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Petrography and Petrogenesis of Basal Laki and Ranikot Sediments from PMDC's Lakhra Wells PS-1 and PS-13

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ABSTRACT

Petrographic analysis was carried out on 22 core samples from depth interval 30 to 70 metres from Pakistan Mineral Development Corporation's (PMDC) Lakhra PS-1 and PS-13 wells, drilled to find out lithologic entity and depositional framework of horizons of the Basal Laki (E. Eocene) and Ranikot (Paleocene) sediments.

Granulometric analysis, thin section study, bituminosity and calcimetry reveal that the rocks in the interval consist of shallow marine, high to low energy sediments with some lagoonal influence and fresh water phareatic interfingering. Basinal mud also came in during rise in sea level.

Sand-shale and lime-mud sediments form the lithologic units from bottom to top. Bioturbation and gravity flow in sediments are prominent. Siliciclastic carbonate facies is found to be dominant.

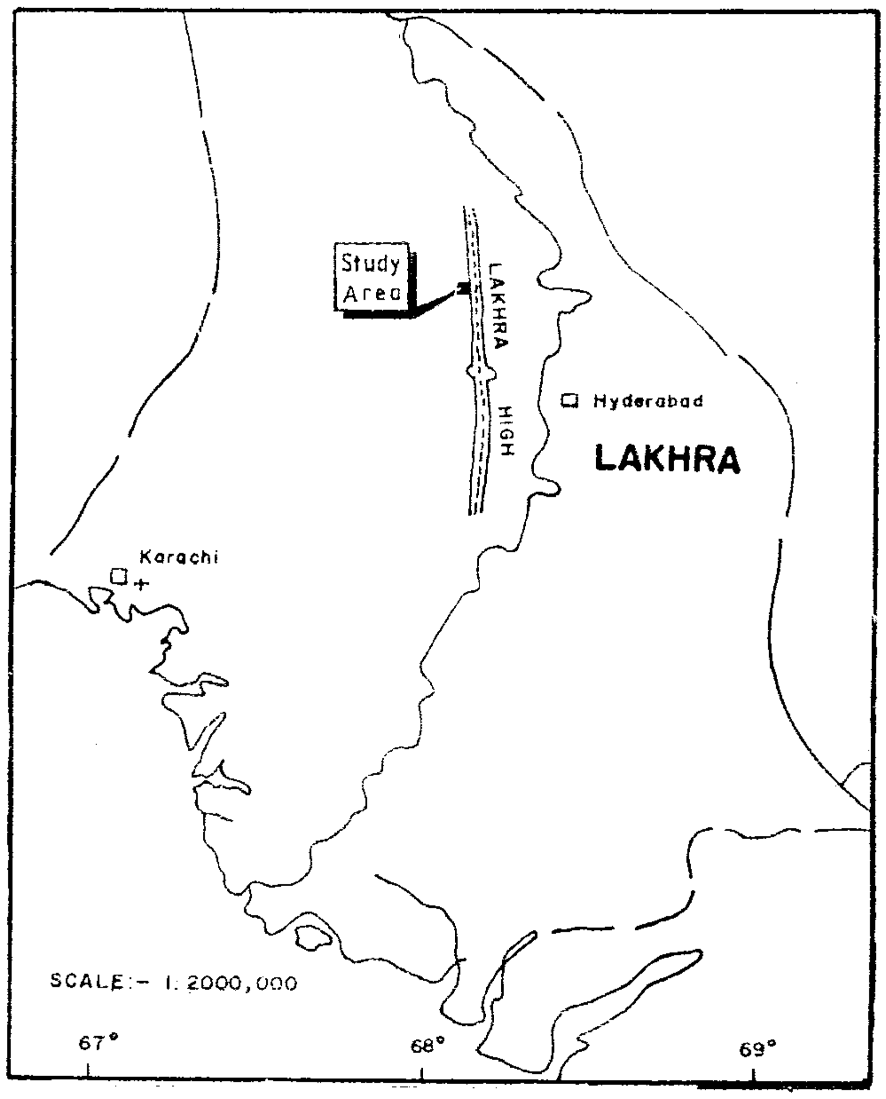

Figure 1— Location map of study area.

INTRODUCTION

Since the commencement of OGDC's exploratory activities in sixties in southern Indus basin, gas/condensate has been discovered in Paleocene/Eocene sequences in some wells e.g. Sari, Hundi, Kothar, etc.

The present study highlights the variation in lithologic characters and sedimentary environments of a part of the Paleocene-Early Eocene section in PMDC Lakhra wells PS-1 and PS-13 (Figure 1, 2), and correlates it with other equivalent units in the area to establish the oil/gas source and reservoir potentials.

