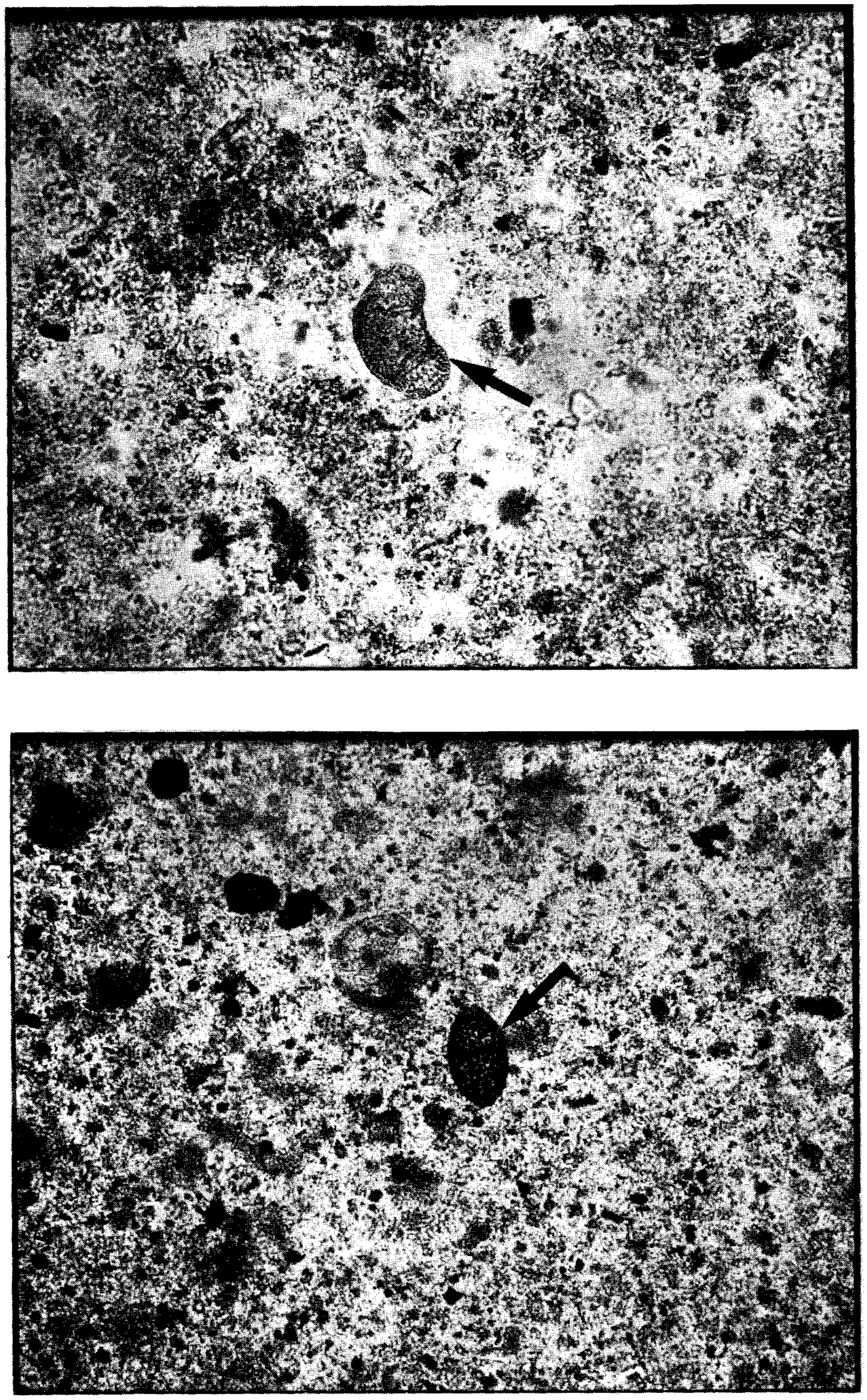
An important terrestrial contribution to the OM in some of the Eastern Mediterranean sapropel has also been claimed by Sigl et al. (1978), Bates (1982), Calvert (1983); and Shaw and Evans (1984).

TOC concentration, pyrolysis, visual observations and petrographic studies of the samples obtained from Lower Goru and Sembar Formations indicate mostly high concentration of OM, particularly confined to shaly horizons. TOC contents in Lower Goru core sediments obtained from exploratory wells i.e. Almani-1, Sakrand-1, Pasaki-1 and Dhamraki-1) occur in the range of 0.21-1.22%, 0.3-1.35%, 0.25-1.04% and 0.86-1.79%, respectively (Figure 11, Table 2). TOC contents in flush cutting sediments of Sembar Formation from Dhamraki-1 occur in the range of 1-2.16% and Bhadmi-1 0.93-2.53%. This range of TOC indicates characteristics of potential source rock for hydrocarbon, because 0.5% of TOC in argillaceous sediments is generally considered good enough to generate commercial accumulation of hydrocarbon subject to maturity of OM. Less than 0.5% TOC as noticed in few samples of Lower Goru Formation is mostly confined to coarse grained lithologies such as sandstone and sandy shale. This is an evidence in favour of predominant occurrence of OM in fine grain argillaceous sediments as explained earlier.

