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PETROLEUM SOURCE ROCK STUDIES OF THE NON-MARINE BARAKAR SEDIMENTS, JHARIA, BIHAR, INDIA

A THESIS

submitted in fulfilment of the
requirements for the award of the degree
of
DOCTOR OF PHILOSOPHY
in
APPLIED GEOLOGY

ROORKEE CENTRAL
Acc. No. 245894
Date 20-7-93
ROORKEE

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FEBRUARY, 1992

In the Name of God
the Merciful, the Compassionate

DEDICATED
TO
MY PARENTS
WIFE & CHILDREN

CANDIDATE'S DECLARATION

I hereby certify that the work, which is being presented in the thesis entitled **"PETROLEUM SOURCE ROCK STUDIES OF THE NON-MARINE BARAKAR SEDIMENTS, JHARIA, BIHAR, INDIA"** in fulfilment of the requirement for the award of the Degree of Doctor of Philosophy, submitted in the Department of Earth Sciences of the University, is an authentic record of my own work carried out during a period from January 1987 to February 1992 under the supervision of Prof. A.K. Awasthi.

The matter embodied in this thesis has not been submitted by me for the award of any other Degree.

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ACKNOWLEDGEMENTS

I wish to express my heartfelt gratitude and indebtedness to my supervisor, Dr. A.K.Awasthi, Professor of Geology for his valuable guidance throughout the course of this work. I heartily acknowledge his eminence in proposing the topic and giving valuable, stimulating and thought provoking ideas. Without his encouragement, help, continual vigilant guidance and constructive criticism, it would not have been possible for me to complete this thesis. I owe him my sincere gratitude.

I am thankful to Professors B.B.S.Singhal and R.K.Goyal who successively as Head of the department of Earth Sciences, University of Roorkee, provided uninhibitedly all facilities.

I also wish to thank Prof.A.K.Jain, Dr.P.C.Mohan, Dr.S.S.Srivastava, Dr.R.Manikavasagam, Dr.H.R.Wason, Dr.A.K.Sen, Dr.M.S.Pandian, Dr.S.Balakrishnan and all other faculty members for their valuable help at various stages of this work.

The permission to avail the laboratory and library facilities by Dr.S.K.Biswas, Director and Mr.K.Chandra, General Manager (Geochemistry) in the K.D.M. Institute of Petroleum Exploration, Dehra Dun, India is gratefully acknowledged. I place on record my sincere appreciation to them for this and to Dr.Y.K.Mathur and Mrs.Mathur, Mrs.Thomas, Mrs.Neelam Patta, Mr.V.N.Sharma, Mrs.Berry, Mr.Khan and Mr.Kapoor for their valuable helps while I was working in the laboratories of KDMIPE.

I am extremely thankful to Mrs.S.Mittal, Mr.Bachchan Kumar and Mr.Rahul Ganju for providing all help in terms of additional samples and raw data collected by them initially.

During the field work, I received valuable assistance from Dr.Hussain, Reader, Indian School of Mines (ISM) Dhanbad for which I express my heartful appreciation.

This thesis would not have come in this form without the sincere and generous helps from my friends Mrs.K.Gaur, Messers, Dr.R.C.Patel, Vineet Gahalaut, M. Irfan ullah, B.Ghobadian, M.S.Sadeghian, S.Zohdi, A.Asokan and P.Sridhar.

I find myself short of words to express my gratefulness to my beloved parents, my wife Seema and daughters who could not receive my full attention due to my extensive involvement with this thesis. I shall ever remain indebted to them and a host of my relatives.

My sincere thanks are due to Mr.Balu, WRDTC for his vigorous efforts in typing this manuscript and Mr. K.Gupta, Earth Sciences for drafting the figures.

The assistance of all individuals who have in any way been associated with the completion of this work but have not been mentioned is sincerely acknowledged.

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ABSTRACT

Commercial generation of petroleum, till recent years was thought mainly to be of marine origin. However, with the findings of substantial quantities of petroleum generated in the non-marine sediments, from many parts of the world, the continental sediments have, of late, also become attractive for their hydrocarbon prospects. In India, the Gondwana Supergroup (Upper Carboniferous to the Jurassic/Middle Cretaceous) forms one of the two prominent nonmarine sedimentary sequences. It is also noteworthy that under similar geological setting, their equivalent nonmarine sediments in other parts of the world, notably the Patchawara and Toolachee formations of Permian age, have proved to be major source of gas in the Cooper Basin of Australia. The present study, therefore, is mainly aimed to make source rock investigations in this direction. Nonmarine Permian sediments of the Barakar Formation exposed in and around Jharia, Bihar, India, form the locale of these studies.

Geologically, these areas fall in the Damuda Graben. In this basin the sedimentary fill is of over 3 km in thickness. These sediments have been stratigraphically subdivided into four units viz., Talchir, Barakar, Barren Measures and Raniganj formations. Of these, the Barakar Formation consisting of shale-coal-sand sequences, is well developed and occupies an area of about 220 sq.km. with a maximum thickness of more than 1250 m (Verma et al., 1989). The sandstone-shale-coal sequences are found to repeat vertically. As many as 50-60 cycles of such sedimentary sequences are encountered in this formation. These sediments have been intruded by mica peridotite and dolerite igneous

intrusions in the form of sills and dykes.

These nonmarine sediments of fluvial origin, show unidirectional cross beddings at outcrop level. It is northwesterly in the western segment, towards north in the central part and northeasterly towards or in the eastern part.

Shales of the Barakar Formation found in Bhaunra, Chasnala and Phulwaritand-Maheshpur in Jharia, Bihar form the major object of source rock studies in terms of organic matter richness, quality, nature, maturation of organic matter, affect of intrusion on organic matter, clay mineral crystallinity and spectral reflectance of shales, time of generation and volumetric yield of petroleum.

The total organic carbon (TOC) content of 128 samples (102 from shale and 26 from coaly shale) varies, as expected from higher values in coal rich sediments to lower values in shales. The coal rich samples have TOC values, at times, as high as 61.46%. In Chasnala area, TOC content of 13 coaly shale samples ranges from 0.94 to 57.8% with an average of 32.01% whereas the TOC of 21 shale samples in this area varies from 4.09 to 49.86% with an average of 13.19%. In Bhaunra area, the TOC of 9 coaly samples range from 13.58 to 61.46% with average of 44.83% and the shales (39 samples) in this area have wide range of TOC varying from 36.86 to 0.22% within an average of 10.97%. In Phulwaritand, the TOC range from 1.91 to 53.98% with 33.23% as an average, for 4 coaly shale samples, and 0.22 to 3.85% with an average of 1.55% for 21 shale samples was determined. Maheshpur situated northwest of Phulwaritand shows a TOC range of 0.34 to

0.11% with 0.21% as an average for 20 shale samples collected from this organic matter lean area.

These sediments, thus, have TOC invariably more than the threshold value of 0.5% and are, therefore, of interest from the point of view of source rock investigations. TOC increases towards south and southeastern part of the area of study in Bhaunra and Chasnala. It is also important to note that the thickness of the Barakar Formation also increases towards south and southeast implying thereby higher prospects of these sediments in Bhaunra and Chasnala.

Nature and Quality of Organic Matter:

Even though there is sufficient organic matter in these rocks, it is important to know the nature and the type of the protopetroleum source material.

Examinations of kerogen under transmitted light for 92 recovered organic matter slides from Bhaunra, Chasnala and Phulwaritand - Maheshpur areas, exhibit a mixed type of organic matter, but with domination of humic matter in which plant tissues are major contributors. Fusinite matter is also dominant in some samples. Amorphous, cloudy looking sapropelic matter is also recorded in few samples. It is, therefore, concluded that the sedimentary organic matter in these areas is mostly land derived and therefore, gas prone.

Extracts of bitumens from 91 samples (49 from Bhaunra, 34 from Chasnala and 8 from Phulwaritand - Maheshpur) reveal their variation from 0.01 to 1.16% in Bhaunra, 0.01 to 0.66% in

Chasnala and 0.02 to 0.60% in Phulwaritand - Maheshpur, indicating thereby that these rocks can be classified mainly as `rich to adequate' in terms of source rock potential. The degree of bituminization (ß) measured as extractable bitumens per unit TOC in almost all the samples of these areas, is less than 5%, which indicates that the source rocks are mainly gas prone. Organic matter mainly of humic type, or the kerogen of Type III, is considered to be gas prone. It is confirmed by low value (0.11 to 1.69) of saturate/aromatic ratio in the bitumen. Since the degree of bituminization (ß) is less than 10%, it can be summarised that the hydrocarbons are syngenetic and not migratory.

Gas chromatography of C_{15+} normal alkane fraction (saturates) of 39 selected samples from Bhaunra, Chasnala, and Phulwaritand - Maheshpur areas was also used to determine the type of organic matter. Bivariate plot of Pristane/ nC_{17} against Phytane/ n C_{18} indicates that all the samples fall in the humic organic matter region, suggesting thereby Type III kerogen.

The plot of Hydrogen Index (HI) and Oxygen Index (OI) on a modified van Krevelen diagram based on pyrolysis of 100 samples (50 from Bhaunra, 34 from Chasnala and 16 from Phulwaritand - Maheshpur) confirms the quality of organic matter to be mainly the Type III kerogen. However, a few samples (8) from Phulwaritand - Maheshpur area exhibiting very low hydrogen index and comparatively high oxygen index & are classed into Type IV kerogen. Similarly the HI- T_{max} plot also confirms the Type III kerogen as the dominant constituent of the organic matter along with a little Type II and Type IV kerogens.

These studies indicate that the biogenic matter is terrestrial, deposited in peat swamps and intermediate between peat swamp and open water. These Type III Kerogens are rich in aromatic and oxygen rich compounds, and are prone to generate mainly petroleum gas on optimal maturation.

Maturation of Organic Matter

Kerogens generate petroleum only when they undergo optimal thermal maturation. Undercooked and overcooked kerogens do not yield hydrocarbons. Hence thermal maturation of these kerogen was determined using vitrinite reflectance (VR_o), Thermal Alteration Index (TAI), and micro- spectrofluorescence measurement.

Vitrinite reflectance values measured on 93 samples (51 from Bhaunra, 34 from Chasnala and 8 from Phulwaritand - Maheshpur areas) show variations between 0.41 to 1.60% with a mean of 0.95% in Bhaunra area, 0.43 to 1.30% with a mean of 0.74% in Chasnala area, and 0.40 to 1.50% with a mean of 0.69% in Phulwaritand - Maheshpur area. Thus the kerogens found in the Barakar Formation in Bhaunra and Chasnala areas have matured to catagenetic stage implying thereby that these sediments have undergone sufficient thermal degradation to generate petroleum hydrocarbons. As against this, the kerogens in the sediments of Phulwaritand - Maheshpur area are found mainly in the diagenetic (undercooked) stage. These observations are supported by the TAI determinations, for 92 samples (51 from Bhaunra, 33 from Chasnala and 8 from Phulawaritand - Maheshpur).

The TAI values are centered around 2.75 showing not much variation and implying that the organic matter has undergone sufficient to adequate thermal maturation.

Microspectrofluorescence measurement of organic matter was employed to determine maturity of 8 samples from Bhaunra. It is about 8.46% (Maxima) at 530 nm. for the samples unaffected by igneous intrusions. This indicates that the fluorescence has just crossed the maturity level beyond the oil window, thereby further corroborating similar deductions made from the vitrinite reflectance and TAI measurements.

The foregoing investigations indicate that the Barakar sediments have sufficient organic matter, mainly of humic type. The kerogens are predominantly Type III with little Type II and Type IV. These have undergone maturation above the onset of oil window zone. The TOC and maturity of sediments increase towards south and south eastern part (Bhaunra and Chasnala) of Jharia basin where the sediments also attain maximum thickness (+1250 m). Thus, the areas around Bhaunra and Chasnala holding high potentials, have formed petroleum kitchens.

Time of generation of Hydrocarbon

Lopatin Model, based on the burial history curves and geothermal gradients was applied to determine Time - Temperature Index (TTI). The TTI of 15 at which petroleum begins to generate from kerogen of Type III was attained at about 235 million years ago before present. These sediments reached maximum maturity level corresponding to TTI of about 79 at about 200 million years ago. It is therefore inferred that these sediments with increasing burial, had undergone maturation to produce petroleum during a period ranging from about 235 to 200 million years.

Effect of Igneous Intrusions on Organic Matter

These sediments have been intruded by mica peridotite. These, therefore, provide excellent opportunity for studying the effect of temperature on organic matter found in the rocks of same age, same type, at the same pressure. Because of the steep thermal gradient across the intrusion, the organic matter in the rocks close to the intrusion has been exposed to high temperatures while the organic matter farther away has been heated to only a little above the normal temperature of the country rock.

Across 18 intrusions (12 dykes and 6 sills) of mica peridotite, a total of 146 samples were collected systematically at spacing varying from 5 to 150 cm, with a view to study the thermal effects on organic matter dispersed in the sedimentary rocks, in terms of variation in vitrinite reflectance (VR_o) values, thermal alteration index (TAI), fluorescence, bitumen content, pyrolytic parameters, and the nature of gas chromatograms of saturates.

Reflectance of vitrinite maceral indicates that the VR_o for the samples just at the contact with igneous intrusions, is high (as much as 6.27%) and decreases away from the intrusive bodies till it attains a ground value (where effect of intrusions is negligible) which varies from 0.40 to 1.00% in different areas.

The thickness of this thermally affected zone varies with the thickness of intrusive body. It is generally twice the thickness of igneous body. The thermally affected zone is characterised by contact metamorphism, metagenetic and catagenetic zones, depending upon the thickness of igneous body. In general, the widths of the metamorphic, metagenetic and catagenetic zones are about 15%, 32% and 180% (nearly twice) of the thickness of the intrusive body, respectively. As the thickness of the igneous intrusions increases, the width of various maturity zones also increases.

Similar observations are also made with regard to TAI and Fluorescence spectral analysis. Thermal alteration index (TAI) values are all around 2.75 except for the samples intruded by the mica-peridotites. It becomes as high as 4.5 close to the contact with the igneous body. Also, Fluorescence spectrum values are increasing towards the intrusive body. Spectral analysis, results show maximum fluorescence (maxima) of 168.44% at 730 nm wavelength in the samples at the contact with igneous intrusion and decreases to 8.46% at 530 nm wavelength, in the samples away from the contact.

Pyrolysis of samples also, clearly indicates these effects. T_{max} values (spike of S_2 peak) as high as 554°C is observed near the contact of igneous intrusion. It decreases to about 330°C (ground value) away from the contacts. It is very interesting to observe that nearly all the samples close to the contact with igneous intrusions have hydrogen index values zero or near zero, but just after a short distance comes a peak value (about 150 mg/g TOC or more) of HI and again it decreases to normal ground value, of 70 mg/g TOC of HI or less depending upon its TOC, where the effect of intrusions is negligible.

Igneous intrusions have their effect on the extractable organic matter (Bitumen) too. At contacts or very close to intrusive bodies, volatiles appear, in general, to have been lost. This suggests that pyrolysis products from organic rich sediments at or near contacts of intrusions, were either diffused or driven away to get collected in the so called "microreservoirs".

The high value of HI at a short distance from the igneous body, as observed, may be attributed to the collection of pyrolysed products in the "Microreservoirs".

The gas chromatograms of these three areas also indicate that in some cases of the contacts the nC_{max} (maximum percentage of normal alkanes) is as low as nC_{18}, at or near the contact and it gradually increases to ground value, of that particular bed, which is sometimes as high as nC_{22} or even nC_{24} and occasionally upto nC_{25}.

From the foregoing evidences it is seen that immediately adjacent to the intrusion, the organic matter is destroyed and only the carbon rich graphitic material remains. Also further, at the contact, the extractable material is present in large quantities but decreases with the increase in the distance from the contact and eventually reaches the values characteristic of the host shale. These intrusions of mica peridotite have thus enhanced the maturity of organic matter and have generated additional hydrocarbons when they were emplaced in the sediments around 100 my during lower Lower Cretaceous.

Genetic potential and hydrocarbon yield of shale

The genetic potential of shales has been calculated using S_1 and S_2 peaks from the pyrolysis of shales. It varies between 0.01 to 89.48 kg of hydrocarbons per ton of source rock (kgt^{-1}) with an average of 13.2888 $kg.t^{-1}$ based on 49 samples in Bhaunra area; 0.05 to 102.4 $kg.t^{-1}$ with an average of 11.698 $kg.\ t^{-1}$ based on 34 samples in Chasnala area and 10.03 to 67.38 $kg.\ t^{-1}$ with an average of 5.959 $kg.t^{-1}$ based on 16 samples in Phulwaritand - Maheshpur area. From these results it is apparent that Bhaunra and Chasnala areas are good source rocks whereas Phulwaritand area is having a moderate source rock potential.

The quantitative (volumetric) estimation of hydrocarbons generated from the shales of the Barakar Formation from these three areas in Jharia coalfield was carried out following Waples (1985).

Samples for this study were selected from Chasnala, Bhaunra and Phulwaritand areas. The organic matter in the sediments is mainly terrestrial- kerogen of type III. It is matured to various levels at Chasnala and Bhaunra areas. However, it is generally immature at Phulwaritand area. Besides the maturation of organic matter during burial of sediments due to basement heat, igneous intrusions have further enhanced the maturity of these organic sediments in their vicinity.

In Chasnala area, volumetric estimation of hydrocarbon yield was made at three sampled locations. Of these three locations, the sediments from the area B, situated about 200 m north of Dhanbad Sindri bridge over Domohani naala (river) (Sample No. 82-93) expelled 6 million barrels of oil along with 1285174.3 million cubic metre of gas, from each cubic kilometer of source rock. However, in the other two areas, negligible amount of oil & gas (insufficient for expulsion) was generated. From these three locations, due to igneous intrusions 30 million barrel of additional oil and oil equivalent hydrocarbons were generated.

In Bhaunra area, four locations were investigated, only two contributed. The location B, 6 km situated NNW of Gorkhuti, generated 23.294 million barrels of oil and oil equivalent from each cubic kilometer of source rock. The other location, b, about 3 km north-west of the above mentioned location, generated about 16 million barrels of oil and 1488423.7 million cubic metre of gas for each cubic kilometer of source rock, out of which 7.984 million barrel of oil along with 1190738 million cubic metre of gas expelled. In Bhaunra from these two locations, an additional 16.5 million barrel (average) of oil and 5.9 x 10^6 million (.6 billion average) cubic metre of gas is generated from the shales in the vicinity of igneous intrusions of the area.

Phulwaritand area though having a moderate source rock potential, due to their low level of maturity have generated little oil or gas.

It is observed that in the vicinity of the igneous intrusions the immature organic matter has witnessed enough thermal maturity to generate additional oil and gas for their appropriate areas. The smaller the distance to the intrusions, the more the maturity of sediments and hence more the generation and expulsion of hydrocarbons. Also the thicker the intrusive body, more the effect, and hence more the generation of oil and gas.

Clay Mineral Crystallinity as an Indicator of Maturity

Physical properties of sediments as well as organic matter are changed during the process of maturation, besides changes in chemical properties. Therefore an attempt has been made to correlated crystallinity of clay mineral with the maturity of organic matter.

Igneous intrusions have generated different zones of maturation of the organic matter found in the argillaceous sediments of the Barakar Formation. These intrusions must have also affected the crystallinity of clay minerals found in these sediments. If this is so, then clay mineral crystallinity may help in deciphering various stages of organic matter maturation. With this premise an attempt has been made to look into the possibility of use of clay mineral crystallinity as a maturity indicator.

Clays in the shales of the Barakar Formation are kaolinite, illite and chlorite, the predominance being that of the kaolinite. Kaolinite is very sensitive to temperature changes as compared to other clay minerals. It is destroyed at temperatures of 550°C. In fact, it has been destroyed in the samples very close to intrusive bodies. However, the degree of crystallinity of kaolinite measured as crystallite size at half the height of its peak decreases towards the intrusive body indicating the thermal effect of the igneous bodies on the sediments as well. Using crystallite size, an attempt has been made to identify various zones of maturation.

The zone of catagenesis is characterised by crystallite size between 250 A° to about 450 A°. It is observed that samples in metagenetic stage have almost negligible crystallite size of kaolinite and samples in diagnesis stage or in border with catagnesis have higher average crystallite size. Values above 550 A° may be taken as indicative of a diagenetic stage. In the metamorphic zone, it is destroyed. These results may be area specific. Variation in crystallite size of kaolinite is more apparent for the thicker intrusions.

Spectral Signatures of Shales as Indicator of Maturity

Apart from changes in the chemical properties of organic matter rich sediments, their physical properties are also expected to change through the process of maturation. Spectral responses to electromagnetic radiation, in the wavelengths 350, 400, 450 .... 850 nm for the samples collected at varying distances from the igneous intrusions, were measured. These responses could be best studied in the Bhaunra area, as the intrusions there, are thicker and are of the order of 0.75 to 2.25 m. The reflectance increases with the increase in wavelength in the range of 350 to 600 nm and then decreases with increase in wavelength in the range from 600 to 850 nm . Also, the reflectance response for any given wavelength increases with increase in the distance (of samples) from igneous intrusions and it is best exemplified at the wavelength 600 nm.

The reflectance response of shales appear to be inversely related with the vitrinite reflectance. At 600 nm, the zones of metamorphism & metagenesis, catagenesis and diagenesis are maximally discriminated , and fall in the reflectances of < 3.18 x 10^{-6} W/cm^2.nm & between 3.18 and 3.25 x 10^{-6} W/cm^2.nm, between 3.25 and 14.05 x 10^{-6} W/cm^2.nm, and > 14.05 x10^{-6} W/cm^2.nm respectively.

The study has demonstrated that the clay mineral crystallite size and the spectral responses to electromagnetic radiations, of shales appear to hold promise as new valuable simple tools to gauge the degree of maturity of organic matter in the argillaceous rocks.

Petroleum Prospects

Petroleum prospects of the area have been assessed on the basis of organic matter richness, quality and maturity of organic matter, time of generation and availability of traps. The shales of the Barakar Formation are rich in organic matter which is mainly of terrestrial type (kerogen type III) and have undergone adequate maturation to generate petroleum, mainly gas. These hydrocarbons were generated in two separate phases by two distinct sources of heat. In the first phase, petroleum hydrocarbons were generated during Permo-Triassic (235-200 my) period due to `basement heat' while the sediments were undergoing burial. In the second stage, the igneous intrusion, specially the mica peridotite, further matured these initially matured sediments during Lower Cretaceous time (100 my), slightly away from their contacts with these sediments. These hydrocarbons were expelled as they had crossed the Mompar's (1978) threshold value of 12 m bbl.

The thick pile of sediments consists of more than 50-60 cycles of shale-coal-sandstone sequences. The sandstone can act as good reservoir rocks, and shales both as source rocks and cap rocks. If the traps in the form of anticline and syncline were formed before the generation and expulsion of hydrocarbons, then these could form a good prospects.

According to Mukherjee (1977) and Verma et al. (1989) the major structures in the form of folds faults were developed in two stages -the first generation of major folding took place at about 100 my during Lower Creteceous time with NW - SE axis. The second generation cross folds at about 65 m years or so during Paleocene. If this is so, then the oil/gas generated due to burial process at about 235 - 200 my had little traps available and therefore from this angle, the prospects of getting this petroleum are poor. However, since the area falls in a rift basin (Dutta 1983), some structures specially the growth faults, roll over anticlines might have been formed during or just after the deposition of these sediments. Under such conditions there may be some prospects for the petroleum generated around 235-200 my ago. In view of this, detailed basin evoluation and structural studies are required to be done to evaluate the prospects of these sediments more objectively.

Due to the intrusion of mica peridotite around 100 my the organic matter was matured. As the major folding, faulting and intrusion took place more or less contemporaneously, the petroleum thus generated due to intursion could have got accummulated into these trap forming st~~u~~ructure provided these are good cap rocks. In this connection this may be mentioned that the shales of the shale-coal-sand sequences (more than 50-60) are if found extensive, can also serve as good cap rock.

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CHAPTER - 1

INTRODUCTION

1.1 BACKGROUND

Till recent years, commercial generation of petroleum was thought mainly to be of marine origin. However, with the findings of substantial quantities of petroleum generated in the sediments of non-marine origin from many parts of the world (such as Songliao basin NE China (Demaison, 1984), the Upper Tertiary Kerai gas of Alaska, oil and gas from the Powder Wash Field of Colorado and the Red Wash Field of Utah, oil in the Middle Ecca beds in Natal, gas from the Evander Field east of Johannesburg, oil from the lake Alberta sediments in Uganda), the continental sediments have, of late, also become attractive for their hydrocarbon prospects.

In India, the Gondwana Supergroup (Upper Carboniferous to the Jurassic/Middle Cretaceous) forms one of the two prominent nonmarine sedimentary basins. Considering biogenic origin of petroleum, it is significant to note the occurrence of substantial quantities of vegetal organic matter dispersed in these sediments. It is also noteworthy that under similar geological settings, the Gondwana sediments or their equivalent nonmarine sediments in other parts of the world, notably the Patchawara and Toolachee formations of Permian age, have proved to be major source of gas in the Cooper Basin of Australia (Smyth, 1983; Jain et al. 1985; Clark and Cook, 1987). Therefore, by analogy, the Gondwana sediments in India too, goad us to look into the possibilities of generation of petroleum hydrocarbons in these rocks.

Although these sediments have received attention of geoscientists for more than hundred years or so, very limited studies on their petroleum prospects have been made despite presence of vegetal organic matter of varying maturation in these rocks of Gondwanas. The present study was, therefore, taken up to investigate these rocks for petroleum generating potential with an attempt to fill in the gap in our knowledge about this important aspect.

1.2 AREA OF STUDY

The Gondwana rocks in India, are mainly developed along two sides of a great triangular area, one side of which formed the northern part of the East Coast of the Peninsula from the Godavari Valley to the Rajmahal Hills (Fig. 1.1). The northern side of this triangular area roughly corresponds to the Damodar, Son and Narmada Valleys trending roughly E-W, while the south-western side runs along the Godavari Valley with a NW - SE trend. In these long and narrow tracts the Gondwana rocks are found in a series of faulted troughs or rifts (Krishnan, 1982; Jain et al. 1985).

The major Gondwana basins in the Peninsular India are associated with four zones of block faulting (Fig. 1.1) namely -

i) the Narmada Son Valley Zone,
ii) the Damodar Valley Zone,
iii) Mahanadi Valley Zone,
iv) the Godavari - Pranhita Valley Zone.

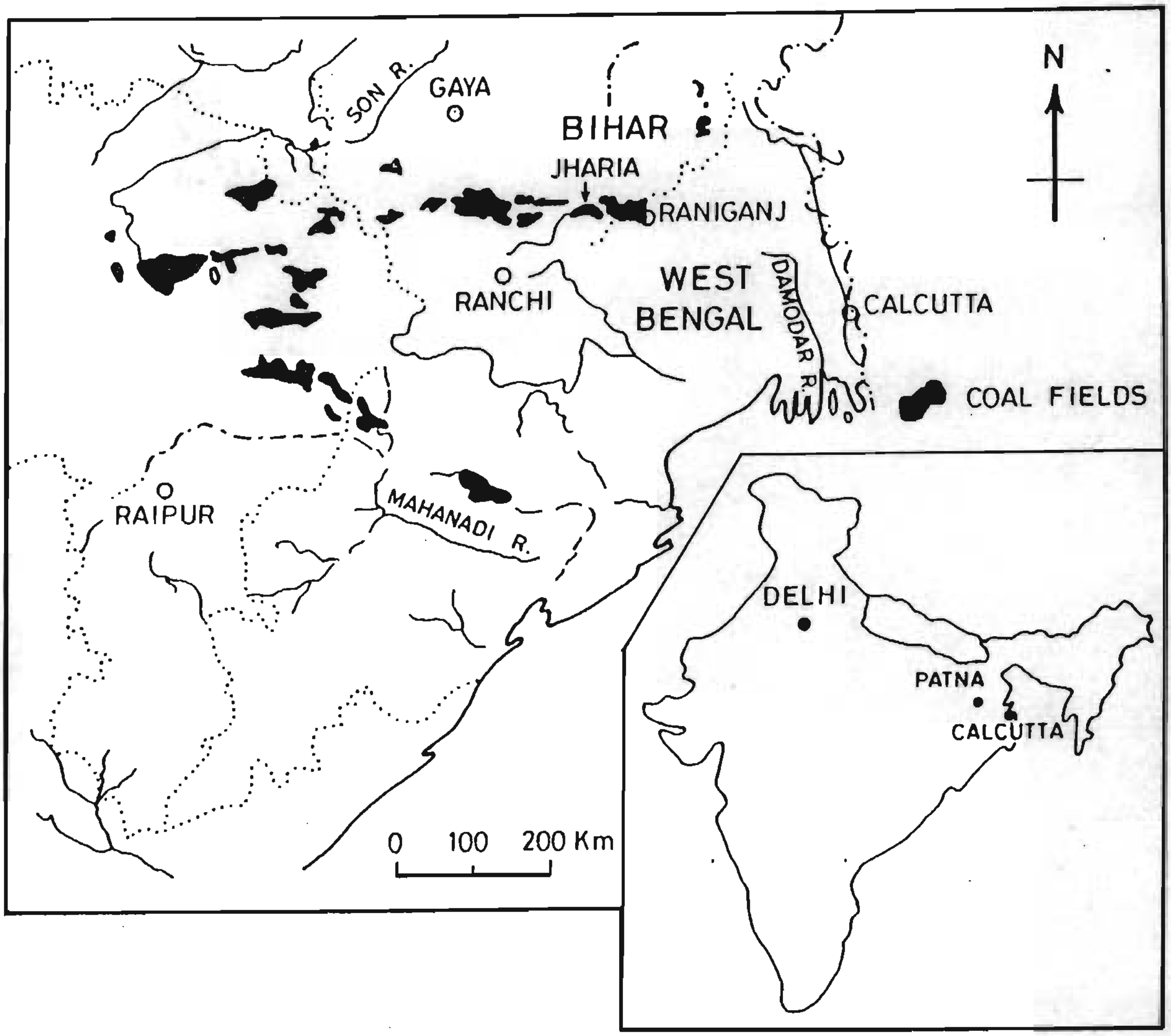


Fig. 1.1 Distribution of the major coal fields of Gondwana in India.

These depressions served as depocentres for the deposition of Gondwana sediments (Jain et al. 1985).

Damodar Basin in Bihar is one of the most important basins of the Gondwana sediments of the Indian Peninsula. In this basin, the non-marine Permian sediments of the Barakar Formation exposed in and around Jharia, Bihar, form the locale of the present studies (Figs. 1.2 & 1.3). Since this formation with large number of coal seams (46), is being exploited for coal, it offers good test area for the present studies at three sampled areas around Chasnala, Bhaunra, Phulwaritand-Maheshpur (Fig.1.3).

Jharia Coalfield of Damodar Basin occupies an area of about 760 sq.km..It is bounded between the latitudes 23°37' -23°52'N and the longitudes 86°06'-86°30'E.This area falls in the Survey of India Toposheet Nos. 73I/1,73I/2,73I/5 and 73I/6.

The area can be reached both by road and rail. The nearest city is Dhanbad on the north eastern fringe of the area. Jharia is a small town situated 7 km. south of Dhanbad and 275 km west of Calcutta. The river Damodar, a tributary to the river Hooghly, flows through the southern part of the area.

1.3 GEOLOGY OF THE AREA

Among the Gondwana basins, the Damodar Graben is the second largest (6300 sq km) basin and contributes the highest amount of coal output. It contains sedimentary fill of over 3 km and is associated with an active gas show in West Bokaro Coalfield (Chandra et al. 1985). In this basin the most important coalfield of India is the Jharia Coalfield which accounts for about 40 percent of the total Indian coal production and is the

Fig. 1.2 Sickle shape structure of the Jharia coal field.

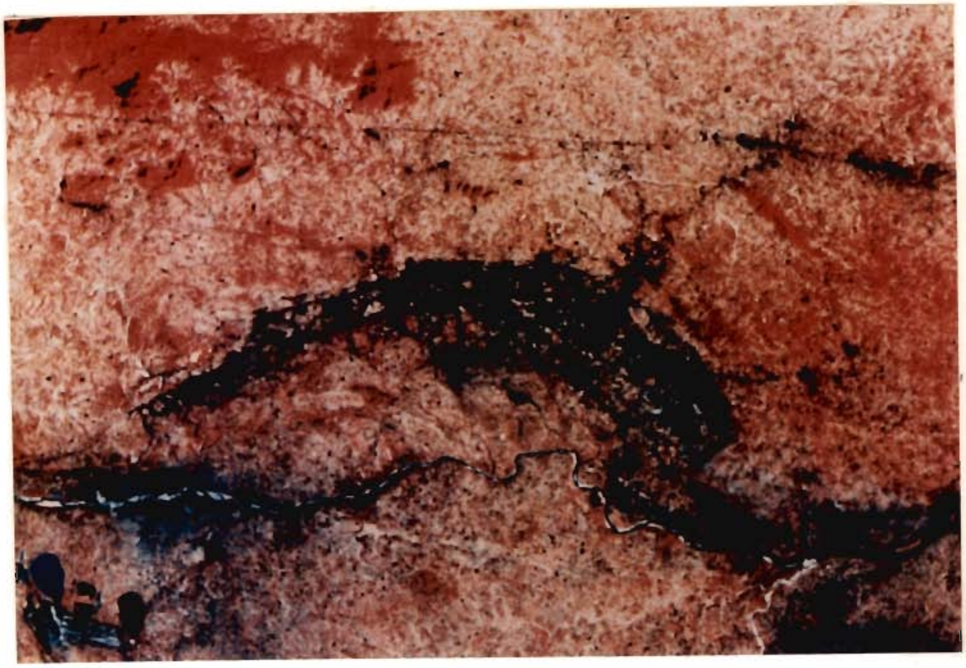


FIG. 1 . 2

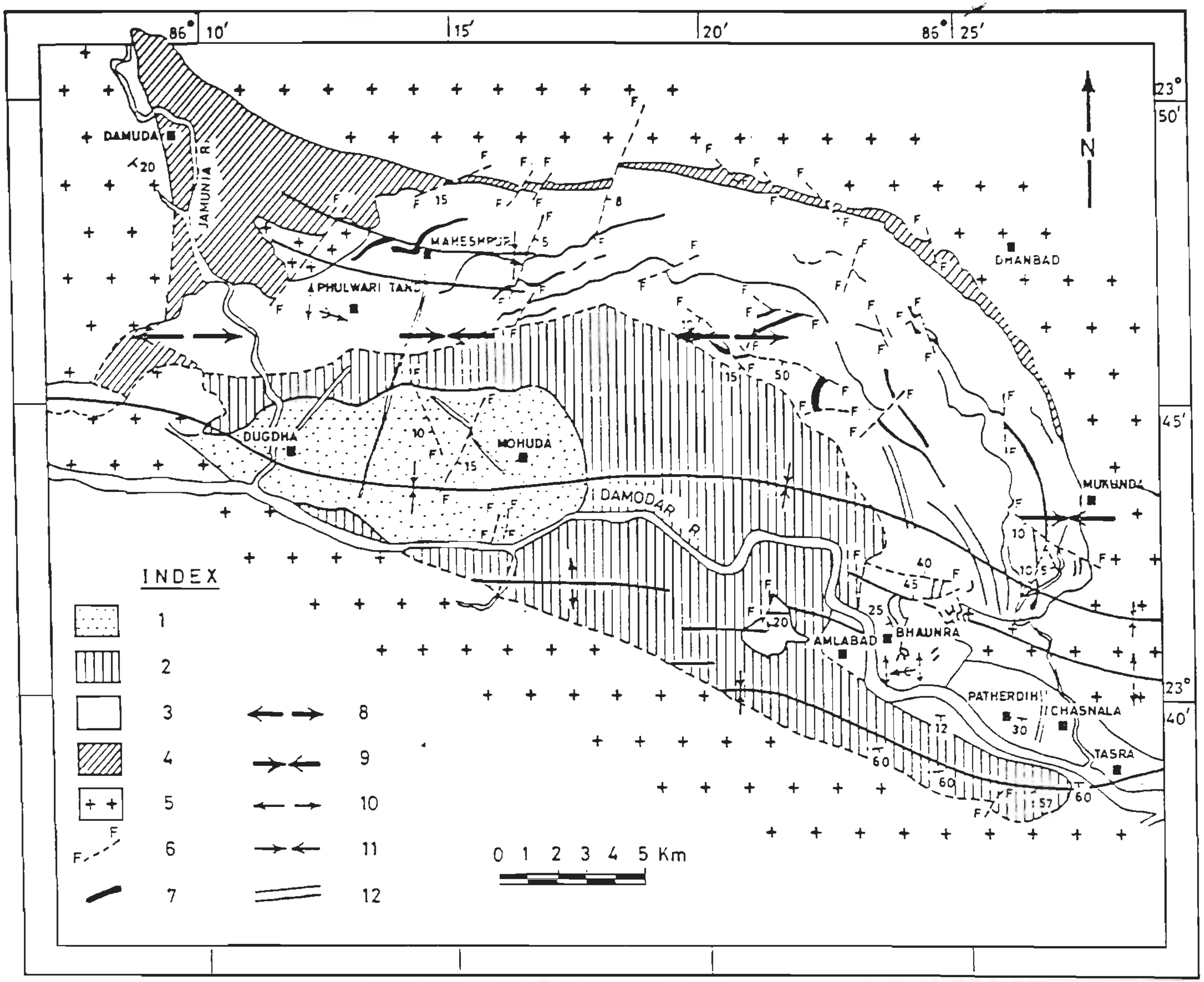


Fig. 1.3 Geological Map of the Jharia Coal Basin. 1. Raniganj Formation, 2. Barren Measures, 3. Barakar Formation, 4. Talchir Formation, 5. Archean Gneiss, 6. Faults, 7. Coal seams, 8. Major Anticlinal folds, 9. Major Synclinal folds, 10. Minor Anticlinal folds, 11. Minor Synclinal folds and 12. Major Igneous Intrusions.

most important storehouse of the best coking coal (Krishnan, 1982).

Jharia Coalfield has attracted a number of geologist in the past hundred twenty five years or so. However, the first comprehensive record of study on the geology and coal reserves of the coalfield was given by Fox (1930). These studies were subsequently revised and updated by Mehta and Narayanamurty (1956) and later by Verma et al. (1989). Based on these studies, a generalized stratigraphic succession, maximum thickness of the formations and chronology of geological events, are given in Table 1.1.

Table 1.1. Time-Stratigraphy of Jharia
(modified after Verma et al. 1989)

Stratigraphic Unit	Thickness (m)	Age
Raniganj formation	725	Upper Permian
Barren measures Formation	625	Middle Permian
Bar^{a}kar/Karharbari Formation	1250	Lower Permian
Talchir	250	Upper Carboniferous
---------------Unconformity---------------		
Metamorphic		Precambrian

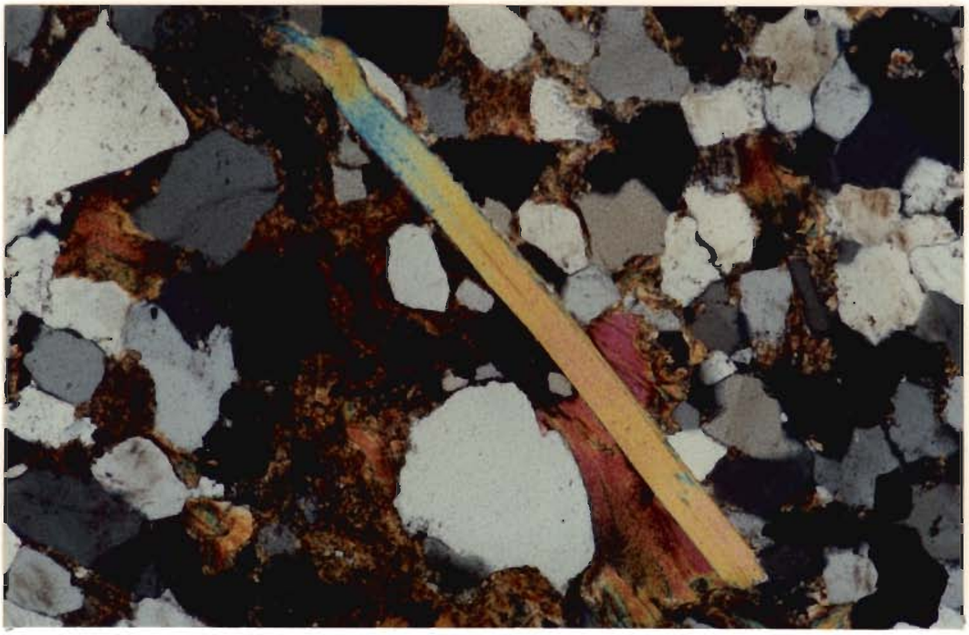
Jharia Coalfield is roughly sickle-shaped in plan (Fig.1.2), being about 20 km N-S, and 38 km E-W. It occurs in the form of asymmetrical synclinal basin with its axis trending roughly east-west direction and plunging towards west (Fig. 1.3). The southern flank is truncated by a major fault, known as Boundary Fault. The total area of Gondwana rocks exposed in this coalfield is 710 sq.km.

1.4 BARAKAR FORMATION

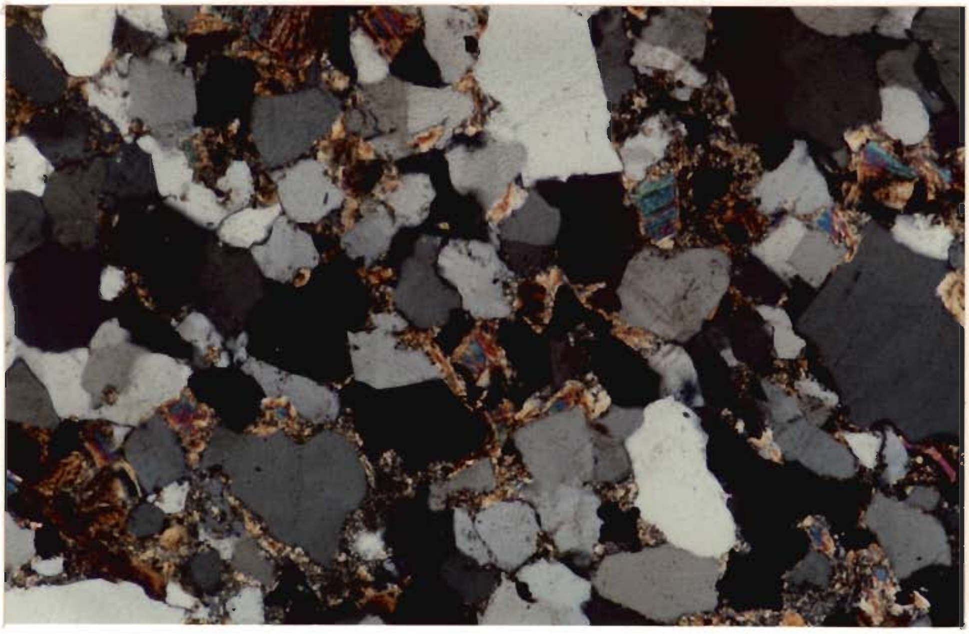
Though coal seams occur in both the Barakar and the Raniganj formations, those in Barakars are by far the most important. Barakar sediments occupy an area of about 220 sq km and attain a maximum thickness of more than 1250 m (Verma et al. 1989). It contains as many as 46 (50 cm or more thickness) seams with the proportion of coal to strata being roughly 1 to 8.