The Paleocene-Eocene unconformity which is well marked in some areas e.g. Sonhari beds of Ongar hill and the Lateite bed at the base of Laki formation at Kotri and Makli (Williams, 1959) can not be well judged in other areas of the southern Indus basin. Therefore petrographic study can prove to be an effective tool in delineation of stratigraphic boundaries and regional correlation in such cases.

The present paper gives the petrographic results of the 22 core samples from the aforementioned wells which were studied physically and with a binocular microscope. Also thin section study was carried out to assess the depositional fabric, mineral composition and diagenetic characters of the rocks.

The stratigraphic scheme of Shah (1977) and carbonate classification of Dunham (1962) have been followed in the present study.

LITHOLOGY AND PETROGRAPHY

The rock types encountered belong to shallow marine sand units associated with lime-mud, silt-shale, basal conglomerate and rock fragments.

Petrographically, the rocks comprise calcarenite, wackestone with grainstone matrix of intergranular nature, siltstone and calcareous leutite with ferru-calcareous cement (weak) at intervals.

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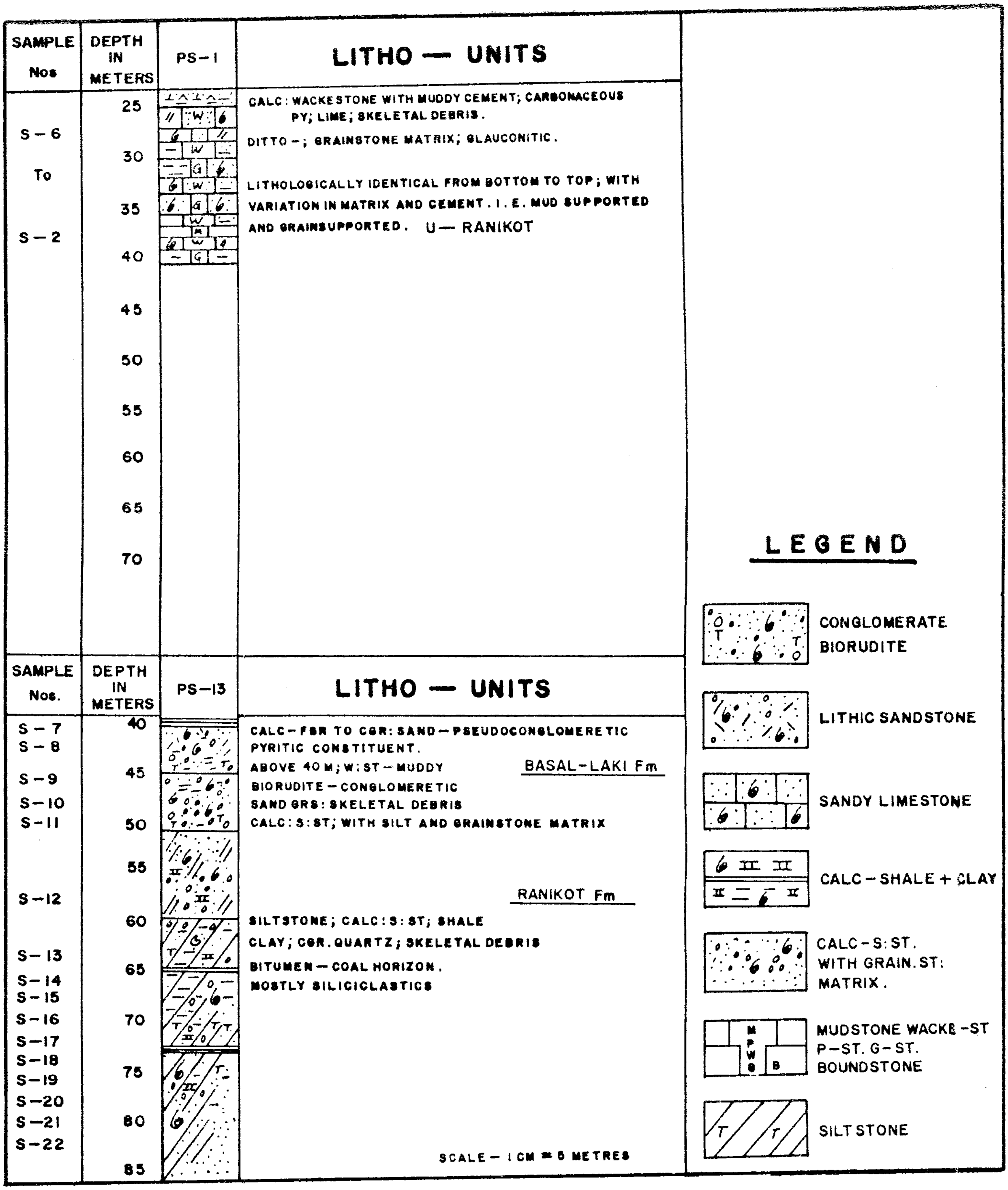


Figure 2— Lithology of Lakhra wells 1 and 13.