Rock-Eval pyrolysis data of the selected samples from Lower Goru and Sembar Formations reveal predominance of Type III terrestrial OM (Figure 12, Table 2). However, table 2 also indicates the occurrence of Type II OM. This organic matter is predicted to be analogous to OM of recent Mediterranean Sea sapropelic layers and sediments off the Goksu Delta. The occurrence of woody organic matter as observed in samples from Sembar and Goru Formations indicates the nearness of the sediments to the source area from where the terrestrial sediments are carried to the basin (Ali, 1995). It may be possible that the depositional interface was exposed to the land derived material. Drifted wood accumulates along the shoreline as has also been observed in the modern sediments of the Cilician Basin northeastern Mediterranean, which is in close proximity to the Turkish mainland (Ali, 1992). The woody material usually floats in water because of lighter than water. The floating woody organic matter usually accumulates near the shoreline. Goru and Sembar Formations were also proposed to be a part of shoreline system (Kemal et al. 1991), which are considered to be the major source rocks for hydrocarbon in the Lower Indus Basin (Raza, H.A, 1991).

The drifted floating wood is normally deposited on depositional interface in the intertidal area at low tide. Similarly the algal mats also occur in the intertidal environment, where blue green algae grow on the surface of sediments. Most probably this accumulation of organic matter (Terrestrial and insitu) occurs at or above the high water mark shoreline. Next periodic storm covered this organic film with inorganic sediments carried by turbid layer

(A)



(B)

Figure 6- Photomicrograph showing TOM (pollen, spore and plant fragments) and degraded AOM from sapropelic horizons of core SH/166 and 182. Magnification: 20x10x3.2.