Barakar Formation is characterized by shale-coal-sandstone sequences. These sequences are repeated vertically as many as 50 to 60 times. The sandstones are fine to medium grained (Fig. 1.4 a & b). These show imprints of northerly paleodrainage in the post- glacial continental fluviatile deposits and are profusely recorded as successive sets of large and small scale cross bedding (Fig. 1.5), ripple marks, erosional river channels, to quote those considered as reliable paleocurrent indicators (Casshyap, 1977). Likewise, there are reasons to believe that pebble and grain imbrication in conglomerates (Jhingran, 1970) and sandstones (Ganguli, 1960; Srivastava and Israili, 1963; Biswas, 1967) and embedded fragments of vegetal debris in fine grained sandstone and siltstone, owe their orientation to rivers and streams which flowed at the time of deposition. These directional structures have been extensively investigated inducing the paleocurrent direction of the Permian and Mesozoic fluviatile rocks, during the past two decades or so. There are many published contributions on Barakar Paleocurrents, some of which are Banerjee, 1960; Niyogi and Sanyal, 1962; Sengupta, 1966, 1970; Ghosh and Bandyopadhyay, 1967; Casshyap, 1970, 1973. Casshyap and Jain, 1970; Ghosh and Mitra, 1970; Roy Chowdhuri et al. 1973; Casshyap, 1977. Paleocurrent is northwesterly in the

Fig. 1.4 a & b Micaceous sandstone with large muscovite flakes. Sub-rounded quartz grains embedded in micaceous biotite-rich matrix.



(a)



(b)

FIG.1.4

Fig. 1.5 Cross bedding in sandstone from Barakar Formation.

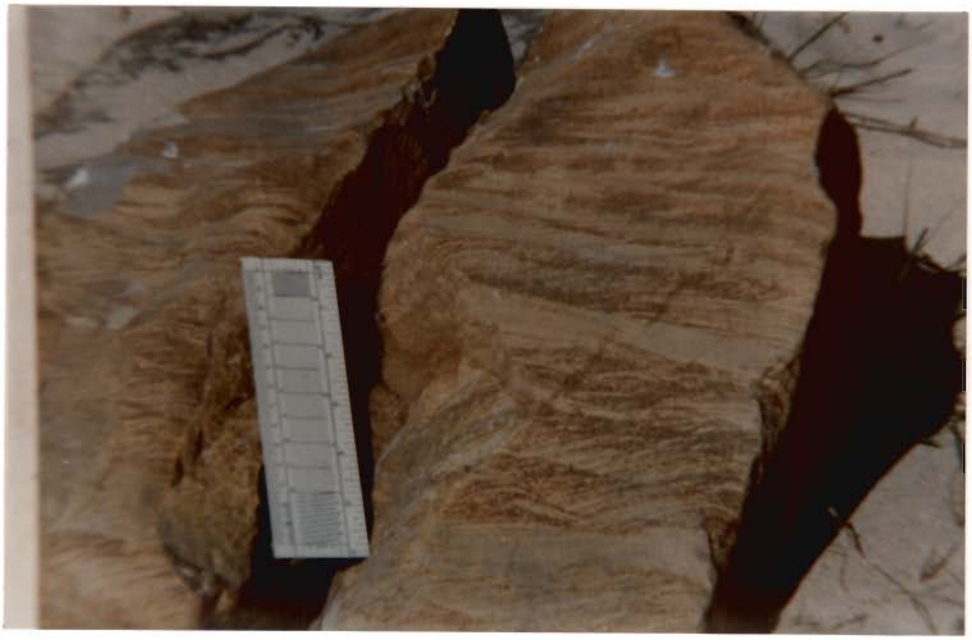


FIG. 1.5

western part; it is towards north in central part and northeasterly in the eastern part of the Jharia basin (Fig. 1.6).

The Barakar Formation occurs in the form of an asymmetrical synclinal fold, plunging easterly and faulted southerly by boundary fault (Fig. 1.3). The axis of the fold trending WSW-ESE in the western part, swings to NW-SE in the central part. It swings further to become N-S towards east in Mukunda area (Fig. 1.3).

The dips of these beds are gentle in general, varying from about 5° to 15°. However, in the vicinity of the faults, dips become steeper (20° to 30° or more). Dips as high as about 70° are observed in the southern part of Tasra area (Fig. 1.3)

In between the northern and southern synclines, which abut against the southern boundary fault, a zone of `uplift' or `anticlinal' area has been recognized extending from Patherdih to Aluara. The zone of uplift has been attributed to `vertically directed force' (Sen, 1971).

Fox (1930,34) has described the occurences of following anticlinal and synclinal axes in Jharia coalfield.

i) Jharia - Jitpur - Mohuda - Chandrapura Syncline
ii) Bhaunra - Amdabad - Parbatpur Anticline
iii) Tasra - Bhojudih syncline

He has also mentioned about occurrences of Amlabad and Parbatpur domes in the coalfield.

Verma and Singh (1979) have recognized three sets of folds (1) Early folds: Early folds along NW-SE axes oriented parallel

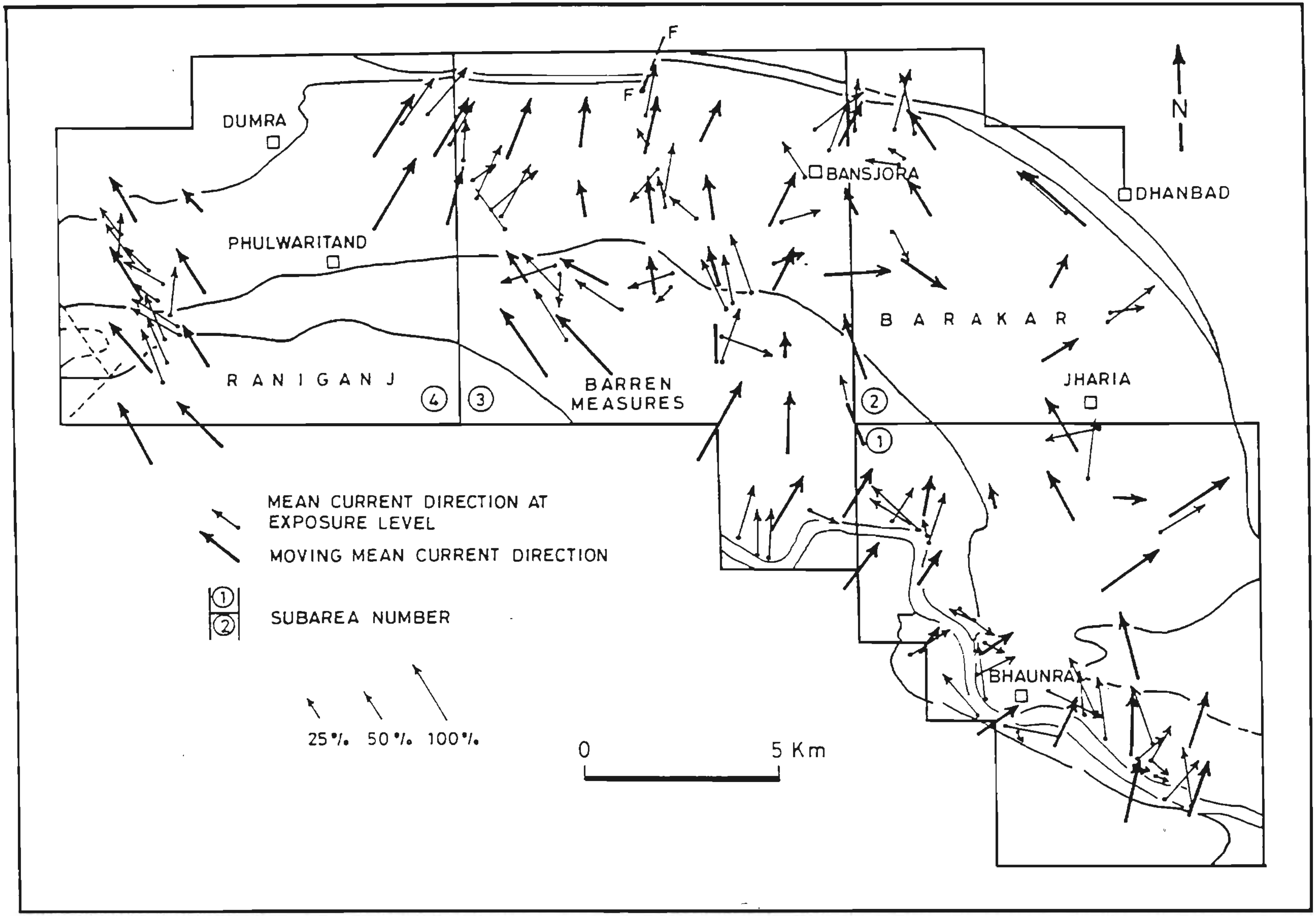


Fig. 1.6 Paleocurrent map of Barakar and Barren Measures in the Jharia coal field (After Casshyap, 1977).

to the lineament of the depositional valley in which paleodrainage has been recently established to be north-westerly (Casshyap, 1973). (2) Cross Folds: Cross folds along E-W axes, which are parallel to the alignment of present Gondwana outlines in the Damodar valley coalfields, and (3) Later folds: Later folds along NNE- SSW axes, which have formed smaller warps within the coalfield, and are largely coeval to the cross folds.

In addition to the above major folds, smaller expressions of E-W trending cross folds, represented by a few minor folds have been recognized.

i) Baghmara - Muraidih syncline;
ii) Baghmara - Barora Anticline;
iii) Balidari - Analgaria Anticline and
iv) Igri Anticline.

In addition, domal structures are found in Bhaunra and Amlabad. As mentioned earlier, Jharia coalfield is faulted against the Archaeans along the southern margin where the strata dip inward towards the centre of the field. Two small horsts of gneiss are found, one in the northeastern and the other in the northwestern part. There are also faults on the other sides as well as cross faults within the field, most of them being of the sag fault type. Recent findings and updated data reported by Verma et al. (1989), about faults in the Jharia Coalfield are :

- The Dungri Petia fault which were earlier thought to extend only from near Amlabad to Dungri Petia village in a stretch of about 5 km has now been found to have a stretch of 11 km. extending from southern portion of Bhaunra to north of Moonidih (Fig. 1.3).

- Several new major faults having stretch of about 5-10 km occur particularly in the western part which were not known to exist earlier. One such fault having a throw of 320 m towards south, divides the Damuda block into open cast and underground blocks (Fig. 1.3).
- A major fault occurring in Dharmabad extends eastward and forms the down dip limit of open cast blocks in the northwestern part of the coalfield (Fig. 1.3).

1.4.1 METAMORPHIC HIGH

Occurrence of "Basin High" (Metamorphic High) has been observed in Sitanala area located in the south eastern part of Jharia coalfield (Verma et al., 1989). This "High" has resulted in wide variation in the thickness of individual coal and non coal sedimentary strata and has controlled the pattern of deposition of the sediments containing lower coal seams. Due to occurrence of this "High" several older seams have been missed in part of the area.

1.4.2 IGNEOUS INTRUSIVES

Two types of igneous intrusions are met within the Jharia Coalfield. These are the mica-peridotite and the dolerite. The mica-peridotite having bronze coloured mica occurs as dykes and sills all over the area, although they are concentrated over the anticlinal portion of Bhaunra and towards south of Dumra. The mica-peridotites give an evidence of high fluidity and high temperature, as they have devolatilised the coal wherever they came in contact with seams and thereby has spoilt extensive reserves of coal in this coalfield. In Sudamdih, a fault has been intruded by the mica-peridotite dyke. The dolerite occurs as dykes which are confined mainly to the western part of the coalfield. The destructive effect of dolerite on coal is limited as compared to that of the lamprophyric mica-peridotite.

1.5 REVIEW OF PREVIOUS WORK ON PETROLEUM SOURCE ROCK STUDIES IN THE AREA

Although a number of geologists have studied these sediments ever since the earlier geological works of Fies~~t~~mantle (1876), Holland (1894) and Fox (1930, 31, 32). Some of the important works done on the chemical properties and rank of coals of Jharia and Raniganj field are those of Mazumdar (1959), Sengupta and Gupta (1968), Ghose (1969), [illegible] and Sen (1970); on the intrusions of Jharia coalfield are by Fox (1930), Banerjee (1953), Choudhuri et al. (1972), Ghose et al. (1977) and Singh (1987); on tectonics, sedimentation and basin analysis of Jharia coalfield by workers such as Fox (1930), Sen (1971), Rao et al. (1968) and Ghosh et al. (1969); and finally on paleocurrents and basin framework of Jharia Coalfield by Casshyap (1977) and Mukherjee (1977). However, it was Desikachar in the year 1971 who aroused the consciousness about the importance of Gondwana sediments for hydrocarbon prospects. In view of the evidences for the occurrence of petroleum of continental origin, as cited by Hedberg (1967), such as Upper Tertiary Kenai gas of Alaska, oil and gas from the Powder Wash Field of Colorado and the Red Wash field of Utah, Oil in the Middle Ecca beds in Natal, gas from the Evander field east of Johanesburg, oil from the Lake Alberta sediments in Uganda and oil of Mendoza field in Argentina, Desikachar (1971), suggested the Gondwana basins as possible testing ground for the exploration of hydrocarbons of continental origin. He further brings to notice that no effort for exploration of natural gas from the coalfields has been made in India, so far. It is therefore, necessary to make a thorough study of the stratigraphy and structure of the coalfields with this object in view and look for traps which are likely to yield commercial quantities of natural gas.

Sastri et al. (1972) studied the Lower Gondwana sediments of Pranhita-Godavari Graben, in India, as possible source rocks of hydrocarbons. They concluded that the Lower Gondwana sediments are rich in plant vegetal organic matter. The organic matter contained in the Barakars, appears to designate a stage of maturation which does not exclude these sediments as probable source rocks of hydrocarbons. They further indicate that an inter-disciplinary approach for evaluating hydrocarbon-generating potential of the lithotypes of Lower Gondwana sediments, in general, and Barakar Formation in particular, should precede any intensive hydrocarbon exploration programme in Pranhita-Godavari Graben and similar sediments.

Mukhopadhyay (1977) while correlating the generation of petroleum like substances with its n-alkane distribution and isoprenoids from Indian Gondwana coal basins of Permian revealed that in the high rank coals of different basins (i.e. coals from the lower most horizons of the Barakar Formation manifest a slight predominance of lower homologues whereas the reverse is the case for low rank coals (upper horizons of Barakar Formation).

Asthana and Valluri (1984) studied the geology and hydrocarbon potential of South Rewa Gondwana basin and concluded that Karharbari, Barakar and Lameta formations could serve as source, reservoir and caprock, depending upon the lateral lithofacies variations in the basin.

Jain et al. (1985) comparing the Gondwanas of Australia (Cooper Basin) with that of India strongly support the hypothesis given by Desikachar (1971) and Sastri et al. (1972). They conclude that the Gondwana sediments have sufficient thickness of potential source rocks, reservoir rocks and also the structures for their accumulation. Now it is apparent that coaly carbonaceous matter can be the source for hydrocarbons. Since these rocks elsewhere, under similar structural setting, have generated hydrocarbons, therefore we must look for the same in the Gondwana of India too.

Chandra et al. (1985) have done geochemical study of sedimentary organic matter of Barakars and Barren Measures of Damodar Graben. After evaluating nearly all the geochemical parameters they have concluded that the Barakars and Barren measure shales of Damodar Graben have witnessed an abundant influx of sedimentary organic matter in anoxic conditions resulting in relatively good preservation of organic matter which is reflected in high concentration of organic carbon and low losses of organic carbon during diagenesis. The sediments are well within the oil window and show good remaining generation potentials.

1.6 SCOPE FOR PRESENT STUDY

A review of petroleum related studies done by previous workers as mentioned above, indicates that these sediments are very interesting from the standpoint of hydrocarbon generation. Yet there has been paucity of systematic detailed investigations of these sediments specially the Barakar Formation which holds high promise. Additionally, the growing evidences of commercial occurrences of petroleum hydrocarbons in similar basins with non-marine sedimentary sequences in other parts of the world, thus, leave ample scope for present studies to be carried out to fill in the gaps in our knowledge about the petroleum source rock potential of the Barakar sediments of Jharia Coalfield area.

Barakar Formation of Jharia Coalfield in the Damodar Valley Basin has been selected for present study because it is in this basin, the Barakar Formations has attained maximum thickness (more than 1250 m) of sediments characterized by as many as 50-60 cycles of shale-coal-sandstone sequences. Also, since it contains largest number of coal seams, these have been mined extensively and thus offer excellent sites for investigating source rock signatures of these non-marine Barakar Formations of Lower Permian age. Additionally these sediments have been intruded by mica-peridotite as well as dolerites and must have acted as a source of high heat to affect organic matter present in these sediments. These efforts are also of great interest. The present study thus aim at investigating the following aspects:

i) To evaluate organic matter richness in the fine grained sediments.

ii) To evaluate the genetic potential of these sediments.

iii) To evaluate the maturation of organic matter.

iv) To study the effect of igneous intrusions on the organic matter.

v) To study the effect of igneous intrusions on clay shales and work out criteria for organic matter maturation.

vi) To study the spectral response to electromagnetic radiation and work out criteria for organic matter maturation.

CHAPTER - 2

REVIEW OF TECHNIQUES USED FOR SOURCE ROCK EVALUATION

2.1 PRELIMINARY

Petroleum is generally accepted to have been generated from organic matter originating from biological materials deposited with fine grained sediments. The origin of petroleum is characterized by a series of strongly linked processes: (a) accumulation and preservation of right type of organic matter in fine grained sediments in sufficient amounts; (b) optimal thermal maturation of organic matter during burial, for transformation to hydrocarbons; (c) expulsion of hydrocarbons (oil/gas) from the fine-grained source rocks. The biogenic theory of origin of petroleum has, thus, generated the concept of source rock.

Basic concepts of hydrocarbon generation in source rocks have been reviewed by several workers such as Hedberg, (1964), Welte (1965), Phillippi (1965), Kortsev (1971), Tissot (1971), Klemme (1971), Tissot and Welte (1978), Waples (1985). Source rock has been defined differently by many workers. Among recent workers, Dow (1977) defined source rock as a unit of rock that has generated and expelled oil or gas in sufficient quantity to form commercial accumulation. He classified them into two types - effective and potential source rock. He defined an effective source rock as the one that has already generated commercial quantities of petroleum, where as potential source rock indicates a unit of rock that has the capacity to generate oil or gas in sufficient quantities to form commercial accumulation but has not yet done so because of insufficient thermal maturation.

Tissot and Welte (1978) defined source rock in more general way as, "Rocks that are, or may become, or have been able to generate petroleum are commonly called source rocks". Hunt (1979) defined source rock as "fine grained sediments that in its natural setting has generated and released enough hydrocarbons to form a commercial accumulation of oil or gas".

Barker (1979) modified the definitions pertinent to source rock given by Dow (1977). Waples (1985) while defining source rocks, subdivided them as (i) Effective; (ii) Possible and (iii) Potential source rocks. He defined effective source rock as sedimentary rock that has already generated and expelled hydrocarbons; possible source rock as sedimentary rock whose source potential has not yet been evaluated but which may have generated and expelled hydrocarbons; and finally potential source rock as any immature sedimentary rock known to be capable of generating and expelling hydrocarbons if its level of thermal maturity were higher.

A possible source rock must, therefore, qualify the following conditions in order to generate petroleum hydrocarbons commercially.

i) The rock must contain sufficient amount of organic matter.

ii) The organic matter must be of such chemical composition which is favourable for high yield of oil and gas.

iii) The organic matter must undergo such thermal maturation so as to generate large amount of petroleum hydrocarbons which could be expected under optimal conditions.

iv) Hydrocarbons thus generated must be expelled out of the fine grained rocks.

2.2 TECHNIQUES USED FOR SOURCE ROCK EVALUATION

The above mentioned parameters of possible source rock, are evaluated using a number of techniques. Some of the commonly used techniques which have been employed in the present study, are discussed herewith.

2.2.1 Organic Matter Richness and Its Determination:

The main requirements for generation of hydrocarbons within a sedimentary basin is the presence of sufficient organic matter of the correct type. The amount of organic material present in sedimentary rocks is almost always measured as the total-organic-carbon (TOC) content. This simple, quick and cost effective analysis serves as the first and most important technique in source-rock analysis (Waples, 1985).

A source rock can only be formed when significant amount of organic matter is deposited and protected from diagenetic destruction. The three primary factors influencing the amount of organic matter in a sedimentary rocks as mentioned by Waples (1985) are, productivity, preservation and dilution. Productivity itself is influenced by many factors, such as nutrient availability, light intensity, temperature, carbonate supply, predators and general water chemistry. Preservation of organic matter is the governing factor among the three, for controlling the organic matter richness and is itself influenced by the nature and concentration of oxidizing agents, the type of organic matter deposited (organic matter of algal origin is consumed more readily by organisms than other types of organic materials, like that of terrestrial origin, as it lacks nitrogen and phosphorus and has a little nutritional value), rate of sedimentation (rapid sedimentation and burial can also enhance preservation and the TOC values increase with the increase of sediment - accumulation rate. This was observed by Muller and Suess (1979), while studying the productivity, sedimentation rate and sedimentary organic matter in the oceans). Dilution, the third factor influencing the amount of organic matter in sedimentary rocks, depends upon the lithology of the rocks. Although high sedimentation rates enhance preservation of organic matter, at the same time if this rate is too high it will increase the volume of the rock in which the organic matter is preserved and causes its dilution per unit volume of the source rocks.

Determination of Total Organic Carbon : Concentration of organic carbon is measured firstly by pulverizing the rock and removing the carbonate carbon by acid treatment (carbonate is removed from the preweighed rock sample with hydrochloric acid prior to combustion, because carbonate minerals would also decompose during combustion to yield carbon dioxide). The equation for chemical reaction can be given by -

$$CaCO_3 + 2HCL \text{ ----> } CaCl_2 + H_2O + CO_2$$

After acid treatment (Appendix II) to check the complete removal of acid (Chloride ions), silver nitrate ($AgNO_3$) is used. If chloride ions are still present, cloudy white precipitate of silver chloride (AgCl) is formed whose reaction may be shown as -

$$AgNO_3 + HCL \text{ ----> } AgCl + HNO_3$$

Then the carbonate free rock is combusted at very high temperature in the presence of large amount of oxygen in the combustion apparatus. Such organic carbon analysis is conveniently performed on a Leco carbon analyzer. Its induction furnace converts all organic carbon to carbon dioxide, which is trapped within the instrument and then released into a detector when combustion is complete. The amount of carbon dioxide produced is proportional to the organic carbon content of the rock and not the total organic matter or kerogen. To compensate for other elements (H, O, N, S) present in kerogen the amount of total organic carbon determined has to be multiplied by a conversion factor, because the elemental composition of kerogen depends on its type and the level of evolution. Forsman and Hunt (1958) have determined same conversion factors ranging from 1.07 for metamorphosed rock upto 1.40 for non-metamorphosed organic matter rich in oxygen. Tissot and Welte, (1978) have given a more detailed ones with respect to type of organic matter and stage of maturation (Table 2.1)

TABLE 2.1: Conversion factors for computation of total organic matter from organic carbon content (After Tissot & Welte, 1978)

Stage	Type of Kerogen			Coal
	I	II	III	
Diagenesis	1.25	1.34	1.48	1.57
End of Catagenesis	1.20	1.19	1.18	1.12

2.2.2 Determination of Quality or Type of Organic Matter

Organic matter comprises two parts, the one which is soluble in organic solvents is referred to as "Bitumen", and the part insoluble in aqueous saline or common organic solvents is known as "Kerogen". Kerogen forms about 90% of the total organic matter (Barker, 1979). It is found in both coals and oil shales, as well as dispersed organic matter in sedimentary rocks. Lack of solubility of kerogen is a direct result of the large molecular size and molecular weights. Each molecule is unique with its chemical and physical characters strongly influenced by the type of biogenic molecules from which the kerogen is formed and by diagenetic transformation of their organic molecules.

Kerogen is the most important form of organic carbon on earth (Fig. 2.1). It is 1000 times more abundant than coal plus petroleum in reservoirs and is 50 times more abundant than bitumen and other dispersed petroleum in non-reservoir rocks (Hunt, 1972). It is of great interest because it is the source of most of the oil and gas. Kerogen comprises various types of macerals, the important ones are liptinite, vitrinite and inertinite. Accordingly it has been classified into a number of classes, discussed below.

2.2.2.1 Types of Kerogen

Because each kerogen molecule is unique, generally the gross kerogen composition and its relation to hydrocarbon-generative capacity is of interest. A graph of H/C versus O/C ratios was first used by a well known coal petrologist van Krevelen in 1961, to characterize coals and their coalification path, and was modified step by step by Forsman (1963), McIver (1967), Welte (1965), Durand and Espitalie (1976), Tissot et al. (1977), and

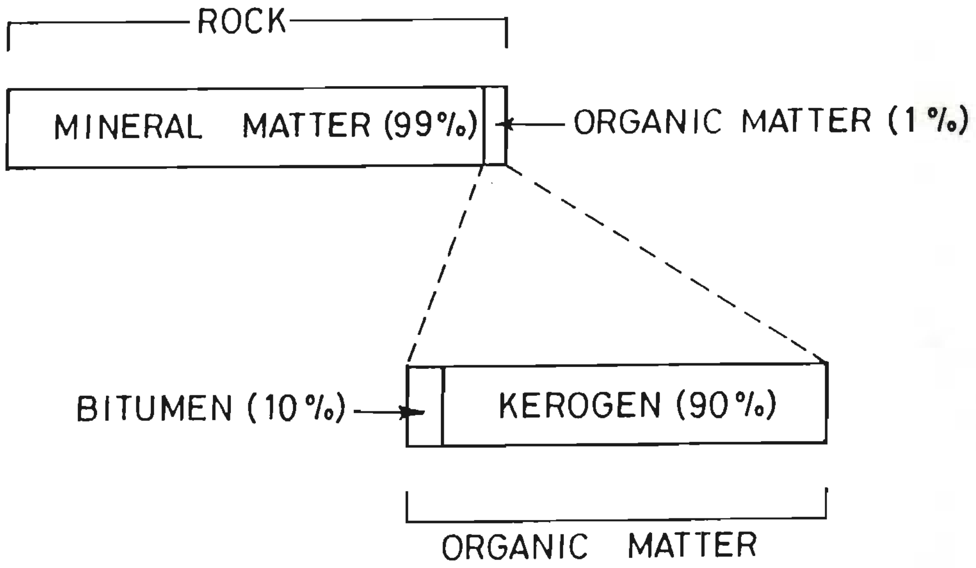


Fig. 2.1 Kerogen and bitumen in average shales (After Barker, 1979).

finally by Tissot and Welte (1978) who call it "van Krevelen diagram" (Fig. 2.2). This diagram indicates three prominent trends characterizing the following three types of kerogens containing various types of macerals (Table 2.2). The thermal maturation of each kerogen type is described by pathways, the most mature samples are near the lower left corner (little hydrogen or oxygen relative to carbon in the kerogen).

TABLE 2.2: Kerogen with its main sub-groups and terminologies (After Brooks 1981)

Origin	Terminologies					
Aquatic	Liptinite	Type I	Algal Amorphous (Sapropel)	AMORPHOUS	Amorphous debris	Exinite
	Exinite	Type II	Herbaceous			
Terrestrial	Vitrinite	Type III	Woody Coaly	Humic	Structured Plant Debris	Vitrinite
	Inertinite	Type IV or Type III b	Inertinite			Inertinite

a) Type I Kerogen:

Type I Kerogen has got high hydrogen, but low oxygen content due to presence of aliphatic carbon chains. The content of polyaromatic nuclei or oxygen containing functional groups and heteroatomic bond is low compared with the other types of organic

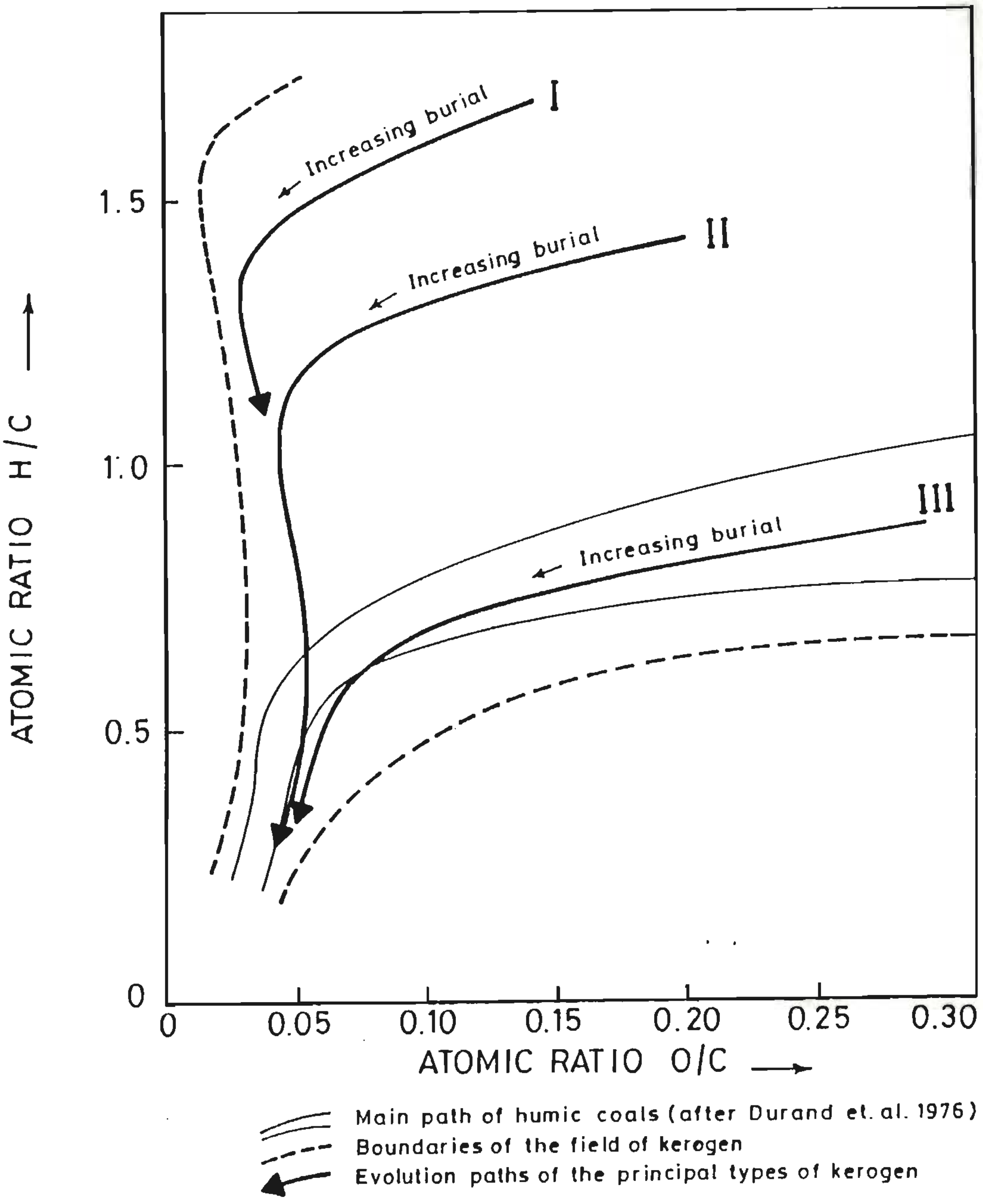


Fig. 2.2 Principal types and evolution paths of kerogen: Type I, II and III are frequent (After Tissot & Welte, 1978).

matter. It is quite rare being derived principally from lacustrine algae eg., Botryococcus (Brooks, 1981). Microscopic examination is generally showing no identifiable remains or organisms. Such kerogen comprises much lipid material similar to liptinite and/or alginite macerals. It has a high potential for petroleum.

b) Type II Kerogen:

Type II Kerogen is frequent in many petroleum source rock and oil shales, with high hydrogen content (but lower than Type I) and with aliphatic chains, some saturated naphthene, aromatic rings and oxygen containing functional groups. Type II kerogen sometimes referred to as Exinite type, is usually related to marine sediments where an autochthonous organic matter, derived from a mixture of phytoplankton, zooplankton and microorganisms (bacteria) or from membranous plant materials such as spores, pollen cuticle or in general terms, the structural portions of plants, has been deposited in a reducing environment. It has a high capacity to generate liquid hydrocarbons.

c) Type III Kerogen:

Type III Kerogen refers to relatively low hydrogen content and high oxygen content. The chemical structure consists mainly of polyaromatic nuclei, heteroatomic ketone and carboxylic acid groups but no ester groups (Robin, 1975 in Tissot and Welte, 1978). Aliphatic groups are only minor constituents of the organic matter usually connected to aromatic structures by oxygen - containing functions. Type III Kerogen is derived essentially from continental plants and contains much identifiable structured woody vegetal debris (lignified)). Plant organic matter is incorporated in sediment either directly or through its alteration products in soil humic acids. Coals are a special variety of this terrestrially derived organic matter which has a limited potential for oil, but high potential for gas.

d) Type IV Kerogen:

Subsequent investigations have identified Type IV Kerogen as well, besides the three main types of kerogen. Type IV kerogen resembling Inertinite maceral is defined as black opaque residual or reworked organic debris with high carbon, low oxygen and highly oxidized material of various origins. They are generally considered to have essentially no hydrocarbon source potential and are called as residual organic matter or "dead carbon" (Tissot, 1984). However, Smyth (1983) is of dissenting opinion, believing (on the basis of petrographic analysis of over 300 samples from Patchawara trough in the Gidgealpa Group being the source rocks for the hydrocarbons of Cooper basin in Australia) that not only vitrinite but also inertinite could be the source of liquid as well as gaseous hydrocarbons..

2.2.2.2 Techniques used for identifying the nature of organic matter:

To distinguish the type of kerogen present in any source rock and to know the status of its proneness to gas or oil, various techniques are used. The techniques used to identify the kerogen types and employed in the present study are briefly discussed herewith.

a) Rock-Eval Pyrolysis performed on the whole rock

b) Analysis of extractable organic matter

    i) Bitumen analysis

    ii) Gas Chromatography

c) Optical Methods

i) Microscopic studies under transmitted light

ii) Microscopic studies under reflected light

(a) Rock-Eval Pyrolysis of Rocks

There are two chemical approaches to characterise the organic matter present in the sediments. In first one, the kerogen is separated from sediments and analyzed for its elemental composition in terms of carbon, hydrogen, oxygen, nitrogen and sulphur etc. The elemental composition of kerogen mainly in the diagenetic stage is used to classify it as Type I, Type II, Type III and occasionally Type IV.

This approach is time consuming and laborious, therefore a quick and direct method developed by Espitalie et al. (1977), is commonly used. This approach of high temperature pyrolysis of whole rock sample mimics in the laboratory the natural hydrocarbon generation process occurring over a large span of time at much lower temperature in the earth. The pyrolysis gives three peaks, designated as S1, S2 and S3 (Fig. 2.3). S1 is hydrocarbons already present in the rock in a free or adsorbed state, S2 represents hydrocarbons generated by pyrolytic degradation of kerogen and S3 represents carbon dioxide generated. The ratio (S2/TOC) x 100 expressed as milligrams of HC per gram of TOC is known as Hydrogen Index (HI). The ratio (S3/TOC) x 100 expressed as milligrams of carbon dioxide per gram of TOC is known as Oxygen Index (OI). The HI and OI reveal a good deal when correlated with the atomic H/C and O/C ratios obtained by elemental analysis of kerogen isolated from rocks (Espitalie et al., 1977).

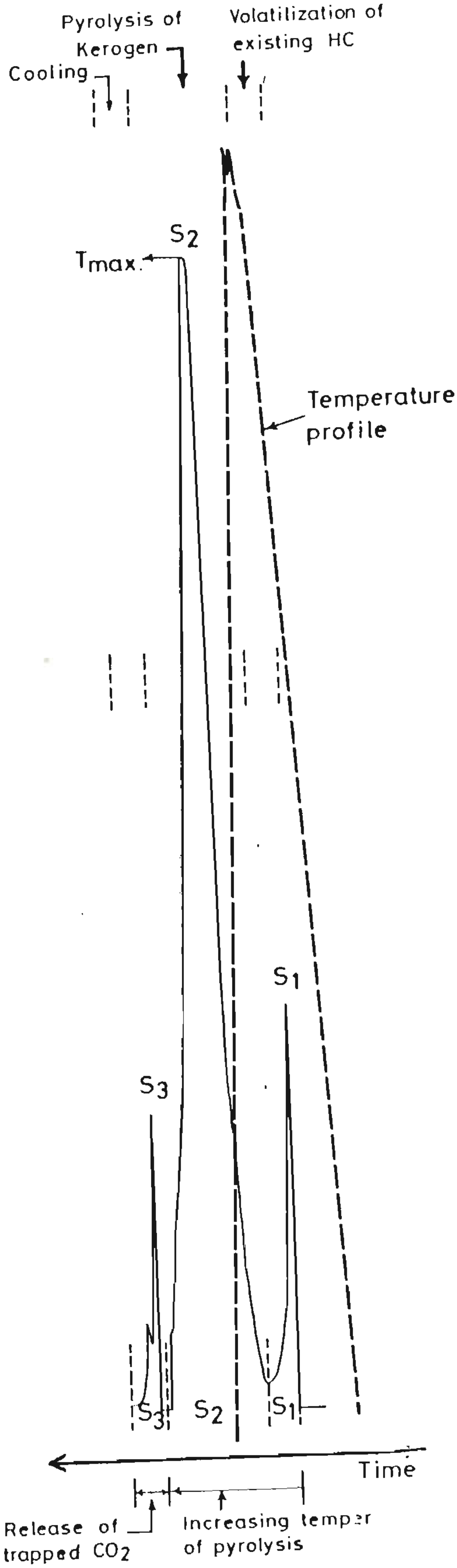


Fig. 2.3 Rock-Eval pyrolysis record. An example from Barakar Shale (Sample No. 84).

Pyrolysis of Whole Rock Sample

A small amount of powdered rock (about 100 mg) in the standard Rock-Eval instrument, is pyrolysed slowly in the absence of oxygen (to ensure that only thermal decomposition reactions occur and not combustion) to a maximum temperature of 550° C. During the assay, the free hydrocarbons are first volatilized at a moderate temperature. The amount of these hydrocarbons (S1), representing milligrams of hydrocarbons that can be thermally distilled from one gram of the rock, is measured by a flame ionization detector (FID). The second peak (S2) represents milligrams of hydrocarbons generated by pyrolytic degradation of the kerogen in one gram of rock and is detected by FID too. The third peak (S3) represents milligrams of carbon dioxide generated from a gram of rock during temperature programing up to 390° C, and is detected by thermal conductivity detector (TCD). During pyrolysis, the temperature is monitored by a thermocouple. The temperature at which the maximum amount of S2 hydrocarbons are generated is called Tmax (Fig. 2.3).

(b) Analysis of Extractable Organic Matter:

(i) Bitumen analysis:

Bitumen found in fine grained rocks contains geochemical fossils which carry information about the origin, type and environment of deposition of the organic matter. Therefore, bitumen is extracted to estimate the source rock potential, to know whether the source rocks are prone to gas or oil, and finally to recognize the nature of hydrocarbons whether syngenetic or migratory.

The extracted bitumen is fractionated to saturates, aromatics and resins (NSO) by thin liquid column chromatography. The ratios of these fractions indicate the origin of organic matter, whether marine or terrestrial.

Extraction of Bitumen: For the present study the extraction of bitumen from the powdered rock was done (Appendix III) with the help of a specially designed apparatus known as Soxhlet. Grease-free cellulose extraction thimbles were used as the sample container and Chloroform ($CHCl_3$) was used as the organic solvent. Oil fluoroscope in which ultra violet light was the source of excitation was used to check whether the extraction is complete or to be continued.

Elemental sulfur is often present in sedimentary rocks. In the extraction procedures commonly used for the isolation of hydrocarbons from such samples the sulfur is also recovered, and it sometimes exceeds the small amount of hydrocarbons. The sulfur interferes with the analysis of hydrocarbons by absorption and mass spectroscopy and leads to erroneous results in molecular weight determination.

Copper in finely divided state reacts with elemental sulfur even at room temperature and it is prepared easily as a spongy precipitate with a large surface.

$$CuSO_4 + Zn \xrightarrow{HCl} ZnSO_4 + Cu$$

This activated copper is used to remove the elemental sulfur.

After complete extraction of bitumen and removal of elemental sulfur, the extraction solvent must be removed by evaporation. Though solvent evaporation is carried out slowly at low temperatures, virtually all of the extracted molecules having fewer than ten carbon atoms are evaporated with the solvent, and those having between ten and fifteen carbon atoms will be partially removed. For this reason the extract, or bitumen is often referred to as the C_{15}^{+} extract.

Removal of asphaltenes through its precipitation was done using petroleum ether (40 - 60° C), prior to column chromatography (Appendix - III).

Column Chromatography The deasphalted extract was chromatographed on an Alumina/silicon dioxide filled column. It has been observed that if sample mixture is run on two layers of adsorbents packed in order of their polarity,a far better separation is achieved than on a single adsorbent column. Most of the literature suggest that a combination of silica gel and alumina combines the benefit of silica gel for separating saturates and aromatics and of alumina for sub-separation of aromatics (Snyder, 1975; Siefert, 1977).

Activation programme was done following Connon (1974). Elutants namely petroleum ether (40 - 60°C), benzene and methanol were used successively to separate saturated hydrocarbons, aromatic molecules and resins, respectively.

ii)Gas Chromatography

Gas Chromatography of C_{15}^{+} alkane fraction (saturate) is used to determine the type of organic matter and environment of deposition. A gas chromatograph is an oven containing a long, thin coiled column of metal or glass. One end of the column is attached to a heated injection port, through which the sample can be introduced into the column. The other end is attached to a detector that can monitor the passage of the compounds out of the column after they have been separated.

The column itself can be either a packed column or a capillary; capillary columns are far more common today. Packed columns contain a porous solid support material coated with a nonvolatile liquid (organic polymer). The much thinner capillary columns have no solid support: the polymer is coated directly on the walls of the column.

At the beginning of an analysis the sample is injected with syringe into the hot injection port. The molecules in the sample are vaporized rapidly and swept onto the column by an inert gas flowing continuously through the column. The components of the injected mixture separate as a result of difference in vapour pressure above the liquid phase and in solubility in the liquid phase. The rate of the movement of a particular molecule through the column, therefore, depends upon how much time it spends in the vapor phase (in which it can be swept along) and how much time it spends immobilized in the liquid phase. Heavy molecules generally move more slowly than light ones, and polar molecules move more slowly than non-polar ones. During the analysis the oven can be gradually heated to increase the volatility and mobility of the heavier molecules. This gradual increase in column temperature, which is called temperature programming, permits both light and heavy components to pass through the column in a reasonable length of time.

As the compounds emerge from the column, they are detected, and a signal proportional to their concentration is recorded. The trace representing all the emerging compounds is known as a gas chromatogram. Each peak ideally represents a single compound, but sometimes two or more compounds emerge simultaneously, and their peaks overlap.

Identification of the compounds represented by the peaks is done by their retention time (time required for components to emerge from the column). Quantification of these compounds is accomplished by measuring the areas under the peaks using an automatic integrator attached to the detector (Appendix - IV).

c) Optical Methods

For the evaluation of the quality of organic matter, the environment of deposition and the source of the biogenic matter, the optical methods constitute an important tool. The optical examination of organic matter provides good information on the type and evolution of Kerogen. It is also possible, in addition, to recognise the intermixing of different types of organic matter from different sources, either contemporaneous or reworked from previous sedimentary cycles. This technique has two main tools:-

i) Microscopic studies under transmitted light.
ii) Microscopic studies under reflected light.

i) Microscopic studies under transmitted light.

The microscopic studies under transmitted light for the study of Kerogen is done to identify spores, pollens, phytoplanktons and other associated fossils such as cuticles, cellular remains, resins, tracheids, fusinite or charcoal, vitrinite, bituminite, colloidal organic matter like amorphous organic matter, gray amorphous organic matter and bacterial remains of the organic matter. This study helps in classifying rocks in terms of their genetic potential.

Staplin (1969) attempted a detailed classification under primary and modified material. The primary material included terrestrially and marine derived organic matter.

Primary Material

a) Terrestrial Sources:
   - Plant leaf and stem
   - Plant spores and pollens
   - Lignified wood fragments - partially fusinised
   - Mineral charcoal - fusain, micrite, resin
   - Planktonic fresh water algal.

b) Marine Sources:-
   - i) Phytoplankton
   - ii) Benthos-Bacteria, algae and fungi.