DESCRIPTION OF PLATES

PLATE I
(All photographs x10)

1. CALCARENITE: Intergranular; grainstone matrix with finer quartz and calcite (Recrystallized-CO_3-C) with sparry calcite and subrounded quartz crystals. Skeletal debris, obliterated.

2. CALCARENITE: Clastic and recrystallized CO_3 minerals enveloped in microcrystalline cemented matrix and muddy matrix.

3. DETRITAL SKELETAL LIMESTONE: White and black detrital grains (qtz and calcite grs), coagulated grains of calleutitic nature (Bioturbated). Faunal debris prominent.

4. CALCARENITE: Angular quartz grs with calc-leutitic, ferruginous cement/matrix, detrital grains. Sparry calcite. Terrigenous pyrite (crushed) and carbonaceous matter (black).

5. ALLOCTHONOUS BIOGENIC LIMESTONE: Faunal fragments abundant. Large crystals of recrystallized CO_3 minerals also detrital quartz enveloped in microcrystalline cement.

6. IDENTICAL TO SAMPLE 1 AND 2: Qrtz-fine and uneven, recryst; carbonate, glauconite grs; both making grainstone matrix. Faunal debris broken, enveloped, pseudoconglomeratic. Gypsum rare and pyrite in dissemination.

PLATE II
(All photographs x10)

1. CALCARENITE: Subrounded grains of quartz, grey and white. Carbonaceous, ferruginous and pyritic matrix (black). Calcite, both as cement and spar.

2 & 4. CALCARENITE WITH CALC-MUDSTONE: Grey-lime-mud; above soft detrital quartz and sparry calcite; gypsum, subangulary, white and dirty white. Black ferruginous and carbonaceous bituminous matter.

3. CALCARENITE WITH ASSOCIATED CLAY: Large crystals of CO_3 mineral and obliterated fossil debris. Grey and black microcrystalline cement/matrix with pyrite (crushed). Hydrated iron oxide, gypsum and abundant fauna enveloped.

5. SILTSTONE WITH ASSOCIATED CLAY (SILICICLASTIC): Equigranular silty fraction. Rare carbonate. Clayey constituents grey in colour. Coloured minerals, chlorite prominent.

6. WACKESTONE WITH GRAINSTONE: 10% grains (Detrital). Leutitic constituents i.e. clay, gypsum and mud. Coloured minerals (black) and hydrated iron oxide, crushed pyrite.