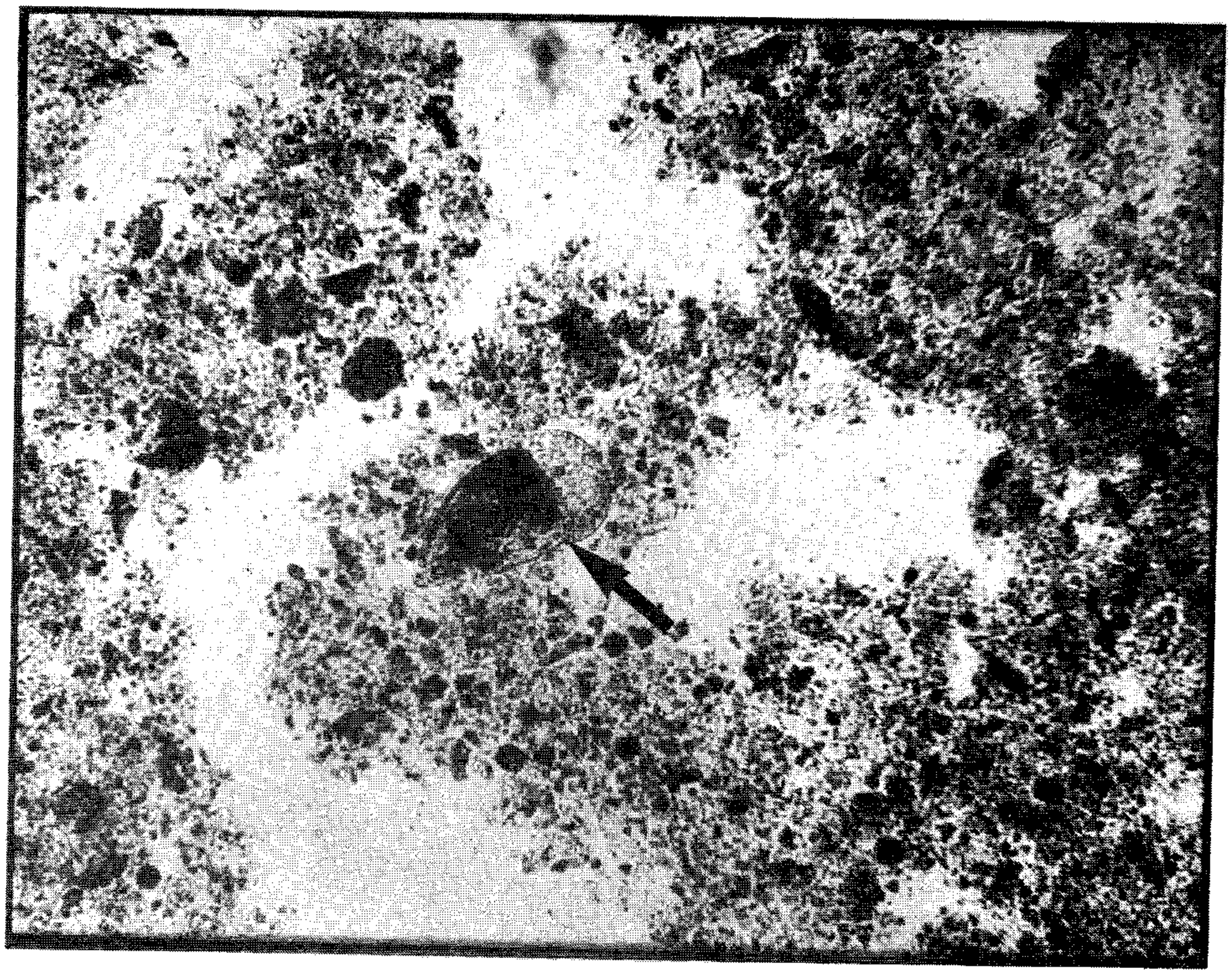


Figure 7- Photomicrograph showing degraded pollen. Magnification: 