Modified Products:-

a) Fluffy to semi coherent masses

b) Finely dispersed organic matter

c) Platy, translucent, brittle amber material

d) Resistant, inert platy modified cuticular remains.

Palynological examination of Kerogen under transmitted light is done on organic matter slides. Organic matter slides were prepared for present study (Appendix V) out of the samples crushed to pea size and treated with HCl and HF. Separation of palynofossils/organic matter and the mineral residue was done by heavy liquid density flotation/sink procedures. Heavy liquid with specific gravity of 2.3 was prepared. Glacial acetic Acid (CH_3COOH) was used for cleaning and polishing the spores and pollens. (Appendix V). This palynological study is very important for the study of evaluation of organic matter as well as for the type of organic matter.

ii) Microscopic Studies under reflected light.

This technique which is used in the study of organic particles has been from coal petrology. Under microscope sedimentary organic matters are not homogeneous substances. They are composed of macerals. A maceral is defined as optically homogeneous, aggregate of organic substances that possess distinctive physical and chemical properties. All the macerals can be grouped in three main groups, Vitrinite, Liptinite or Exinite and Inertinite.

In order to study the source rock samples under reflected light polished pellets were prepared. For that the samples were crushed and the grain were mounted in araldite epoxy resin. The ratio of araldite and hardner varies with atmospheric temperature. The mounted sample is grounded and polished with Isopropyl alchohol $(CH_3)_2CHOH$ as lubricant.

Organic matter, as mentioned earlier consists of three constituents in the form of maceral grains viz. Vitrinite, Liptinite, and Inertinite. Predominance of one over the other is an indicator of the environment of deposition and the source of the biogenic matter.

2.2.3 . Maturation of Organic Matter

Fine grained sediments having right type of organic matter and sufficient amount may not generate petroleum hydrocarbons unless the organic matter is not optimally matured. Thus it is also necessary to investigate the extent of thermal maturation of organic matter in the sediments.

As, the effect of temperature and time are now recognized as essential parameters in evaluating maturation processes, various individual workers (Laptante, 1974 ; Momper, 1978 ; Hood et al. 1975 and Waples, 1980) studied the effect and independently concluded that the rate of chemical reactions in organic maturation of organic matter appears to approximately double with every 10° C rise in temperature.

Kerogen maturation is not a reversible process (Waples, 1980). Furthermore, the chemical process of maturation never stops completely, even if drastic decrease in temperature occurs, as per chemical reaction-rate theory. As per this theory, at any temperature above absolute zero, reactions continually take place at some definable rate. For practical purposes, however, the rates of catagenesis are generally not important at temperatures below 70° C (Waples 1980).

During thermal metamorphism or 'Catagenesis" the term suggested by Vassoevich (1957) and Tissot and Welte (1978) ,the organic matter experiences major changes, first liquid petroleum then at a later stage "wet gas" and condensate and finally methane is produced.

2.2.3.1 Stages of Thermal Maturation

An admirable account of evolution of the organic matter from the time of deposition to the beginning of metamorphism, is given by Tissot and Welte, 1978, (Fig. 2.4). The evolutionary paths, with increasing thermal degradation of various types of kerogen, have been demarcated into successive stages of diagenesis, catagenesis and metagenesis on the van Krevelen diagram by these workers (Fig. 2.5). These stages of Kerogen evolution are discussed herewith.

a) Diagenesis

Diagenesis is a process through which the organic material alongwith minerals, large amounts of water and numerous living microorganisms deposited in subaquatic environments tends to approach equilibrium under conditions of shallow burial, and through which the sediments normally becomes consolidated.

During early diagenesis, one of the main agents of transformation is microbial activity. Aerobic microorganisms that live in the uppermost layer of sediments consume free oxygen. Anaerobes reduce sulfates to obtain the required oxygen. Within the sediments, organic material proceeds also towards equilibrium, previous biogenetic polymers or "Biopolymers" (proteins, carbohydrates) are destroyed by microbial activity during sedimentation and early diagenesis. Then their constituents become progressively engaged in new polycondensed structures ("geo-polymers") precursing Kerogen. The most important hydrocarbon formed during diagenesis is methane.

The end of diagenesis of sedimentary organic matter is most conveniently placed at the level where extractable humic acids

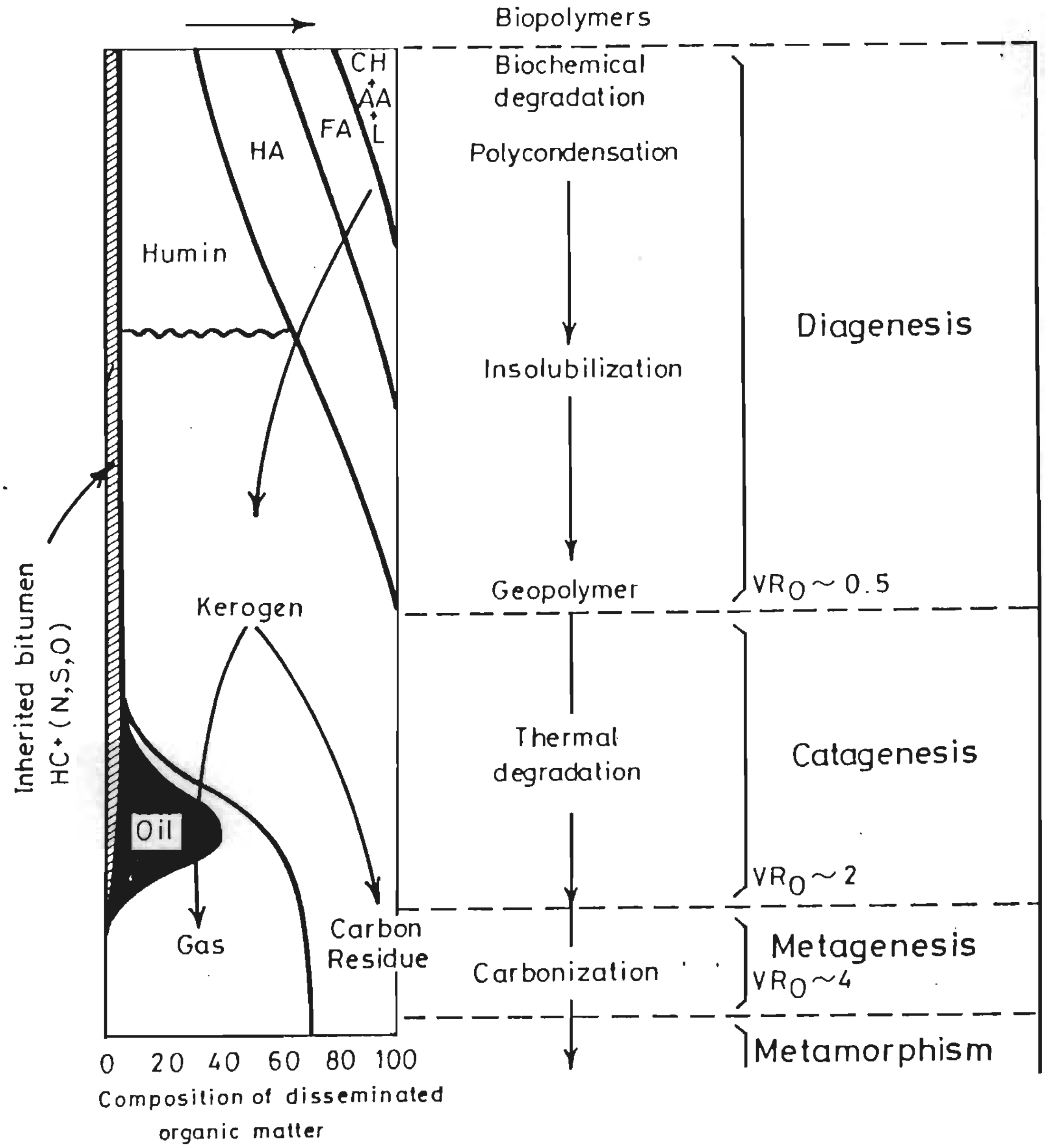


Fig. 2.4 General scheme of evolution of the organic matter, from the freshly deposited sediments to the metamorphic zone. CH : carbohydrates, AA : amino acids, FA : fulvic acids, HA : humic acids, L : lipids, HC : hydrocarbons, N,S,O : non-hydrocarbons (After Tissot & Welte, 1978).

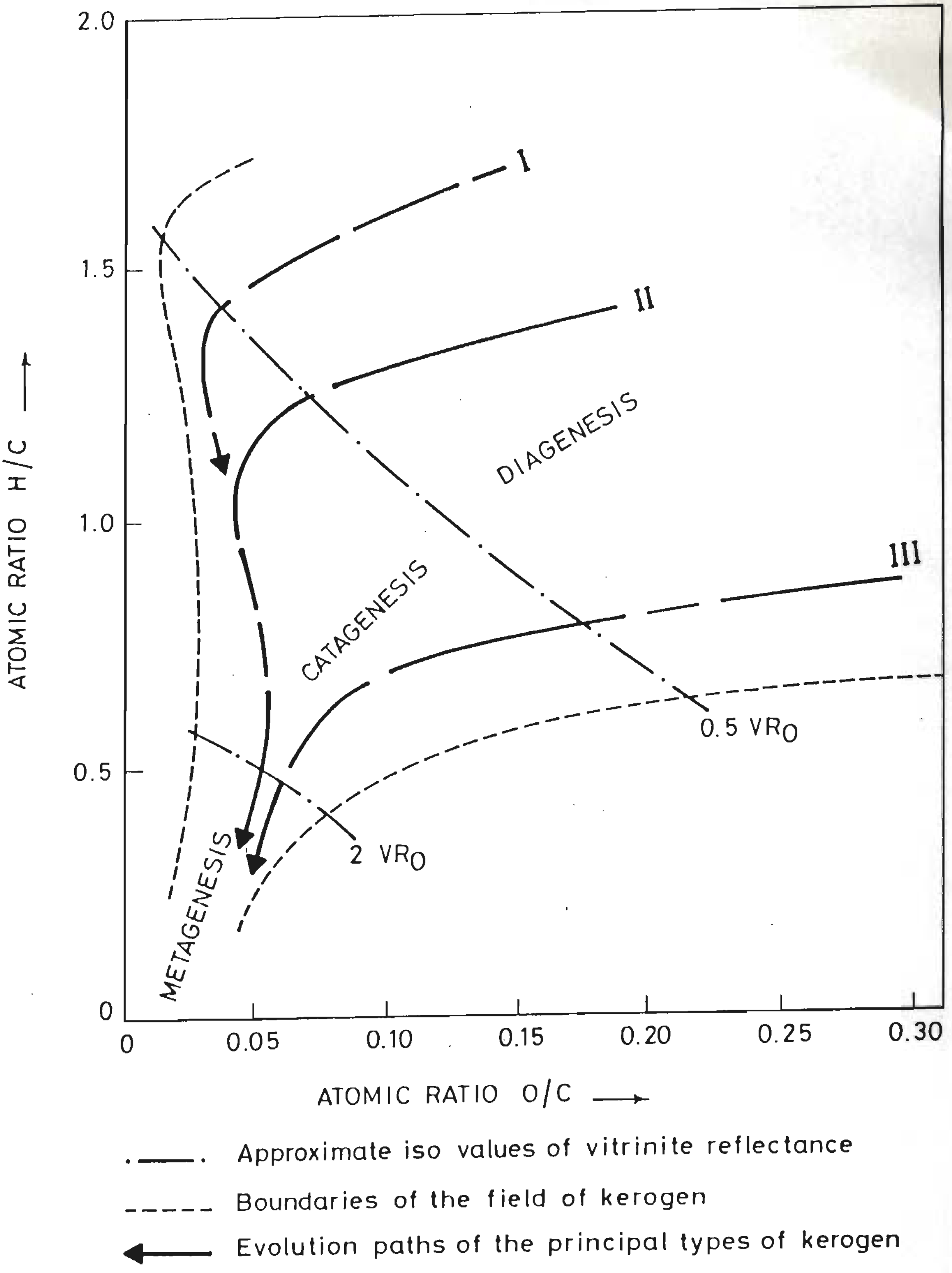


Fig. 2.5 Evolution of kerogen from diagenesis to metagenesis in the van Krevelen diagram (After Tissot & Welte, 1978)

have decreased to a minor amount and where most carboxyl groups have been removed.

Diagenesis of Kerogen is marked by an important decrease of oxygen and a correlative increase of carbon content with increasing depth. When referring to the van Krevelen diagram (Fig.2.5), this stage of evolution results in a slight decrease of H/C and marked decrease of O/C ratios. In terms of petroleum exploration, this stage corresponds to an immature Kerogen.

b) Catagenesis

Consecutive deposition of sediments results in burial of previous beds to a depth reaching several kilometers of overburden in subsiding basins. This means a considerable increase in temperature and pressure. Tectonics and other natural phenomena such as volcanic activities may also contribute to this increase. Tissot and Welte, 1978, suggested the word catagenesis for this stage and mentioned its previous proposal by Vassoevich (1957) and Strakhov (1962).. Temperature may range from about 50 to 150°C and geostatic pressure due to overburden may vary from 300 to 1000 or 1500 bars. Such increase again places the system out of equilibrium and results in new changes.

Organic matter experiences major changes : through progressive evolution, the Kerogen produces first liquid petroleum; then in a later stage "Wet Gas" and condensate; both liquid oil and condensate are accompanied by significant amounts of methane. Massive organic deposits progress through the various ranks of coal, and also produce hydrocarbons, mostly methane. Due to generation and release of these hydrocarbons, an important decrease of the hydrogen content and of the H/C ratio is observed.

The end of catagenesis is reached in the range where the disappearance of aliphatic carbon chains in kerogen is completed, and where the development of an ordering of basic kerogen units begins. This corresponds to vitrinite reflectance of about 2.0% which, according to various coal classification, is approximately the beginning of the anthracite ranks.

In terms of petroleum exploration, the state of catagenesis corresponds to the main zone of oil generation and also to the beginning of the cracking zone, which produces "wet gas"with a rapidly increasing proportion of methane. Since with further evolution there is no more generation of petroleum except a limited amount of methane, according to Tissot and Welte, 1978, this point can be a break and border line for the subsequent stage, metagenesis.

c) Metagenesis

Metagenesis of kerogen can be observed in very deep samples or in locations with a high geothermal gradient. Elimination of hydrogen is slow and the carbon content may reach in an extreme case to 91% by weight and the H/C atomic ratio is only 0.4. Aliphatic and C = 0 bonds have vanished (Tissot and Welte, 1978).

The beginning of metagenesis corresponds approximately to a vitrinite reflectance of 2% at this stage, a major rearrangement of the aromatic nucleus occurs. The stacks of aromatic layers, previously distributed at random, now gather in clusters with a preferential orientation. Beyond the level of 2% reflectance, anisotropy of vitrinite begins to appear.

Metagenesis is the last stage of kerogen evolution which concerns the petroleum geologist. At this stage of metagenesis the organic matter is composed only of methane and a carbon residue. Therefore in terms of petroleum exploration, this stage is entirely situated in the dry gas zone.

d) Metamorphism

The last stage of the evolution of sediments, which is known as metamorphism, is reached in deep troughs and in geosynclinal zones. Here temperature and pressure reach high values; in addition, rocks are exposed to the influence of magma and hydro thermal effects. This stage is succeeding metagenesis stage which has been variously characterized and designated as early metamorphism, epimetamorphism, anchimetamorphism etc. (Tissot & Welte, 1978)

True conditions of metamorphism result in greenschist, and amphibolite facies development. Coal is transformed into meta-anthracite, which has a vitrinite reflectance of more than 4%.

The constituents of the residual kerogen are converted to graphitic carbon.

2.2.3.2 Technique Used to Determine the Stages of Maturation:

During the process of maturation many physical or chemical properties of the organic matter change. These changes can be used to differentiate, diagenesis, catagenesis and metagenesis stages of thermal maturation from each order. The parameters used in this study are (i) Tmax data of Rock-Eval Pyrolysis, (ii) componental analysis of extractable organic matter, (iii) gas chromatographic data, (iv) Vitrinite Reflectance VR_o, (v) Thermal Alteration Index (TAI), (iv) Fluorescent study, (vii) crystallite size of Kaolinite, (viii) electromagnetic signatures. Since the last two parameters are not done on the organic matter, but the sediments, therefore, they will bee separately discussed in Chapter 6. Rest of the parameters are more or less discussed before and therefore will not be repeated here.

2.3 SUMMARY

Petroleum source rocks are evaluated by knowing amount of organic matter content in terms of their insoluble (kerogen) and soluble (bitumen) constituents, type or quality and the state of maturity of organic matter.

The quantity or amount of organic matter is generally estimated by Total Organic Carbon (TOC) content of a source bed.

The quality or type of organic matter is categorized into Type I, Type II, Type III and Type IV kerogen. There are various techniques to determine type of organic matter, such as chemical methods, pyrolysis and optical methods. Transmitted light microscopy is among the strong tools for determining the type of organic matter.

The successive stages of maturation towards the thermodynamic equilibrium are, diagenesis, catagenesis metagenesis and metamorphism of organic matter. Maturation of organic matter can also be determined by various physico chemical or optical techniques.

CHAPTER - 3

SOURCE ROCK ANALYSIS OF BARAKAR SEDIMENTS

3.1 PRELIMINARY

Barakar sediments consist of shale-coal-sandstone sequences forming more than 1250 m in terms of their thickness. Shales which constitute about 60-65% of these sediments form the major object of the present studies. The study is confined to Chasnala, Bhaunra and Phulwaritand-Maheshpur areas of the Jharia coalfield (Fig.1.2) As mentioned earlier, these sediments have been intruded by numerous intrusions of mica-peridotite and dolerite in the form of dykes and sills. In view of this, samples were collected systematically across the intrusive bodies so that source rock potential of these sediments affected by intrusions can also be studied along with those of the unaffected sediments. A total of 146 samples were collected from Bhaunra, Chasnala Phulwaritand- Maheshpur areas. Details of these samples along with sample number, area of collection, distance from the corresponding intrusion across which collection was done, thickness of the intrusion and finally lithology of the samples are given in Appendix-I.

3.2 MODE OF SAMPLING

Linear systematic sampling technique was adopted to collect samples from Chasnala, Bhaunra and Phulwaritand-Maheshpur areas across the igneous intrusives (12 dykes and 6 sills). The samples were collected at spacing varying from 5 to 150 cm apart, along a line normal to the trend of the igneous intrusives. Care was taken to collect fresh and unweathered samples of size 5" x

5" x 5". The detailed sampling plan for Chasnala, Bhaunra and Phulwaritand-Maheshpur areas is shown in figure 3.1.

3.3 CHASNALA AREA

This block is located between latitudes N 23° 39'36" to 23° 40'15" and longitudes E 86° 27' 24" to 86 28' 12" in the south eastern most part of the Jharia coalfield and about 35 km from Dhanbad towards Sindri. It is bounded on the north, east and south by metamorphics and on the west by Bhaunra Block (Fig.3.2).

The general strike of the formation is NW-SE. It changes gradually to NNE-SSW in the central part and finally to NE-SW in the southern part. The corresponding dip of the formations in major part of the block is south-westerly. The amount of dip varies from 30° in the north to about 60° in south but over a greater part it is around 45°.

The beds are folded into a broad syncline with northern limb well preserved in the block and much of the southern limb is cut-off by fault. The remaining southern limb has been subjected to further folding into an anticline and syncline. The direction of plunge of the major synclinal fold and also that of the minor anticlinal fold is westerly. A total of 5 major faults with throw of upto 170 m have been deciphered (Verma et al 1989).

At three locations in the Chasnala area, a total of 42 samples across five intrusions were collected (Fig. 3.2). The first location is within hundred meters north of the Dhanbad - Sindri road bridge, upstream on the Domohani nala. On either side of an intrusion the samples were collected along the trends A and B. Further upstream side, about 200 m north of the first

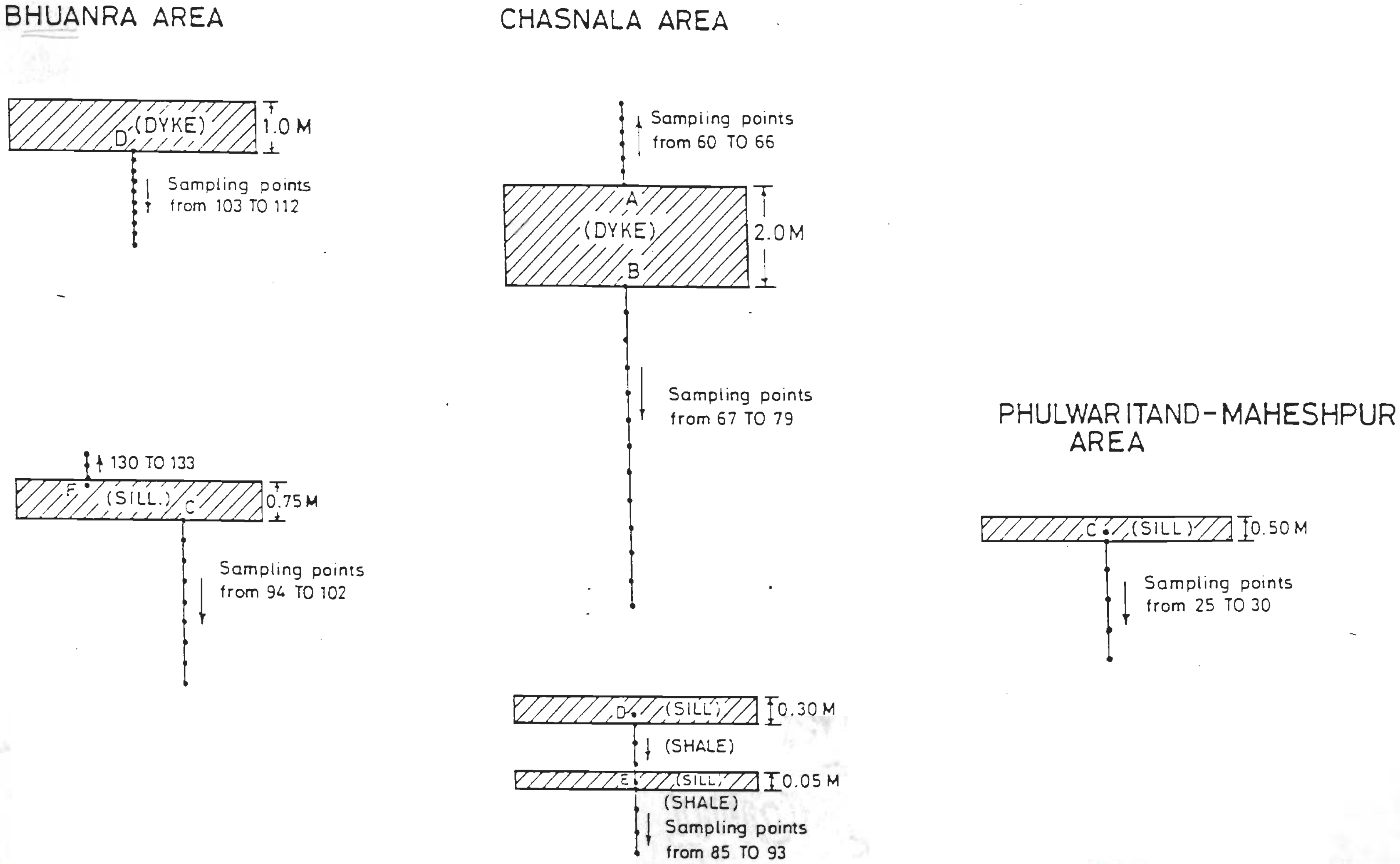


Fig. 3.1 Detailed plan showing the mode of sampling for selected sections.

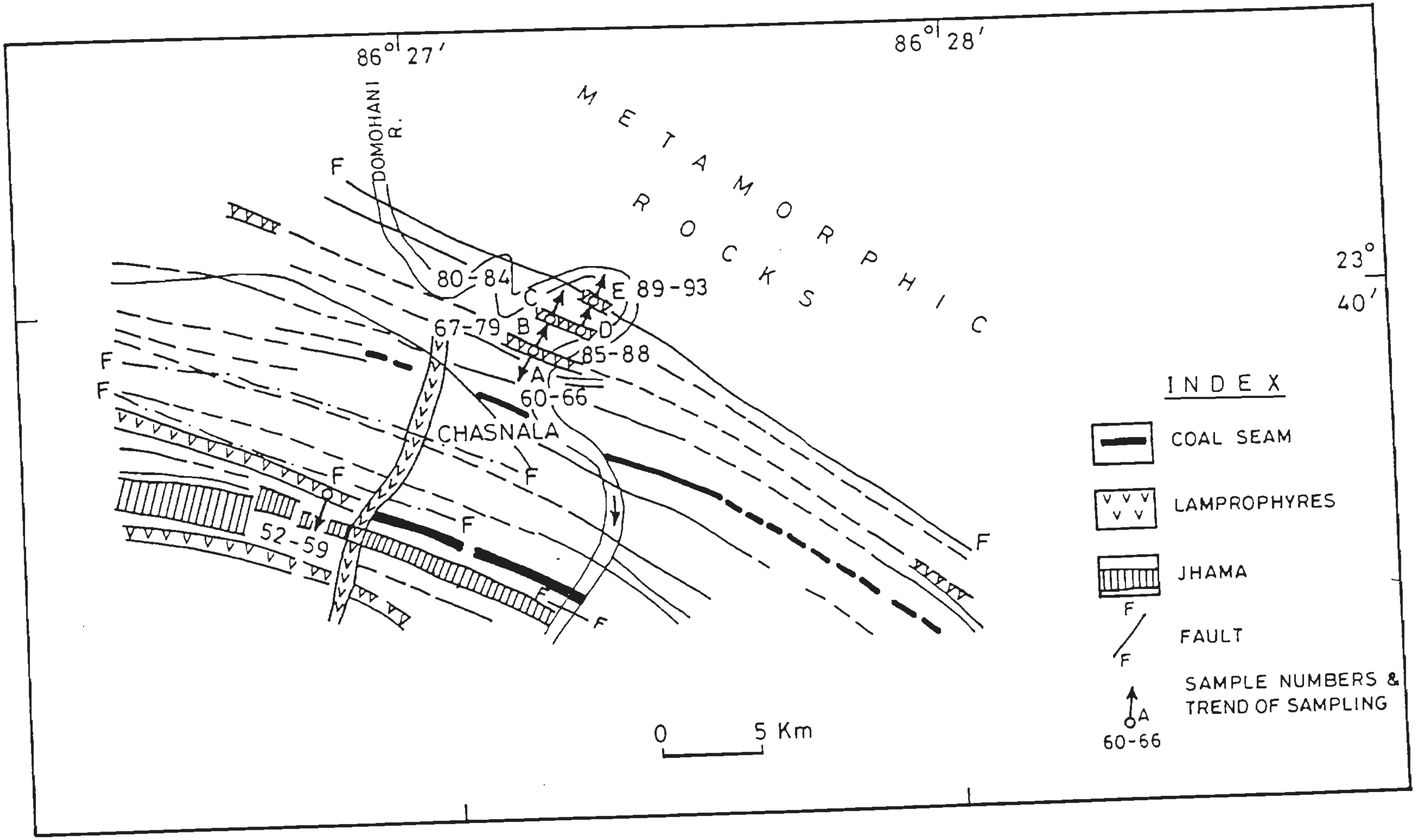


Fig. 3.2 Geological map of Chasnala area (Modified after G.S.I., Mittal, 1987).

location lies the second location where three thin intrusions are observed and the samples were collected along the trends C, D and E. The third location is situated about 16 km southwest of two above mentioned locations and across a good exposure of an intrusion as shown in the map (Fig. 3.2) the samples were collected along the trend F. Details of these samples are given in Appendix - I.

3.4 BHAUNRA AREA

This block is located between latitudes N 23° 40' 29° 41' 4" and longitudes E 86° 23' 12" - 86° 25' 29" in the south eastern part of Jharia coalfield (Fig. 3.3). It is bounded on the north mostly by metamorphics and on the west by Damodar river.

The general strike of the strata in the southern part of the field is WNW - ESE. It swings to almost N-S in the western part and E-W in the eastern part. Correspondingly the dip of the strata is towards WSW, west and south respectively with dip generally varying from 20° to 30°. But gentler dips of 15° or less have been met within the axial region of the fold or central part of Bhaunra. The strata of this block are folded forming a westerly plunging asymmetrical anticline. The major part of the block constitutes the southern limb of the fold. The important structural features of the block are Petia Dungri fault occurring in the west and Patherdih horst in the north east. The strata of this area appears to have been faulted repeatedly by various generations of faults. Faults in the area are about 54 in numbers with maximum throw upto 350 m (Verma et al., 1989). There are 50 correlatable coal horizons/sections, out of which 30 coal seams are found to be affected by igneous intrusives (Verma

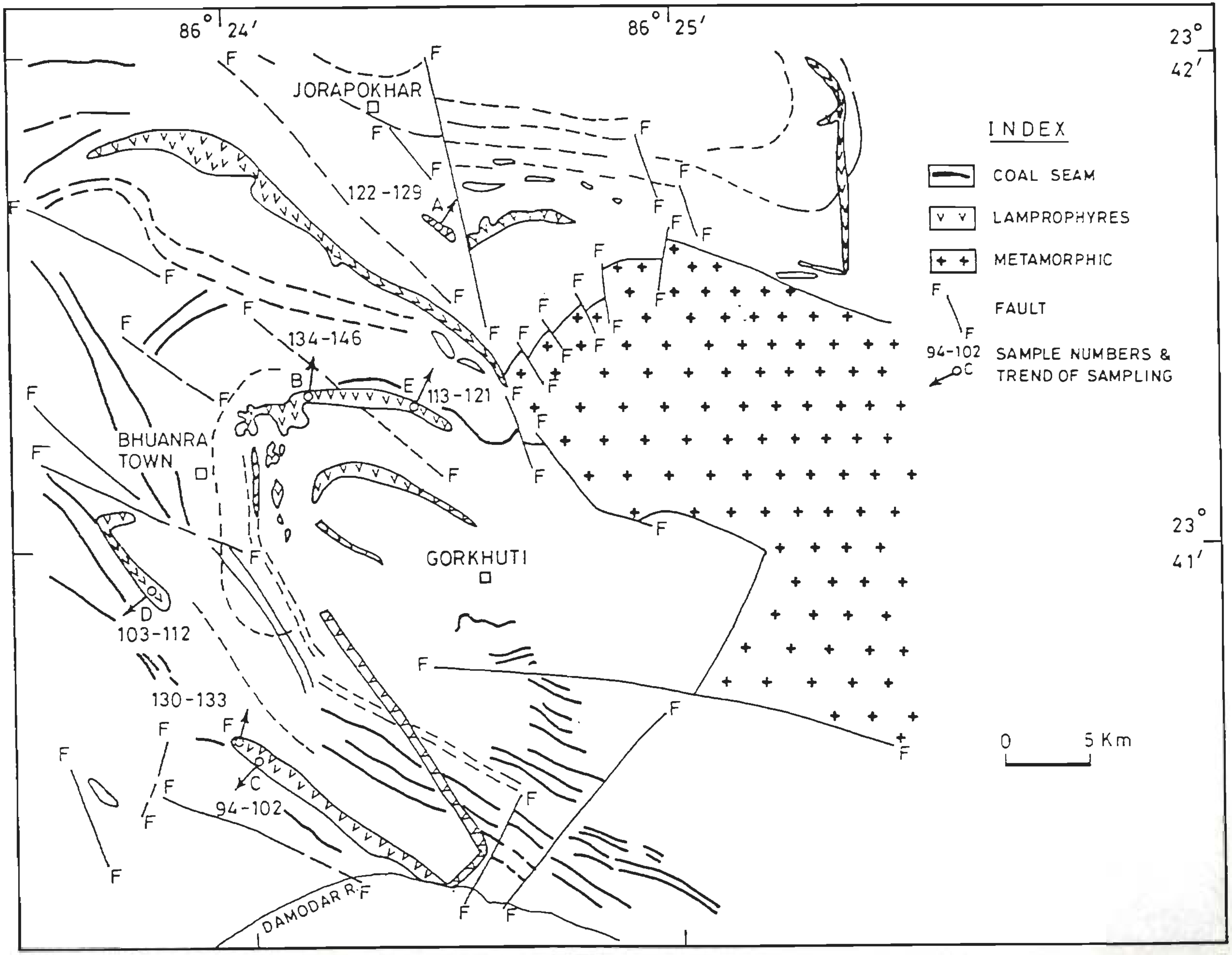


Fig. 3.3 Geological map of Bhaunra area (Modified after G.S.I., Mittal, 1987).

et al., 1989).

A total of 54 samples were collected along the trends A, B, C, D, E and F (Fig. 3.4) across 4 intrusions on one or the either sides.

At one intrusion, situated about 6 km southeast of Jorphokhar, 8 samples were collected at spacing 25 cm along A. From a location 15 km NNW of Gorkhuti towards southwest of A, 23 samples, were collected at spacing of 10 cm and 50 cm along B and E respectively. Along C & F which are situated 19 km SW of Gorkhuti, 13 samples were collected at spacing of 25 cm and 10 cm respectively. At another location, towards northwest of the points C and F, 10 samples at spacing of 20 cm were collected along D for the present study. The lithology of the samples along with other details such as thickness of intrusions across which the samples were collected and the distance from the intrusions are given in Appendix - I.

3.5 PHULWARITAND - MAHESHPUR AREA

Since Phulwaritand and Maheshpur areas are very close they have been grouped as one area. The block is located between latitudes N 23° 45' 54" to 23° 47' 12" and longitudes E 86° 12' 27" and 86° 14' 57" in the western part of the Jharia coalfield.

The strike of the formation is generally ENE - WSW swinging to NNE-SSW in the western part. The dip generally varies from 8° to 35° towards south. Steep dip is observed in the southern part. About 23 faults with a maximum throw upto 240 m are recorded in the area (Verma et al., 1989) 33 out of 38 coal seams are pyrolitised to varied extent by igneous intrusions in the

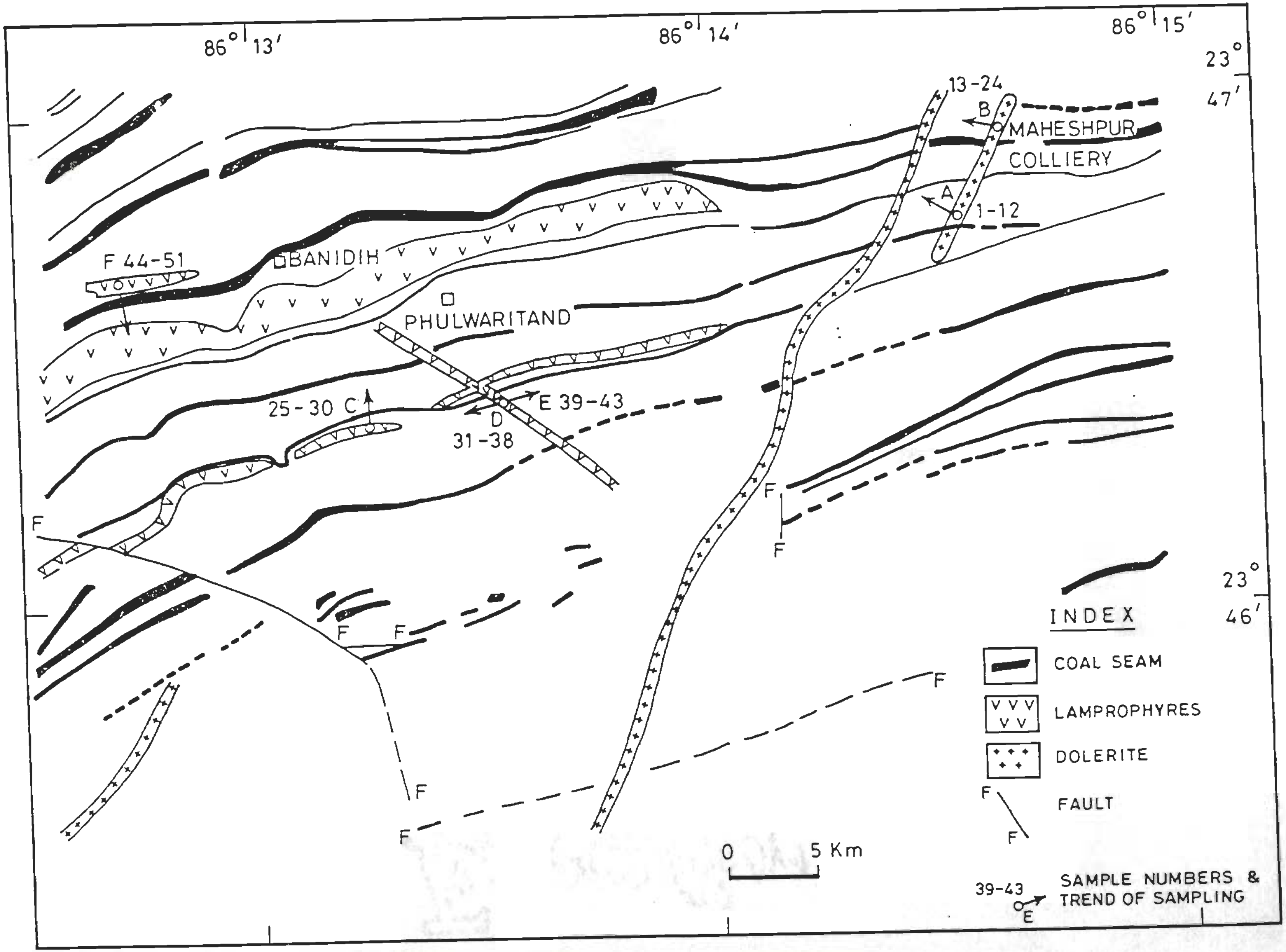


Fig. 3.4 Geological map of Phulwaritand - Maheshpur area (Modified after G.S.I., Mittal, 1987).

region.

Samples were collected across an igneous intrusion just west of Maheshpur Colliery A and B. In and around Phulwaritand town samples along C,D and E. Finally, to the west of Banidih, samples were collected along F were collected (Fig. 3.4). Details of samples and their field position are given in Appendix - I.

3.6 SOURCE ROCK STUDIES

The present study is based on a total of 10 different analyses on 146 samples (Fig. 3.5). The investigations were made in order to determine the organic matter richness, quality of organic matter, maturation and time of generation of petroleum hydrocarbons. The details are discussed herewith.

3.6.1 ORGANIC MATTER RICHNESS

Organic carbon in sediments is normally determined by high-temperature combustion of pulverized rock to CO_2 in an oxygen atmosphere after removal of inorganic (carbonate) carbon by acid leaching. This total organic carbon (TOC) concentration is related directly with the organic matter richness of a source rock. Tissot and Welte (1978), have given a multiplication factor of 1.48 and 1.18 for diagenesis and end of catagenesis stages of type III Kerogen (Table 2.1) respectively.

For the present study 128 samples (49 from Bhaunra, 34 from Chasnala, 25 from Phulwaritand and 20 from Maheshpur) were selected and their total organic carbon (TOC) was determined.

3.6.1.1 Determination of Total Organic Carbon (TOC)

The combustion apparatus used here was Leco carbon analyser, model CR12 (located in KDM Institute of Petroleum Exploration in

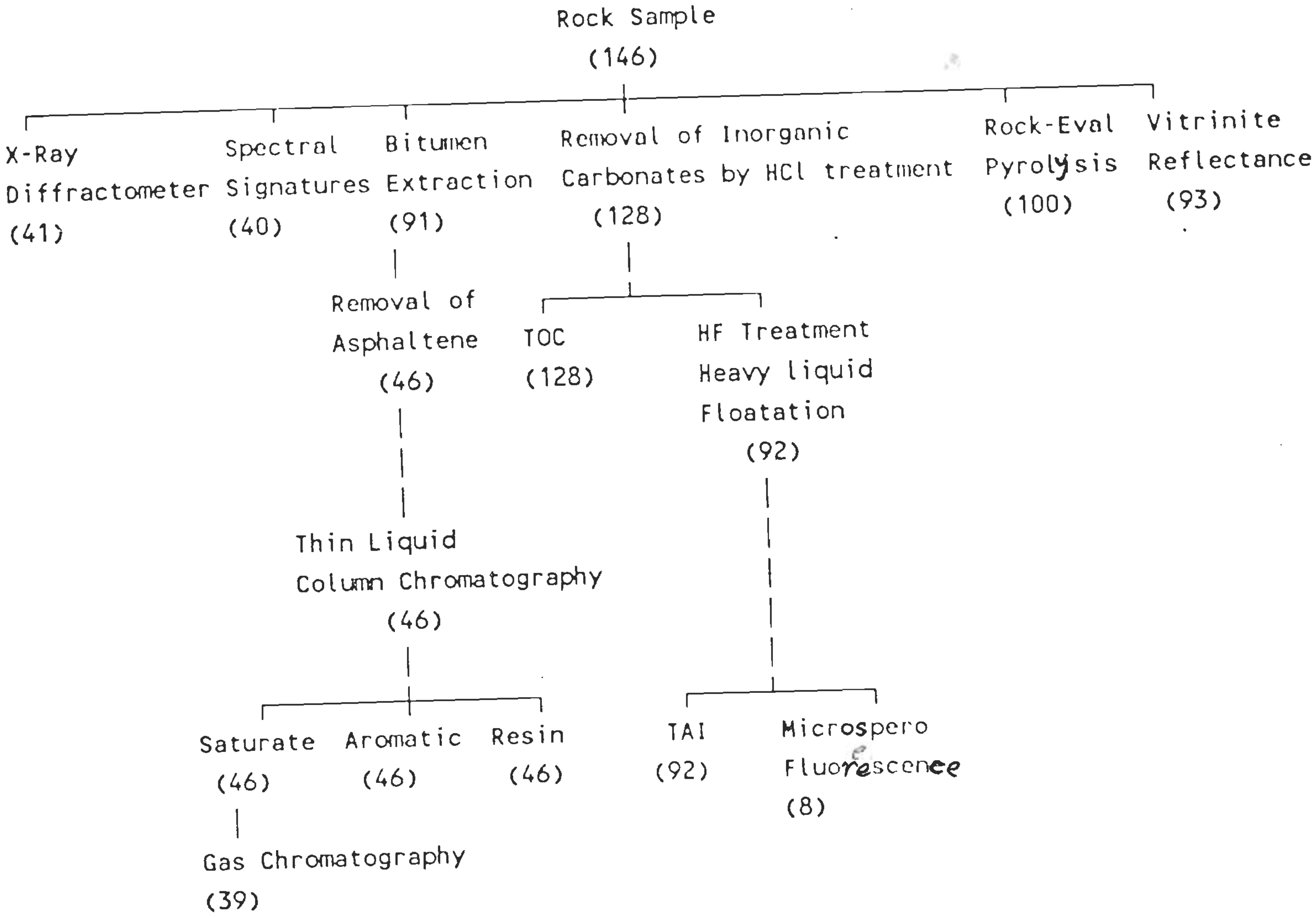


Fig.3.5. Chart showing Geochemical and Geooptical studies carried out on sediments of the Barakar Formation. The numbers in bracket indicate the samples studied.

Dehradun, India) which utilizes an induction furnace with an IR detector to measure the organic carbon which is converted to carbon dioxide. The Co_2 trapped within the instrument and then released into other detector when combustion is complete.

For standardization of the instrument, calcium carbonate ($CaCO_3$) was used. 0.05 gm of calcium carbonate was combusted. The molecular weight of calcium carbonate is 100 and Leco instrument gives 12 percent of organic carbon for it.

After standardization of the instrument about 0.01 gm in the case of coals and about 0.05 gm for shales which were acid treated and dried, were taken in the `Boat' (3" long and 1/2" dia.) and were analyzed in Leco carbon determinator.