PLATE I

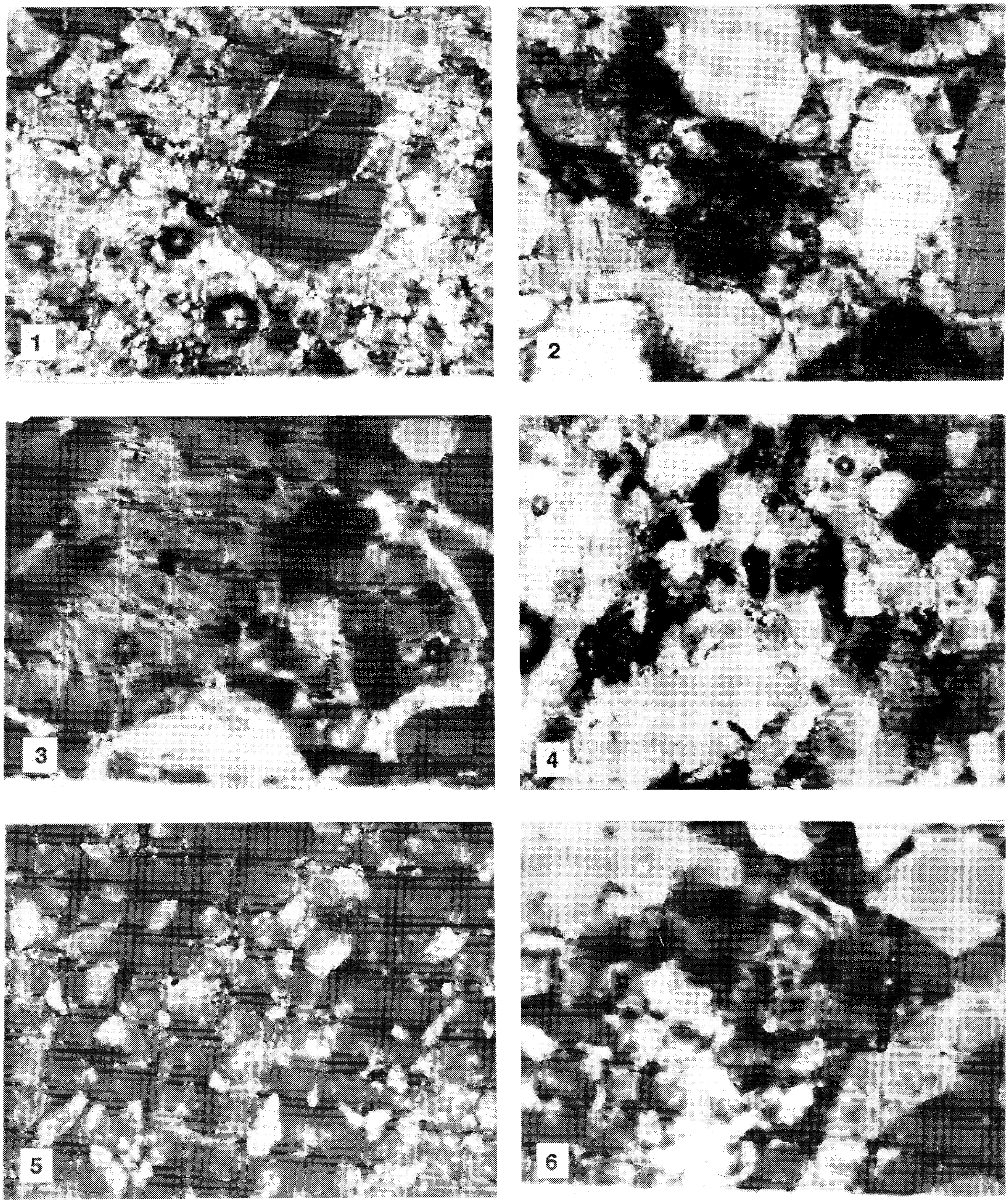
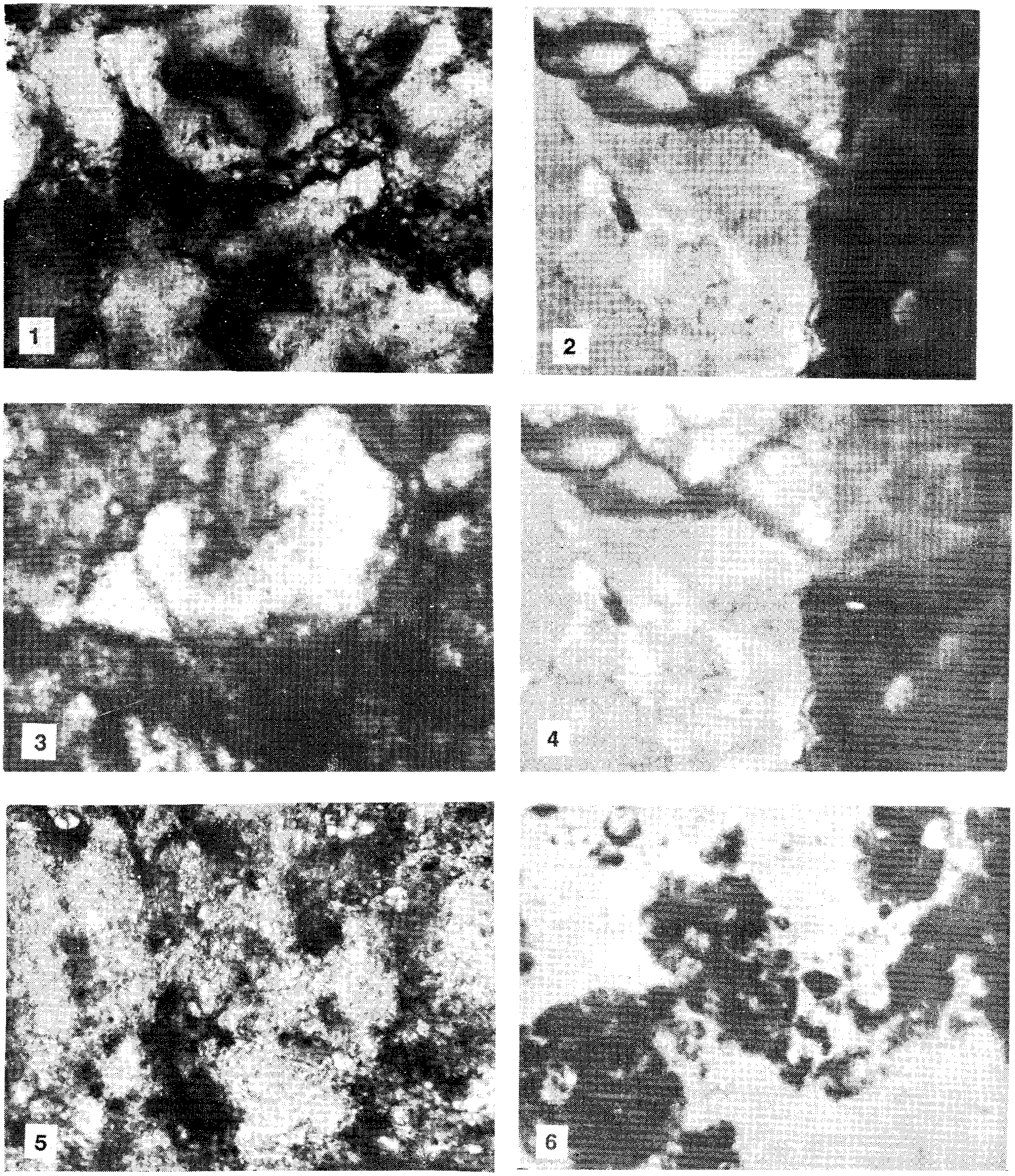