20x10x3.2.

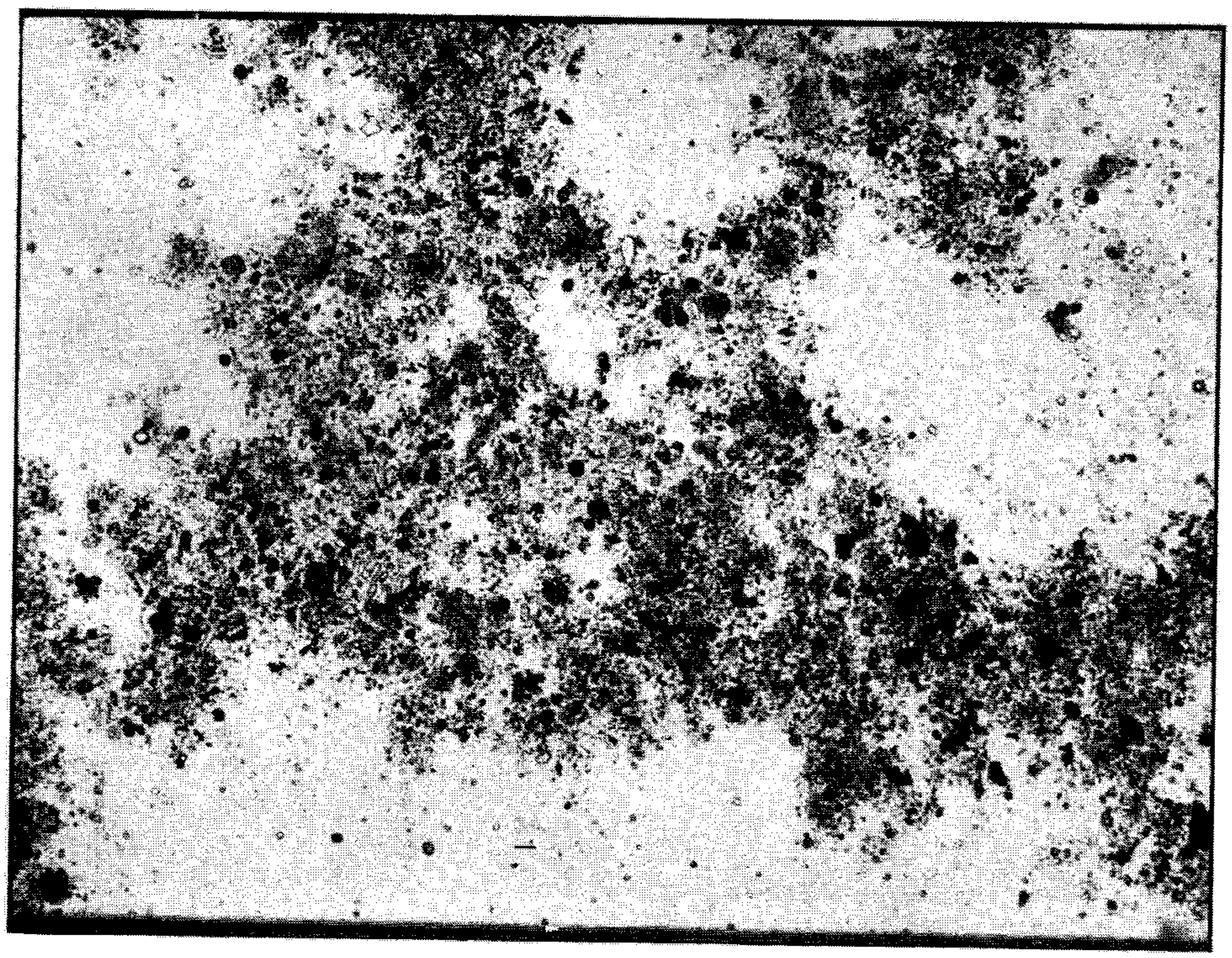
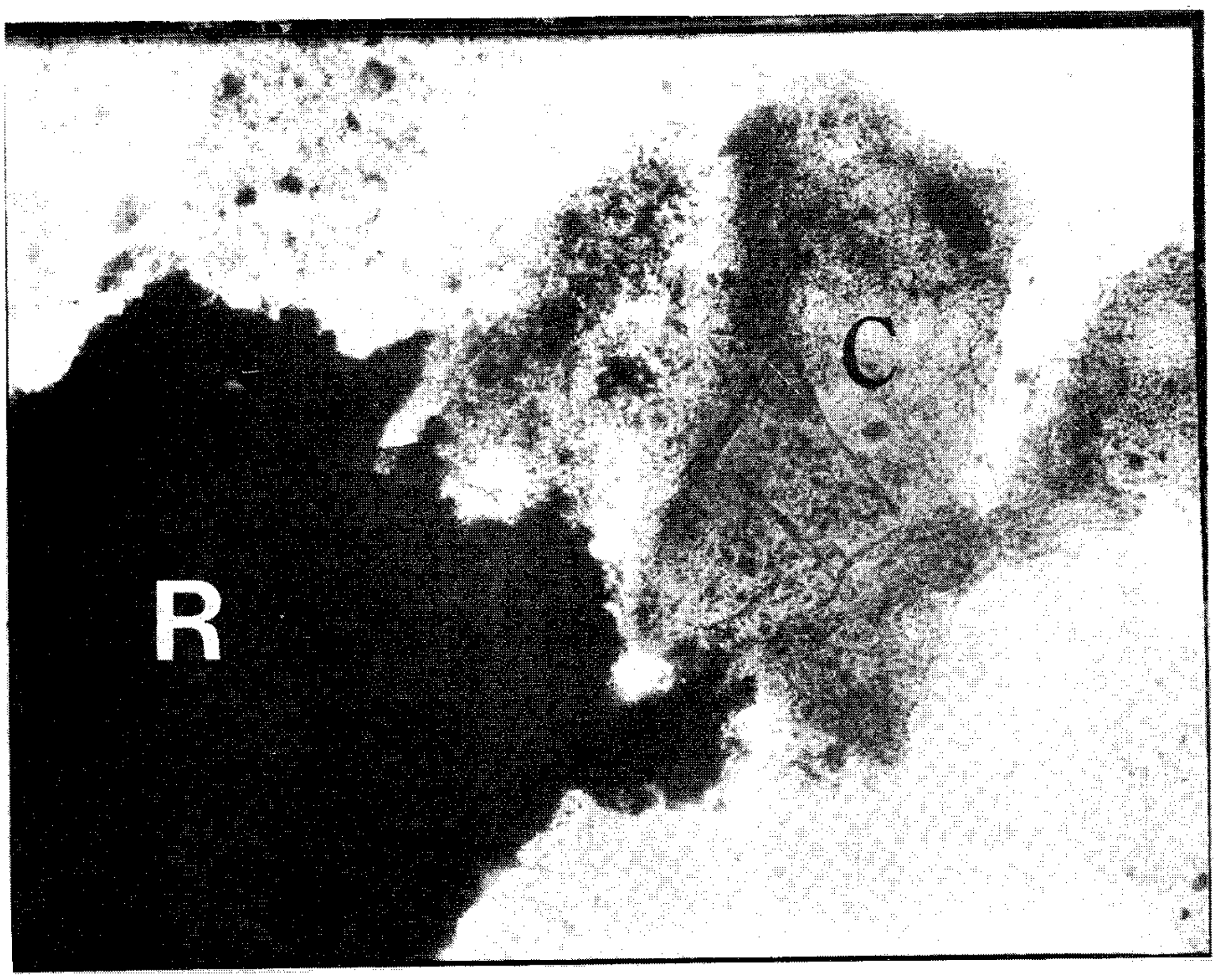