3.6.1.2 Total Organic Carbon Content of Sediments

The Total Organic Carbon (TOC) content of these samples (102 from shale and 26 from coaly shale) varies as expected, from higher values in coal rich sediments to lower value in shales (Table 3.1). The coal samples have TOC values, at times, as high as 61.46%. In Chasnala area, the TOC content of 13 coaly shale samples range from 0.94 to 57.8% with an average of 32.01%, whereas the TOC of 21 shale samples in this area varies from 4.09 to 49.86% with an average of 13.19%. In Bhaunra area the TOC values of 9 coaly samples range from 13.58 to 61.46% with an average of 44.83% and the shales (39 in number) in this area have wide range of TOC ranging from 0.22 to 36.80% with an average of 10.97%. In Phulwaritand a TOC range of 1.91 to 53.98% with 33.23% as an average for 4 coaly shale samples and 0.22% to 3.85% with an average of 1.55% for 21 shale samples was

TABLE 3.1 **Total organic matter content in the shales of the Barakar Formation**

Sl.No.	Sample	Distance from Intrusion m)	Total Organic Carbon content Percentage	Organic Matter Percentage
		CHASNALA AERA		
1.	52	0.00	0.94	1.05
2.	53	0.50	57.80	64.74
3.	54	1.00	33.92	40.03
4.	55	2.50	4.88	7.22
5.	56	3.00	2.83	4.19
6.	57	3.50	17.37	25.71
7.	58	4.50	4.09	6.05
8.	59	7.50	50.39	51.90
9.	60	0.00	12.77	14.30
10.	61	0.25	1.95	3.06
11.	62	0.50	3.35	5.26
12.	63	0.75	49.23	61.54
13.	64	1.00	32.62	14.78
14.	65	1.25	49.86	62.33
15.	66	1.50	39.10	50.83
16.	67	0.00	55.03	61.63
17.	68	0.50	34.81	38.99
18.	69	1.00	48.23	54.02
19.	70	1.50	16.67	18.67
20.	71	2.00	52.31	75.85
21.	72	2.50	14.37	21.56
22.	74	3.50	4.81	6.97
23.	77	5.00	7.58	10.99

24	79	6.00	6.81	9.87
25.	82	0.00	10.47	12.35
26	83	0.10	5.01	5.91
27	84	0.20	14.53	17.15
28.	86	0.00	7.30	8.61
29.	87	0.10	10.39	12.26
30.	88	0.20	11.42	16.56
31.	90	0.00	13.58	16.02
32.	91	0.05	6.30	9.32
33.	92	0.10	4.54	5.36
34.	93	0.15	7.88	9.30

U

BHANRA AREA

35.	94	0.00	34.38	39.54
36.	95	0.25	5.60	7.00
37.	96	0.50	6.33	9.18
38.	97	0.75	3.37	4.55
39.	98	1.00	9.36	12.82
40.	99	1.25	12.21	18.07
41.	100	1.50	2.89	4.28
42.	101	1.75	2.98	4.41
43.	102	2.00	13.58	21.32
44.	104	0.20	39.03	43.71
45	106	0.60	41.17	46.11
46.	107	0.80	39.71	44.48
47	108	1.00	11.49	12.87
48.	109	1.20	10.16	12.70
49.	110	1.40	1.41	1.76

50.	111	1.60	2.48	3.22
51.	112	1.80	1.41	1.69
52.	113	0.00	50.24	56.27
53.	114	0.50	0.58	0.70
54.	115	1.50	27.21	40.27
55.	116	2.00	20.79	41.19
56.	117	2.50	21.83	32.31
57.	118	3.00	18.23	27.35
58.	119	3.50	0.57	0.86
59.	120	4.50	15.67	23.51
60.	121	5.50	36.80	55.20
61.	122	0.25	0.22	0.26
62.	123	0.75	0.35	0.42
63.	124	1.50	34.33	38.45
64.	125	2.50	18.81	22.57
65.	126	3.00	3.73	4.48
66.	127	3.75	3.87	4.64
67.	128	4.50	34.77	52.16
68.	129	5.50	61.09	85.53
69.	131	0.00	61.02	68.34
70.	132	0.10	13.65	16.38
71.	133	0.20	14.81	19.25
72.	135	0.00	61.46	68.84
73.	136	0.10	14.10	16.92
74.	137	0.20	12.87	15.44
75.	138	0.30	15.23	20.56
76.	139	0.40	15.26	20.60
77.	140	0.50	12.80	16.64
78.	141	0.60	5.39	6.74

79.	142	0.70	10.98	13.73
80.	143	0.80	11.61	14.51
81.	144	0.90	1.42	1.85
82.	145	1.00	1.44	1.94
83.	146	1.10	1.68	2.18

PHULWARITAND-MAHESHPUR AREA

84.	26	0.00	0.54	0.74
85.	27	0.05	1.57	2.36
86.	28	0.10	1.74	2.26
87.	29	0.15	0.69	0.97
88.	30	0.20	0.61	0.92
89.	32	0.10	0.64	0.77
90.	33	0.20	0.22	0.29
91.	34	0.30	2.38	3.33
92.	35	0.40	1.28	1.79
93.	36	0.50	3.50	5.25
94.	37	0.60	0.81	1.22
95.	38	0.70	2.89	4.34
96.	39	0.00	0.46	0.60
97.	40	0.10	0.51	0.66
98.	41	0.20	0.63	0.82
99	42	0.30	0.77	1.16
100	43	0.40	0.85	1.28
101	44	0.75	46.30	69.45
102	45	1.00	1.91	2.67
103	46	2.00	30.73	34.42
104	47	2.50	2.31	3.47

105	48	3.00	2.84	4.26
106	49	4.00	3.85	5.78
107	50	5.00	3.56	5.34
108	51	6.50	53.98	75.57
109	1	0.00	0.15	0.20
110	2	0.50	0.15	0.20
111	3	1.00	0.34	0.44
112	4	1.50	0.11	0.15
113	5	2.00	0.28	0.42
114	6	2.50	0.19	0.29
115	7	3.00	0.24	0.36
116	8	3.50	0.32	0.48
117.	9	4.00	0.19	0.29
118.	10	4.50	0.20	0.30
119.	11	5.00	0.19	0.29
120	12	5.50	0.16	0.24
121	13	0.00	0.14	0.21
122	14	0.20	0.15	0.23
123.	15	0.40	0.31	0.47
124.	16	0.60	0.28	0.42
125.	17	0.80	0.19	0.29
126.	18	1.00	0.19	2.29
127.	19	1.20	0.20	0.30
128	20	1.40	0.18	0.27

determined. Maheshpur area situated in north west of Phulwaritand, shows a TOC range of 0.11 to 6.81% with 0.21% as an average for 21 shale samples collected from this lean organic matter area.

Although the minimum organic carbon content required to make a source rock effective has not been scientifically determined, statistical analysis of the data from petroleum rich and petroleum poor areas indicates a lower limit of 0.5% for shale and 0.3% for carbonates (Welte, 1965; Philippi, 1969; Tissot and Welte, 1978; and Kraus and Parkers, 1979) and the organic matter richness is classified as -

TOC (%)	**Organic Richness**
0.1 - 0.5	Lean (non-source)
0.5 - 1.0	Fair (marginal)
1.0 - 2.0	Average (good)
2.0 - 10.0	Above average (rich)

This, minimum organic carbon values as a source rock criteria, no longer applies to the rocks in a very advanced stage of maturation, i.e. in a metagenetic stage when only dry gas is generated. At this stage 0.3 or 0.5% organic carbon may merely indicate a residual amount of organic matter that initially might have been more than twice as high (Tissot and Welte, 1978).

On the basis of above mentioned criteria, a perusal of Table 3.1, indicates that these sediments have TOC invariably more than the threshold value of 0.5% and are, therefore, of interest from the point of view of source rock investigations and these sediments have varying levels of organic matter richness -

marginal to good to rich.

It is observed that TOC increases towards south and southeastern part of the area of study (towards Bhaunra and Chasnala, (Table 3.1). It is also important to note that the thickness of the Barakar Formation also increases towards south and southeast (Verma et al.1989), implying thereby higher prospects of these sediments in Bhaunra and Chasnala. In view of this, therefore, further detailed studies were pursued mostly on these two organic rich sediments.

3.6.2 QUALITY OR TYPE OF ORGANIC MATTER

Even though there is sufficient organic matter in these rocks, it is important to know the nature and the type of the protopetroleum source material.

To identify the type of kerogen in the Barakar Formation of Jharia and to know the status of its proneness to gas or oil, the following techniques were adopted and are discussed herewith.

- Rock Eval Pyrolysis.
- Analysis of Extractable Organic Matter
  - a) Componental analysis of Bitumen
  - b) Gas chromatography.
- Optical Examination of Organic Matter
  - a) Transmitted light
  - b) Reflected light.

3.6.2.1 Rock Eval Pyrolysis

This method is developed by Espitalie et.al (1977). A small amount of powdered sample (about 100 mg) is pyrolysed to 550° C.

A total of 100 selected samples (50 from Bhaunra, 34 from Chasnala, and 16 from Phulwaritand areas) of Shales and carbonaceous shales (Fig.3.6) of Barakar Formation were analysed to determine the quality of organic matter in the untreated bulk samples. The results of this analysis are given in Table 3.2. The cross plot (Fig. 3.7) of Hydrogen Index (HI) and Oxygen Index (OI) on modified Van krevelen type diagram indicates that the organic matter is characterized by kerogen Type III, although few samples from Phulwaritand area having very low HI and comparatively high OI are classed into Type IV kerogen. But these samples hardly comprise 8-10% of the samples.

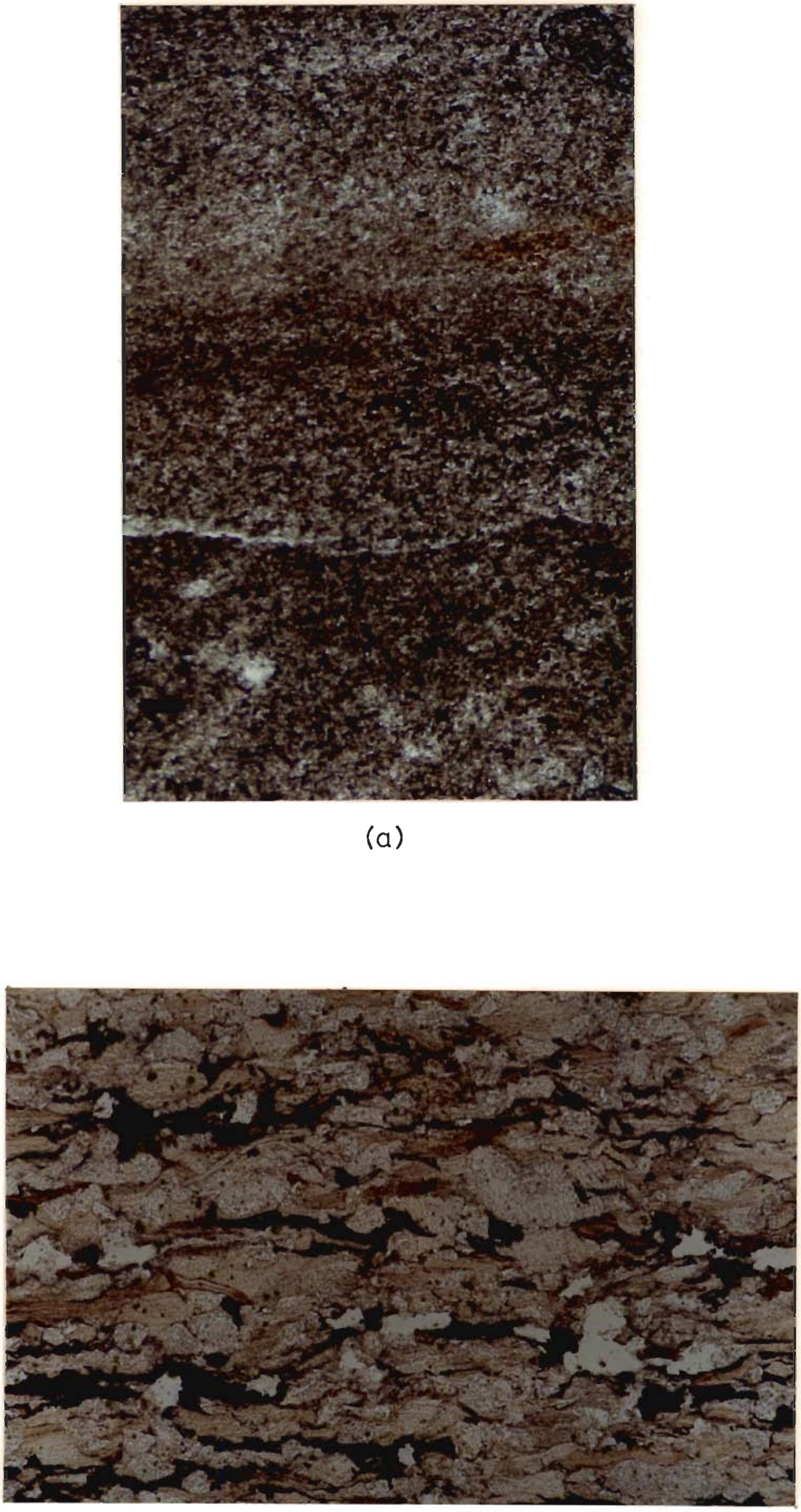
For argillaceous (clay rich) rocks containing less than 0.5% TOC the HI values are likely to be too low and Tmax too high because of adsorption of pyrolytic organic compounds into the mineral matrix. This adsorption generally decreases in the following order: Illite, montmorillonite, calcite, kaolinite (Espitalie et al,1980). Type III kerogen is most prone to this problem because it generates less pyrolyzate per gm of OM than do Type I or Type II. Fortunately all the samples selected for pyrolysis had TOC greater than 0.5% and the dominant clay mineral present in the sample is kaolinite and the expandable three layer clays which are more active in retaining pyrolyzates are absent in these samples (as discussed in chapter -6).

To differentiate maturation pathways, plots of HI vs Tmax is a method to avoid OI problems (Espitalie et al.,1984), particularly for the samples containing less than 0.5% by wt. TOC. This very strong parameter as an indicator of the type of organic matter (Fig. 3.8) picturizes that only about 10% of the

Fig. 3.6

a. Photomicrograph of carbonaceous shales (Brown: carbonaceous).

b. Photomicrograph showing carbonaceous silty shales.



(a)

(b)

FIG. 3.6

TABLE : 3.2 Rock Eval Pyrolysis Results of Shales of the Barakar Formation

Sl. No.	Sample	Tmax	S1	S2	S3	PI	S2/S3	PC	S1+S2	TOC	HI	OI
1	2	3	4	5	6	7	8	9	10	11	12	13
CHASNALA AREA												
1.	52	435	0.05	0.00	0.09	1.00	0.00	0.00	0.05	0.94	0	9
2.	53	337	0.18	0.10	2.91	0.64	0.63	0.02	0.28	57.8	0	5
3.	54	437	1.36	46.53	1.37	0.03	33.96	3.99	47.89	33.92	139	4
4.	55	438	0.15	4.08	0.36	0.04	11.33	0.35	4.23	4.88	81	7
5.	56	435	0.08	1.90	0.04	0.04	1.22	0.16	1.98	2.83	67	16
6.	57	424	1.34	47.28	0.94	0.03	50.29	1.04	48.62	17.37	272	5
7.	58	426	0.17	3.17	0.39	0.05	8.12	0.27	3.34	4.09	78	10
8.	59	419	1.43	100.61	2.32	0.01	43.36	8.50	102.04	50.39	199	5
9.	60	458	0.59	13.52	0.28	0.04	48.28	1.17	14.11	12.77	105	2
10.	61	472	0.45	2.33	0.90	0.16	2.58	0.23	2.78	1.95	110	46
11.	62	451	2.33	8.47	0.68	0.22	12.45	0.90	10.80	3.35	252	20
12.	63	470	2.73	4.17	0.63	0.40	6.61	0.57	6.90	49.23	8	1
13.	64	458	0.62	5.24	0.26	0.11	20.15	0.48	5.86	32.62	16	0
14.	65	449	2.27	41.05	1.35	0.05	30.40	3.61	43.32	49.86	82	2
15.	66	463	1.53	9.38	0.35	0.14	26.80	0.90	10.91	39.10	23	0
16.	67	547	1.58	0.16	0.82	0.91	0.19	0.14	1.74	55.03	0	1
17.	68	509	0.71	1.64	0.03	0.30	54.66	0.19	2.35	34.81	4	0
18.	69	522	0.68	0.26	0.48	0.72	0.54	0.07	0.94	48.2	0	0
19.	70	488	0.45	3.08	0.0	0.13	-	0.29	3.53	16.67	18	0
20.	71	478	0.94	3.75	0.0	0.20	-	0.39	4.69	52.31	7	0
21.	72	468	0.75	25.07	0.0	0.03	-	2.15	25.82	14.37	174	0
22.	74	458	0.87	9.57	0.35	0.08	27.34	0.87	10.44	4.81	198	7

Contd.....

Contd...table 3.2.

1	2	3	4	5	6	7	8	9	10	11	12	13
23.	77	480	1.23	3.09	0.19	0.28	16.26	0.36	4.32	7.58	41	3
24.	79	471	1.20	8.04	0.09	0.13	89.33	0.77	9.24	6.81	118	1
25.	82	477	0.06	4.68	0.80	0.01	5.85	0.39	4.74	10.47	44	7
26.	83	479	0.04	2.24	0.34	0.02	0.02	6.58	2.28	5.01	44	6
27.	84	458	0.10	13.73	0.27	0.01	50.85	1.15	13.83	14.53	94	1
28.	86	488	0.01	2.11	0.88	0.00	2.39	0.17	2.12	7.30	28	12
29.	87	451	0.01	5.89	1.27	0.00	4.63	0.49	5.90	10.39	56	12
30.	88	448	0.03	3.62	1.73	0.01	2.06	3.30	3.65	4.42	31	15
31.	90	452	0.03	7.17	1.46	0.00	0.91	0.60	7.20	13.58	52	10
32.	91	497	0.02	3.75	0.45	0.01	8.33	0.31	3.77	6.30	59	7
33.	92	480	0.02	2.07	0.21	0.01	9.85	0.17	2.09	4.54	45	4
34.	93	469	0.04	4.07	0.82	0.07	4.96	0.34	4.11	7.88	51	10
						BHAUNRA AREA						
35.	94	447	0.72	57.37	0.22	0.01	260.77	4.84	58.09	34.38	166	0
36.	95	536	0.28	1.31	0.25	0.18	5.24	0.13	1.59	5.60	23	4
37.	96	490	0.39	0.67	0.06	0.37	11.16	0.18	1.06	6.33	10	0
38.	97	458	3.39	3.40	0.45	0.10	7.55	0.31	6.78	3.37	100	13
39.	98	478	0.50	2.20	1.12	0.19	2.0	0.23	2.78	9.36	23	11
40.	99	448	0.81	10.66	0.47	0.07	20.68	0.95	11.47	12.21	87	3
41.	100	455	0.48	3.01	0.55	0.14	5.47	0.29	3.49	2.89	104	19
42.	101	470	1.07	2.69	0.95	0.28	2.83	0.39	3.76	2.98	90	31
43.	102	447	1.26	3.65	0.69	0.26	5.28	0.40	4.91	13.58	26	5
44.	103	544	0.49	1.41	0.00	0.26	-	0.15	1.90	-	-	-
45.	105	554	0.85	4.45	0.00	0.16	-	0.44	5.30	-	-	-
46.	106	553	1.85	6.26	1.26	0.23	4.96	0.67	8.11	41.17	15	3

Contd....

Contd...table 3.2

1	2	3	4	5	6	7	8	9	10	11	12	13
47.	107	544	3.53	13.14	2.33	0.21	5.63	1.38	16.67	39.71	33	5
48.	108	433	1.38	0.33	0.0	0.81	-	0.14	1.71	11.49	2	0
49.	109	470	1.44	0.94	0.0	0.19	-	0.86	2.38	10.16	87	0
50.	110	479	0.95	0.03	0.0	0.97	-	0.08	0.98	1.41	2	0
51.	111	401	0.42	0.13	0.0	0.78	-	0.04	0.55	2.48	5	0
52.	112	330	0.85	0.28	0.0	0.76	-	0.09	1.13	1.41	19	0
53.	113	440	0.35	0.13	2.91	0.73	0.04	0.04	0.48	50.24	0	6
54.	114	464	0.01	0.07	0.08	0.12	0.87	0.00	0.08	0.58	12	14
55.	115	535	0.01	0.18	23.55	0.06	0.00	0.01	0.19	27.21	0	87
56.	116	428	0.74	22.17	5.87	0.03	3.77	0.90	22.91	20.79	106	28
57.	117	434	0.95	33.27	3.28	0.03	10.14	2.85	34.22	21.83	152	15
58.	118	433	0.85	27.69	3.66	0.03	7.56	2.37	28.54	18.23	152	20
59.	119	470	0.0	0.04	0.35	0.0	0.16	0.6	0.04	0.57	7	43
60.	120	434	0.64	23.12	0.13	0.03	5.59	1.98	23.76	15.67	148	26
61.	121	433	3.99	77.51	1.71	0.05	45.32	6.79	81.50	36.80	211	5
62.	122	458	0.0	0.01	0.43	-	0.02	0.0	0.001	0.22	4	170
63.	123	449	0.00	0.16	0.46	0.00	0.34	0.01	0.16	0.35	46	131
64.	124	428	1.70	61.86	5.04	0.03	12.27	5.29	63.56	34.33	180	15
65.	125	448	0.20	6.91	9.29	0.03	0.74	0.59	6.11	18.81	37	49
66.	126	455	0.9	2.80	0.30	0.06	9.33	2.24	2.99	3.73	75	8
67.	127	439	0.24	5.33	0.40	0.04	13.22	0.46	5.57	3.87	138	10
68.	128	437	1.31	32.60	7.29	0.04	4.47	2.87	33.91	34.77	94	21
69.	129	439	2.2	37.26	4.65	0.02	18.76	7.45	39.46	61.01	143	8
70.	131	471	0.02	0.55	11.64	0.04	0.04	0.04	0.57	61.02	0	19
71.	132	456	0.20	17.40	0.0	0.01	-	1.46	17.60	13.65	127	0
72.	133	454	0.16	21.44	024	0.01	89.33	1.80	1.60	14.81	145	1

Contd....

Contd....table 3.2

1	2	3	4	5	6	7	8	9	10	11	12	13
73.	135	516	0.03	1.80	1.60	0.02	1.12	0.15	1.83	61.46	2	2
74.	136	457	0.20	13.52	0.28	0.01	48.28	1.14	13.72	14.10	95	1
75.	137	456	0.18	10.86	0.62	0.02	17.51	0.92	11.04	12.87	84	4
76.	138	452	0.25	15.27	0.55	0.02	27.76	1.29	15.52	15.23	100	3
77.	139	453	0.21	16.05	0.61	0.01	26.31	1.35	16.26	15.26	105	3
78.	140	453	0.18	11.16	0.70	0.02	15.94	0.94	11.34	12.80	87	5
79.	141	456	0.06	2.84	0.53	0.02	5.35	0.24	2.90	5.39	52	9
80.	142	453	0.07	8.51	0.61	0.01	13.95	0.71	85.8	10.98	77	5
81.	143	459	0.05	2.44	0.57	0.02	4.28	2.20	2.49	11.61	52	12
82.	144	474	0.04	0.69	1.01	0.06	0.68	0.06	0.73	1.42	48	71
83.	145	465	0.03	0.62	0.57	0.05	1.08	0.05	065	1.44	43	39
84.	146	473	0.02	0.72	1.22	0.03	0.59	0.06	0.74	1.68	42	72
PHULWARITAND - MAHESHPUR AREA												
85.	27	393	0.01	0.06	2.71	0.17	0.02	0.00	0.07	1.57	3	172
86.	28	368	0.0	0.06	1.80	0.0	0.03	0.0	0.06	1.74	3	103
87.	34	370	0.01	0.16	0.81	0.06	0.19	0.01	0.17	2.38	6	34
88.	35	337	0.0	0.03	1.07	0.0	0.02	0.0	0.003	1.28	2	83
89.	36	378	0.0	0.13	1.65	0.0	0.07	0.01	0.13	3.50	3	47
90.	38	375	0.0	0.11	1.21	0.00	0.09	0.0	0.11	2.89	3	41
91.	42	330	0.01	0.06	0.88	0.17	0.06	0.00	0.07	0.77	7	114
92.	43	330	0.05	0.56	1.20	0.25	0.13	0.01	0.61	0.85	18	141
93.	44	366	0.76	0.26	2.30	0.75	0.11	0.28	1.02	46.30	0	5
94.	45	364	0.01	0.18	1.94	0.06	0.09	0.01	0.19	1.91	9	102
95.	46	431	1.48	65.90	1.93	0.02	34.14	5.61	67.38	30.73	214	6

Contd....

Contd....table 3.2.

1	2	3	4	5	6	7	8	9	10	11	12	13
96.	47	430	0.12	1.81	0.51	0.06	3.54	0.16	1.93	2.31	78	22
97.	48	426	0.13	2.06	0.40	0.06	5.13	0.18	2.19	2.84	73	14
98.	49	429	0.11	2.59	0.40	0.04	6.47	0.22	2.70	3.85	67	10
99.	50	415	0.15	3.80	0.37	0.04	10.27	0.32	3.95	3.56	107	10
100.	51	420	0.12	15.51	1.36	0.01	11.40	1.30	15.63	53.98	29	3

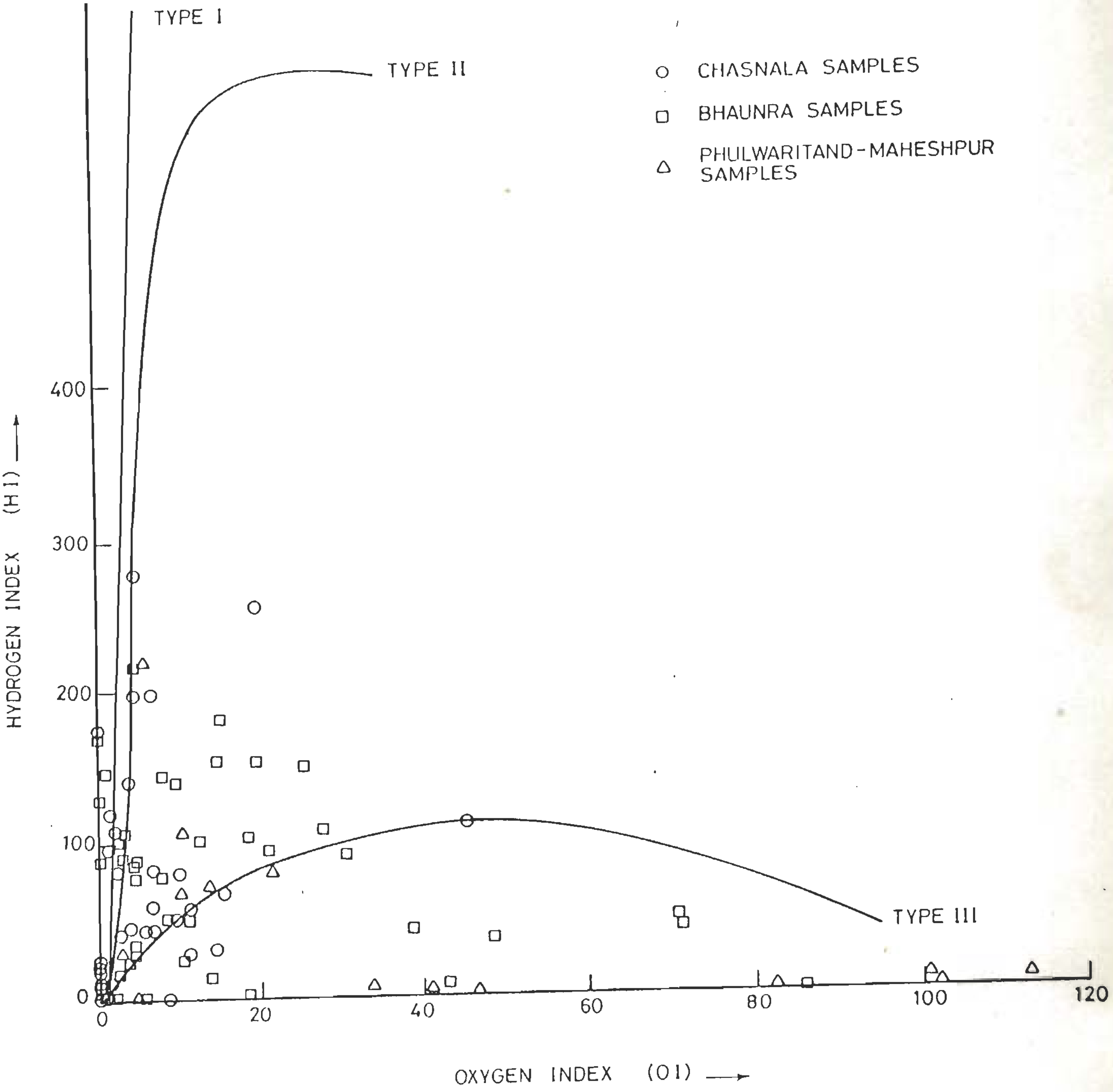


Fig. 3.7 Location of samples on modified van Krevelen diagram.

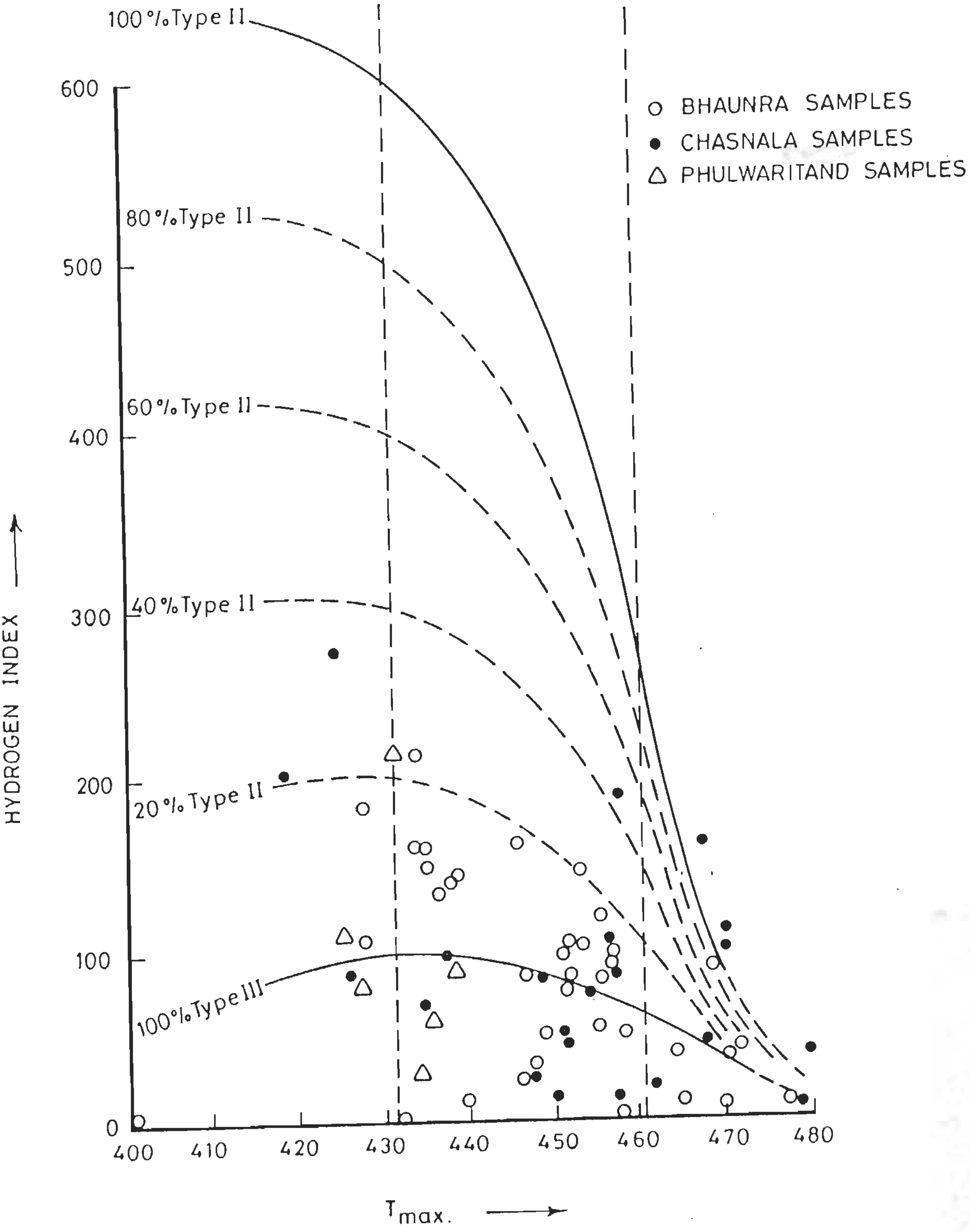


Fig. 3.8 Bivariate plot of Hydrogen Index (HI) and Tmax indicating domination of Type-III kerogen.

samples are having OM comprising of 20 to 40% Type II kerogen and thus indicating that OM is of terrestrial origin and therefore is favourable for gas generation.

The genetic potentials estimated for different areas (Table 3.2) are 0.01 to 89.48 with an average of 13.288 kg t^{-1} for 29 samples in Bhaunra area, 0.05 to 102.4 kg t^{-4} with an average of 11.69 kg t^{-1} for 34 samples in Chasnala area, 0.03 to 67.38 kg $t^{-1}$with an average of 5.59 kg t^{-1} for the samples in Phulwaritand area. From these results it is apparent that Bhaunra and Chasnala areas are good source rocks whereas Phulwaritand area is having a moderate source rock potentials.

Pyrolysis was not intended to be used without the supporting geochemistry data. For critical samples the interpretations from pyrolysis results should be verified by other analyses, such as optical examination of kerogen, vitrinite reflectance, and gas chromatography.

3.6.2.2 Analysis of Extractable Organic Matter:

(a) Componental Bitumen analysis:

Extraction of bitumens for 91 selected samples (49 from Bhaunra, 34 from Chasnala and 8 from Phulwaritand) were done by the extraction method explained in chapter -2 and Appendix - III.

Table 3.3 reveals that the bitumen content varies from 0.01 to 1.16% in Bhaunra, 0.01 to 0.66% in Chasnala and 0.02 to 0.60% in Phulwaritand areas, indicating thereby that the source rocks are mainly rich to adequate in terms of source rock potential.

The degree of bituminization (ß) measured as extractable bitumens per unit TOC can be used to know whether the source

TABLE 3.3 : Extractable hydrocarbon and degree of bituminization (ß) in the shales of Barakar Formation

Sl. No.	Sample	Bitumen extracted	Bitumen percentage	TOC percentage	Bitumen % /TOC % (ß)
			CHASNALA AREA		
1.	52	0.0223	0.021	0.94	2.247
2.	53	0.0003	0.016	57.8	0.027
3.	54	0.0157	0.533	33.92	1.510
4.	55	0.0182	0.089	4.88	1.816
5.	56	0.0290	0.082	2.83	2.885
6.	57	0.0206	0.357	17.37	2.054
7.	58	0.0154	0.063	4.09	1.549
8.	59	0.0131	0.658	50.39	0.013
9.	60	0.0208	0.060	12.77	0.467
10.	61	0.0085	0.023	1.95	1.159
11.	62	0.0582	0.186	3.35	5.546
12.	63	0.0034	0.009	49.23	0.0183
13.	64	0.0028	0.008	32.62	0.025
14.	65	0.0035	0.10	49.86	0.020
15.	66	0.0034	0.10	39.10	0.024
16.	67	0.0082	0.200	55.03	0.036
17.	68	0.0150	0.036	34.81	0.105
18.	69	0.0087	0.021	48.23	0.044
19.	70	0.2001	0.050	16.67	0.303
20.	71	0.0985	0.332	52.31	0.634
21.	72	0.0604	0.194	14.37	1.350
22.	74	0.0524	0.102	4.81	2.124
23.	77	0.0529	0.103	7.58	1.360

24.	79	0.0394	0.099	6.81	1.447
25.	82	0.0495	0.186	10.47	1.776
26.	83	0.0340	0.111	5.01	2.218
27.	84	0.0431	0.152	14.53	1.082
28.	86	0.0308	0.111	7.30	1.522
29.	87	0.0321	0.110	10.39	1.059
30.	88	0.0380	0.126	11.42	1.102
31.	90	0.0360	0.124	13.58	0.915
32.	91	0.0287	0.089	6.30	1.410
33.	92	0.0275	0.093	4.54	2.042
34.	93	0.0459	0.155	7.88	1.968

BHAUNRA AREA

35.	94	0.1460	0.490	34.38	1.425
36.	95	0.0512	0.110	5.60	1.957
37.	96	0.0573	0.123	6.33	1.940
38.	97	0.0328	0.093	3.37	2.760
39.	98	0.0175	0.056	9.36	0.596
40.	99	0.0538	0.115	12.21	0.944
41.	100	0.0569	0.122	2.89	4.215
42.	101	0.0265	0.083	13.58	2.789
43	102	0.0792	0.309	39.71	2.277
44.	104	0.0229	0.058	11.49	0.150
45.	106	0.1207	0.398	41.17	0.967
46.	107	0.1974	0.662	39.71	1.668
47.	108	0.0273	0.069	11.49	0.598
48.	109	0.1110	0.208	10.16	2.044
49.	110	0.0131	0.032	1.41	2.266
50.	111	0.0201	0.057	2.48	2.364

51.	112	0.0129	0.032	1.41	2.237
52.	113	0.0376	0.096	50.24	0.191
53.	114	0.0231	0.074	0.58	2.713
54.	115	0.0253	0.082	27.21	0.300
55.	116	0.1144	0.384	20.79	1.847
56.	117	0.1216	0.408	21.83	1.869
57.	118	0.1186	0.397	18.23	2.180
58.	119	0.0246	0.073	0.57	12.762
59.	120	0.0836	0.281	15.67	1.796
60.	121	0.2046	0.686	36.80	1.865
61.	122	0.0089	0.023	1.95	10.340
62.	123	0.0052	0.014	0.35	3.928
63.	124	0.3204	1.074	34.33	3.127
64.	125	0.0798	0.310	18.81	1.648
65.	126	0.0608	1.130	3.73	3.492
66.	127	0.0852	0.075	3.87	1.931
67.	128	0.2180	0.755	34.77	2.172
68.	129	0.3444	1.155	61.09	1.891
69.	131	0.0208	0.90	61.02	0.147
70.	132	0.0813	0.285	13.65	2.084
71.	133	0.0862	0.289	14.81	1.948
72.	135	0.0552	0.087	61.46	0.141
73.	136	0.0574	0.195	14.10	1.380
74.	137	0.0622	0.183	12.87	1.425
75.	138	0.1131	0.200	15.23	1.313
76.	139	0.0614	0.212	15.26	1.387
77.	140	0.0209	0.131	12.80	1.022
78	141	0.0662	0.060	5.93	1.111
79	142	0.0662	0.129	10.98	1.174

80.	143	0.0220	0.056	11.61	1.204
81.	144	0.0134	0.033	01.42	2.296
82.	145	0.0135	0.036	0.44	2.479
83.	146	0.0394	0.099	0.68	5.875

PHULWARITAND-MAHESHPUR AREA

84.	44	0.0078	0.023	46.30	0.050
85.	45	0.0081	0.022	1.91	1.147
86.	46	0.1794	0.602	30.73	1.959
87.	47	0.0217	0.064	2.31	2.771
88.	48	0.0199	0.060	2.84	2.114
89.	49	0.0215	0.061	3.85	1.595
90	50	0.368	0.093	3.53	2.626
91.	51	0.0687	0.193	53.98	0.358

rocks are prone to gas or oil (Fig. 3.9) and whether the bitumens are migratory or syngenetic in nature (Fig. 3.10).

The degree of bituminization (ß) measured as extractable bitumen per unit TOC in ß, almost all the samples of these three areas, is less than 5% indicating that the source rocks are mainly gas prone. Organic matter of humic type i.e. kerogen of Type III is considered to be gas prone. Also, since the degree of bituminization (ß) is less than 10% it can be surmised that the hydrocarbons are syngenetic in nature and not migratory.

It is observed that aromatics form the dominant components as compared with saturates (Table 3.4). The ratio of saturates/aromatics which is very low and is of the order of 0.11 to 1.69 confirms the previous observations and proves the terrestrial origin of organic matter the kerogen of being Type III .

(b) Gas chromatography:

Gas chromatography of C_{15+} alkane fraction (saturates) was used to determine the type of OM the and environment of deposition. Out of 91 Extractable Organic Matter (EOM) samples, 39 selected samples from Bhaunra, Chasnala and Phulwaritand areas were analyzed by gas chromatography. Bivariate plot of Pristane/nC_{17} against Phytane/nC_{18}, (Fig. 3.11) indicates that all the samples fall in the zone representing humic organic matter, suggesting thereby Type III kerogen deposited an environment varying from the peat swamp to open water however most of the samples lie in the zone, intermediate between the two zones.

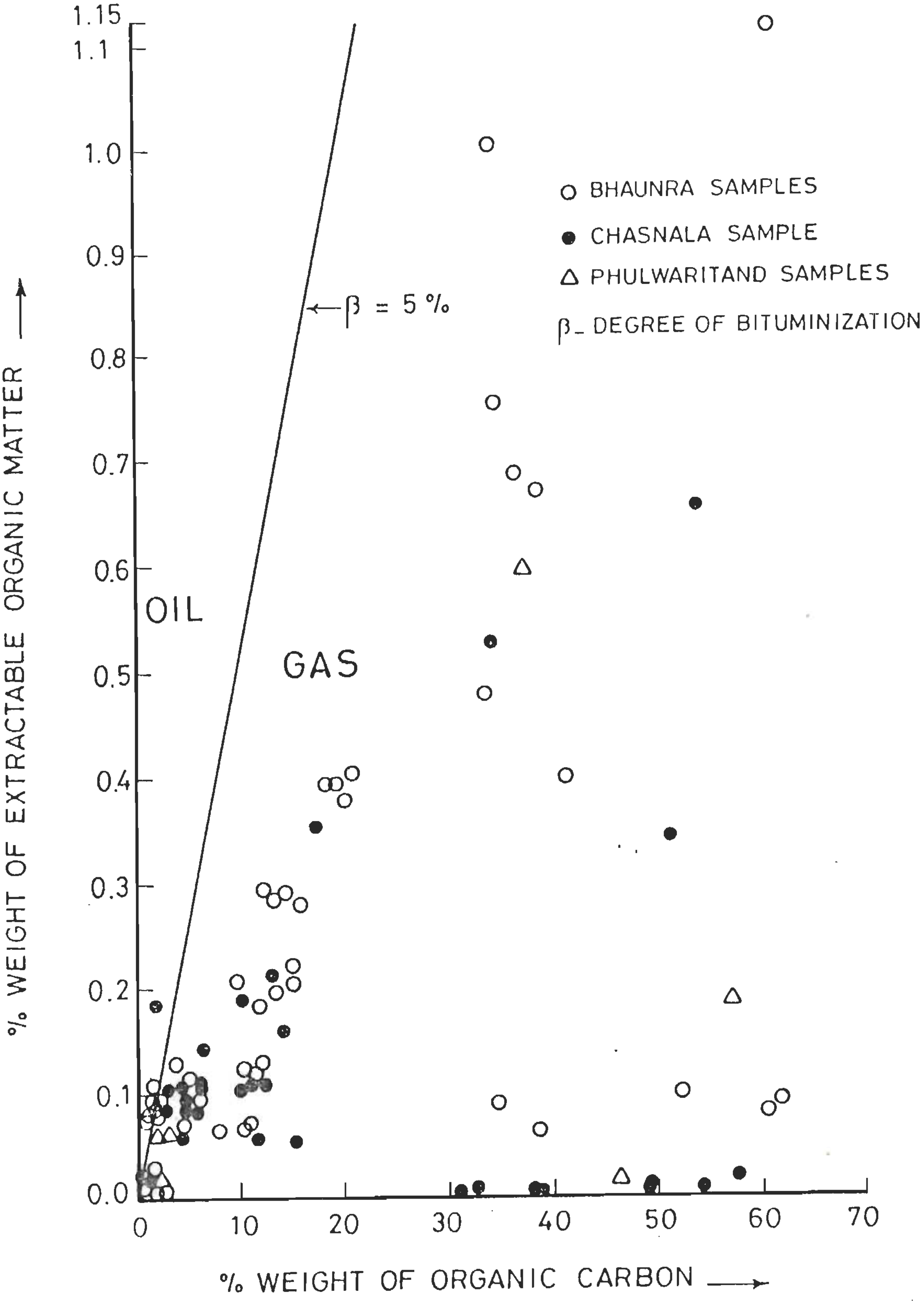


Fig. 3.9 Cross plot of weight of extractable organic matter (%) and weight of organic carbon (%) as an indication of oil/gas generation.