PLATE II



The lithology and petrography of the samples is illustrated in Plates I and II and described below:

Sample-1

Calcarenite.— Greenish grey to brownish and olive in colour, medium hard, medium to coarse grained, inequigranular, subrounded, weakly welded, somewhat pseudoconglomeratic, calcareous, marly, pyritic, limonitic, coarser quartz grains enveloped, forams and bivalves with replaced shell materials, obliterated, broken and found embedded in grainstone matrix (high energy); greenish hue due to glauconite and chlorite.

Sample-2

Wackestone with muddy matrix.— Dirty grey to black and brownish black in colour, soft to medium hard, brittle, concretionary, nodular, crumbly, calcareous, gypseous, carbonaceous (bitumen), silty, somewhat laminated. Pyrite and limonite prominent (reducing environment-low energy), skeletal debris welded with ferru calc-clayey cement.

Sample-3

Lithologically identical to Sample-2, but olive and muddy, calc., skeletal debris even chitonous also.

Sample-4

Similar to Sample-1 but lime content increased with more obliterated skeletal debris. Grainstone matrix, less ferruginous, glauconite, chlorite and some clastics with abundant fossil debris welded with calc-muddy cement.

Sample-5

Identical to Sample-4 but more marly and slightly coarse textured.

Sample-6

Lithologically identical to Sample-5 but differs in compositional and diagenetic grain fabric. Gypsum, selenite type, brownish black glauconite, abundant forams and gastropod shell debris pseudoconglomeratic, intraclastic, some fossils pyritized.

Samples-7 and 8

Identical to Sample-3 and to lesser extent similar to Sample-2.

Sample-9

Ferruginous sandstone (Regressive phase-erosion and oxidation, pH-high).— Brown grey, soft, fine to medium grained, mostly even but few coarser engulfed, poorly sorted, non-calcareous, ferruginous, marly, pyritic and limonitic. High energy gravity flow is noticed; mostly fine grained, silty, shaly, laminated, brittle and carbonaceous, moderate to high ferruginity-basinal mud with lagoonal set up.

Sample-10

Biomdstone (Conglomeratic-Intraclast).— Greenish grey, soft to medium hard, coarse to medium grained, inequigranular, poorly sorted, calcareous, less ferruginity and terrigenic drop in. Abundant fossil debris welded with calc grainstone-mudstone matrix/cement-high energy, bioturbated.

Sample-11

Sandy conglomerate.— Brown to cherryred and yellowish brown in colour, with greenish and black tinges. Pellets, pisolites and concretions enveloped. Limonitic, chamosite, laterite and jarosite with quartz and coloured minerals, fine granular-matrix with clayey ferrucalcareous cement. Bivalves, forams welded with soft inequigranular matrix/cement. High energy gravity flow in setting. Samples 9 to 11 suggest a short pause in deposition and oxidizing water conditions prevailing; then transgression resulted from downward in soft sediment deposition also fresh water phareatic clays and lagoonal condition developed, and the coal mostly formed in muddy-wacke type or silty mudstone and mudstone rocks.

Sample-12

Calcarenite.— Grainstone matrix and muddy calc cement, pseudoconglomeratic, ferruginous, marly, few fossil debris enveloped.

Sample-12A

Siltstone (siliciclastic) with associated clay.— Dirty grey to earthy black in colour, soft fragile, brittle. finer grained, even-granular, subrounded to rounded grains, poor sorting; calcareous, crushed pyrite, gypseous; somewhat laminated and fossiliferous.

Sample-13 and 14

Similar to Sample-12A but more clayey content and diagenetic minerals.

Sample-15

Sublitharenite.— Brown to greenish white in colour, hard, medium to fine grained inequigranular, fair sorting, coarser quartz grains and glauconite enveloped in interparticle matrix and calc and ferru argillaceous cement, pyritic; sparse fossil debris.

Sample-16 and 17

Identical to Sample-12. Argillaceous, ferru-marly calc cement (weak), skeletal debris enveloped.