Figure 8- Photomicrograph of degraded AOM from SH/1092 off the Seyhan Delta. Magnification: 20x10x3.2.

(A)



(B)

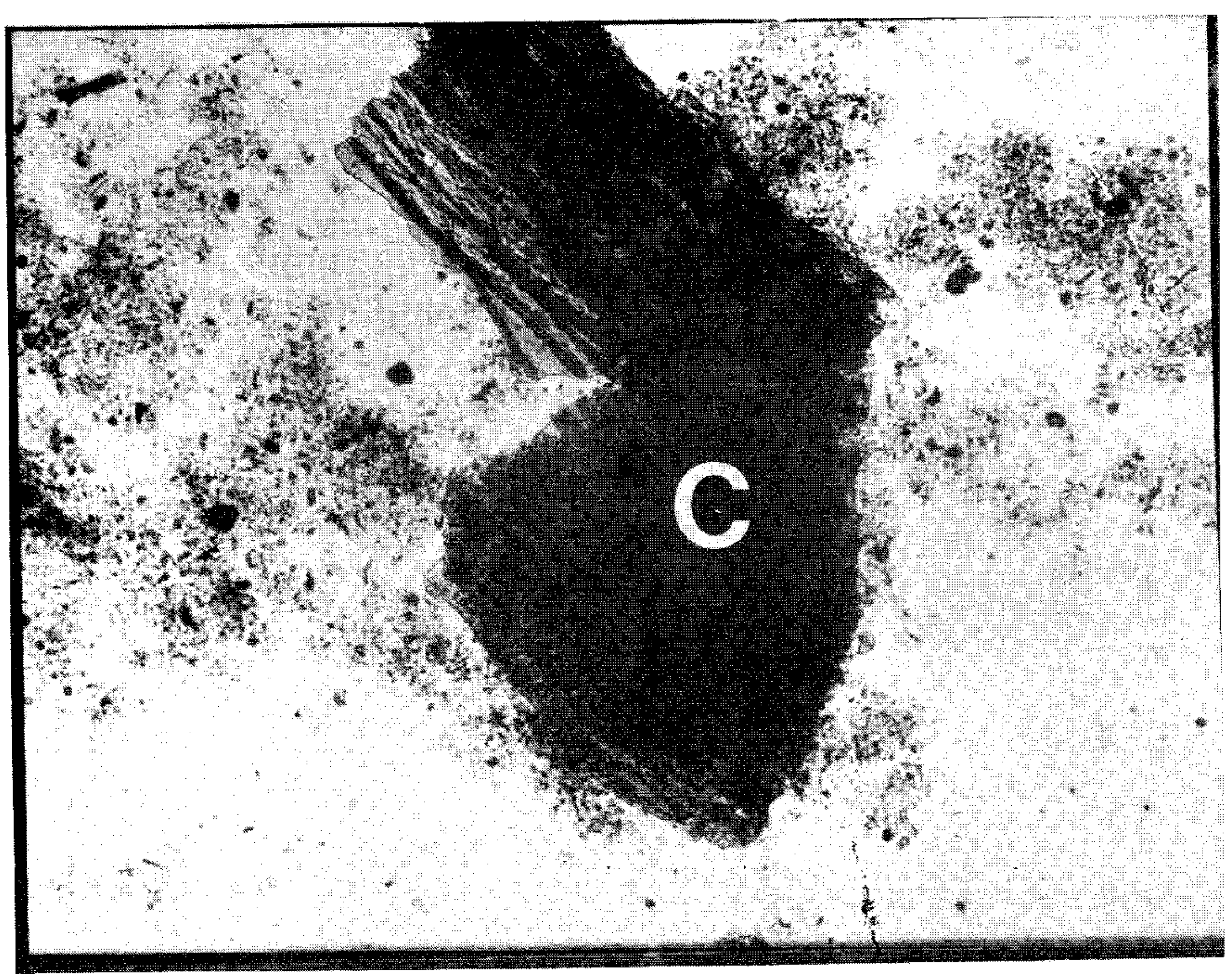


Figure 9- Photomicrograph showing plant cuticle (C) and recycled organic matter (R) from core SH/1063 off the Goksu Delta. Magnification: 20x10x3.2.