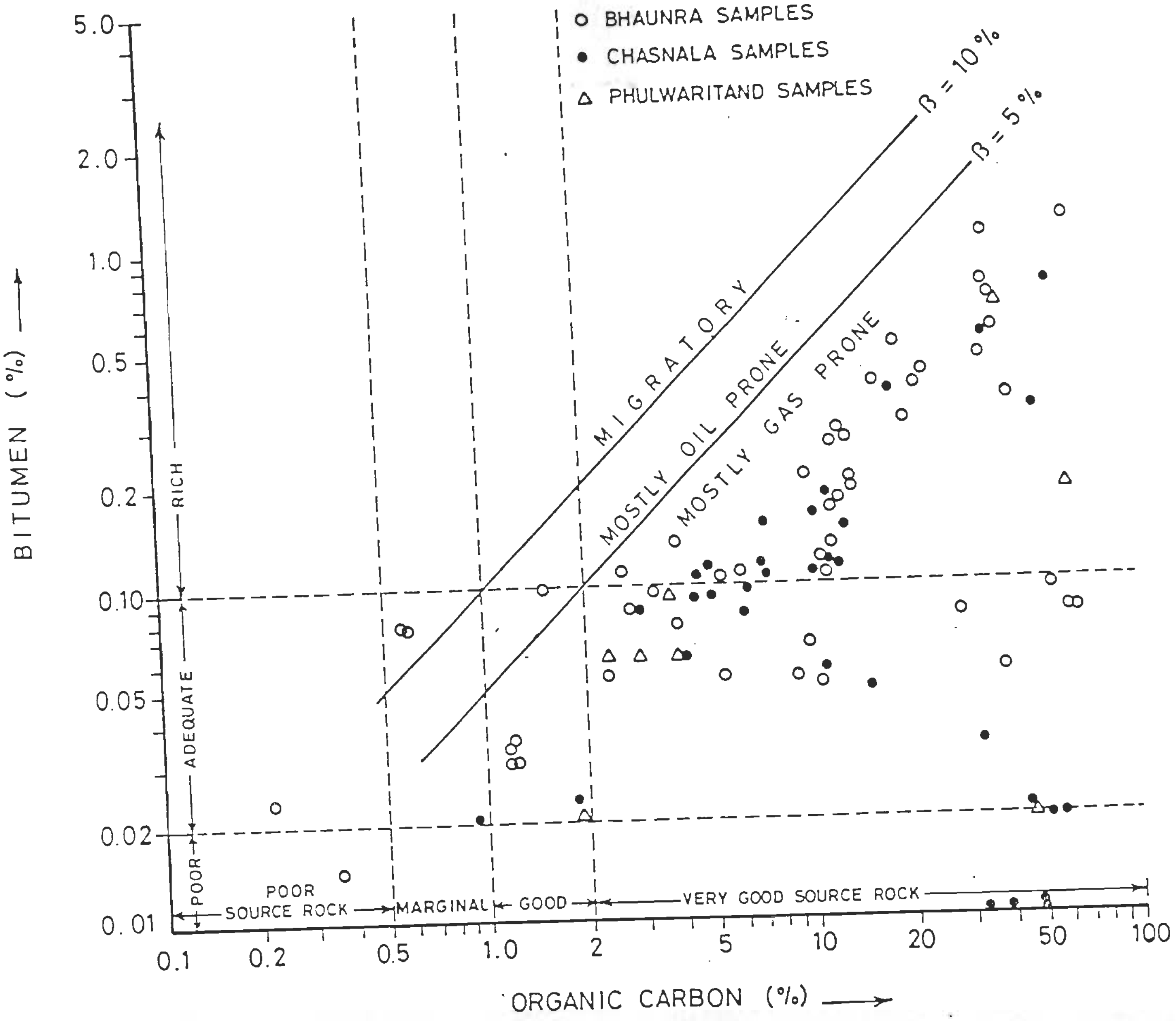


Fig. 3.10 Bivariate plot of bitumen percentage and organic carbon percentage indicating degree of bituminization (β) and nature of organic matter.

TABLE 3.4. Extractable organic matter components from the selected shales of Barakar formation

Sl. No.	Sam- ple	EOM %	SAT (gm)	AROM (gm)	SAT %	AROM %	NOS %	HC %	HC/ Non- HC	SAT/ AROM	AROM/ SAT
					CHASNALA AREA						
1.	62	0.5326	0.0130	0.0135	14.35	14.90	70.75	29.25	0.41	0.96	1.04
2.	63	0.0886	0.0025	0.0043	7.99	13.74	78.27	21.73	0.28	0.58	1.72
3.	64	0.0816	0.0025	0.0037	8.65	12.80	78.55	21.45	0.27	0.68	1.47
4.	65	0.3567	0.0155	0.0129	23.52	19.58	56.9	43.1	0.76	1.20	2.83
5.	66	0.0634	0.0026	0.0035	11.66	15.70	72.64	27.36	0.38	0.74	1.35
6.	67	0.6581	0.0125	0.0166	13.69	18.18	68.13	31.07	0.47	0.75	1.33
7.	82	0.1859	0.0049	0.0141	11.34	32.64	56.02	43.98	0.79	0.35	2.86
8.	83	0.1111	0.0048	0.0271	14.46	81.63	3.91	96.09	24.58	0.18	5.56
9.	84	0.1572	0.0060	0.0226	15.92	59.95	24.13	75.87	3.14	0.27	3.70
10.	86	0.1111	0.0029	0.0014	10.04	4.84	85.12	14.88	0.18	2.07	0.48
11.	87	0.1100	0.0043	0.0078	14.83	26.90	58.27	41.73	0.72	0.55	1.82
12.	88	0.1258	0.0039	0.0077	10.77	21.27	67.96	32.04	0.47	0.51	1.96
13.	90	0.1242	0.0044	0.0104	13.10	30.95	55.95	44.05	0.79	0.42	2.38
14.	91	0.0888	0.0039	0.0075	14.29	27.47	05.24	41.76	0.72	0.52	1.92
15.	92	0.0927	0.0072	0.0083	27.27	31.44	41.29	58.71	1.42	0.87	1.15
16.	93	0.1551	0.0074	0.0332	16.52	74.11	9.37	90.63	9.67	0.22	4.55
					BHAUNRA AREA						
17.	113	0.0960	0.0017	0.0029	5.90	10.06	84.04	15.96	0.19	0.59	1.69
18.	114	0.0737	0.004	0.0027	4.75	9.15	86.1	13.9	0.16	0.52	1.92
19.	115	0.0815	0.0024	0.0019	7.36	5.83	86.81	13.19	0.15	1.26	0.79

20.	116	0.3839	0.0038	0.0024	13.36	8.45	78.19	21.81	0.25	1.58	0.63
21.	117	0.4080	0.0077	0.0050	17.99	11.68	17.33	29.67	0.42	1.54	0.65
22.	118	0.3974	0.0035	0.0031	12.59	11.15	76.26	23.74	0.31	1.13	0.88
23.	119	0.0727	0.0013	0.0022	4.47	7.56	87.97	12.03	0.14	0.59	1.69
24.	120	0.2815	0.0091	0.0054	15.24	9.04	75.72	24.28	0.32	1.69	0.59
25.	121	0.6864	0.0057	0.0068	9.74	11.62	78.64	21.36	0.27	0.84	1.19
26.	124	1.0741	0.0103	0.0097	12.84	12.09	75.07	24.93	0.33	1.06	0.94
27.	125	0.3099	0.0071	0.0073	11.43	11.76	76.81	23.19	0.30	0.97	1.03
28.	126	0.1302	0.0024	0.0072	4.61	13.82	81.52	18.43	0.23	0.33	3.03
29.	127	0.0747	0.0031	0.0043	10.37	14.38	75.25	24.75	0.33	0.72	1.39
30.	128	0.7551	0.0063	0.0073	10.13	11.74	78.13	21.87	0.28	0.86	1.16
31.	129	1.1554	0.0070	0.0146	8.58	17.89	73.53	26.47	0.36	0.48	2.08
32.	132	0.2845	0.0111	0.0340	16.92	51.33	31.78	68.15	2.20	0.33	3.03
33.	133	0.2885	0.0088	0.0169	14.33	27.52	58.15	41.35	0.72	0.52	1.92
34.	136	0.1946	0.0059	0.0116	12.61	24.79	62.60	37.40	0.60	0.51	1.96
35.	137	0.1834	0.0047	0.0074	15.62	24.59	59.79	40.21	0.67	0.64	1.56
36.	138	0.1999	0.0055	0.0115	13.10	29.26	57.64	42.36	0.74	0.45	2.22
37.	139	0.2116	0.0049	0.0077	6.27	9.85	83.88	16.12	0.19	0.64	1.56
38.	140	0.1308	0.0043	0.0057	9.86	13.07	77.07	22.13	0.30	0.75	1.33
39.	142	0.1289	0.0023	0.0041	5.35	9.54	85.11	14.89	0.18	0.56	1.79
40.	143	0.0555	0.0017	0.0072	10.43	44.17	45.40	54.60	1.20	0.24	4.17
41.	145	0.0357	0.0016	0.0033	15.24	31.43	53.33	46.67	0.88	0.49	2.04
42.	146	0.0987	0.0065	0.0135	14.87	30.89	5.27	45.76	0.84	0.48	2.08

PHULWARITAND - MAHESHPUR AREA

43.	46	0.6019	0.0093	0.0070	14.83	11.16	74.01	25.99	0.35	1.32	0.76
44.	47	0.0640	0.0030	0.0048	13.33	21.33	65.34	34.66	0.53	0.62	1.61
45.	50	0.0934	0.0008	0.0039	2.42	11.78	85.8	14.20	0.17	0.21	4.76
46.	51	0.1933	0.0076	0.0174	11.19	25.63	63.18	36.82	0.58	0.44	2.27

[illegible]: SAT = Saturates; AROM = Aromate; NOS = Nitrogen; Oxygen, Sulfur;

HC = Hydrocarbon; Non - HC = Non hydrocarbon

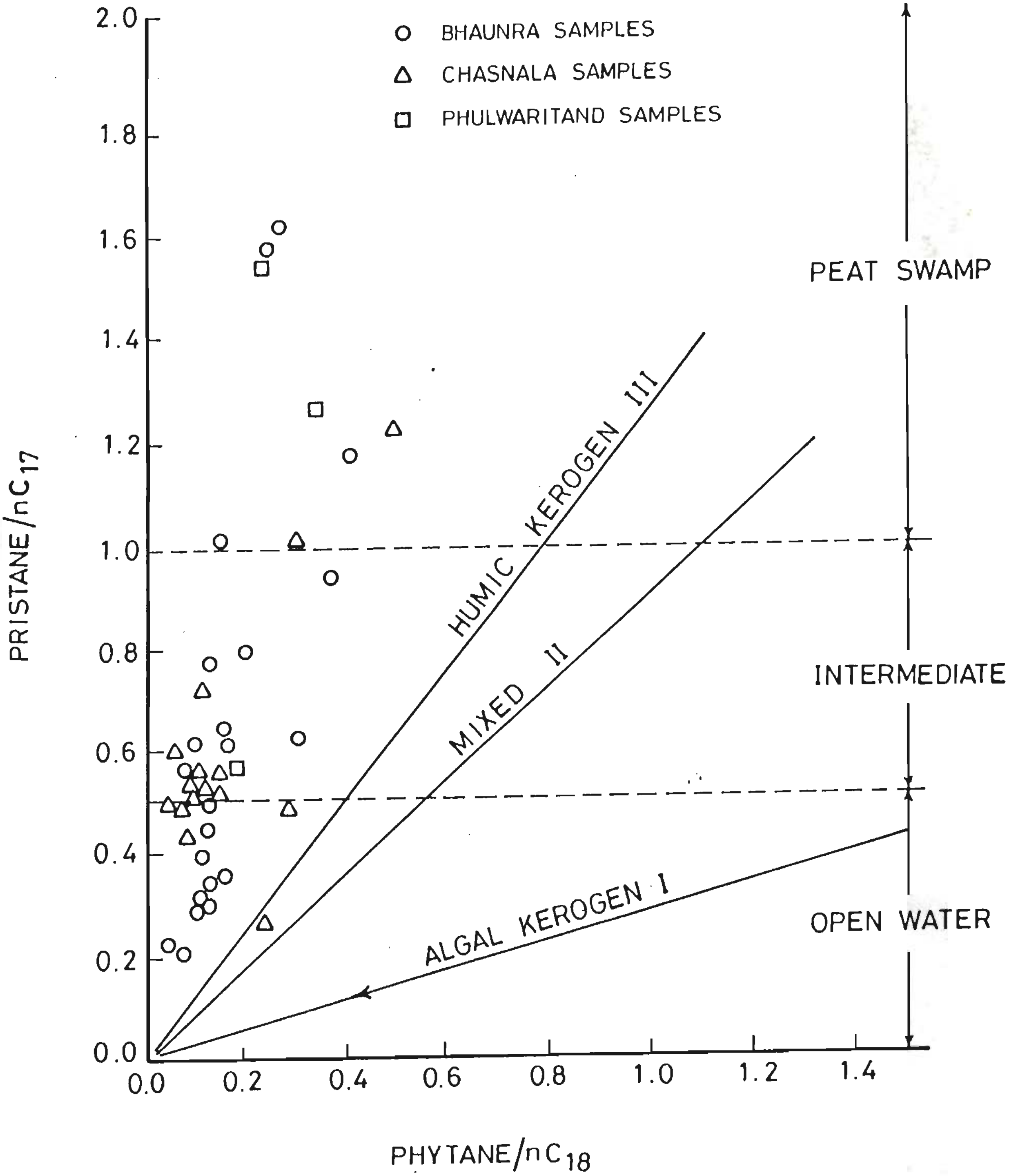


Fig. 3.11 Bivariate plot between pristane/nC_{17} and phytane/nC_{18} on diagram of Connan and Cassou (1980).

The ratio of Pristane to Phytane is used to find oxidizing/reducing environments. These ratios determined for 39 samples (Table 3.5) are generally less than 3 indicating thereby mainly reducing environment of deposition.

3.6.3 Optical Examination of Organic Matter

a) Transmitted light:

When studied under transmitted light these samples exhibit a mixed type of organic matter (Table 3.6), with dominance of humic matter. Fusinite matter is also dominant in some samples, whereas sapropelic matter though present, is recorded in few samples (Figs. 3.12 to 3.16) It is, therefore, concluded that the sedimentary organic matter in these areas is mostly land derived and thus is gas prone.

b) Reflected Light:

Organic matter, as discussed earlier, consists of three constituents in the form of maceral grains viz. vitrinite, liptinite and inertinite. Predominance of one over other is an indicator of the environment of deposition and the source of the biogenic matter. As such, the prepared slides of 93 selected samples were examined under microscope. The examination reveals that vitrinite and inertinite with its characteristic `Bogel Structure' dominate (Figs.3.17-20). It indicates terrestrial biota as a source of organic matter. Also, the cross plot of VRo against HI (Fig. 3.21) corroborates Type III kerogen.

On the basis of all these studies pertaining to quality and environment of deposition, following conclusions can be drawn:

i) The biogenic matter is mainly humic and land derived. It is

TABLE 3.5: Gas chromatography results of saturated hydrocarbons from the Barakar Formation

Sl No.	Sample	Pri/phy	Pri/ nC_{17}	Phy/ nC_{18}	nCmax	Envir.	CPI	Phy/pri
				CHASNALA AREA				
1.	54	4.96	0.71	0.11	nC_{23}	O	2.3	0.20
2.	55	1.17	1.22	0.50	nC_{22}	R	0.7	0.85
3.	56	0.79	0.49	0.29	nC_{24}	R	1.0	1.27
4.	58	1.83	1.01	0.31	nC_{24}	R	1.2	0.55
5.	82	0.72	0.53	0.10	nC_{18}	R	0.4	1.39
6.	83	0.57	0.53	0.11	nC_{18}	R	0.4	1.75
7.	84	0.84	0.49	0.08	nC_{18}	R	0.5	1.19
8.	86	0.34	0.57	0.10	nC_{20}	R	0.6	2.94
9.	87	0.63	0.55	0.06	nC_{20}	R	0.7	1.59
10.	88	0.41	0.59	0.07	nC_{20}	R	0.7	2.43
11	90	0.60	0.49	0.07	nC_{20}	R	0.6	1.67
12.	91	0.42	0.55	0.12	nC_{20}	R	0.5	2.38
13.	92	0.98	0.26	0.27	nC_{20}	R	0.8	1.02
14.	93	0.19	0.43	0.10	nC_{20}	R	0.5	5.21
				BHAUNRA AREA				
15	94	3.84	1.63	0.28	nC_{20}	O	1.6	
16	95	2.24	0.79	0.22	nC_{19}	R	1.1	
17.	96	2.95	0.43	0.14	nC_{18}	R	1.3	
18.	97	2.68	1.55	0.29	nC_{20}	R	1.2	
19.	113	0.93	0.34	0.17	nC_{22}	R	0.8	1.08
20.	115	2.09	0.63	0.17	nC_{23}	R	1.3	0.48
21	117	2.79	0.49	0.14	nC_{19}	R	1.9	0.36

22	118	2.78	0.60	0.18	nC_{19}	R	1.5	0.36
23.	124	4.53	0.78	0.14	nC_{21}	O	1.3	0.22
24.	126	1.69	0.96	0.37	nC_{20}	R	1.0	0.59
25	128	2.40	1.17	0.41	nC_{19}	R	1.1	0.42
26	132	0.66	0.39	0.12	nC_{18}	R	0.6	1.52
27.	133	0.57	0.30	0.11	nC_{18}	R	0.4	1.75
28	136	0.71	0.32	0.12	nC_{18}	R	0.6	1.41
29.	137	0.51	0.33	0.12	nC_{23}	R	0.3	1.98
30	138	0.62	0.31	0.12	nC_{20}	R	1.6	1.61
31	139	1.43	0.22	0.10	nC_{20}	R	0.9	0.70
32.	140	1.20	0.23	0.08	nC_{20}	R	0.9	0.83
33.	142	1.20	0.64	0.31	nC_{20}	R	0.4	0.83
34.	143	0.34	0.57	0.08	nC_{22}	R	0.5	2.94
35.	145	0.57	0.63	0.09	nC_{22}	R	0.7	1.74
36.	146	0.74	1.01	0.15	nC_{22}	R	0.9	1.35

PHULWARITAND - MAHESHPUR AREA

37	46	2.77	0.55	0.18	nC_{23}	R	1.4	0.36
38	47	1.88	1.27	0.35	nC_{25}	R	3.0	0.53
39.	51	4.37	1.52	0.24	nC_{21}	O	2.5	0.23

Pri = Pristane; Phy = Phytane; CPI = Carbon Preference Index (Bray and Evans, 1961); Env.=Environment of deposition; R = Reducing; O = Oxidizing.

TABLE 3.6: Type of Organic Matter and Thermal Alteration Index (TAI) of Selected samples of Barakar Formation:

Sl. No.	Sample No.	Cuticle & Wood	Fusinite & semi-fusinite	Biodegeraded	Amorphous	Amount	TAI
CHASNALA AREA							
1.	52	20	80	-	-	M	-
2.	53	10	90	-	-	A	-
3.	54	30	10	60	-	A	3.00
4.	55	20	10	60	10	G	3.00
5.	56	20	30	45	5	G	3.00
6.	58	20	30	45	5	G	3.00
7.	59	20	30	50	-	A	3.00
8.	60	10	10	30	50	A	2.75
9.	61	15	10	15	60	G	2.75
10.	62	10	10	30	50	G	2.75
11.	63	20	5	30	45	A	2.75
12.	64	10	5	30	55	A	2.75
13.	65	20	5	30	45	M	2.75
14.	66	20	5	30	45	M	2.75
15.	67	20	70	5	5	M	4.0-4.5
16.	68	15	80	-	5	A	3.25-3.5
17.	69	25	70	-	5	M	3.25
18.	70	20	50	10	20	A	3.00
19.	71	10	5	50	35	M	2.75
20	72	5	5	45	45	G	2.75
21.	74	5	-	60	35	G	2.75
22.	77	10	40	25	25	G	2.75
23.	79	5	20	45	30	G	2.75

24.	82	5	5	70	20	A	-
25	83	10	5	50	35	M	-
26	84	15	10	65	10	A	2.75^+
27.	86	15	10	75	-	M	-
28.	87	20	15	50	15	M	3.00
29.	88	20	20	55	5	M	2.75
30	90	25	10	55	10	A	3.00
31.	91	25	5	50	20	A	-
32	92	30	10	45	15	G	3.00
33.	93	20	15	45	20	G	-

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34.	94	35	55	10	-	A	2.75-3.00
35.	95	5	15	65	15	M	2.75
36.	96	20	60	15	5	M	2.75
37	97	20	40	35	5	M	-
38.	98	10	75	10	5	M	2.75
39.	99	20	20	50	10	G	2.75
40.	100	10	30	40	20	G	2.75
41.	101	50	10	20	20	G	2.75
42.	102	50	10	20	20	M	2.75
43.	103	20	30	40	10	G	4.5
44.	104	15	80	-	5	A	4.0-4.5
45.	105	30	55	10	5	G	-
46.	106	25	60	15	-	G	-
47	107	15	80	5	-	G	-
48	108	25	50	25	-	M	2.75^+
49.	109	20	5	70	5	M	2.75
50.	110	30	20	40	10	G	2.75

51.	111	30	20	40	10	G	2.75
52.	112	10	30	40	20	G	2.75
53.	113	10	90	-	-	M	-
54.	114	20	60	20	-	G	-
55.	115	20	10	60	10	A	2.75^{+}
56.	116	10	15	70	5	A	2.75^{+}
57.	117	20	20	60	-	A	2.75^{+}
58.	118	20	20	60	-	M	2.75^{+}
59.	119	15	25	50	10	M	2.75^{+}
60.	120	20	20	55	5	A	2.75^{+}
61.	121	10	30	50	10	A	2.75^{+}
62.	122	-	-	-	-	A	2.75^{+}
63.	123	-	-	-	-	M	2.75^{+}
64.	124	20	20	55	5	A	2.75^{+}
65.	125	20	10	60	10	A	2.75^{+}
66.	126	10	80	10	-	M	2.75^{+}
67.	127	20	40	35	5	M	2.75^{+}
68.	128	20	40	40	-	G	2.75^{+}
69.	129	30	25	30	15	A	2.75^{+}
70.	131	15	10	15	60	A	-
71.	132	20	15	20	45	M	3.25
72.	133	15	20	20	45	M	3^{-}
73.	135	10	10	30	50	A	-
74.	136	45	25	20	-	M	3.00
75.	137	55	15	15	15	M	2.75^{+}
76.	138	50	10	25	15	G	2.75^{+}
77.	139	55	5	20	20	M	2.75^{+}
78.	140	35	15	40	10	M	2.75^{+}
79.	141	25	10	45	20	G	2.75

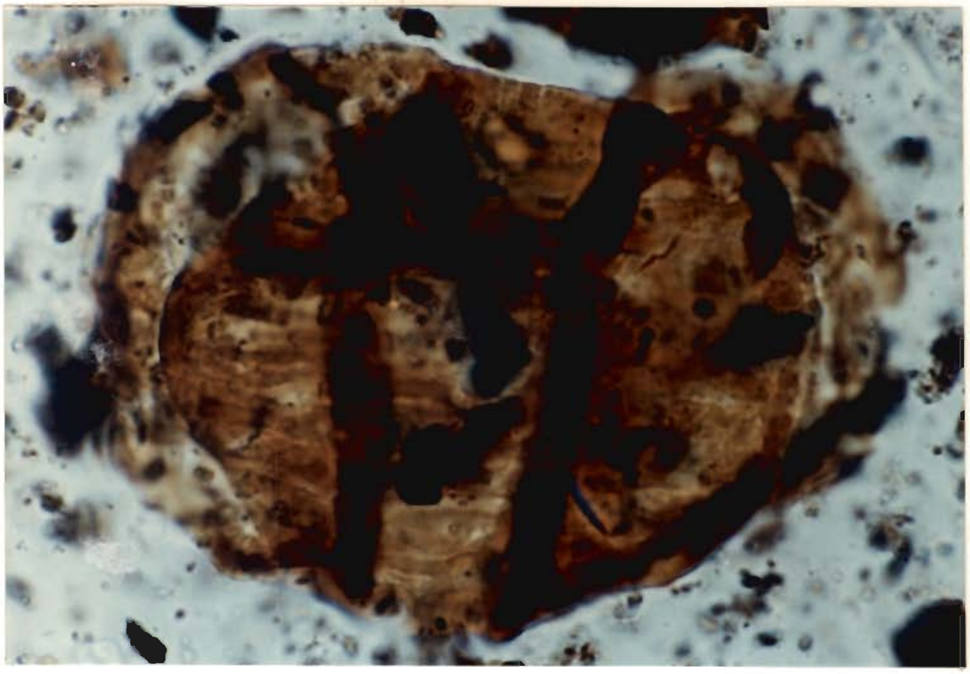
80.	142	30	20	35	15	M	2.75
81.	143	40	30	25	5	G	2.75
82.	144	50	5	30	15	G	2.75
83.	145	40	25	30	5	G	2.75
84.	146	-	-	-	-	G	-
85.	44	20	80	-	-	M	3.00
86	45	20	80	-	-	M	3.00
87.	46	20	10	70	-	M	3.00
88.	47	30	10	50	10	G	3.00
89.	48	20	20	55	5	G	3.00
90.	49	20	20	60	-	G	3.00
91	50	20	25	50	5	G	3.00
92.	51	20	30	45	5	M	3.00

A = Abundant; M = Moderate; G = Good;

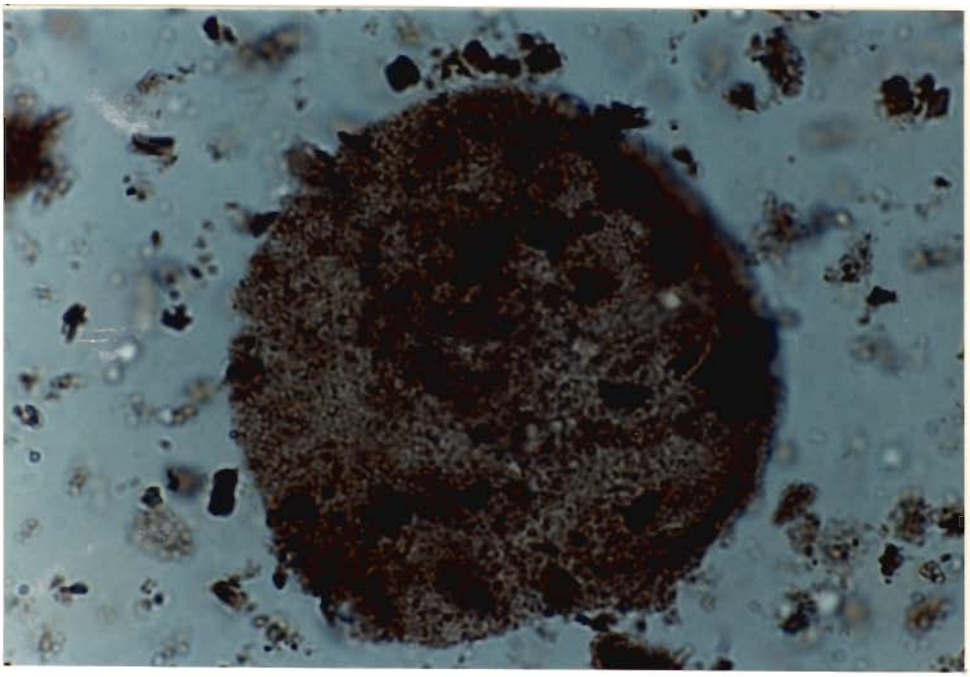
TAI = Thermal Alteration Index.

Fig. 3.12 Palynomorphs from kerogen (X 1200).

a. <u>Taenii</u> <u>sporites</u> sp. (sample no. 139, Bhaunra)
b. Trilete grain (sample no. 86, Chasnala)



(a)

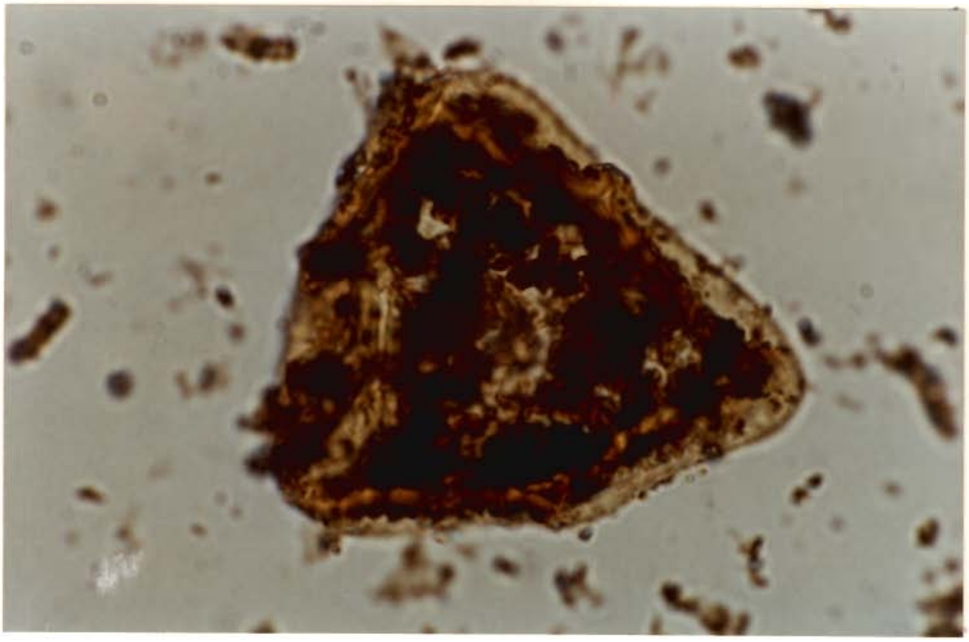


(b)

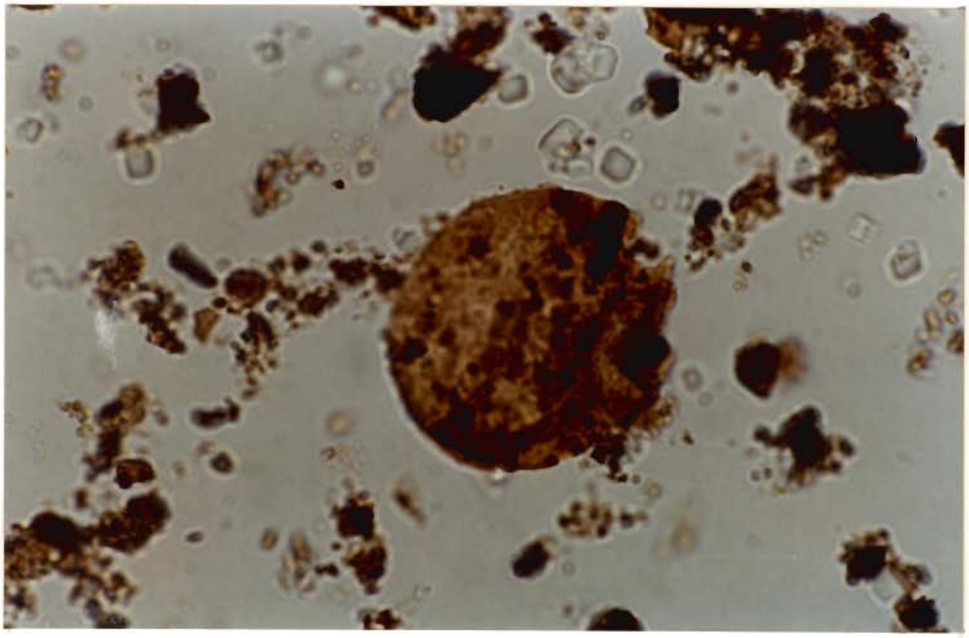
FIG. 3.12

Fig. 3.13 Palynomorphs from kerogen, (X 1200).

a. *Leiotriletes* sp. (sample no. 82)
b. cf. Osmunda cidites sp. (sample no. 83)



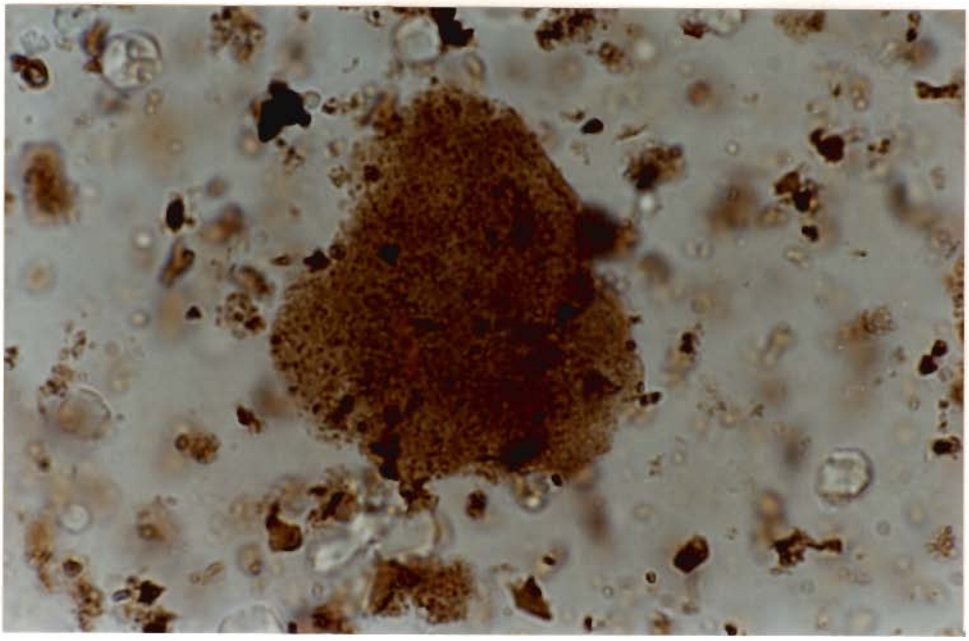
(a)



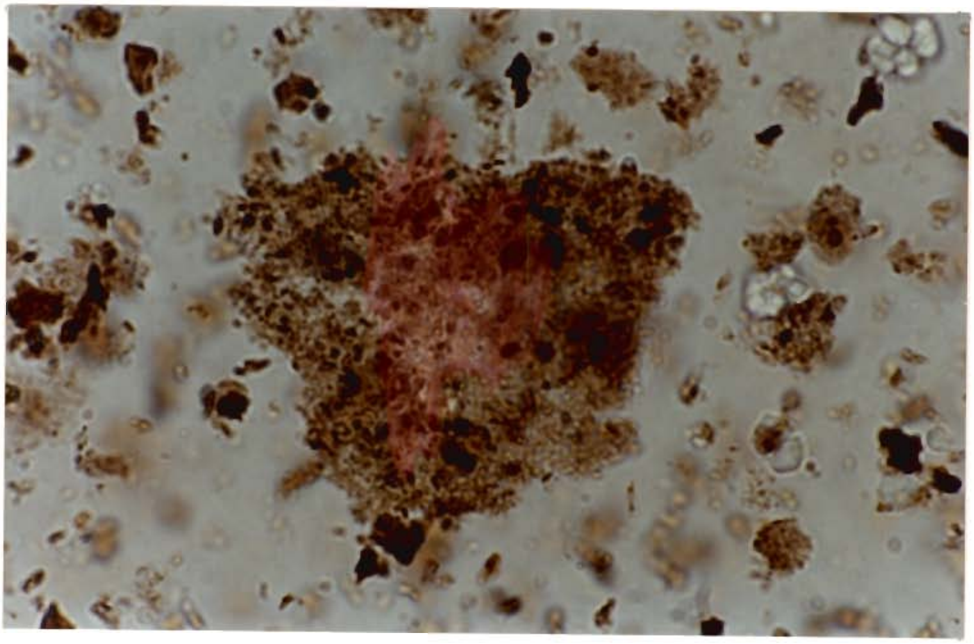
(b)

FIG. 3.13

Fig. 3.14 a & b Finely devided organic matter (sample no. 86, Chasnala, X1200)



(a)

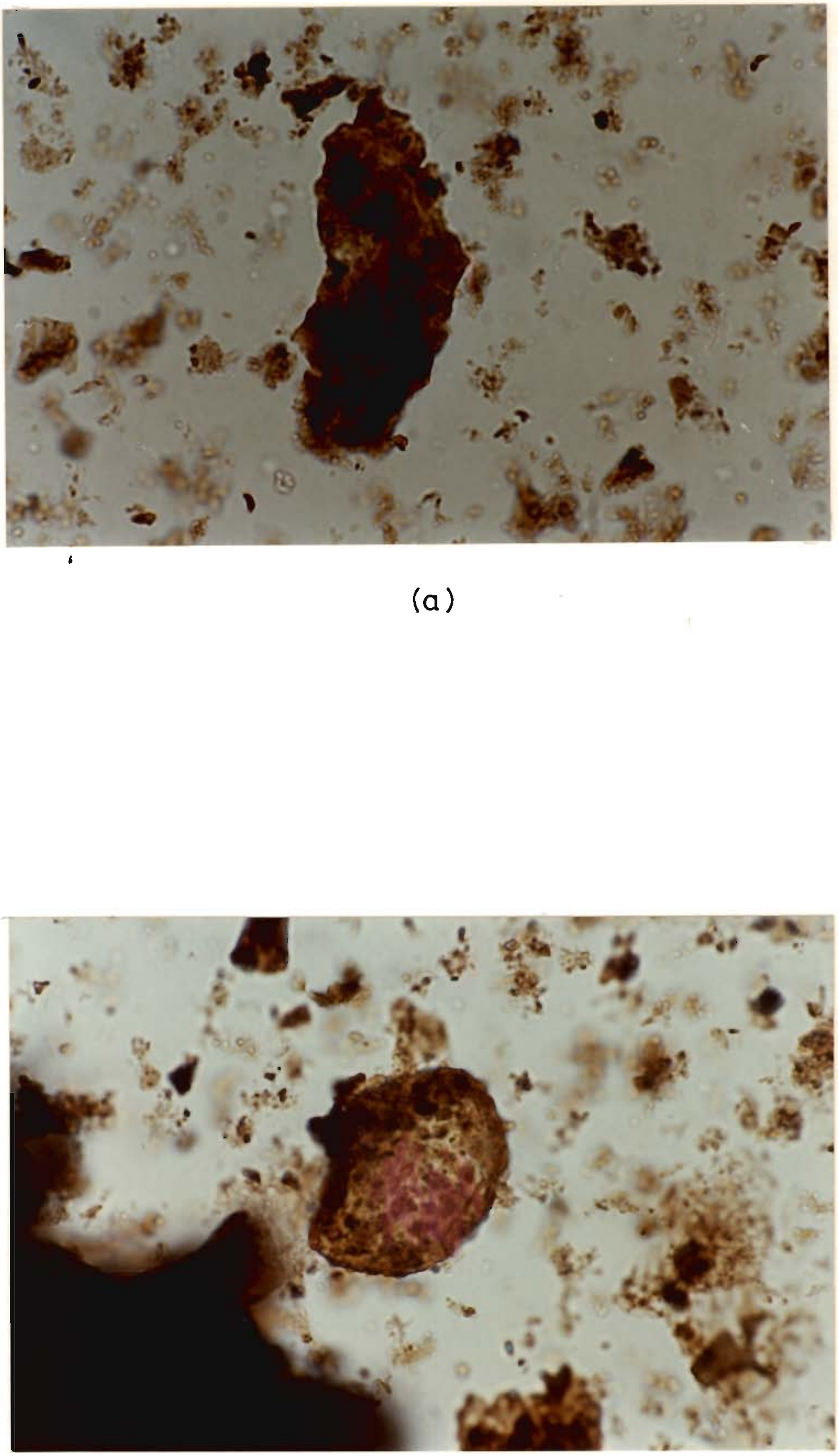


(b)

FIG.3.14

Fig. 3.15 a. Amorphous organic matter (sample no. 87, Chasnala), (X 1200)

b. <u>Horridi</u> <u>triletes</u> sp. (sample no. 87, Chasnala), (X 1200).



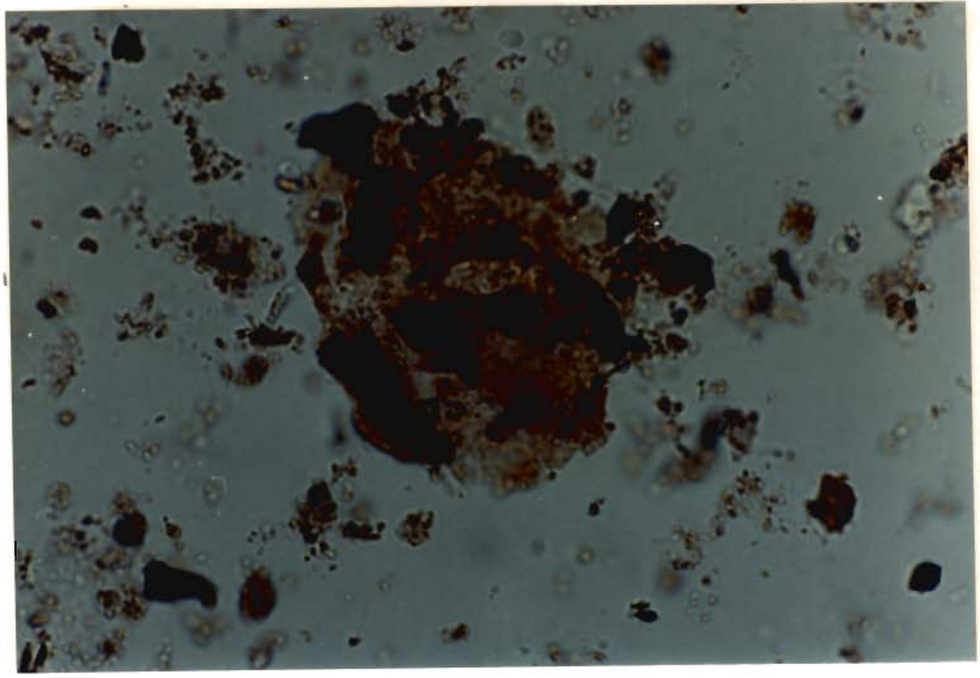
(a)

(b)

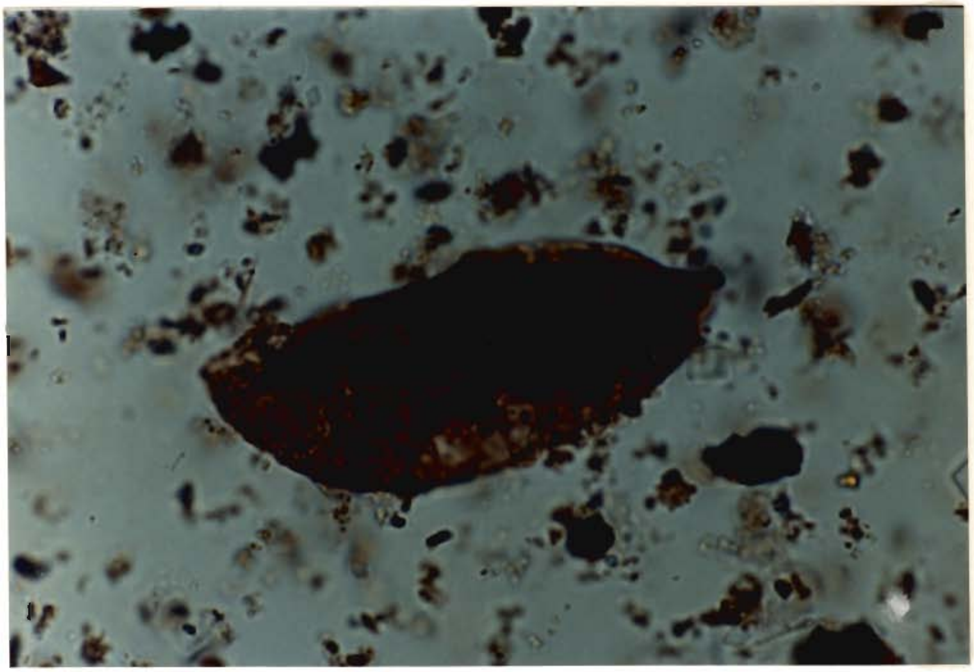
FIG. 3.15

Fig. 3.16 a. Amorphous organic matter (sample no. 88, Chasnala) (X 1200).

b. *Cycadopites* sp. (sample no. 88, Chasnala) (X 1200).