Sample-18

Lithologically identical to Sample-13 and 14.

Sample-19

Similar to Sample-16 and 17.

Sample-20

Calcarenite with Interclation of shale.— Two types of sandy rocks encountered, one olive grey, inequigranular, soft, poorly sorted, with abundant glauconite and lesser chlorite and rock fragments, besides quartz and carbonate minerals; the other brownish white with yellow and grey hue filled with greenish, silty, sandy and clayey content. Low Mg-calcite, gypsum, pyrite and limonite observed. Skeletal fragments embedded. Sand grades to limy and clayey rocks (fresh water phareatic zone).

Sample-21 and 22

Siltstone with clayey interfingering as in Sample-12A. At places both sand, silt/shale were coal bearing.

MINERAL COMPOSITION AND PARAGENESIS

The major rock types named after its mineral constituents (thin section) and other parameters along with the carbonate percentages are given in Table 1.

GRANULOMETRIC ANALYSIS

Study of grain size, shape, roundness, etc. reflects the textural maturity and reveals source of the sediments, the basinal conditions, post depositional changes, diagenesis, thermochemical and geodynamic influences over the sediments. The cement and matrix help in evaluating porosity, permeability, textural properties and changes due to alternation of mineral constituents and energy index. Inclusions of paler coloured minerals and iron suggest the environment of deposition and help in linking a basin with other parts of the area. Also with the percentage of particular class of grains (mesh), roundness, etc. a good picture regarding clastic and non clastic ratio could be obtained.

Two groups of rock samples from Lakhra PS-1 were taken for processing and granulometric analysis (Table 2, Figure 3) considering the hardness of rock, carbonate content, iron content and cement/matrix, etc.

85 grams of each sample, after processing were fed to a mechanical shaker, having a complete sieve set. After removing the different fractions through sieves the following fractions were obtained:

Group-I

i) Psamatic (PS) 0.1 mm to 1.0 mm	36.60 %
ii) Aleuritic (AL) 0.01 mm to 0.1 mm	49.21 %
iii) Peletic (PL) <0.01 or slightly more	12.53 %

Goupr-II

i) PS	37.86 %
ii) AL	51.91 %
iii) PL	8.79 %

BITUMEN-LUMINISCENCE ANALYSIS

The bitumen-luminiscence study carried out on some samples has been detailed in Table 3. The results generally show a low bitumen or below average percentage for most of the samples, but the bitumen is oily.

ENVIRONMENTS OF DEPOSITION

The paragenetic association of minerals depicts shallow marine platform shelf with drowned ramp and rim, so as with the rise of sea level, basinal mud might have come up with channel and bar, leaving sandy deposits. Bioturbation, high energy and gravity flow formed a cyclic sequence with facies sequences, while intertonguing could not be ignored. So siliciclastic carbonate deposition can be inferred in the lagoonal set up together with clastics present near shore or shore face.

Table 1. Carbonate percentage of various rock types.

Sample No.	Name of the Rock	Carbonate Percentage
1, 4, 5, 7, 12 & 16	Arenaceous limestone (skeletal), calcareous sandstone (calcarenite)	65-70% varies from sample to sample
1, 9, 10, 15, 17 & 19	Calcarenite, at places marl (coarse to medium grained), ferruginous sandstone at places with clay	34-50% varies from sample to sample
2, 3, 8, 13, 14, 18, 21 & 22	Siltstone, claystone or calc-leutite	5-10% varies from sample to sample
	Wackestone	Nil

Lithologically and petrographically the rock of cores from PS-1 have the following mineral composition

GROUP I

Calcite Low-Mg-CO_3	High in percentage
Skeletal debris	Abundant
Gypsum	Low
Pyrite	Low to moderate
Clastics (terrigene)	More than 15 %
Coloured and diagenetic constituents	Glauconite chlorite etc 10-15%
Hydrated iron oxide and claycy metter	Low to moderate

GROUP II

Quartz	High
Co-minerals	Moderate
Clayey matter & marl	Low to moderate
Skeletal debris	Abundant
Gypsum	Low
Pyrite & other hydrated iron oxides	Moderate
Other ferruginous and coloured minerals	Low to moderate

GROUP III

(A)	Silty fractions (quartz siliceous & micaceous)	Moderate
	Clayey fractions	High
	Glauconite, pyrite, gypsum, hydrated iron, co-minerals chlorite & other terrigene	Low to moderate
	Coloured minerals mud constituents	Low
	Skeletal debris	Moderate
(B)	Silty fractions	High
	Clayey fractions	Low-moderate
	Pyrite, gypsum, glauconite , chlorite	Low
	Skeletal debris	Low-moderate
	Hydrated iron oxide	Low
	CO_3 minerals	Low
	Terrigene & coloured minerals	Low to moderate

Table 2. Granular analysis.