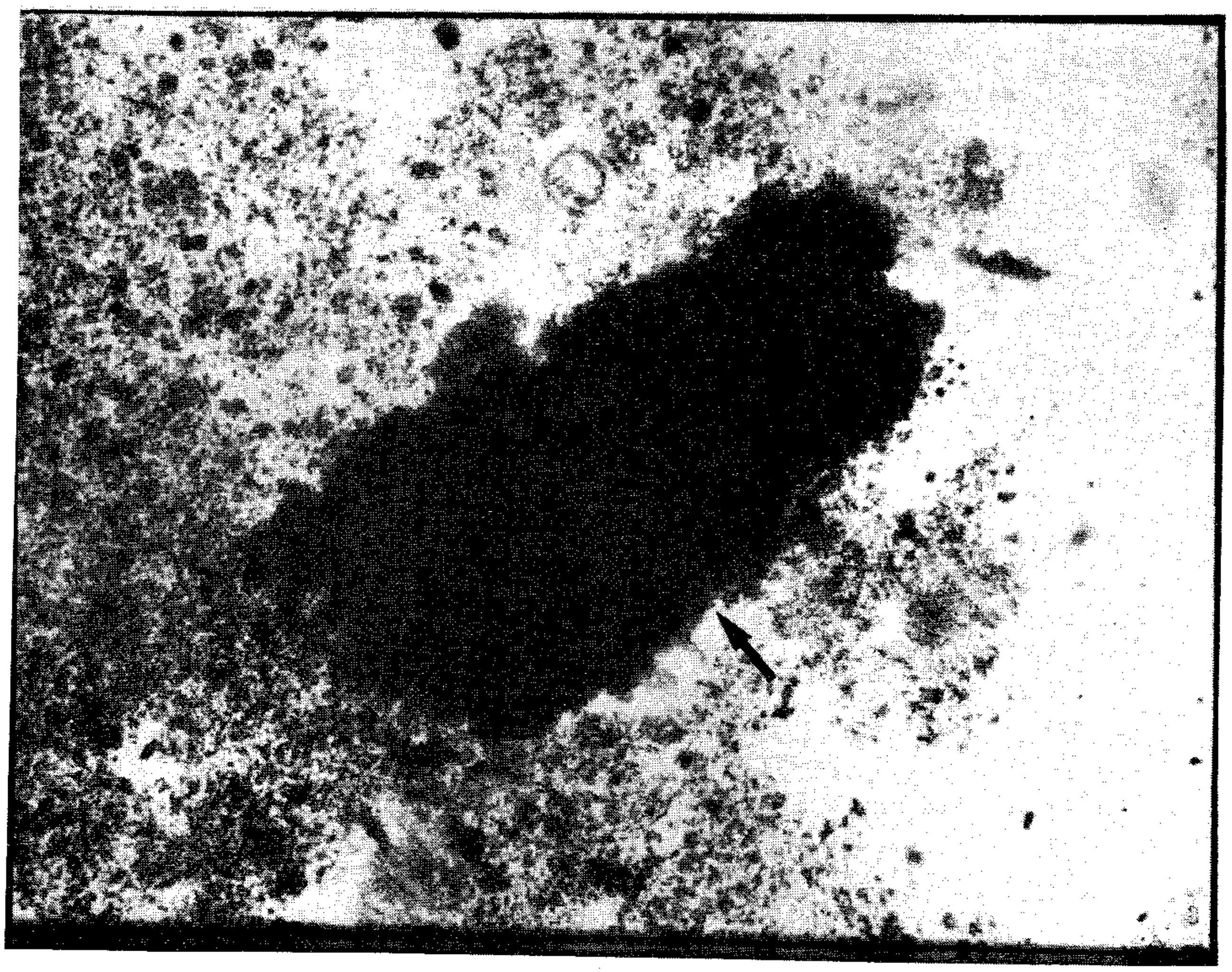


Figure 10- Photomicrograph showing well preserved AOM from sapropelic horizon of core SH/2035. Magnification: 20x10x3.2.

Table 2. Rock-Eval pyrolysis data of the selected samples from lower Goru and Sembar Formations.

Almani-1 (Lower Goru)							
TOC	S1	S2	S3	TMax	GP	HI	OI
0.86	8.15	0.50	0.64	439	8.65	58	74
0.48	2.80	0.44	0.64	439	3.24	92	133
0.31	1.36	0.31	0.37	439	1.67	100	119
1.22	1.83	2.66	0.70	439	4.49	218	57
0.40	12.48	0.39	0.64	439	12.87	98	160
Pasaki-1 (Lower Goru)							
0.92	19.65	1.04	0.34	432	20.69	133	37
0.91	23.83	0.82	0.41	432	24.65	90	45
0.86	17.90	0.22	0.22	430	18.12	26	26
0.85	25.25	0.44	0.30	430	25.69	52	36
1.04	18.12	0.33	0.56	432	18.45	32	54
1.35	1.36	0.58	0.38	439	1.94	43	28
Bhadmi-1 (Sembar)							
1.58	0.09	0.68	0.83	434	0.77	43	53
1.92	0.09	0.70	1.61	434	0.79	36	84
2.53	0.32	3.93	0.75	435	4.25	155	30
1.83	0.33	3.35	0.58	437	3.68	183	32
1.07	0.18	1.28	0.56	441	1.46	120	52
0.93	0.04	0.74	0.52	441	0.78	80	56