(a)



(b)

FIG.3.16

Fig. 3.17 Vitrinite (V) maceral - Diagenetic (VRo-0.45%) (X 1280).

Fig. 3.18 Semifusinite showing bogel structure (X 1600) (sample no. 87, Chasnala).

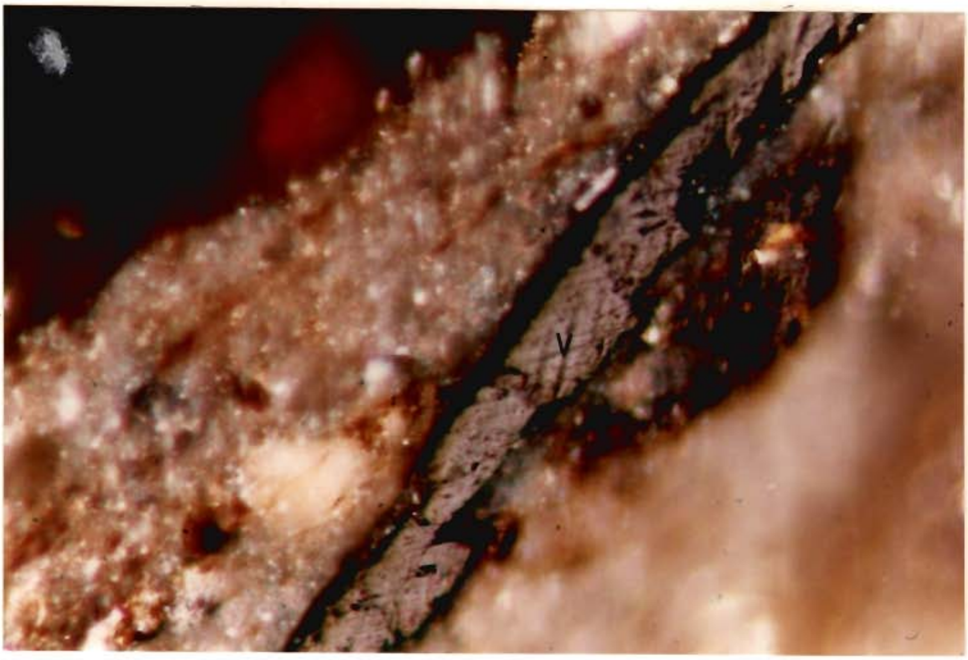


FIG. 3.17

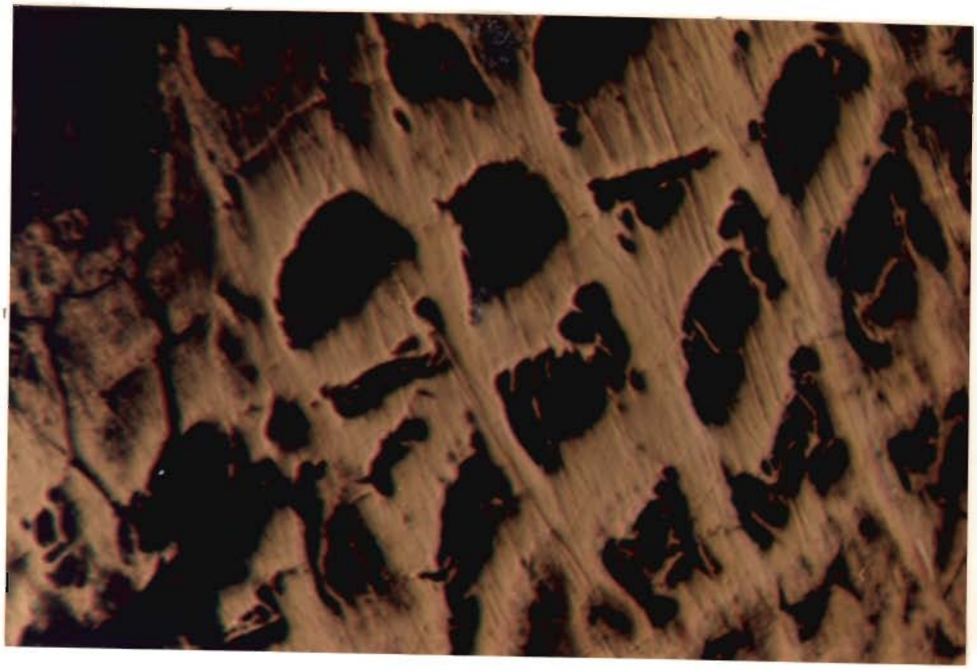


FIG. 3.18

Fig. 3.19 Band of vitrinite (V) with pyrite (yellow) and Inertinite (I) (X 800) (sample no. 142, Bhaunra).

Fig. 3.20 Semifusinite in natural coke (Jhama) (X 1008) (sample no. 131, Bhaunra).

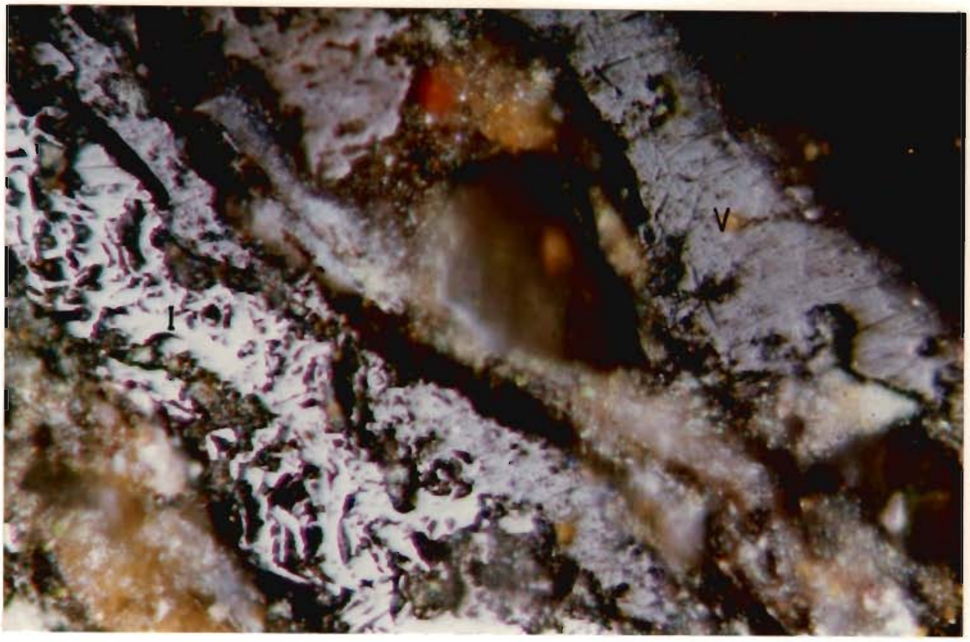


FIG. 3.19

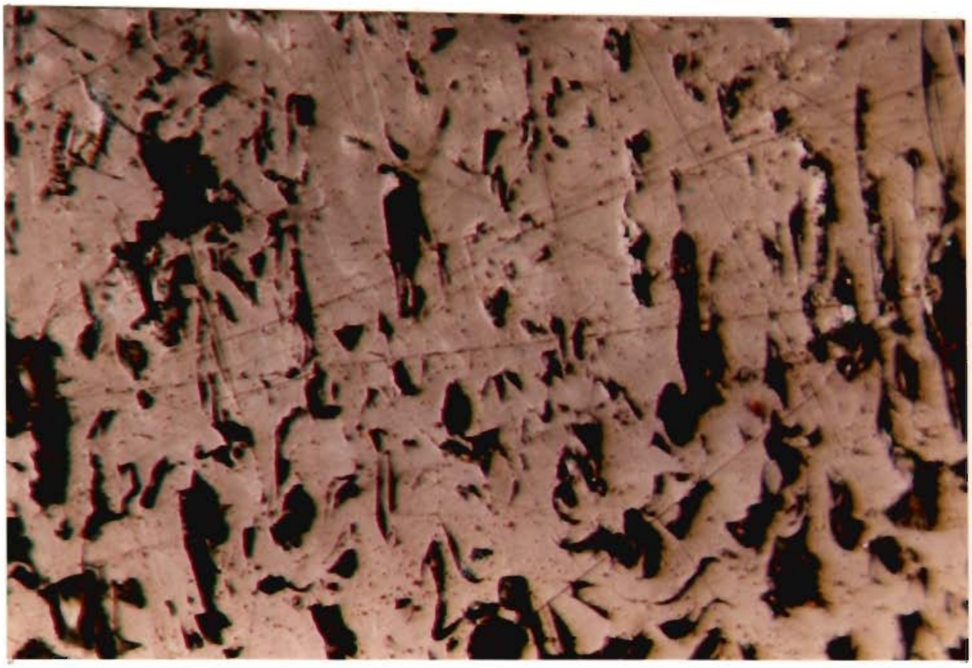


FIG. 3.20

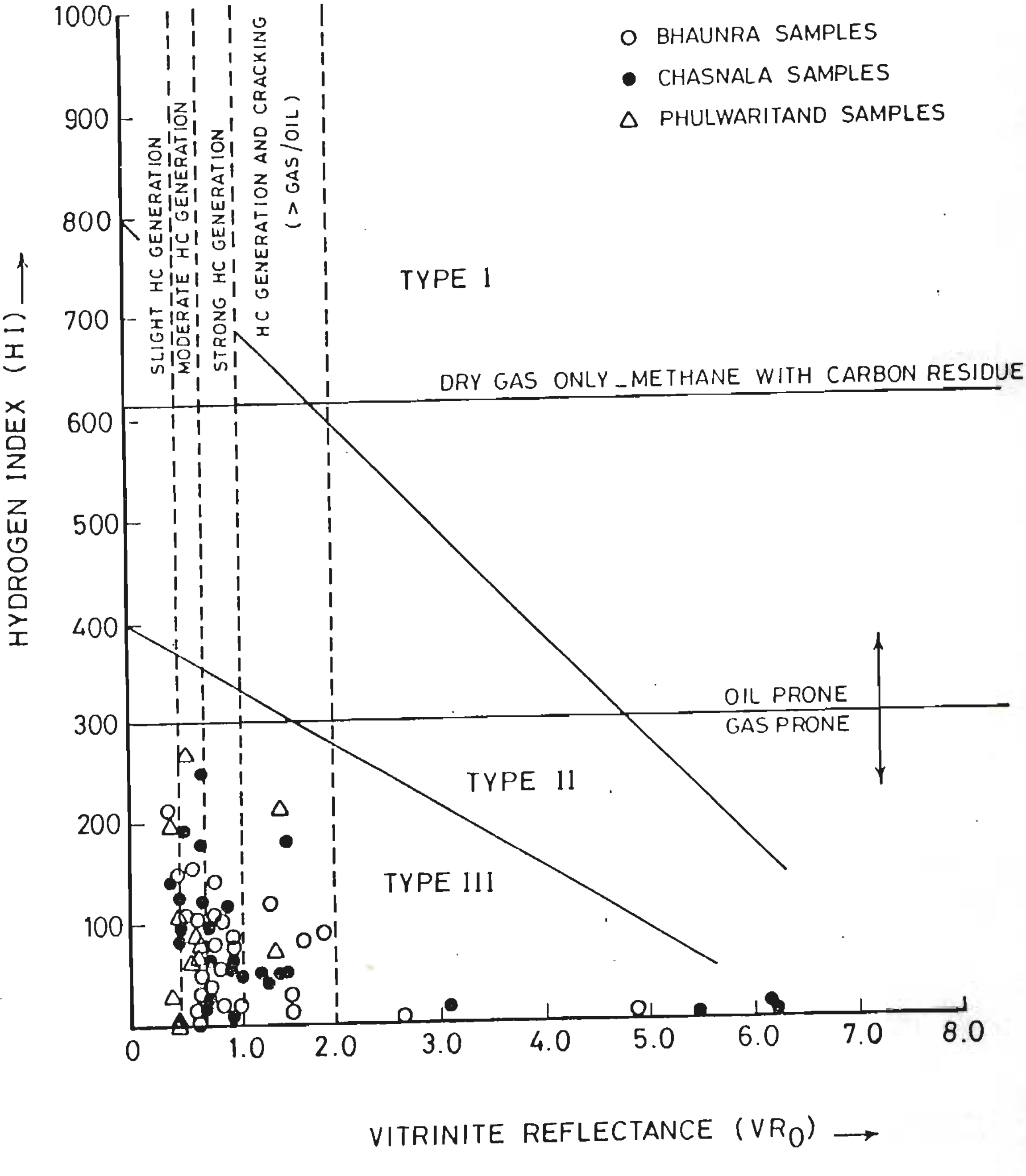


Fig. 3.21 Bivariate plot between Hydrogen Index and vitrinite reflectance on the diagram of Espitalie et al. (1977).

characterized by mainly the kerogen of Type III and traces of Type II and Type IV.

ii) The biogenic matter is mainly syngenetic.

iii) The deposition of the OM took place in reducing environments.

iv) The physical environments worked out to be peat swamps and coastal with fluvial influx.

v) These organic matters are mainly gas prone.

3.7 MATURATION OF ORGANIC MATTER

Thermal evolution of the source rocks, during diagenesis, catagenesis and metagenesis, brings about changes in many physical or chemical properties of the organic matter. These properties may be considered as indicators for maturation. The parameters most commonly used in petroleum exploration are optical examination of kerogen, physicochemical analysis of kerogen and chemical analysis of extractable bitumen. The following methods were used for determination of maturity of organic matter:

i) Rock Eval Pyrolysis

ii) Analysis of extractable organic matter

    a) Componental analysis of Bitumen

    b) Carbon Preference Index (CPI)

iii) Vitrinite reflectance (VRo)

iv) Thermal alteration index (TAI)

v) Fluorescence study.

3.7.1 Rock Eval Pyrolysis:

Organic matter pyrolysis is conducted under an inert atmosphere (nitrogen or helium with a preselected rate of heating (approximately 10-50° C min^{-1})

Barker (1974), Claypool and Reed (1976) and Espitalie et.al. (1977) have shown that two indicators are of great interest in characterizing the rank of evolution of organic matter - the ratio S1 : (S1+S2) and the temperature Tmax obtained at peak S2. A perusal of Table 3.2 indicates that nearly in all the sections towards the mica peridotite intrusions the ratio S1: (S1+S2) is increasing with a peak at or very close to contact. This peak, the so called microreservoirs will be discussed in detail in chapter- 4.

The temperature Tmax is influenced by the type of organic matter during the diagenetic stage and at the beginning of catagenesis. It is lower in the terrestrial kerogen of type III. (Tissot and Welte, 1978). This maturity parameter also indicates (Table 3.2) that away from intrusions the samples having their ground value of Tmax are moderately matured and only in Phulwaritand they are immature.

Van Krevelen diagram clearly shows that with increasing thermal evolution, the rate of decrease of HI is faster than OI for both type I and type II kerogens. However reverse is the situation for type III kerogen i.e the OI drops faster than HI in the case of type III kerogen. Since kerogen of type III is the most dominant constituent in the organic sediments in this area, OI is more meaningful in gauging their maturity. Plot of samples on Van Krevelen diagram (Fig.3.7) clearly indicates that OI in

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most of the samples from these three areas namely Chasnala, Bhaunra and Phulwaritand-Maheshpur areas is 50 mg CO_2/g TOC, and therefore fall in the moderately matured level of thermal evolution of organic matter. Tmax in these samples vary from 330°C to 458°C and this further confirms moderate maturity level for organic sediments.

3.7.2 Analysis of Extractable Organic Matter as Maturity Indicator:

Abundance and chemical composition of petroleum compounds (hydrocarbons, resins and asphaltenes) present in source rocks depends on the nature of the original OM and the degree of thermal maturation. Thus, numerous methods have been developed using the amount or the composition of the extractable bitumen to characterize the stage of thermal evolution. However, it should be pointed out that migration of hydrocarbons may affect their abundance and composition. Certain shale beds, silt or carbonate source rocks may acquire a slight porosity and permeability (due to microfractures and recrystallization etc). Then they can be affected by a short range migration with preferential accumulation of hydrocarbons, especially those of low molecular weight. This situation can usually be detected by abnormally high transformation ratio obtained by the pyrolysis method (Table 3.2) or by degree of bituminization (ß) i.e. bitumen organic carbon ratio (Table 3.3). As is apparent from Table 3.3, the bitumen extracted from these sediments, containing mainly kerogen of type III varies from 0.01 to 1.2% and degree of bituminization (ß) varies from 0.01 to 12.8%, together with the oxygen index (OI) indicating the maturation in early stage of principal zone of oil genesis.

(a) Componental analysis of bitumen :

As mentioned earlier the extract composition is generally expressed in percent of hydrocarbons (HC), resins (res) and asphaltene (asp). The hydrocarbons are subdivided into aromatic (A) and saturated (S) components. In general, for a sedimentary sequence where the organic matter is homogeneous the A/S ratio tends to decrease with increasing thermal cracking (Heroux et al., 1979). However, homogeneous organic matter is not common, and the nature of extracted bitumen is dependent on type, the level of microbial activity (Connan et al., 1975), and the subsequent history of organic matter (Allan and Douglass, 1977).

As is apparent from of the Table 3.4, the mean ratio of S/A for 46 sample is about 0.7 which indicates moderately matured organic matter.

b) Carbon Preference Index (CPI)

The carbon preference index (CPI) , the parameter relevant to gas chromatography (GC) analysis of total alkanes , has received the greatest attention among the methods using chemical composition of bitumen. It was originally proposed by Bray and Evans (1961), and is based on the progressive change of the distribution of long chain n-alkanes during maturation. Long-chain alkanes reflect the contribution of higher plants in non-marine or terrestrial environments. Therefore, a strong predominance of molecules with an odd number of carbon atoms in recent sediments is observed. Thermal degradation of kerogen during catagenesis subsequently generates new alkanes without predominance. Thus the preference for odd numbered molecules progressively disappears (Tissot and Welte, 1978).

Several expressions of the odd preference have been proposed

1) The original definition by Bray and Evans (1961) used the C_{24} - C_{34} interval.

$$CPI = 1/2 \left(\frac{C_{25} + C_{27} \ldots + C_{33}}{C_{24} + C_{26} \ldots + C_{32}} + \frac{C_{25} + C_{27} \ldots + C_{33}}{C_{26} + C_{28} \ldots + C_{34}} \right)$$

2) Philippi (1965) used the predominance of the C_{29} n-alkane in the C_{28} - C_{30} interval.

$$R_{29} = \frac{2\ C_{29}}{C_{28} + C_{29}}$$

3. Tissot et al. (1977) proposed a mathematical treatment of the distribution based on the best fit of a parabola, and a numerical expression of the deviation from that curve.

Bray and Evans (1961) approach was used in the present study. According to them, CPI values range from 2.5 to 5.3 for recent muds, from 0.98 to 2.3 for sedimentary rocks and from 0.92 to 1.13 for crude oil. Thus values greater than 1.13 indicate immature sediments, from 0.92 to 1.13 mature zones and less than 0.92 supramature zones.

CPI for the Barakar sediments is observed to be either around 1 or less (Table 3.5). This also shows that the samples are matured corroborating thereby previous inferences about adequate to high maturity of organic matter formed in these sediments.

3.7.3 Vitrinite Reflectance (VRo) :

The most consistent and reliable technique for estimating the stages of thermal maturations is the reflectance of vitrinite (Dow, 1977), because optical properties of vitrinite alter very much uniformly during catagenesis and it can be used over the entire evolution path of a particular kerogen type and it is one of the most resistant and common constituents of kerogen and coal. Any new hydrocarbon maturity scale, which is going to be established will be correlated with VRo parameter as a base.

Many workers such as Vassoevich (1969), Hood et al. (1975) Stach et al. (1975) and Tissot & Welte (1978) used their own scales for different stages of maturity. In the present study the scale adopted by Tissot & Welte (1978) is followed (Table 3.7). Since both reflectance and anisotropy of vitrinite increase with increase in its maturity, therefore, it is important to state whether a random or maximum reflectance of vitrinite is determined. For the present study random mean values of VRo are used throughout.

A total of 93 samples (51 from Bhaunra, 34 from Chasnala and 8 from Phulwaritand) were subjected to vitrinite reflectance studies using Leitz MPV 1:1 Ortholix microscope Photometer. Organic matter in the samples very close to igneous intrusions, are over matured or have undergone metagenetic stage of maturation (Table 3.8). However, sediments little affected by intrusion have vitrinite reflectance ranging from 0.41 to 1.60% with mean of 0.95% in Bhaunra area; 0.43 - 1.30% with mean of 0.74% in Chasnala area; and 0.40 - 1.50% with a mean of 0.69% in Phulwaritand area (Table 3.8). These reflectance values indicate

TABLE 3.7: Main stages of evolution of the organic matter, with vitrinite reflectance for comparision

Main stages of evolution			Vitrinite reflectance %
Tissot and Welte,1978	Vassoevich (1969,1974)	Main HC generated	
Diagenesis	Diagenesis Protocatagenesis	Methane	
Catagenesis	Mesocatagenesis	Oil	0.5 1.0
		Wet gas	1.5
Metagenesis	Apocatagenesis	Methane	2.0 2.5 3.0
Metamorphism			4.0

TABLE 3.8 : Mean Vitrinite Reflectance (VR_o) Values of Selected Samples from Barakar Formation

Sl.No.	Sample No.	Distance from Intrusion	No. of Reading	VR_o Percentage
		CHASNALA AREA		
1.	52	0.00	No vit	-
2.	53	0.50	No vit	-
3.	54	1.00	No vit	-
4.	55	2.50	12	0.66
5.	56	3.00	15	0.68
6.	57	3.57	15	0.58
7.	58	4.50	13	0.64
8.	59	7.50	15	0.43
9.	60	0.00	13	1.14
10.	61	0.25	13	0.72
11.	62	0.50	15	0.75
12.	63	0.75	17	0.72
13.	64	1.00	17	0.77
14.	65	1.25	15	0.70
15.	66	1.50	20	0.69
16.	67	0.00	12	6.27
17.	68	0.50	12	6.17
18.	69	1.00	14	5.65
19.	70	1.50	14	3.11
20.	71	2.00	20	0.68
21.	72	2.50	20	0.71
22.	74	3.50	25	0.50
23.	77	5.00	25	0.59

24.	79	6.00	22	0.53
25.	82	0.00	25	1.39
26.	83	0.10	25	1.45
27.	84	0.20	20	0.88
28.	86	0.00	No vit	-
29.	87	0.10	20	1.20
30.	88	0.20	25	0.79
31.	90	0.00	25	1.03
32.	91	0.05	30	0.98
33.	92	0.10	25	1.33
34.	93	0.15	25	1.30

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35.	94	0.00	14	2.44
36.	95	0.25	15	0.91
37.	96	0.50	15	0.79
38.	97	0.75	15	0.77
39.	98	1.00	20	0.74
40.	99	1.25	20	0.68
41.	100	1.50	50	0.61
42.	101	1.75	20	0.55
43.	102	2.00	25	0.61
44.	103	0.00	12	5.35
45.	104	0.20	14	5.79
46.	105	0.40	13	1.48
47.	106	0.60	15	1.60
48.	107	0.80	15	1.47
49.	108	1.00	12	1.15
50.	109	1.20	15	1.05

51.	110	1.40	14	1.07
52.	111	1.60	14	1.00
53.	112	1.80	15	1.15
54.	113	0.00	No vit	-
55.	114	0.50	No vit	-
56.	115	1.50	15	0.68
57.	116	2.00	14	0.55
58.	117	2.50	15	0.65
59.	118	3.00	No vit	-
60.	119	3.50	No vit	-
61.	120	4.50	15	0.47
62.	121	5.50	17	0.41
63.	122	0.25	No vit	-
64.	123	0.75	No vit	-
65.	124	1.50	15	1.50
66.	125	2.50	No vit	-
67.	126	3.00	No vit	-
68.	127	3.75	No vit	-
69.	128	4.50	15	0.51
70.	129	5.50	15	0.44
71.	131	0.00	17	2.75
72.	132	0.10	20	1.44
73.	133	0.20	20	0.90
74.	135	0.00	15	4.92
75.	136	0.10	20	1.97
76.	137	0.20	25	1.80
77.	138	0.30	25	0.99
78.	139	0.40	30	0.91

79.	140	0.50	30	1.10
80.	141	0.60	20	0.85
81.	142	0.70	20	0.89
82.	143	0.80	15	0.91
83.	144	0.90	15	0.85
84.	145	1.00	15	0.82
85.	146	1.10	No vit	-
PHULWARITAND-MAHESHPUR AREA				
86.	44	0.25	17	0.47
87.	45	1.00	15	0.49
88.	46	2.00	15	1.50
89.	47	2.50	15	0.73
90.	48	3.00	14	0.69
91.	49	4.00	16	0.65
92.	50	5.00	15	0.59
93.	51	6.50	15	0.40

that these sediments are well within the petroleum window (VRo between 0.5 to 2.0%).

3.7.4 Thermal Alteration Index (TAI) :

The variation in colour during thermal maturation of spores and pollens has been described by several publications such as Gutjhar (1966), Hood et al. (1975) and Staplin (1969). For the present study the thermal alteration index of Staplin (1969) is used. His index is based on microscopic observations of both colour and structural alteration of organic debris. The colour changes of spores and pollens through maturation stages are from yellow to orange to brown and finally to black. (Appendix - VI).

Visual examination of 92 recovered organic matter slides (33 from Chasnala, 51 from Bhaunra and 8 from Phulwaritand) for thermal alteration index (TAI) gives ground value around 2.75 (Table 3.6) indicating adequate or moderate mature facies away from mica peridotite intrusions.

3.7.5 Fluorescence Study :

Fluorescence is a useful measure of organic matter type and maturity and the presence of non indigenous hydrocarbons (Waples, 1985). Longer wavelengths of fluorescence emissions indicate higher maturity because of greater delocalization of energy and therefore greater stability. Microspectrofluorescence, in addition, provides additional dimension and it enhances certain aspects of the visual observations which results in more objective interpretation of organic maturation stages.

With this in view 8 samples were selected and investigated under MPV-3 microscope photometer equipped with HP 86 B computer through a programme in Basic "M 3 SP 87 BA". It was observed that (Fig. 3.22) away from the contact of intrusions the ground value of the spectral maximum numerical values is of the order of 8.46% at 530 nm, thereby indicating the maturity just above the onset of oil window. This observation is with corroboration with the VR_o and TAI values.

3.8 TIME OF GENERATION OF PETROLEUM

Time of generation of petroleum is an important aspect in the study of source rocks. If hydrocarbons are generated before the formation of traps in an area, no petroleum accumulation is likely. However, if it is formed after the formation of traps, it may form good pool.

Generation of petroleum is temperature - time dependent chemical phenomenon which can be expressed by Arrhenious equation.

$$K = A \exp(-E/RT)$$

where :

K = reaction rate constant

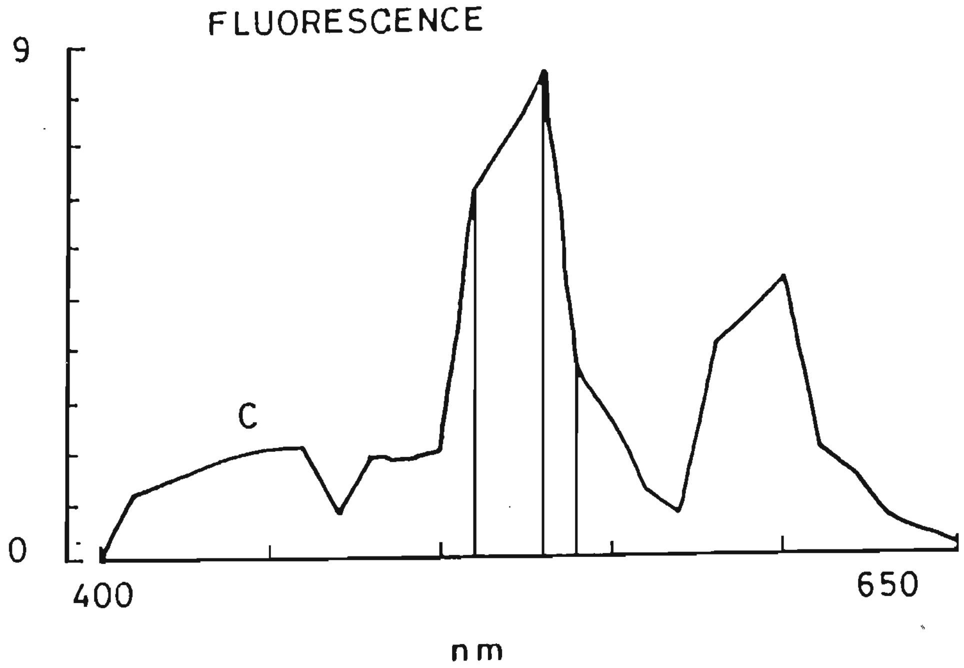
A = constant

E = Activation energy

R = Universal gas constant

T = temperature.

Low temperatures acting over long duration will have same effect on maturation of organic matter as high temperature acting over it for short time duration. Based on these concept a number of models have been developed to predict maturation of organic matter and the time of generation by a number of workers such as Tissot (1969), Tissot and Espitalie (1975) and Hood et al.



Spectral Analysis Result

max = 530 max meas = 8.46
50 = 510 meas = 6.41
50* = 540 meas = 3.16
Quotient 650/500 = 0.108

Fig. 3.22 Fluorescence spectra of kerogen particle from the Barakar Formation (sample no. 145, Bhaunra).

(1975); the method developed by Lopatin (1971) is simple, quick and requires simple input data in terms of time stratigraphic sequence alongwith the temperature gradient. The present study is based on this simple approach.

Lopatin's Model

The basic assumption in the Lopatin approach for calculating maturity of organic matter in terms of a parameter which he calls as time temperature index (TTI) is that the rate of maturation (chemical reactions) approximately doubles for every 10°C increase in temperature. The general validity of this assumption has been confirmed by numerous examples (Waples , 1985). Lopatin defined `Time Factor' as an interval or a length of time (expressed in million years) spent by a rock at each temperature interval of 10°C. Since for each 10°C rise in temperature the maturation is assumed to increase by a factor of 2, he defined `Temperature Factor' (T) as -

$T = 2^n$ where n is index value assigned to each temperature interval of 10°C. For temperature range 100 -110°C, n = 0 forms an arithmetic progression with common difference of 1 i.e. -1, -2, -3... for temperature intervals 90 - 100°C ,80 - 90°C, 70 - 80°C...respectively and 1, 2, 3 ... for temperature intervals 110 - 120°C, 120 - 130° C, 130 - 140° C respectively.

On the basis of time factor and temperature factor, he defined time temperature index (TTI) for any temperature range as TTI values between 15 and 160°C are considered to form `oil window' for type III kerogen.

Application of Lopatin's Model in Jharia

This simple model has been applied to calculate maturity of shales of the Barakar Formation and estimate the time of generation of petroleum during the burial history of these sediments. The present study is based on the time - stratigraphy of the Jharia coalfield given by Verma et al. (1989).

On the basis of the data given in Table 1.1, burial history curves for various formations were prepared (Fig. 3.23). On the burial history curves, a temperature grid of 10° C was drawn taking a temperature gradient of 3° C/km for this area based on the work of Panda (1985). Burial history curves with superimposed temperature grid (Fig. 3.23) was used to work out TTI values for the early and Late Barakar sediments (Table 3.9 and 3.10).

It is inferred on the basis of this simple approach that -

i) The Barakar sediments have undergone maturity level between TTI 15 and about 79 indicating catagenesis of organic matter within the early part of `Oil Window'. These deductions are corroborated by similar inferences regarding maturity determination done using various approaches in section 3.7.

ii) Petroleum hydrocarbons were generated between a time period ranging from 235 to about 200 million year before present i.e. Permo-Triassic time during the burial of these sediments.

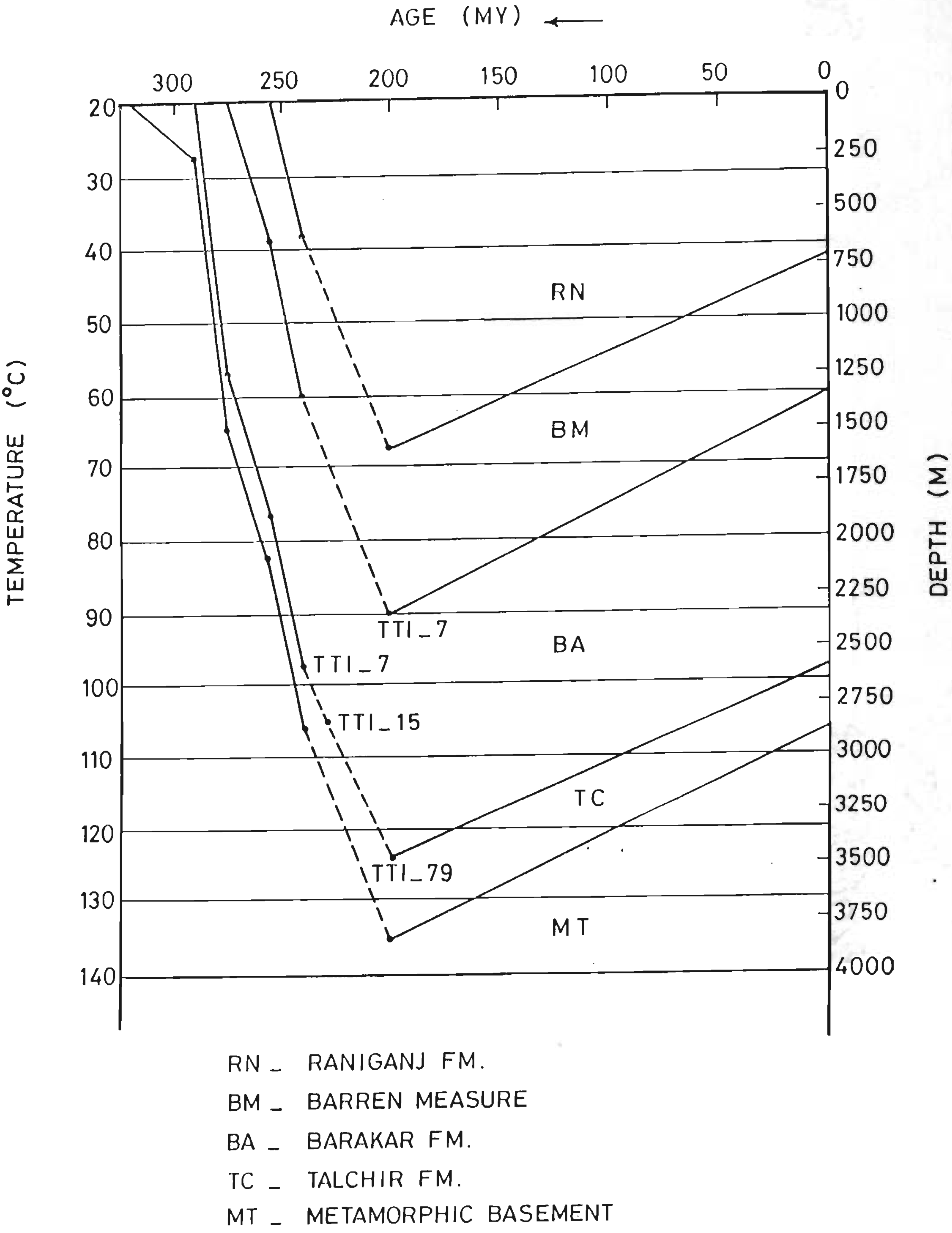


Fig. 3.23 Family of burial-history curves for sediments, Jharia area.

TABLE 3.9: TTI Calculation for the early Barakar Rock (290 M.Y old) Jharia, Bihar

Temperature Interval	Temperature Factor	Time Factor	Interval TTI	Total TTI
20 - 30	1/256	4	0.016	0.016
30 - 40	1/128	4	0.031	0.047
40 - 50	1/64	5	0.078	0.125
50 - 60	1/32	5	0.156	0.281
60 - 70	1/16	10	0.625	0.906
70 - 80	1/8	8	1.000	1.906
80 - 90	1/4	8	2.000	3.906
90 - 100	1/2	8	4.000	7.906
100 - 110	1	17	17.000	24.906
110 - 120	2	17	34.000	58.906
120 - 130	4	5	20.000	78.900

TABLE 3.10 TTI Calculation for the Late Barakar Rock (275 M.Y) Jharia, Bihar

Temperature Interval	Temperature Factor	Time Factor	Interval TTI	Total TTI
20 - 30	1/256	10	0.039	0.039
30 - 40	1/128	10	0.078	0.117
40 - 50	1/64	8	0.125	0.242
50 - 60	1/32	8	0.250	0.492
60 - 70	1/16	13	0.812	1.304
70 - 80	1/8	13	1.625	2.929
80 - 90	1/4	15	3.75	6.679

CHAPTER - 4

EFFECT OF IGNEOUS INTRUSIONS ON ORGANIC MATTER IN SEDIMENTS

4.1 BACKGROUND

Petroleum hydrocarbons are generated as mentioned in Chapter-2, by thermal maturation of organic matter mainly the kerogen under optimal physio-chemical environments. On regional scale, with increasing depth of burial of sediments, the temperature increases. The temperature increases with an average gradient of about 30°C per kilometer depth. Generation of petroleum hydrocarbons is a temperature-time dependent chemical phenomenon. The generation of hydrocarbons from organic matter is universally accepted to be a low temperature (50° to 200° C) and long duration process associated with the burial history of sediments. However, laboratory experiments by workers such as Louis and Tissot (1967), Albrecht et al. (1976), Connan (1974) and Ishiwatari et al. (1976), have convincingly proved that petroleum hydrocarbons can also be generated by high temperature heating for very small periods during pyrolysis of organic matter. Igneous intrusions of sediments thus, offer excellent opportunity to investigate natural pyrolysis of organic matter, by acting as source providing high temperature for short duration.

Occurrences of petroleum associated with igneous rocks in different parts of world have been explained by some workers such as van Tyle and Mclaren (1932), Lahee (1932), Haughton et al. (1953), Felts (1954), Hunt (1962) and Hedberg (1964), as due to the distillation of organic matter found in sediments because of heat of intrusive igneous bodies.

Tissot and Welte (1978), Simoneitt et al.(1978, 1981), Dennis and Maciel (1982), Saxby and Stephenson (1987) and Wang et al.(1989), inferred from their studies that the transformation of organic matter into hydrocarbon, can be observed to a certain distance of the igneous rocks.

As mentioned earlier, the Barakar Formation has been intruded by igneous rocks and therefore, goads to investigate the effect of short duration high temperature on the organic matter dispersed in the sediments of same age, same type, at the same pressure, with a view to evaluate the role of igneous intrusion in transforming organic matter into petroleum hydrocarbons.

4.2 IGNEOUS INTRUSIONS IN THE SEDIMENTS OF JHARIA

Sediments of Lower Gondwana, found in the Jharia, have been intruded by igneous rocks of two types- mica peridotite and dolerite. These intrusions as worked out by Verma et al. (1989), took place in two separate episodes- mica peridotite (lamprophyre) during Lower Cretaceous (100 m.y) and dolerite in Paleocene (65 m.y). They occur in the form of dykes, sills and veinlets.

Dolerite intrusions of viscous fluid material are confined mainly to the western part of Jharia mainly as dykes. Lamprophyres, specially the mica rich varieties (mica peridotite) of these intrusives of high fluidity, are found to occur all over the coalfield as dykes, sills and veins and vary in thickness between 25 cm and 3 metre. At places they occur as isolated pods of lenticular shapes. These veinlets and strings are given out by these intrusives which fill the joints, fractures found in the sediments.

The maximum temperature attained by these intrusions of lamprophyres, has been inferred to be around 800° C (Singh, 1987). Mica peridotites, which have intruded the Barakar Formation thus, provide a geological model to study as to how high heat source affect chemical transformations in the organic matter found in the intruded sediments. The present study was, therefore, taken up in three areas of Bhaunra, Chasnala and Phulwaritand-Maheshpur.

Although there are some research work on the igneous rocks of the Jharia coalfield, but nearly all of them studied the intrusive body having in view the petrology or its effects on the coal seams of the coalfield. Among these are Fox(1930), Ghosh (1949), Sanyal (1964), Choudhuri et al (1977), Ghose et al. (1977) and Singh (1987). The present work is the first attempt to study the igneous intrusions of the area for their effectiveness in transforming organic matter found in the intruded sediments, into petroleum hydrocarbons or graphitic material.