Carbonate contents Gms - %	Name of rock	PL (0.01mm or slightly more)	AL (0.01 to 0.1mm) Sieve No.	Opening (mm)	%age		PS (0.1 to 1.0mm) Sieve No.	Opening (mm)	%age	
GROUP - I										
5 - 10%	Siltstone Claystone Calc-Wackstone	12.53%	140 200 230 325	0.106 0.075 0.063 0.045	15.44] 17.43] 7.93] 8.41]	49.21%	60 100	0.250] 0.150]	13.35] 23.25]	36.60%
GROUP - II										
35 - 40%	Calcarenite Ferruginous Sandstone Conglomeratic Sandstone	8.79%	140 200 230 325		14.99] 20.48] 8.09] 8.35]	51.21%	60 100		16.69] 21.17]	37.86%

Fraction contents (Gms - %)

Table 3. Bitumen luminescence analysis.

Sample No.	Age	Lithology	Formation	Colour	Capillary Width (mm)	Bitumen content (%)	Oil (%)	Benzene Tar(%)	Alcohol Benzene Tars(%)	Asphaltenes (%)
2	Paleocene	Sandstone, Siltstone, Claystone, Shale and Clay	Middle to Lower Ranikot	Brownish Yellow	5	0.04	96.97	1.52	0.76	0.75
3				Yellow	3	0.02	96.97	1.52	0.76	0.75
8				Brownish Yellow	7	0.08	98.46	0.77	0.39	0.38
9				Yellow	5	0.04	96.97	1.52	0.76	0.75
12				Orange Yellow	6	0.04	96.97	1.52	0.76	0.75

Oil, Benzene Tar, Alcohol Benzene Tars and Asphaltenes: Quantitative Fractional Analysis (Paper strip chromatographic method)