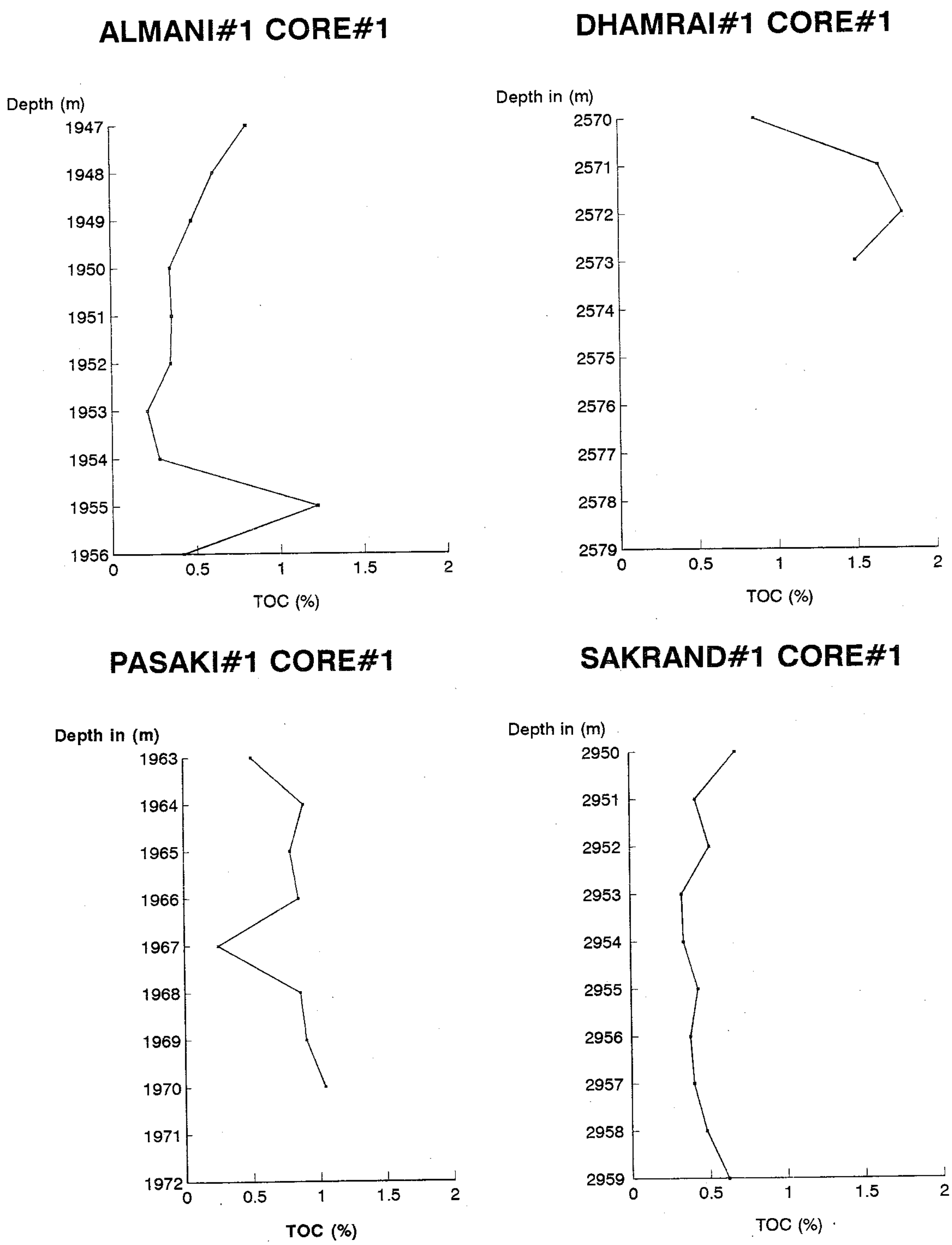


Figure 11- Distribution of TOC in the sediments of Lower Indus Basin.