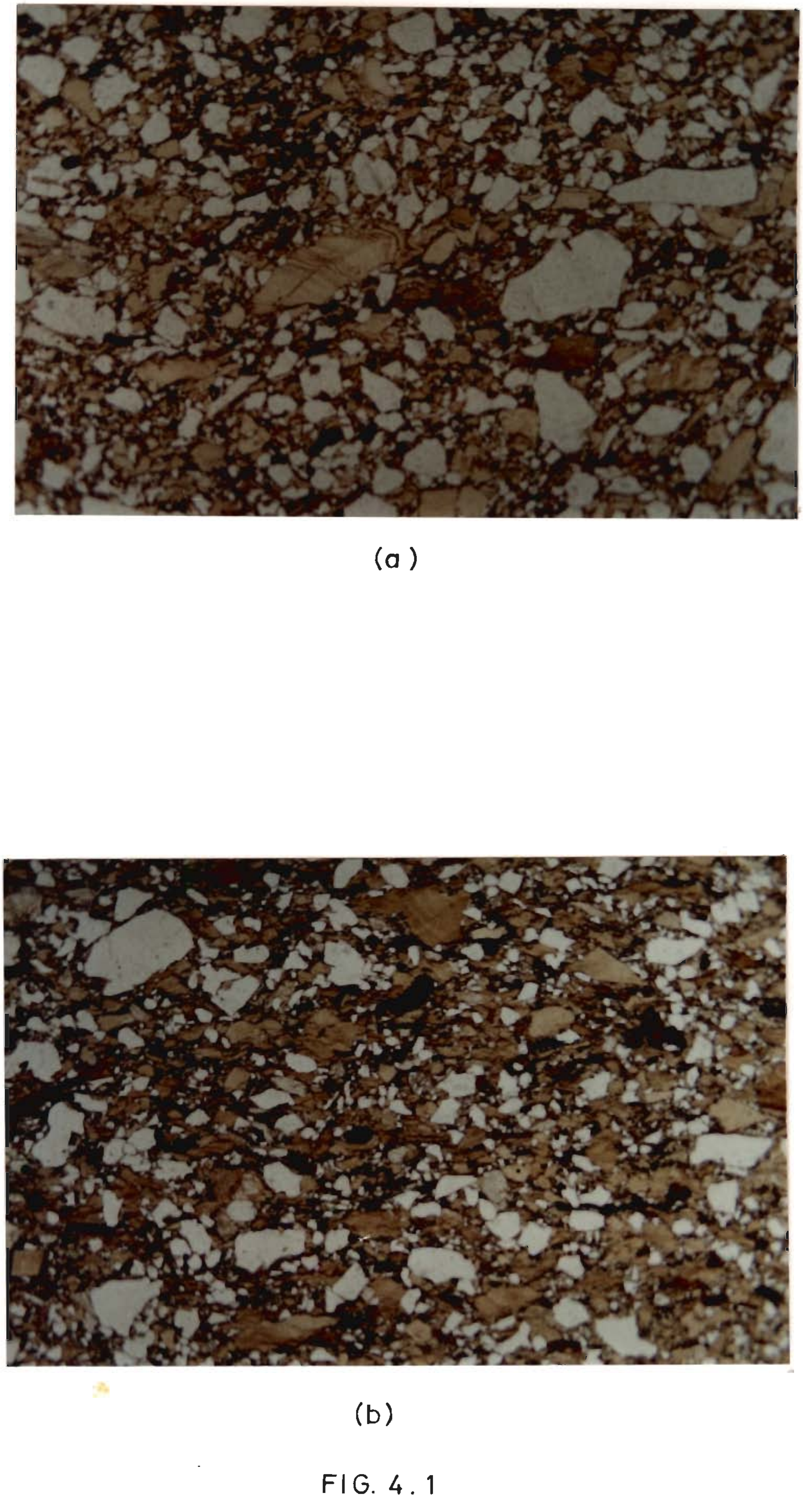
Chasnala Area:

In Chasnala area, within hundred meters north of the Dhanbad Sindri road bridge, upstream on the Domohani nala, the three lowest seams of the Jharia coalfield (I,II & III) are intruded by lamprophyres mainly along the basal contact between the combined seams and the shale. The main intrusive body is about 30 cm thick, a few thin sills and isolated pods also occur within the coal seams. Though the seams are intimately penetrated by the intrusives, banded nature of the original coal, is retained in the natural coke in many places. Here the lamprophyres of microsyenitic composition and medium grained mica lamprophyres are trending N 60° W - S 60° E dipping at 30° in S 30° W. The rock is composed of high proportion of reddish brown titaniferous biotite of two generations Broad tabular phenocrysts of biotite containing groundmass mineral and quartz carbonate lenses along the cleavage traces are kinked (Fig. 4.1 a and b). They are enclosed by flakes of smaller size. Olivine pseudomorphs are represented by greenish gray serpentine and carbonate. The carbonate rich parts show presence of tiny flakes of phlogopite biotite phenocrysts are embedded in mosaic consisting of carbonate, K-feldspar, serpentine and chlorite. Phlogopite, apatite, rutile, epidote and opaques are minor accessories.

Bhaunra Area:

In Bhaunra area two kinds of lamprophyres are observed. In the south western part of the area lies a buff to pinkish brown aplitic rock which show porphyritic texture. The rock is highly feldspathic and the gray hue is imparted by biotite and carbonaceous matter present in the rock. The weathered outcrops show polygonal outlines which represent cooling cracks. On the other hand in the north eastern part of the area grayish white, lens like lamprophyre occurs which are composed of carbonate, apatite needles, long feldspar needles (plagioclase) and minor amounts of opaques (Fig. 4.2).

Fig. 4.1 a & b Photomicrograph of Lamprophyre of Chasnala area.



(a)

(b)

FIG. 4.1

Fig. 4.2 Photomicrograph of Lamprophyre composed of carbonate, apatite needles, long feldspar needles and minor amount of opaques (Bhaunra area).

Fig. 4.3 Photomicrograph of Lamprophyre composed of feldspar, carbonate and crystals of leucite (Phulwaritand area).

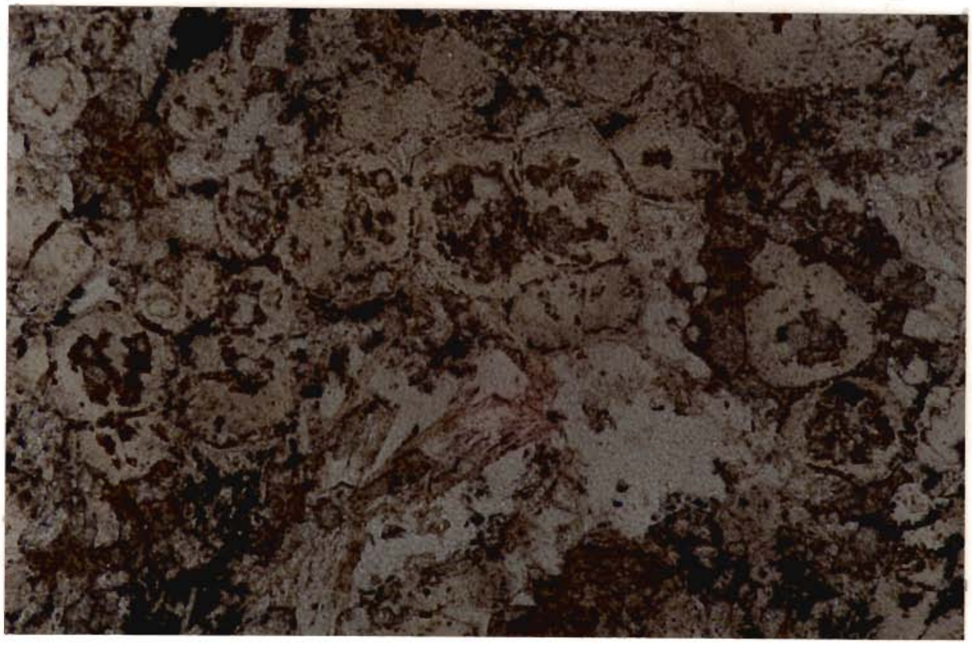


FIG. 4. 2

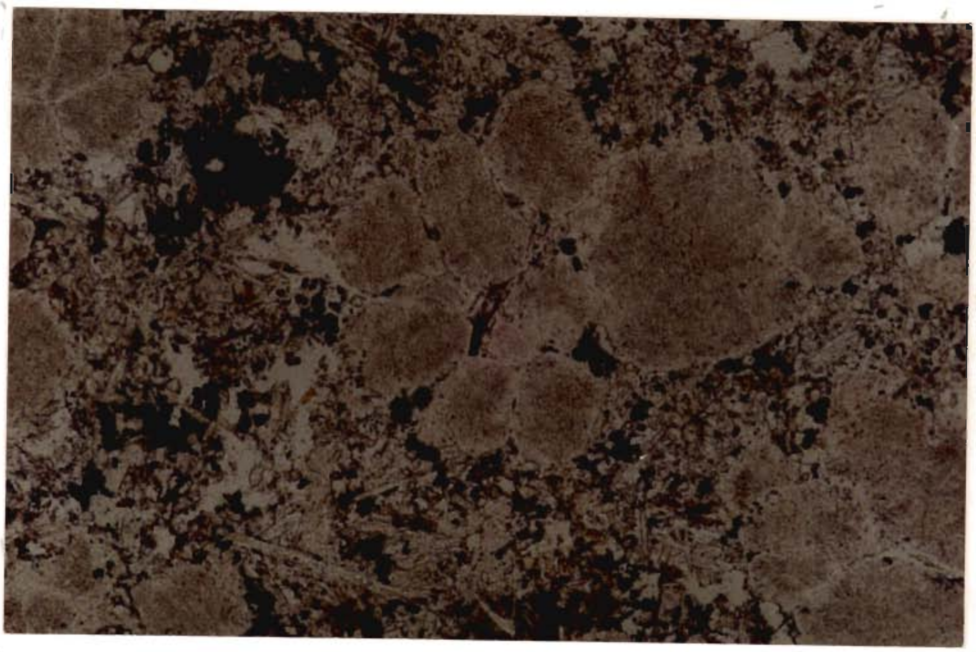


FIG. 4. 3

Phulwaritand-Maheshpur Area:

In Phulwaritand-Maheshpur area, the rock is pinkish gray consisting of feldspar, carbonate and well developed crystals (Fig. 4.3). The rock is composed of euhedral to rounded colourless leucite within chloritic and serpentinous groundmass associated with carbonate and k-feldspar. It shows gradation between mica-lamprophyres and minette. These intrusions occur mostly as dykes and sills of very small thickness.

4.3 EFFECT OF IGNEOUS INTRUSIONS ON ORGANIC MATTER AND ITS MATURITY

The Shales of Barakar Formation in the Jharia coalfield are rich in organic matter. The kerogen found dispersed in them is mostly of Type III with little type II. These shales have been intruded mostly by mica-peridotitic igneous bodies which act as source of heat. This source of heat must have created a thermal flux across the intrusions in these organic matter rich sediments.

Stevens et al. (1956) and Bray and Evans (1961), provided the stimulus for renewed interest in the importance of heat in the generation of petroleum. Gretener and Curtis (1982), here deserve quoting as having said that "Organic metamorphism of kerogen to hydrocarbon transformation is a function of both temperature and exposure time. The effect of temperature is exponential of that of time linear. At very low temperature (<50° C), the conversion rate is so low that time has no effect. At high temperature (>130° C) the reaction proceeds at such a high rate that time also plays no important role. The effect of time is noticeable in the range of 70 to 100° C, where intermediate conversion rates prevail". However, it is now universally accepted that in the intermediate conversion rates, lower temperatures may be compensated by larger time and vice versa.

The thermal effect of igneous intrusions of mica-perdotite was studied by evaluating the total organic matter content and the maturity parameters of organic matter. A total of 146 samples collected systematically across 18 intrusions (12 dykes and 6 sills) at spacing varying from 5 to 3 metre apart, from Bhaunra, Chasnala and Phulwaritand Maheshpur areas, form the basis of the present studies.

4.3.1 Effect of Intrusions on Organic Carbon Content (TOC)

Organic matter in the shales of Barakar subjected to high temperature immediately adjacent to mica-peridotite intrusion have been destroyed leaving graphitic material (Fig. 4.4). Similar observations have been made by Degens, (1965) as described by Barker, (1979) in his study of Pierre shales of Upper Cretaceous. However, if there is a coal intervening between the intrusion and a shale, natural coke locally called Jhama will be formed.

4.3.2 Effect of Intrusions on Maturity of Organic Matter

The maturity parameters studied are the Vitrinite Reflectance (VR_o), Thermal Alteration Index (TAI), Microspectrofluorescence, Pyrolytic parameters and Bitumen and its Componental elements.

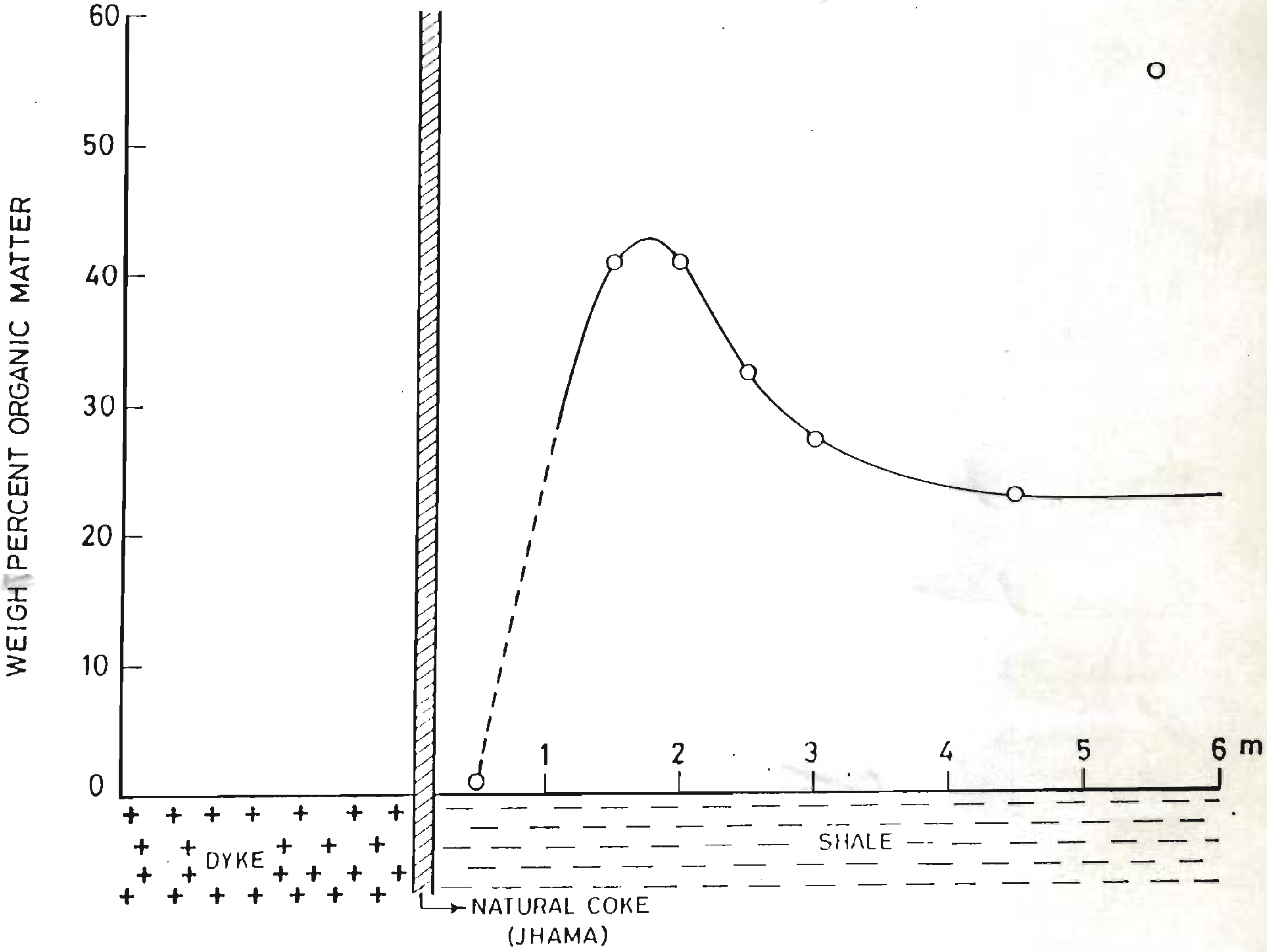


Fig. 4.4 Organic matter in the shale of Barakar Formation adjacent to mica-peridotite intrusion.

Effect of Intrusions on Vitrinite Reflectance

Vitrinite is abundantly found in the Type III Kerogen, and is most commonly used for maturity determinations. As mentioned in Chapter III, the Kerogen in the shales of Barakar Formation of Jharia coalfield is of type III and therefore, the reflectance of vitrinite present in it, which increases with increasing thermal maturity can be used as an important tool to study the effect of igneous intrusions of mica peridotite on organic matter.

Reflectance measurements performed on vitrinite maceral (Table 3.8) indicate that VR_o for the samples just at the contact with the igneous intrusions, is high (as much as 6.27%) and decreases away from the intrusive bodies till it attains a ground value varying from about 0.8 to 0.5% (Figs. 4.5 a and b).

Figure 4.6 further indicates that the thermal effect of igneous intrusion on vitrinite reflectance upto a distance X from the contact between the intrusion and the shale. The thermal maturity beyond the distance X depends on the thermal effects due to `basement heat' during the burial of sediments. This zone (Y, greater than X) has no effect of igneous intrusion.

These intrusions affected the maturity zones. The width `X' of these thermally affected zones vary with the width of intrusive body. It is generally twice the width of igneous body. The thermally affected zone is characterized by contact metamorphism, metagenetic and catagenetic zones, depending upon the thickness of igneous body. Bivariate plot between the width of igneous intrusion and the width of various maturity level zones (Fig. 4.7) indicates linear relationship. Widths of the metamorphic, metagenetic and catagenetic zones are about 15%, 32%

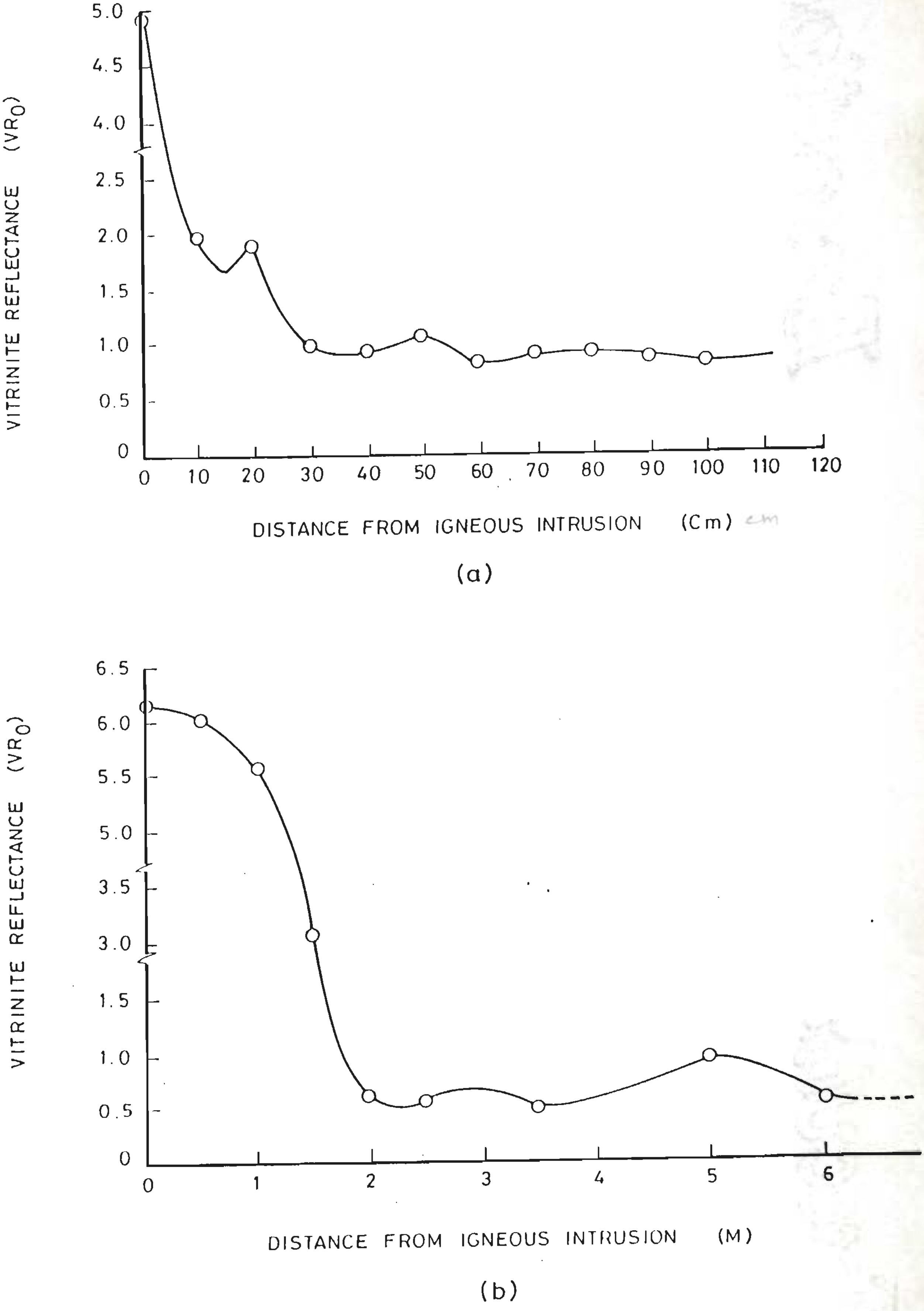


Fig. 4.5 Variation of vitrinite reflectance

a. ground value 0.8%
b. ground value 0.5%

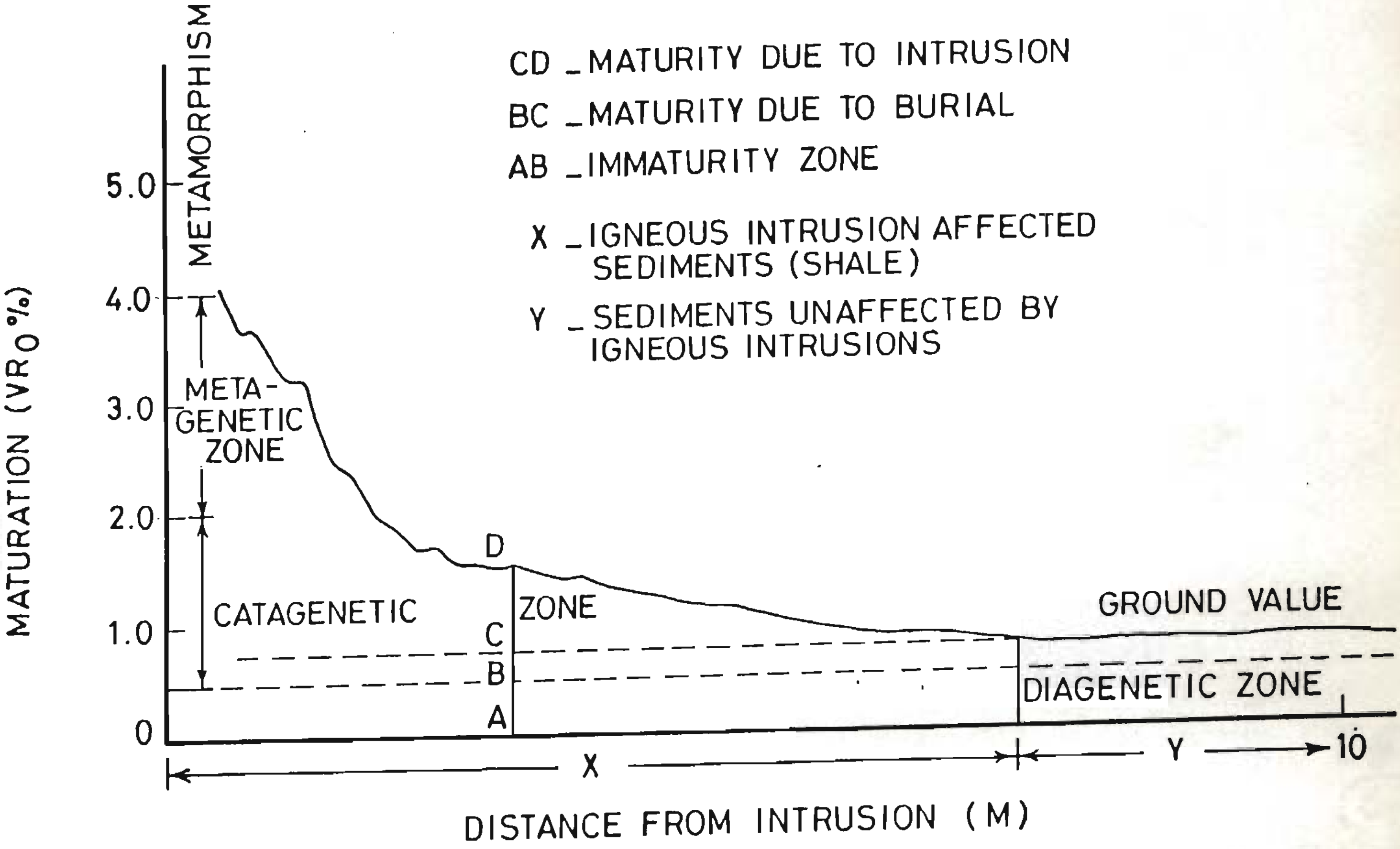


Fig. 4.6 Thermal effect of igneous intrusions on vitrinite reflectance.

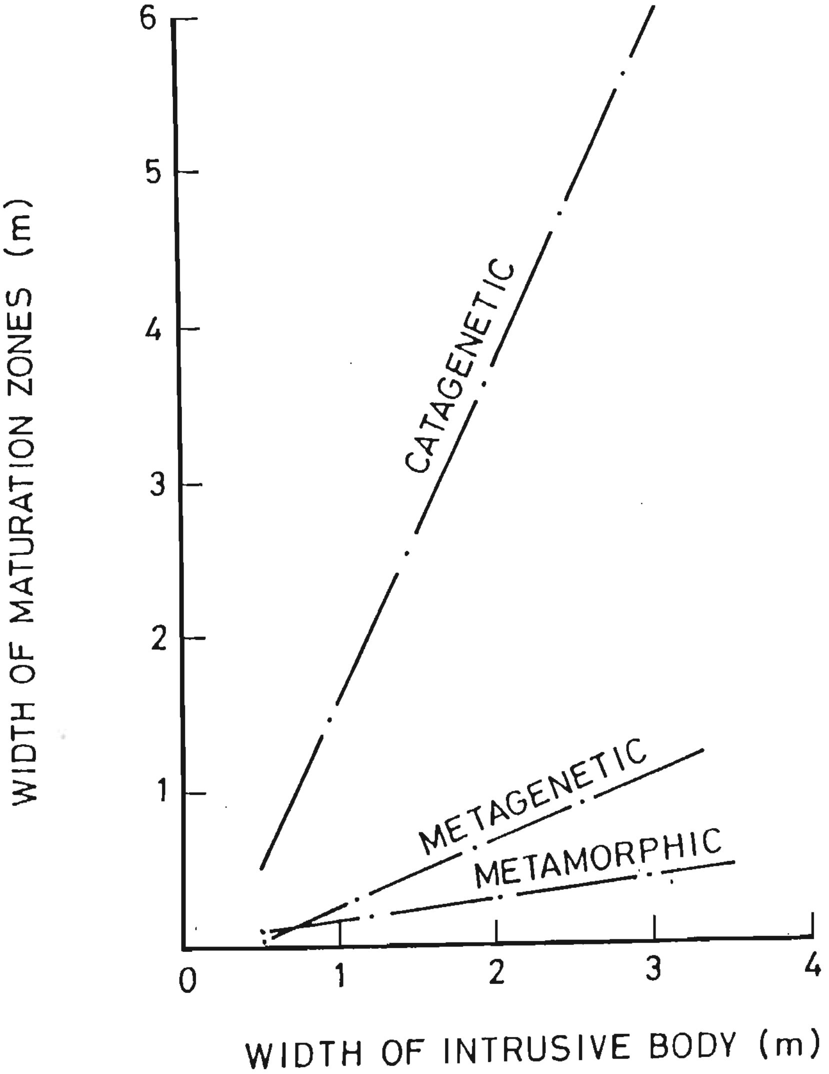


Fig. 4.7 Bivariate plot between the width of igneous intrusion and the width of maturity level zones.

and 180% (nearly twice) of the width of the intrusive body respectively. Thus, as the thickness of the igneous intrusions increases, the width of various maturity zones also increases. However, if the thickness of intrusion is about 0.3 m or less, they have little effect on vitrinite reflectance. Therefore, for mica peridotite intrusions with thickness >0.3 m, the following relationships emerge out :

(a) $Mt = 0.15\ I$

(b) $Mg = 0.32\ I$

(c) $Cg = 1.80\ I$

where;

I - width of igneous intrusion
Mt - width of metamorphic zone
Mg - width of metagenetic zone
Cg - width of catagenetic zone.

Jones and Creaney (1976), Dow (1977), Waples (1981), Reeckmann and Mebberson (1984), Frederick et al. (1985) and Gilbert et al. (1985) worked on contact metamorphism by intrusives and mentioned that the widths of thermally metamorphosed zones are quite different. They indicated that the differences are probably related to variations in intrusions, temperature of the intrusives, differences in thermal properties of the host sediments, and the different temperature sensitivities of thermal indicators. Here, Dow (1977) suggests that as a rule, contact metamorphism affects the maturity of the intruded rocks to a maximum of about twice the thickness of the intrusive body. Further, he states that the actual distance depends upon the temperature difference between the intrusive and the invaded rock, which depends on the temperature of the intrusive and the depth of intrusion. In view of these observations, the effect of igneous intrusions on maturity of organic matter is depicted in the form of a physical model shown in figure 4.8.

Effect of Intrusions on Thermal Alteration Index (TAI):

Thermal alteration Index (TAI) is a measure of kerogen maturity obtained by observing the variation in colour of bisaccate pollen grain in transmitted light under a microscope.

The darkening of kerogen particles with increasing thermal maturity is used as an indicator of maturity. Figure 4.9 a to d, is best illustrative of this effect in which the darkest kerogen is in the contact with the igneous intrusions and the colour is faded, away from the contact.

TAI were determined using colour chart (Appendix-VI) which is routinely employed for such studies in the Keshav Dev Malviya Institute of Petroleum Exploration (KDMIPE), Oil and Natural Gas Commission, Dehra Dun, India.

TAI values from the Barakar Formation of Jharia coalfield are all, around 2.75. A bivariate plot (Fig.4.10) showing variation of TAI with respect to distance from igneous intrusion indicates that TAI is as high as 4.5, close to the contact of shale with the mica peridotite igneous bodies and decreases to its ground value of about 2.75 away from the intrusions.

Effect of Intrusion on Fluorescence of Organic Matter:

Fluorescence radiation is given off by a molecule when it descends from a high energy electronically excited state to a lower energy state. If the wavelength of the emitted radiation

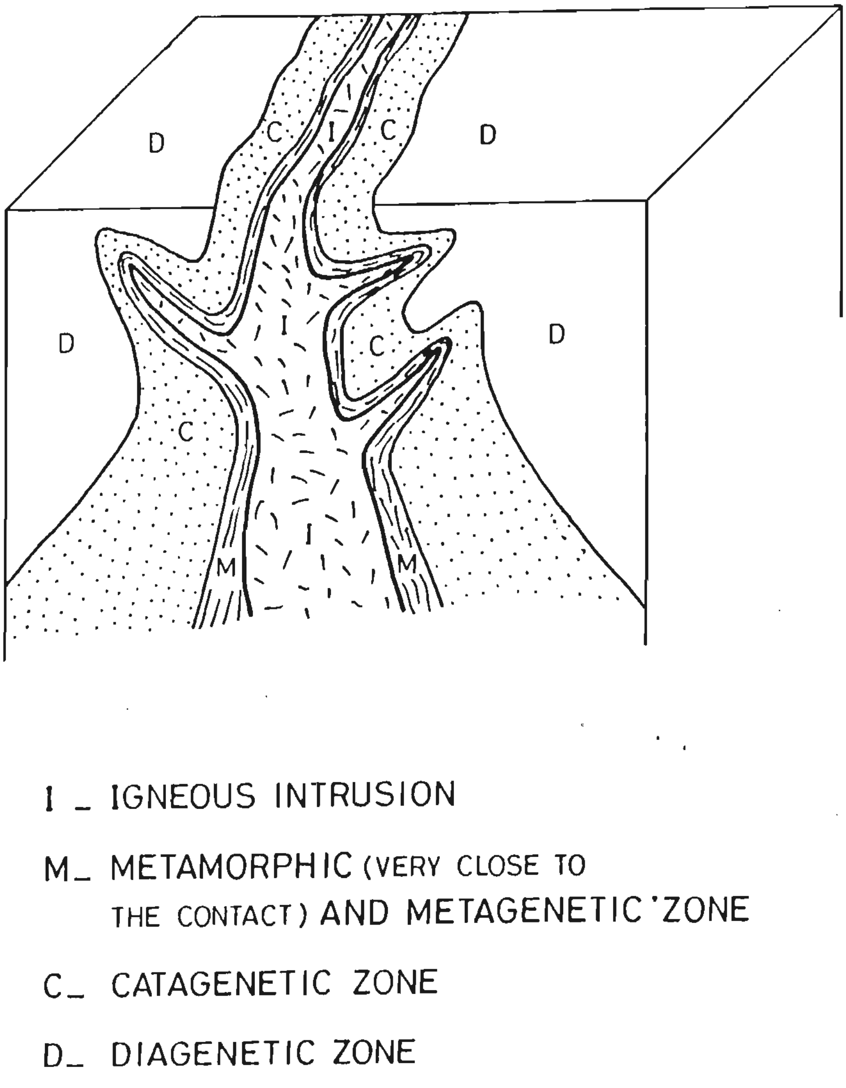
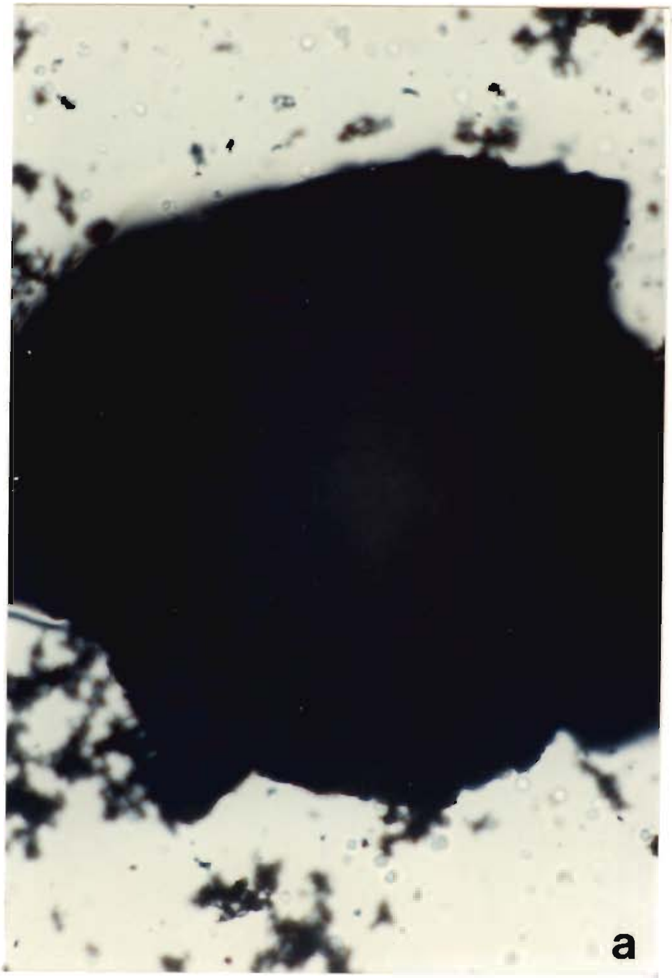


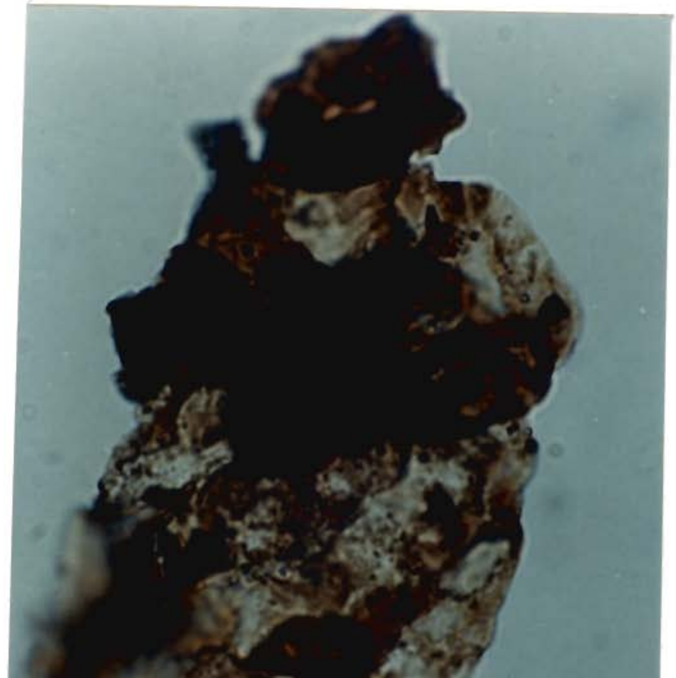
Fig. 4.8 A conceptual model of maturity of shale of the Barakar Formation, Jharia.

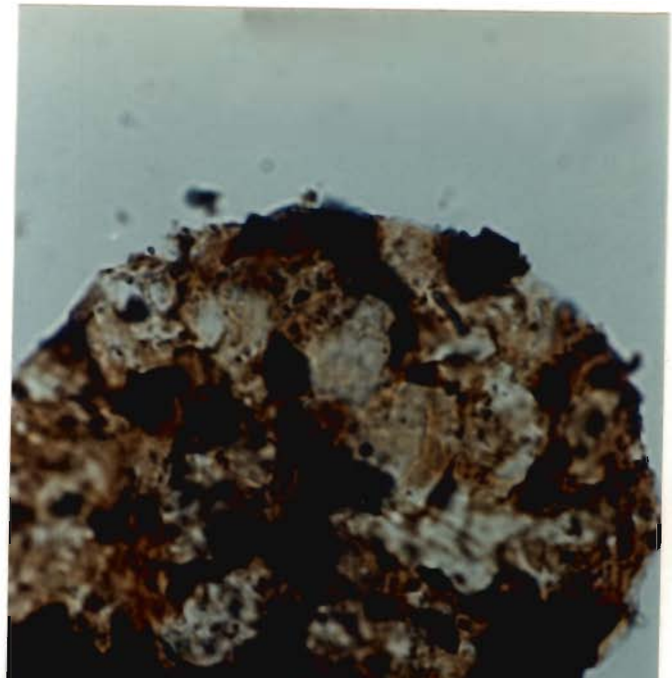
Fig. 4.9 Effect of intrusion on organic matter. Darkening of the organic matter nearer the intrusion.

a. close to the intrusion,
b, c & d. successively away from the intrusion.


a


b


d


c

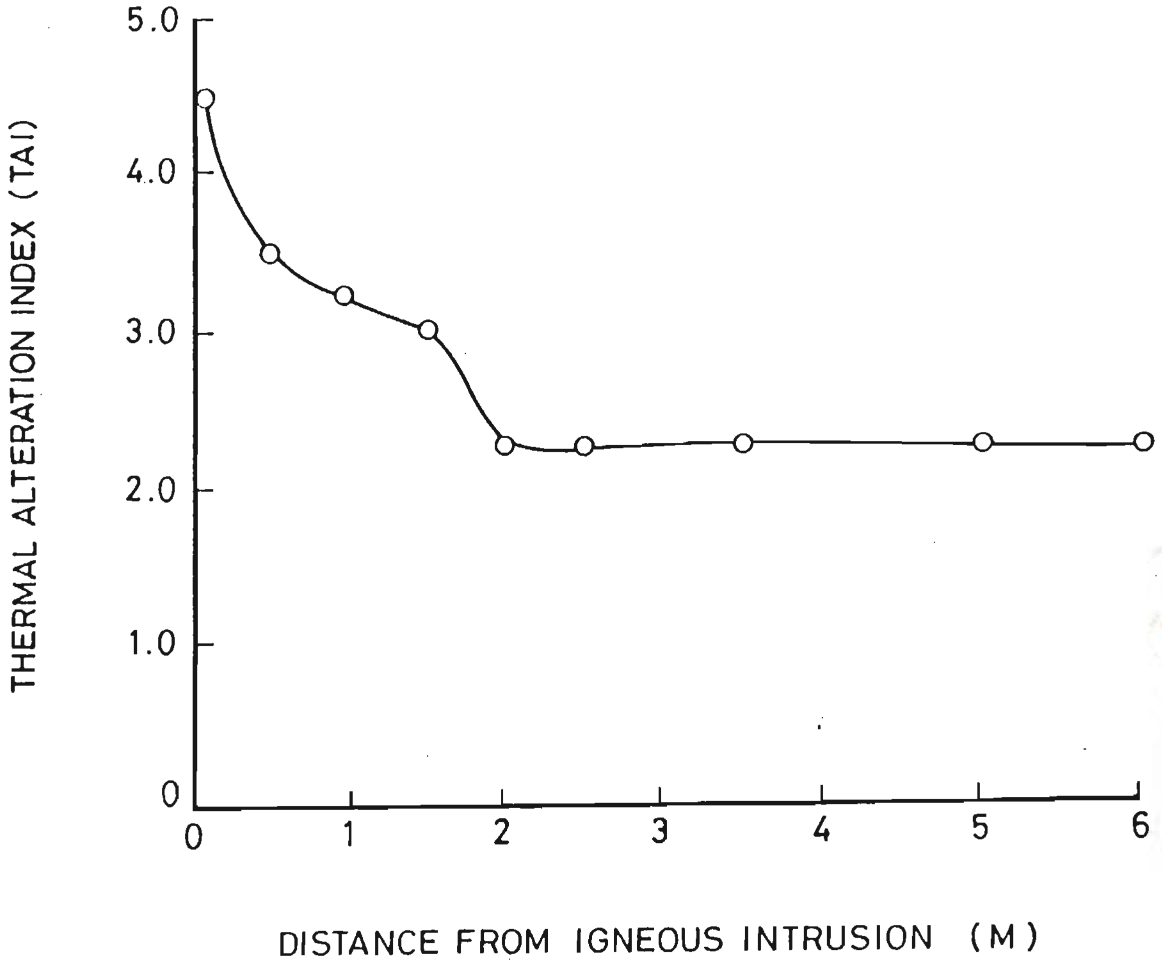


Fig. 4.10 Bivariate plot showing variation of TAI with respect to distance from igneous intrusion.

is in the visible region, the fluorescence will be apparent to the eye. In case it is not, it may be detected by infrared or ultraviolet sensors. Aromatic molecules fluoresce well because of their capability to delocalize (stabilize) the excess energy.

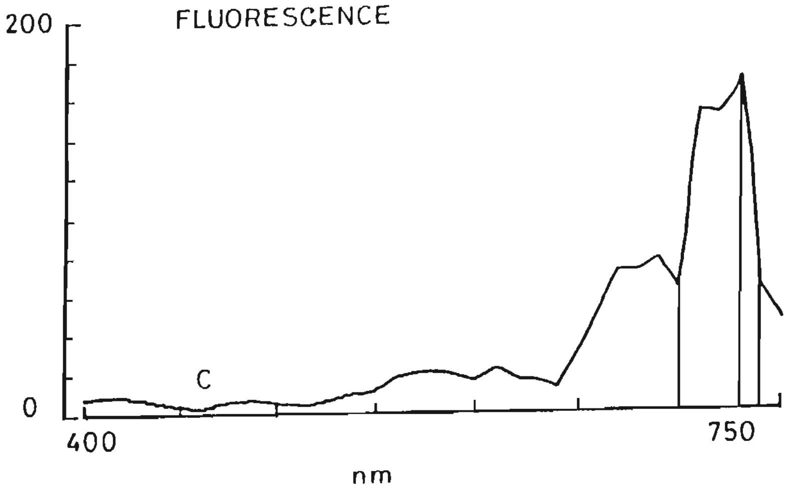
With a view to study the effect of intrusion on fluorescence of organic matter 8 samples were investigated under MPV-3 microscope photometer.

The fluorescence- free mounting média (i.e. Canada Balsam) has been used for slide preparation. The slides have been examined in transmitted light and after selecting the specimens, their fluorescence spectra have been determined using incident light excitation between 400 nm to 450 nm.

Spectral analysis show maximum fluorescence of 168.44% at 730 nm wavelength, for the shales at or near the contact with igneous intrusions (Fig. 4.11) and decreases to 8.46% at 530 nm wavelength (Fig. 4.12) away from the contact. Therefore, the Fluorescence spectrum values are increasing towards the intrusive body.

Pyrolytic Parameters:

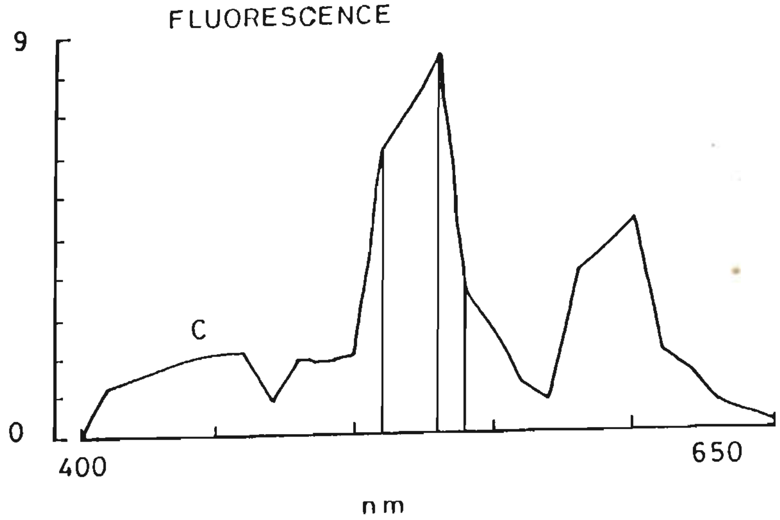
Pyrolysis temperature is frequently used as a maturity indicator, because as the maturity of a kerogen increases, the temperature at which the maximum rate of pyrolysis occurs increases. The parameter Tmax (spike of S2 peak) has become a standard part of Rock-Eval output data.