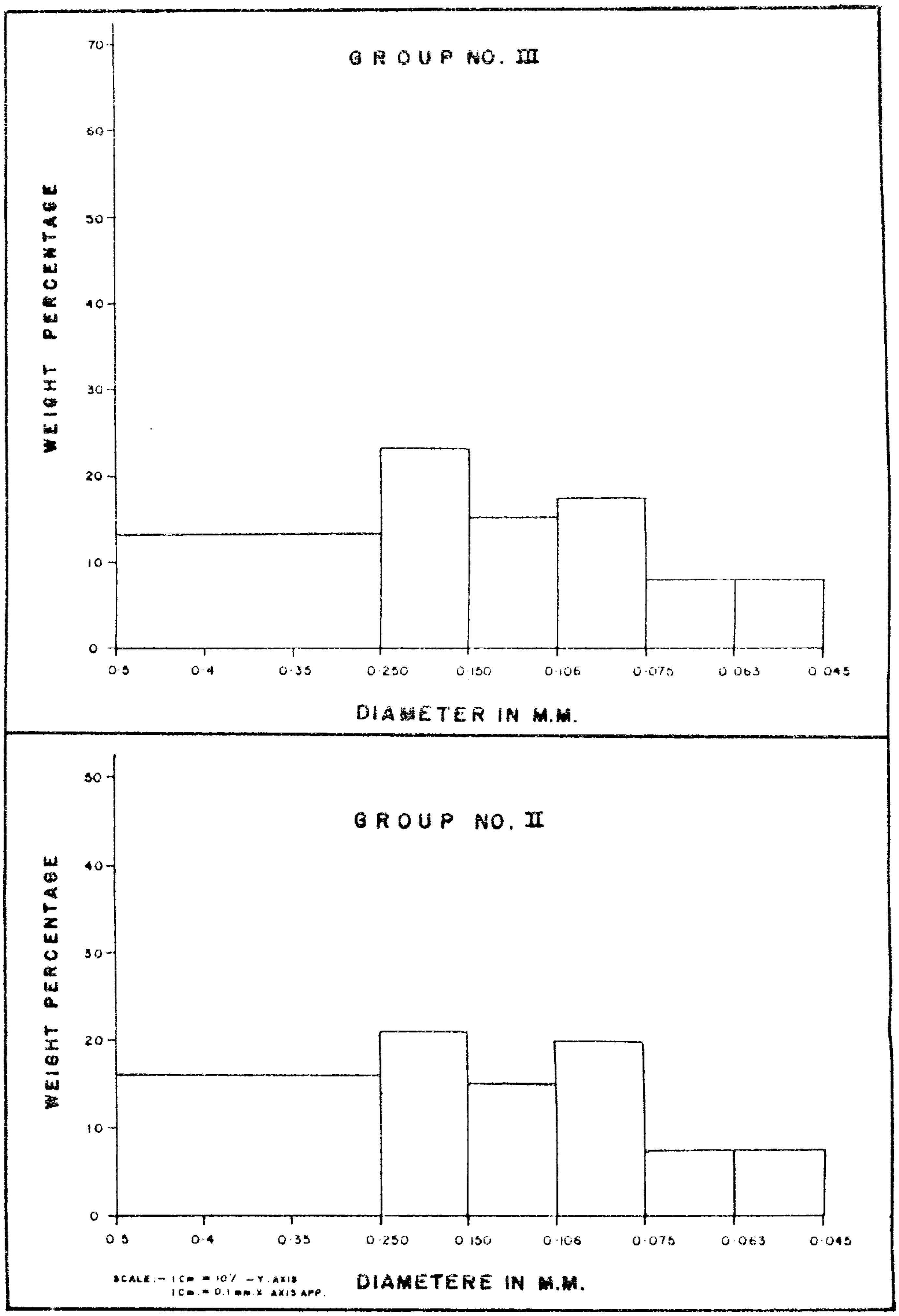


Figure 3— Histogram of grain size of Paleocene sediments.

The lithologic and petrographic study reveals that the rocks are of arenaceous, calc-arenitic, calc-leutitic, argillaceous, silty and wackestone types.

Terrigenic constituents varied in proportion in rocks belonging to three groups made on carbonate percentages similar to the occurrences of syngenetic and epigenetic minerals.

From the study of minerals present in the three groups of rocks (paragenesis), it could be inferred that the physico-chemical conditions and the chemical equilibrium was disturbed probably due to inter-basinal, post-depositional and diagenetic changes. The rapid change in facies was due to varying rate of sedimentation and turbulance. The turbidity underflows and high energy zone resulted in bad preservation of fauna and explain the presence of distorted and obliterated primary features, skeletal debris and reworked planktonic foraminifera enveloped in cement/matrix of the rock. It also indicates deposition in warm, shallow marine, high energy zone with fresh water phareatic clays in a lagoonal set up.

It is interesting to note that Paleocene of Lakhra PS-1 differs from the oil producing wells in southeastwardly located wells. Paleocene of the area also differs in carbonate rock types of Lower Eocene-Paleocene of Sulaiman and Kohat-Potwar regions. It may be further added that near Karachi embayment some wells are producing gas since late sixties and are now depleting, so in southwest and northwest to southeast and in south-northeast one can expect gas prone kerogene to change to condensate/oil prone kerogene.

CONCLUSIONS

1. The rock samples became moderately hard because of the cementing material and physico-chemical influences.

2. Rapid change in lithology was because of high energy, turbidity underflow diagenesis, dissolution, corrosion, crystallization and compaction. Alternating reducing and oxidizing conditions prevailed in the basin. At intervals we find mixed environment as expressed by mixed lithologies (calcarenite, wackestone, calc-leutite, siltstone and sublitharenite).

3. The rocks have variable proportion of mineral constituents and sometimes show equal ratio which results in obliteration of faunal assemblages, reorientation of constituents, changes in the textural maturity, porosity and permeability.

4. The presence of glauconite suggests a slow rate of deposition or no deposition, also iron (Fe^{++}) from glauconite changes to iron (Fe^{+++}) oxide in the form of limonite, jarosite, chamosite, siderite, the brownish hue may be due to the bacterial activity.

5. Angularity and roundness reveals that the sediments are less transported, as some larger grains are enveloped or welded with other skeletal debris or with the parent rock through cement.

6. The rock samples were texturally immature, loose to medium hard, silty clayey, limy etc. having organic content and bitumen only at particular intervals or along planes and pore spaces as the rock shows both intergranular and moldic porosity (poor to fair).

7. The frequency of grains varies from sample to sample and indicates rapid change in lithology from top to bottom due to the reasons mentioned earlier.

8. The rocks possess good reservoir properties. The ratio of clastic to non-clastic shows variability all over. The rock is texturally mature.

9. The thin coal seams present in subsurface are adjusted structurally, chemically and stratigraphically and have got lesser economic utility. The quality of coal ranges from lignitic to ligno-bituminous type.

10. In southern Indus basin and particularly Thatta District (Jherruk, Ongar hills and Makli) one can cite a prominent break in deposition represented by conglomeratic, ferruginous, lime-sand deposition and basal laterite (Ongar hill-Sonhari member), which is not observed in northeast and southeast of the Thatta area.

11. The geological model differs in different wells in southern Indus basin. Due to rise and fall in sea level one area was sub- merged and sedimentation rate varied, while the other area emerged for erosion and oxidation. Lakhra PS-1 got lagoonal sedimentation with the formation of coal. In other wells fluviatile, channel bar were deposited. It made the depositional environment as mixed facies and cycles, with or without the conversion of organic carbon (Kerogene).

12. The bitumen-luminiscence study suggested a low bitumen or below average percentage, except for a few samples the bitumen is oily.

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