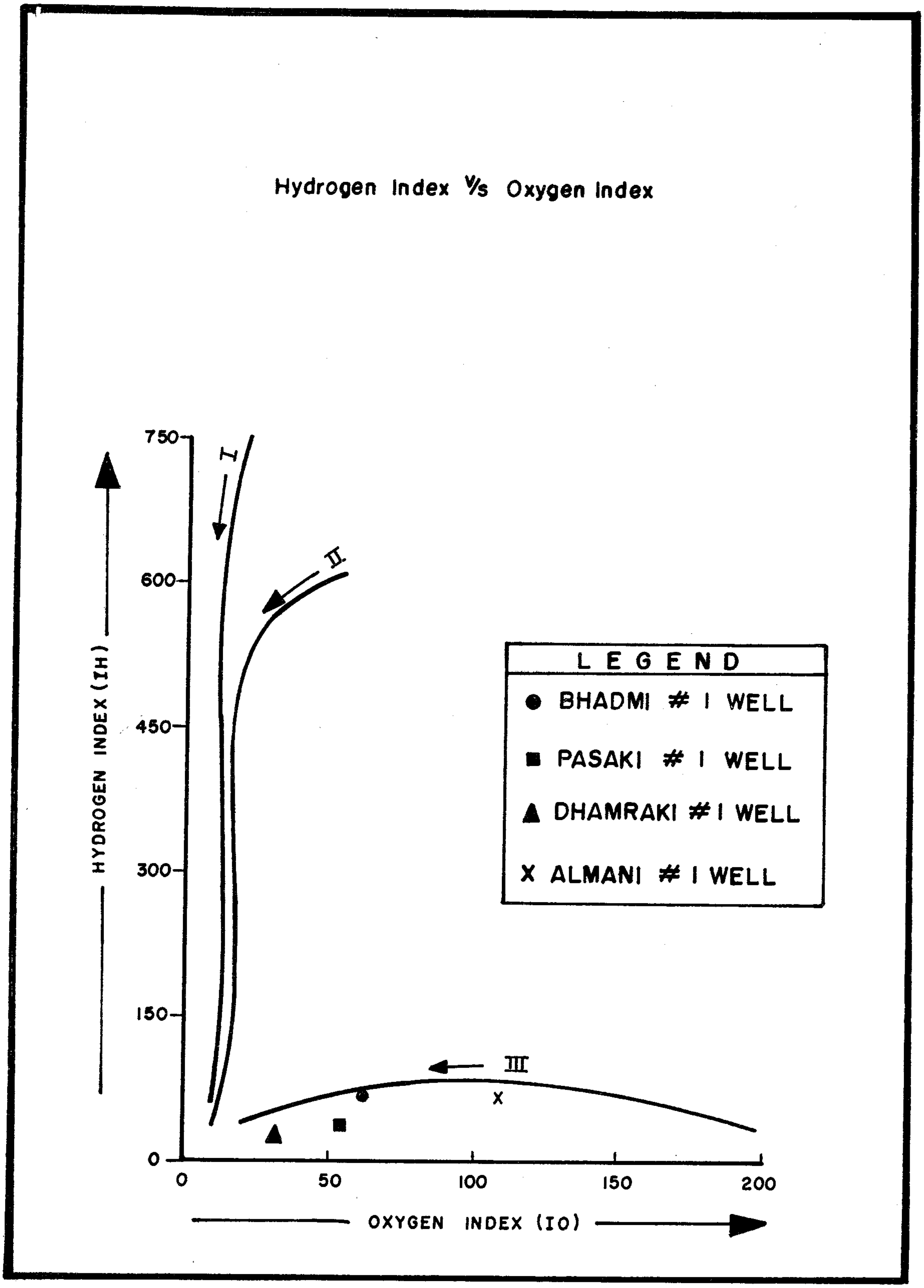


Figure 12- Types of organic matters in the sediments of Lower Indus Basin.

of water and buried it permanently. This repetitive process ultimately results in stack of layers of organic rich material. The increase in concentration of OM by the said process ultimately resulted in anoxic condition. Hydrogen rich material that has been modified under anoxic sapropelic condition plays a major role in the formation of liquid and wet gaseous hydrocarbons through compaction and temperature elevation. This material can be recognized by the presence of amorphous translucent debris. Sediments containing only structured plant cuticles or opaque fusainized (high carbon) material produce mainly dry gas; those containing mixture of the amorphous sapropelic debris and recognizable plant debris normally produce wet hydrocarbon. The OM buried in the sediments is converted to hydrocarbons by catagenesis i.e. paraffinic oil and condensates, then to dry gas and pyrobitumens, and finally to graphitization under severe conditions (Staplin, 1969).

Based on geochemical and petrographic investigations the Mediterranean Sea sapropelic sediments and sediments off the Goksu Delta are predicted to be analogue of the Cretaceous Source Rocks, particularly Lower Goru and Sembar Formations in Lower Indus Basin of Pakistan. Very similar to the facies pattern as noticed in cores from Cilician Basin (Ali, 1992), rocks of the Cretaceous system in Lower Indus Basin are also composed of heterogeneous facies pattern. During most of the Cretaceous time the rocks deposited in shallow marine environment with major influx of detrital material from Indian shield (Raza, 1991). Similarly the sediments of Cilician Basin are derived from Turkish coastal area via major river system (Shaw, 1978; Shaw and Bush, 1978; Ali, 1992).

CONCLUSIONS

Following conclusions were drawn from the organic geochemical and petrographic investigation of the sediments from the Cilician and Lower Indus Basins.

1. Overall contribution of OM in the recent sediments of the Cilician Basin is low as evident from the low amount of TOC. This probably reflects the low input of OM as a result of the poor organic productivity of the Eastern Mediterranean or could be due to the highly oxidizing nature of the environment. The TOC concentration is high in sapropelic horizons and sediments of the Goksu Delta which is due to the increased input of TOM.

2. The petrography of the OM reveals the presence of two major type of OM i.e. OM of mixed origin and TOM mostly pollen, spores and plant cuticles. The dominance of land derived woody material is confined to the sapropelic horizon and present day river mouth deltaic sediments.

3. The OM in the sapropelic sediment appears to be predominantly terrestrial accompanied by OM of mixed origin (marine and terrestrial).

4. The sediments close to the River Goksu show well preserved recognizable structured plant material (plant cuticles and debris) and even a trace of recycled OM which suggests the important influence of the fluvial input of this material by the Goksu River.

5. Significant occurrence of TOC contents in shaly horizons of Lower Goru and Sembar Formation indicates their potentiality being a source of hydrocarbon.

6. Dominant occurrence of Type III (terrestrial) OM are identified in sediments of Lower Goru and Sembar Formation. However, the occurrence of Type II was observed in Almani-1 and Bhadmi-1.

7. Geochemical investigation suggests that recent Mediterranean Sea sediments particularly sapropelic horizons and sediments off the Goksu Delta are predicted to be the modern analogue of Cretaceous Source Rocks (Lower Goru and Sembar Shale) in Lower Indus Basin of Pakistan.

8. The identified OM in Cilician Basin may be a possible source of hydrocarbons.

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