Spectral Analysis Results

max = 730 max meas = 168.44
50 = 700 meas = 59.23
50* = 740 meas = 63.74
Quotient 650/500 = 6.244

Fig. 4.11 Fluorescence intensities near the contact with igneous intrusion (sample no.136, Bhaunra area).



Spectral Analysis Result

max = 530 max meas = 8.46
50 = 510 meas = 6.41
50* = 540 meas = 3.16
Quotient 650/500 = 0.108

Fig. 4.12 Fluorescence intensities away from the contact with igneous intrusion (sample no. 145, Bhaunra area).

Tmax and Production Index (PI):

Higher temperatures imposed by the intrusions in the study area have cracked some of the more labile hydrocarbon side-chains from the kerogen. Figure 4.13 indicates that Tmax increases towards igneous intrusions. It is as high as 554°C near the contact of intrusions with shale and decreases to a value as low as 330°C. As a consequence to this increase in the value of Tmax to 554° C near the contact the pyrolysis products become a part of free compounds causing thereby an increase in the productivity index (PI). Therefore, the peak of PI near the contact with intrusion matches with that of Tmax. Depending on the permeability of the rock, some of these thermally generated products migrated away from the contact and some had little migration, as is apparent from Table 3.2 and Figures 4.14 a and b, thus forming microreservoirs. Similar observations have been made by Saxby and Stephenson (1987) in their studies of effect of an igneous intrusion on oil shale at Rundle, Australia.

Hydrogen Index (HI)

It is very interesting to observe that nearly all the samples close to the contact with igneous intrusions have hydrogen index values zero or near zero, but just after a short distance away (this distance depends upon various factors including the temperature difference between the intruded and the invaded rocks, depth of emplacement, rate of cooling and permeability of the host rocks) HI attains a peak value (about 150 mg/g or more) and again it decreases to normal ground value varying from 110 to 70 mg/g or less. This peak is correlatable with the peak of PI supporting further the concept of microreservoir.

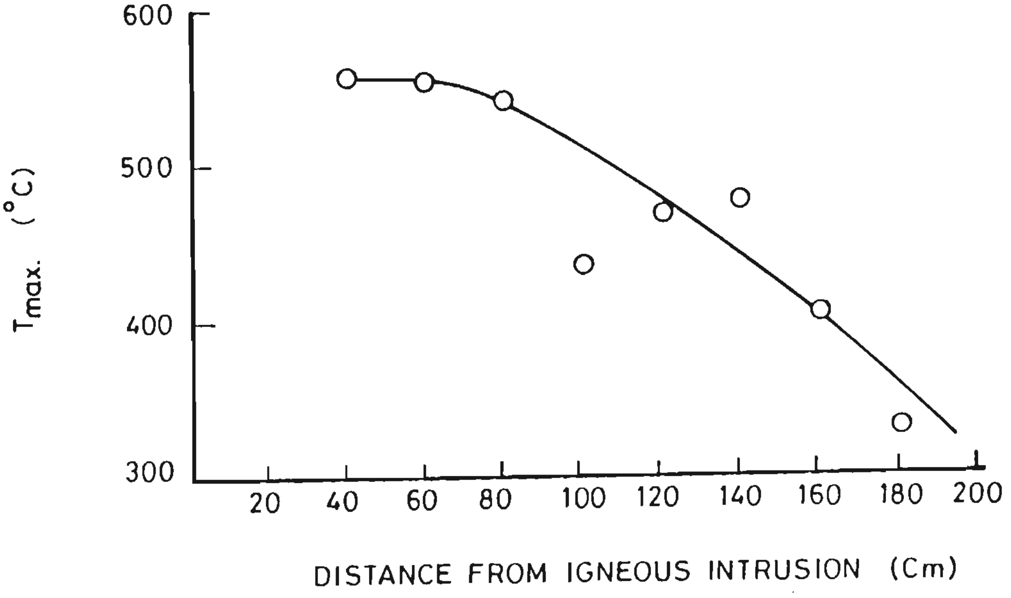


Fig. 4.13 Increase of Tmax towards igneous intrusions.

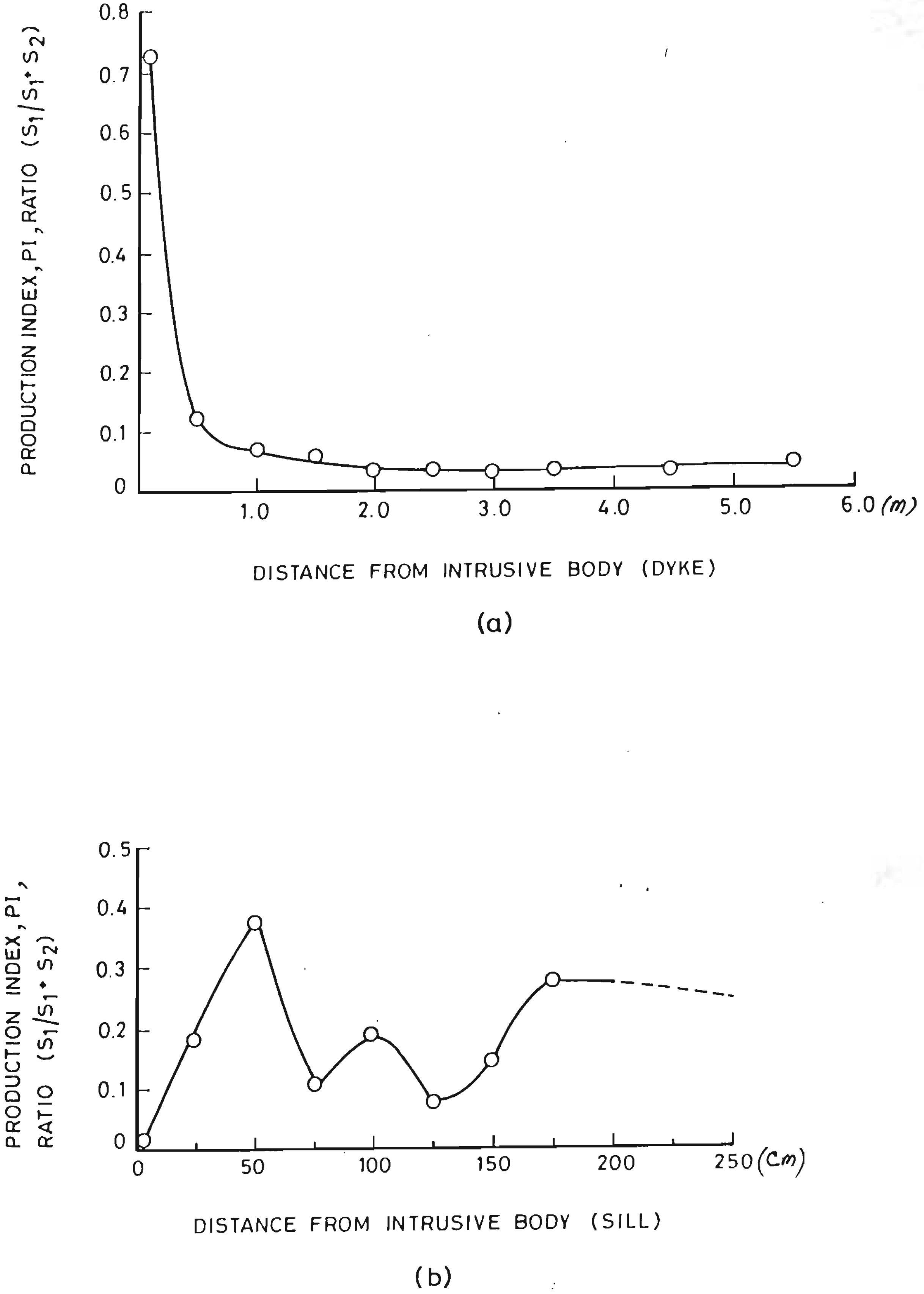


Fig. 4.14 Hydrocarbons accumulated near the contact (a) and away from the contact (b) of the intrusions.

Bitumen and its componental elements:

Igneous intrusions have affected the amount of extractable organic matter (EOM or Bitumen) too. At contacts or very close to the intrusive bodies the volatiles appear, in general to get lost. This suggests that pyrolysis products from organic rich sediments of Barakar Formation in Jharia coalfield, at or near contacts of intrusions, were diffused or driven away and got collected in the so called "microreservoir". The collection of bitumen in these microreservoirs is as high as 1% whereas the average of extractable organic matter in these sediments as seen in Table 3.3, is about 0.2% or less. These volatile organic matter (Pyrolysis products) might have been collected in these microreservoirs at the same depths (now as outcrop) possibly because -

i) the surrounding rocks were cool enough for the vapors to condense and /or

ii) the permeability of the deeper rocks were such that these could not migrate further.

The high value of HI a short distance from the igneous body, as observed, may be attributed to the collection of pyrolysed products in the "microreservoirs"

The extract composition is generally expressed in percent of hydrocarbons (HC), resins (rs) and asphaltene (asp). The hydrocarbons are separated into aromatic (A) and saturated (S) components. The ratio A/S gives the idea about the degree of aromaticity. As is apparent from Table 3.4,the ratio A/S is in general greater than one. It is in general high at the contact and decreases away from the intrusions.

The carbon number of the most prominent component and the molecular weight distribution, both shift to the lighter end with increasing thermal maturity of organic matter or with decreasing distance from the igneous intrusions.

The gas chromatograms of the saturates (Table 3.5) in these three areas also indicate that at some places near the contacts the nCmax (maximum percentage of normal alkanes) is as low as nC18 and gradually increases to ground value of that particular bed, some times it is as high as nC22 or even nC24 and occasionally upto nC25 (Table 3.5). This event clearly shows the effect of the intrusions on cracking of higher molecular weight normal alkanes to the lower ones. Although the sediments are already in mature state but still this effect is very prominently observed.

It may be recall that the organic matter is mainly of terrestrial type and as such has dominance of higher molicular weight n-alkane in the samples affected little by igneous intrusions. However, with increasing thermal effect closer to igneous intrusions, these higher molecular weight n-alkane were degraded to generate low molecular weight n-alkane. Phillippi (1965) had similarly observed predominance of low molecular weight n-alkanes with increasing maturity of terrestrial organic matter in the Los Angeles Basin.

Effect of Igneous Intrusion on Coal:

Millions of tones of coking coal have been converted into natural cole due to extensive intrusions of lamprophyre magma in the Gondwana coalfields of the Damodar Valley region in the

Eastern India (Sanyal, 1964). The destructive effect of these lamprohyres on coal is confined to twice the thickness of the intrusive body. The natural coke, thus formed is locally known as Jhama (Fig. 4.15).

From the forgoing evidences it is seen that immediately adjacent to the intrusion, the organic matter is destroyed and only the graphitic material remains. Further at the contact near the extractable material is present in the greatest quantities but decreases gradually with increasing distance from the contact, eventually reaches the values characteristic of the host shale.

4.4 SUMMARY

The Barakar Formation of Jharia coalfield has been intruded mostly by high fluidity and high temperature mica peridotite. These sediments, therefore, provide excellent opportunity for studying the effect of temperature on rocks of same age and type at same pressure. Because of the steep thermal gradient across the intrusive body, the organic matter in the rocks close to the intrusion have been exposed to high temperatures while the organic matter farther away has been heated only a little above the normal temperature of the country rock.

Due to pyrolysis of organic matter close to intrusion, Total Carbon Content increases and the organic matter has become metamorphosed graphitic material.

Close to igneous intrusion VR_o increases to 6.27%, TAI to 4.5, Tmax to 554, PI upto 1 and Fluorescence to 168.44% at 730

Fig.4.15 The destructive effect of lamprophyre on natural coke (Jharia).

a. Megascopic
b. Microscopic

(a)

(b)

FIG. 4.15

nm. All these maturity parameters then decrease to attain their ground values away from intrusion.

The pyrolysed hydrocarbons appear to have accumulated in the sediments forming microreservoirs a little away from the intrusive body.

It is observed that the intrusions with thickness less than 0.3m have little effect on organic matter.

CHAPTER - 5

VOLUMETRIC ESTIMATION OF PETROLEUM YIELD FROM SHALES OF BARAKAR FORMATION

5.1 PRELIMINARY

Qualitative assessment of sediments of the Barakar Formation, as made in chapter-3 brings out that the shales contain commercially sufficient organic matter mainly of terrestrial type and that these have undergone maturation to produce petroleum hydrocarbons-mainly the gas, in Bhaunra and Chasnala areas. In the present chapter, an attempt has been made to assess quantitatively the amount of petroleum hydrocarbons that have been generated and the remaining potential of sediments to generate oil/gas.

Although a number of workers such as Neruchev (1962), McDowell (1975), Tissot and Welte (1978) and White and Gehman (1979) have worked in this direction, the present evaluation is based on a simple and quick approach given by Waples (1985). A brief account of this approach is given below.

5.2 VOLUMETRIC ESTIMATION OF PETROLEUM YIELD

The volume of petroleum generated by a given volume of source rock depends upon the organic matter content of the source rock, the oil-generative capacity of the kerogen in the source rock, and the thermal maturity achieved by the organic material. If these parameters are known for a source rock, its hydrocarbon-generative capacity at full maturity (Go) can be calculated easily (Moshier and Waples, 1985). Hydrocarbon generative capacity of kerogen may be measured in several ways, the most popular of which is the Rock-Eval Pyrolysis. The Hydrogen Index (HI) from Rock - Eval data, is expressed as milligrams of hydrocarbons/grams of TOC. Accordingly,

$$Go = (TOC) \times (HI) \times (k) \qquad .... (5.1)$$

where TOC is total organic carbon content of the rock, expressed as mg CO_2 per 100 g of dry rock and `k' is a conversion constant governed by the units desired for the hydrocarbon volumes and by assuming the densities of the source rock and hydrocarbons. If the volume units desired are millions of barrels per cubic mile of source rock and if the source rock is a shale with density 2.3 g/cc and if the hydrocarbons correspond to an oil of 25° API gravity (density = 0.9 g/cc), the value of k is 0.7 (Waples, 1985) which becomes 169884.86 if the volume units are desired to be million barrels per cubic kilometer.

If full thermal maturity has not been achieved every where in the source rock, the amount of hydrocarbon actually generated (HC_G) is less than Go. The HC_G varies directly with the level of thermal maturity attained. The fractional conversion of kerogen to hydrocarbons at any given level of maturity is designated by a factor `f' which is between 0 (for completely immature organic matter) and 1 (for fully mature organic matter). The value of f is equivalent to (Go - G)/Go. Thus,

$$Go \times f = HC_G \qquad ..... (5.2)$$

Measured or calculated maturity values of vitrinite reflectance can be used to determine the fractional conversion (f) for a given variety of organic matter, employing their relationship given by Sluijk and Nederlof (1984) in a series of graphs between VR_o and f (Fig. 5.1 a-d).

In addition to the hydrocarbons generated by thermal decomposition of kerogen, diagenetic bitumen DB, (those hydrocarbons that coexisted with the kerogen in the sediment before maturation) will contribute to the total hydrocarbons yield per unit volume of source rock (HC_V). Thus,

$$HC_V = HC_G + DB \qquad \ldots\ldots(5.3)$$

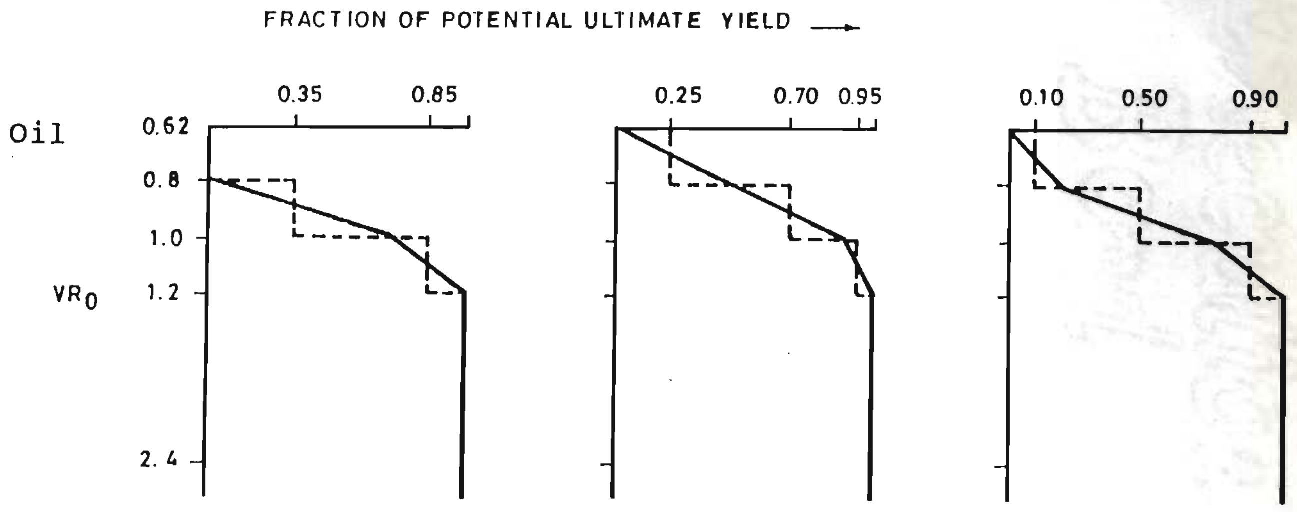
A simplified method of calculation was followed by Waples (1985), to compensate this diagenetic bitumen (DB). He has taken the value of HI, in equation 5.1, where the sample was in the immature state, and f in the equation 5.2 is indicating the present day maturity level with its fractional conversion of kerogen to hydrocarbons and therefore we get,

$$\text{Volume of HC } (HC_V) = (k) \times (TOC) \times (HI) \times (f) \qquad \ldots.(5.4)$$

Once the volume of hydrocarbons expelled per unit volume of source rock has been calculated, total volume of source rock available must be determined. For that simply the volume of source rock in the drainage area is multiplied by HC_V i.e. the volume of hydrocarbons expelled per unit volume of source rock to get the total volume of hydrocarbons expelled (HC_{TV}). Thus,

$$\text{Total Hydrocarbon volume } (HC_{TV}) = HC_V(\text{volume/cubic kilometer}) \times (\text{cubic kilometer of source rock}) \qquad \ldots.. (5.5)$$

Oil generated from a source rock must first be expelled (primary migration). Momper, (1978) has suggested that until 50 million bbl/mile^3 of oil (about 12 million barrel/km^3) is generated and present, no expulsion will occur.



THREE TYPE OF SOURCE ROCK

MAINLY-HUMIC
TO MIXED

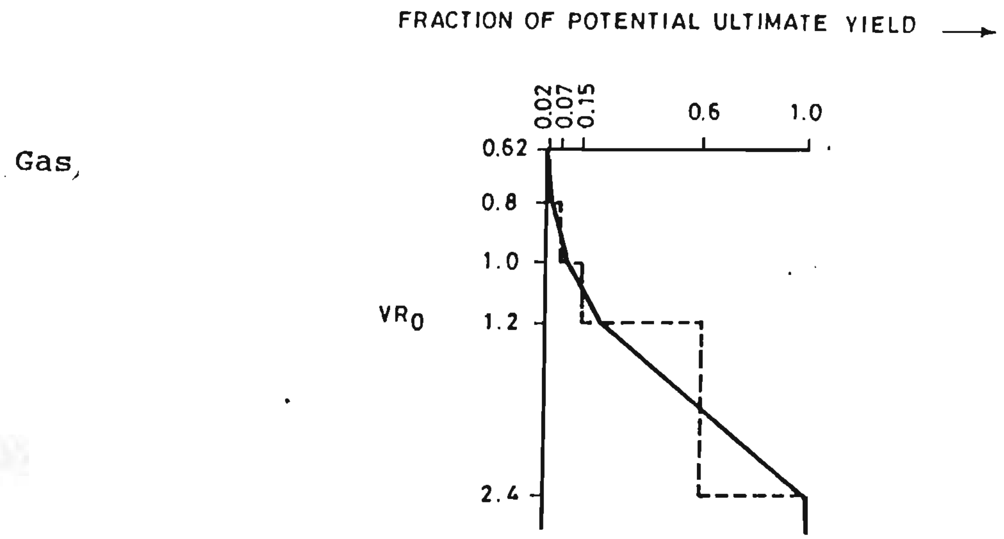
a.

MAINLY KEROG.
TO KEROG. BACT.

b.

KEROGENOUS
ALGAL

c.



ALL SOURCE ROCK TYPES

d.

Fig. 5.1 Curves showing relationship between vitrinite reflectance (VRo) values and fractional conversion (f) for various types of organic matter (After Sluijk and Nederlof, 1984).

5.3 ESTIMATION OF VOLUME OF HYDROCARBONS GENERATED BY BARAKAR FORMATION AT CHASNALA, BHAUNRA AND PHULWARITAND AREAS

The Barakar sediments in the Jharia coalfield have been intruded by igneous rocks - mainly of mica-peridotite. As mentioned in chapter 4, these intrusions have affected the maturity of the organic matter found in sediments. Close to intrusion the organic matter is thermally overcooked but slightly away and upto about twice the thickness of the intrusions, the maturity is enhanced above the overall maturity due to burial of sediments. This phenomenon is schematically shown in figure 4.6. Sediments affected by igneous intrusions (Fig. 4.6) have yielded hydrocarbons in two phases - firstly during the burial of sediments, basement heat matured the organic matter to the ground value C (Fig. 4.6) and later on, due to the intrusion of igneous body the maturity increased further to the level D (Fig. 4.6) to yield hydrocarbons. Beyond the distance X, the hydrocarbons generated owe their origin to burial phenomenon (Fig. 4.6) only.

With this background the shales of Barakar Formation from Chasnala, Bhaunra and Phulwaritand areas were evaluated for volumetric estimation of the hydrocarbons generated, if any, based on Waples (1985) approach. Total organic carbon content (TOC), hydrogen index (HI) and vitrinite reflectance (VR_o) determined for these shales (chapter-3) form the basis of this evaluation.

5.3.1 Chasnala Area:

In Chasnala, three locations were evaluated for this investigation (Fig. 3.2). The first area designated here as A, is within hundred meters north of the Dhanbad - Sindri road bridge, upstream on the Domohani nala, where three lowest seams of the Jharia coalfield (I,II, III) are exposed. The second area B, lies further upstream side (about 200 m) north of the previous exposure. To the west of these exposures is situated the third locale C, in this area, in which a good exposure comprising coal seam No.V from which 5 shale samples (54 - 58) were selected.

5.3.1.1 Petroleum Source Potential Due to Burial of Sediments.

Oil

The ground value of VR_O in the sediments unaffected by intrusions for these three locales A, B and C are 0.7%, 0.9% and 0.6% respectively. The mean of total organic carbon (TOC) content of the selected shale samples from three localities A,B and C are 20%, 9.14% and 12.62% respectively.

The fractional conversions (f) obtained from the Fig. 5.1 for humic kerogen are 0.0, 0.35 and 0.0 respectively. Since for type III kerogen,the oil yield starts at maturity above 0.8% of VR_O, therefore, the shales of only second location 'B' with vitrinite reflectance 0.9% have generated oil

Since the kerogen is of type III, it can be assumed to generate only about 20% oil and 80% gas. Therefore, the amount of organic carbon capable of generating oil is 20% of the 9.12% i.e. 1.83%. The remainder, 7.31% is capable of generating only gas. Also, the value of k is taken as 0.168 for shales with Hydrogen Index of 110 mg/g of TOC for immature kerogen in it.

The amount of oil yield from this location 'B' of Chasnala area works out as under, Volume of oil = K x TOC x H1 x f

(0.168) x (1.83) x (110) x (0.35)

= 11.836 Million barrels oil per cubic kilometer of source rock

Gas

The volume of gas generated has been estimated in a similar manner. The conversion factor f, for gas was determined with the help of figure 5.1 d, as 0.03, 0.07 and 0.0 for VR_o values of 0.7%, 0.9% and 0.6% respectively, as discussed above, for the areas A,B and C. Further, in order to calculate the volume of gas in millions of cubic meters per cubic kilometers of source rock, the constant k must be multiplied by 169884.86 (while computing this, a billion has been taken to be equal to 10^{12} as per Oxford Dictionary for G.B and Europe).

Thus the volume of gas generated in the location `A' is -

= (169884.86) x (0.168) x (16) x (110) x (0.03)

= 1506946.7 million m^3 gas per cubic kilometer of source rock

= 8.87 million barrels of oil-equivalent gas per km^3 of source rock.

And volume of gas generated in the location B is

= (169884.86) x (0.168) x (7.31) x (110) x (0.07)

= 1606467.9 million cubic metre gas per cubic kilometer of source rock

= 9.456 million barrel of oil - equivalent gas per Km^3 of source rock

And volume of gas generated in the location C is -

= (169884.86) x (0.168) x (10.096) x (110) x (0)

= 0.0 million m^3 gas per km^3 of source rock

TABLE 5.1 : Petroleum Hydrocarbons Generated and Expelled in Chasnala area due to Burial Process

Location	PETROLEUM HYDROCARBONS					
	Generated				Expelled	
	Oil	Gas	Oil Eq.	Oil+Oil Eq.	Oil	Gas
A	--	1506946.7	8.870	8.870	--	N
B	11.836	1606467.9	9.456	21.292	5.918	1285174.3
C	--	N	N	N	--	--
Total	11.836	3113414.6	18.326	30.162	5.918	1285174

N - Negligible
Oil in Million barrel per kilometer cube of source rock
Gas in Million cubic metre per kilometer cube of source rock
Oil Eq - Oil equivalent of gas in Million barrel per kilometre cube of source rock

Expulsion of Petroleum

Hydrocarbons generated must be expelled for migration to accumulate in the form of commercial pools. As mentioned in section 5.2., Momper (1978) proposed that a threshold value of 50 million barrels per cubic mile (12 million barrel per km^3) of source rock of hydrocarbons (oil and or oil equivalent) had to be generated in a source rock before any expulsion could occur. Waples (1985) further assumed 20% expulsion efficiency for oil and 80% for gas, after the threshold of 50 million barrel is reached.

A perusal of Table 5.1 indicates that in the Chasnala area, at location `A', only about 1506946.7 million cubic metre of gas which is 8.87 million barrel of oil-equivalent was generated out of each cubic kilometer of source rock. This is not enough for expulsion and migration as per criteria of Momper (1978) and Waples (1985). At location `B', where the VR$_o$ value is about 0.9%, about 11.836 million barrels oil was generated from each cubic kilometer of source rock. From the same location 1606467.9 million cubic metre gas was generated, which is equivalent to about 9.46 million barrels of oil equivalent in gas (1606467.9 ÷ 169884.86) generated per cubic kilometer of source rock. Thus at this location, the total volume of hydrocarbons generated is 11.836 + 9.460 = 21.296 million barrels of hydrocarbons per cubic kilometer of source rock. From this location about 6 million barrels of oil together with 1285175 million cubic metre of gas has been expelled from the source rock. However, in the third location C, the shales with VR_o of about 0.6% negligible amount of hydrocarbons were generated as these rocks are in the diagenetic stage. Nevertheless, these shales hold very high genetic potential of about 26 kg hydrocarbons per ton of rock, mainly due to high TOC values at this location.

5.3.1.2 Petroleum Source Potential Due to Igneous Intrusions:

A source rock at its best can yield oil and/or gas equal to its genetic potential i.e. its maximum potential if it undergoes optimal thermal maturation. Igneous intrusions in this region are the additional source of heat to the sediments. As is apparent from Table 5.2, the igneous intrusions have matured the sediments of Chasnala area so that in three locations in the area and in the vicinity of igneous intrusions from each cubic kilometer of source rock, a total of 68.185 million barrels of oil and oil equivalent was generated. Out of this 26.921 million barrel of oil was generated alongwith 39.963 million bbl of oil equivalent - gas from each cubic kilometer of source rock. This oil may be totally or partially cracked to gaseous hydrocarbons. Barker (1990) in his studies estimates a volume of 85 m^3 of gas formed due to cracking of 1 barrel of oil at standard temperature and pressure.

A perusal of Tables 5.1 and 5.3 indicates that in the three localities of Chasnala area the effect of intrusions are variable. At location 'A', only gas was generated due to burial. It is about 150x10^4 million m^3 per km^3 of source rocks. In this area, since the shale samples are much away from the intrusive body the effect is not much. Igneous intrusions have, thus, increased the maturation of organic matter to increase the gas generation to a total of about 260x10^4 million m^3 per km^3 source rock Table 5.2. At location `B', the total hydrocarbon production due to burial is 21.292 million barrels per km^3 of source rocks. In this location since the shales are more or less in direct contact with the igneous intrusions, therefore, the thermal effect is higher. It has resulted not only in gas generation but also the oil generation, and the total oil and oil equivalent generated is estimated to be 51.606 million bbl/km^3 Table 5.2. At location `C', the effect of the igneous intrusion is negligible because of the coal intervening between the shale and igneous body.

5.3.2 Bhaunra Area:

The Bhaunra area is a very promising area, as is observed from the study of its organic matter richness, type and maturity of its kerogen. The location `A' is situated SE of Joraphokhar (Fig. 3.3); the second location `B' is situated NNW of Gorkhuti, southwest of location `A' at a distance of 13 km. From location `B' a total of 15 shale samples were selected. The third location `C' is situated about 22 km in the southwestern part of the location B, and is adjacent to fire zone and to the north of Damodar river, from which a total of 10 shale samples were selected for hydrocarbon volumetric study. Lastly the fourth

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TABLE 5.2: Petroleum Hydrocarbons Generated and Expelled in Chasnala area due to Burial + Intrusion

Location	PETROLEUM HYDROCARBONS					
	Generated				Expelled	
	Oil	Gas	Oil Eq.	Oil+Oil Eq.	Oil	Gas
A	--	2595401.6	16.278	15.278		2076321.3
B	26.921	4193602.2	24.685	51.606	13.461	3354881.8
C	--	221018.8	1.301	1.301	--	--
Total	26.921	7010022.6	39.963	68.185	13.461	5431203.1

TABLE 5.3: Petroleum Hydrocarbons Generated and Expelled due to Igneous Intrusions in Chasnala area

Location	PETROLEUM HYDROCARBONS					
	Generated				Expelled	
	Oil	Gas	Oil Eq.	Oil+Oil Eq.	Oil	Gas
A	--	1088454.9	6.408	6.408	N	N
B	15.085	2587134.3	15.229	30.314	7.543	2069707.4
C	--	221018.8	1.301	1.301	--	N
Total	15.085	3896608.0	22.938	38.023	7.543	2069707.4

N - Negligible

Oil in Million Barrel per kilometer cube of source rock

Gas in Million cubic metre per kilometer cube of source rock

Oil Eq - oil equivalent of gas in million barrel per kilometer cube of source rock location `D' is northwest of the location `C' at a distance of about 10 km from it. From location D, 5 shale samples were selected for present study.

5.3.2.1 Petroleum Source Rock Potential due to Burial of Sediments

Oil:

The average maturity levels in terms of vitrinite reflectance (VR_O) of the organic matter of the shales unaffected by the thermal effect of igneous intrusions in the Barakar Formation in these four locations A, B, C and D are 0.50%, 0.85%, 0.70% and 1.00% respectively. For the volume of oil generated the value of f determined from the Fig. 5.1(a) is 0.0, 0.25, 0.0 and 0.80 for the locations A,B,C and D respectively. The mean of TOC content in the shales of these locations in Bhaunra area are 10.29%, 12.87%, 10.57% and 5.39% respectively. Therefore, the volume of oil generated from the shales in these locations, assuming that only 20% of TOC contributed for oil in location `A' is -

$$\text{Volume of oil} = (0.168) \times (2.06) \times (110) \times (0.00)$$

$$= 0.00 \text{ million barrels oil per cubic kilometer of source rock}$$

Location `A' in Bhaunra area though having a rich TOC content and high genetic potential of about 8 kg of hydrocarbons per ton of rock, due to its low maturity level has not yet generated oil.

Location `B' - this location having a TOC of 12.87% out of which 2.57% is capable of generating oil and with `f' factor as 0.25, it has generated total volume of oil as -

$$= (0.168) \times (2.57) \times (0.25) \times (110)$$

= 11.873 million barrel oil per cubic kilometer of source rock

Shales at location `C', are matured enough to generate some gas but not oil. The fourth location `D' which has comparatively more matured shale, has TOC value of 5.39% of which 1.08% is capable of generating oil with fractional conversion factor (f) for oil estimated to be about 0.80. The volume of oil therefore calculated is -

$$\text{Volume of oil} = (0.168) \times (1.08) \times (110) \times (0.80)$$

= 15.967 million barrels oil per cubic kilometer of source rock

Gas:

The volume of gas generated for these locations in Bhaunra area has been estimated in similar manner. The mean TOC contents of these shales capable of generating gas are 8.23% 10.30%, 8.461% and 4.31% for locations A, B, C and D respectively. The values of f for generation of gas was determined from Fig. 5.1 d. These values work out to be 0.0, 0.06, 0.03 and 0.11% respectively. Therefore, the volume of gas generated in the four sampled locations in Bhaunra area is similarly estimated (Table 5.4). Location `A', as mentioned earlier, though having high genetic potential is not optimally matured to generate any oil or gas.

TABLE 5.4: Petroleum Generated and Expelled due to Burial Process in Bhaunra area

Location	PETROLEUM HYDROCARBONS					
	Generated				Expelled	
	Oil	Gas	Oil Eq.	Oil+Oil Eq.	Oil	Gas
A	--	N	N	N	N	N
B	11.873	1940193.8	11.421	23.294	5.937	1552155.0
C	--	796798.0	4.690	4.690	--	--
D	15.967	1488423.7	8.761	24.728	7.984	1190739.0
Total	27.840	4225415.5	24.872	52.712	13.921	2742894.0

N - Negligible

Oil in Million Barrel per kilometer cube of source rock

Gas in Million cubic metre per kilometer cube of source rock

Oil Eq - oil equivalent of gas in million barrel per kilometer cube of source rock

Location `B'

Volume of gas = (169884.86) x (0.168) x (10.30) x (110) x (0.06)

= 1940193.8 million cubic metre gas per cubic kilometer of source rock

Location `C':

Volume of gas = (169884.86) x (0.168) x (8.46) x (110) x (0.03)

= 796798.04 million cubic metre gas per cubic kilometer of source rock.

Location `D':

Volume of gas = (169884.86) x (0.168) x (4.31) x (110) x (0.11)

= 1488423.7 million cubic metre gas per cubic kilometer of source rock.

It is apparent from above that in Bhaunra area, location `A' having about 8 kg of hydrocarbon per ton of source rock so far has not generated any oil or gas except in the vicinity of igneous intrusions which will be discussed subsequently. Location `B' generated a total of 23.294 million barrels of oil and oil equivalent of which about 6 million barrels of oil along with 16×10^5 million cubic metre of gas is expelled from each cubic kilometer of source rock. Location `C' though generated about 80×10^4 million cubic metre of gas per cubic kilometer of source rock has not expelled any only or gas because the generated gas is equivalent to 4.690 million barrels of oil which is much lesser than the threshold of 12 million barrels of oil or oil equivalent required for expulsion. Finally location `D' has generated a total of 24.728 million barrel of oil and oil equivalent of which about 8 million barrel of oil along with 12×10^5 cubic meter of gas is expelled.

5.3.2.2 Petroleum Generation due to Thermal Effect of Igneous Intrusions:

In four locations of Bhaunra area as cited, the samples were collected systematically across the igneous intrusions in the area. These shale samples are the subject of the present study. The sample number, with their distance from the corresponding intrusions and other details are given in Appendix-I. From this table it is apparent that these intrusions have affected the organic matter contents and increased their maturity upto certain distance and this caused additional hydrocarbon generation. Tables 5.5 & 5.5A show~~s~~ that there is fascinating additional hydrocarbon generation due to igneous intrusions in the entire area. However, since these effects in location `A' are mostly on coals and coal samples are excluded in this study, in this location the effect is not much visible. Location `B' has generated about 53 million barrels of oil and oil equivalent in the vicinity of the intrusions. Out of this about 17 million barrels of oil is expelled along with $64x10^5$ million cubic metre gas per cubic kilometer of source rock. Location `C' has generated a total of 94 million barrel of oil and oil equivalent out of which about 26 million barrel of oil along with $21x10^6$ million cubic metre of gas from each cubic kilometer of source rock is expelled. Finally, in location `D' a total of 30 million barrel of oil and oil equivalent is generated out of which about 18 million barrels of oil along with $16x10^5$ million cubic metre of gas from each cubic kilometer of source rock is expelled.

From these investigations it is inferred that the Barakar shales of Bhaunra have generated about 11.873 and 15.967 million barrel of oil from areas `B' and `D' respectively; and $19x10^5$,

TABLE 5.5 : Petroleum Hydrocarbons Generated and Expelled due to Burial and Intrusion

Location	PETROLEUM	HYDROCARBONS				
	Generated				Expelled	
	Oil	Gas	Oil Eq.	Oil+Oil Eq.	Oil	Gas
A	--	N	N	N	N	N
B	26.544	5552522.7	32.684	59.228	13.272	4442018.2
C	52.880	12013120.0	70.713	123.593	26.440	9610496.0
D	17.241	2183251.7	12.851	30.092	8.621	1746601.4
Total	96.665	19748894.4	80.235	212.913	48.333	15799115.6

TABLE 5.5 A: Petroleum Hydrocarbons Generated and Expelled due to Igneous Intrusions in Bhaunra area

Location	PETROLEUM	HYDROCARBONS				
	Generated				Expelled	
	Oil	Gas	Oil Eq.	Oil+Oil Eq.	Oil	Gas
A	--	N	N	N	N	N
B	14.671	3612328.9	21.263	35.934	7.336	2889863.1
C	52.880	11216322.0	66.023	118.903	26.440	8973057.6
D	1.274	694828.0	4.090	5.364	--	N
Total	68.825	15523478.9	91.376	160.201	33.776	11862920.7

N - Negligible

Oil in Million Barrel per kilometer cube of source rock

Gas in Million cubic metre per kilometer cube of source rock

Oil Eq. - oil equivalent of gas in million barrel per kilometer cube of source rock

80×10^4 and 15×10^5 million cubic metre of gas from each cubic kilometer of source rock from the areas `B', `C' and `D' respectively due to thermal maturation of organic matter on burial of sediments. Additionally, igneous intrusions during Late Cretaceous have further matured these organic rich sediments and have generated 26.544, 52.880 and 17.241 million barrel of oil from areas `B', `C' and `D' and 56×10^5, 12×10^6 and 22×10^5 million cubic metre of gas from each cubic kilometer of source rock from the locations `B', `C' and `D' respectively. Therefore, it is inferred that over and above excess of 27.840 million bbl/km^3 of oil and 4225415.5 million m^3/km^3 of gas produced due to burial of sediments, about 68.828 million barrel of oil and 15523479 million cubic metre of gas was estimated to be generated from the shales in the vicinity of igneous intrusions of the area.

5.3.3 Phulwaritand Area:

Samples collected from Phulwaritand area are in and around Phulwaritand town to the south and north west of Mejura Colliery. As is apparent from Table 3.1 and Table 3.8 these sediments are moderately rich in organic matter and have average VR_o values around 0.5% or less. Therefore, the shales of this area have not undergone enough thermal maturity to generate petroleum hydrocarbons. However, the average genetic potential of shales of the area was determined to be about 3 kg hydrocarbons per ton of rock from the location northwest of Mejura colliery and about 0.15 kg hydrocarbons per ton of source rock south of Mejura Colliery. In view of the estimates, it is a lean area or at the most, it is capable of generating some gas from south of Mejura Colliery.

The effect of igneous intrusions on organic matter content of these sediments is not much detectable because most of the shales are lean in organic matter, the organic matter rich shales are away from the contact and mostly coals are at the contact. However, at a location northwest of Bandih colliery, there are few shale samples (no. 47, 48, 49 and 50) which are comparatively rich in organic matter (TOC) and have been affected by igneous intrusions. However as is apparent from Table 5.6, these intrusions also could not optimally matured the kerogen and as a result only limited gas was generated, which was not enough for expulsion in plenty.

5.4 PETROLEUM PROSPECTS OF BARAKAR SEDIMENTS

Assessment of petroleum prospects in an area is based on the following critical factors:

i) Organic matter richness
ii) Quality of organic matter
iii) Maturity of organic matter
iv) Time of generation of petroleum
v) Relative availability of traps
vi) Preservation of petroleum pool

Studies in the previous sections indicate that the shales of Barakar Formation are rich in organic matter which is mainly of terrestrial type (Kerogen Type III) and have undergone adequate maturation to generate petroleum, mainly gas. These hydrocarbons were generated in two separate phases by two distinct sources of heat. In the first phase, petroleum hydrocarbon were generated during Permo Triassic (235-200 m.y) period due to `basement heat' while the sediments were undergoing

Table 5.6 : Petroleum hydrocarbon generated due to burial of sediments in Phulwaritand area

Sample No.	Dist. from Intru. CM	TOC Sample of generating		VRO%	F.Fraction		Toltal Oil yield M.bbl per Km^3	Total Gas yield M.C.M.	Total HC Generated M.bbl per Km^3	Total Expelled	
		Oil	Gas		for Oil	for Gas				Oil m.bbl per Km^3	Gas M.C.M
47	250	0.46	1.85	0.73	0	0.04	0	232320.94	1.368	0	Negligible
48	300	0.57	2.27	0.69	0	0.03	0	213798.06	1.258	0	- do -
49	400	0.77	3.08	0.65	0	0.02	0	193391.49	1.138	0	- do -
50	500	0.71	2.85	0.59	0	0	0	0	0	0	0

burial. In the second stage, igneous intrusive specially the mica peridotite further matured these initially matured sediments during lower cretaceous time (100 m.y), slightly away from their contacts with these sediments. These hydrocarbons were expelled as they had crossed the Momper's (1978) threshold value of 12 million bbl/km^3 of source rocks.

The thick pile of sediments consists of more their 50-60 cycles of shale sandstone coal sequences. The sandstone can act as good reservoir rocks and shales both as source rocks and cap rocks. If the traps in the form of anticline and syncline were formed before the generation and expulsion of hydrocarbons, then these could form a good prospects.

Mukherjee (1977) and Verma et al. (1989) studied the chronology of geological events in the Jharia coalfield. According to Major structures in the form of folds, faults were developed in two stages the first generation of major folding took place at about 100 m.y.during Lower Cretaceous time with WW-SE axis and the second generation cross folds at about 65 m.years or so during Paleocene. If this is so, then the oil/gas generated due to burial process at about 235-200 m.y. had little traps available and therefore from this angle, the prospects of getting this petroleum are poor. However, since the areas falls in a rift basin (Dutta, 1983), some structures specially the growth faults, roll over anticlines might have been formed during or just after the deposition of these sediments. Under such conditions, there may be some prospects for petroleum generated around 235-200 m.y. age. In view of this, detailed basin evolution and structural studies are required to be done to evaluate the prospects of these sediments more objectively.

Due to the intrusion of mica peridotite around 100 m.y the organic matter was matured. As the major folding faulting and intrusion took place more or less contemporaneously.

The petroleum thus generated due to intrusion could have got accumulated into these trap forming structure provided these are good cap rocks. In this connection this may be mentioned that the shales of the shale cod sand sequences (more than 50-60 m.y) if extensive, can also serve as good cap rock.

5.5 SUMMARY

The amount of hydrocarbons generated by a given volume of source rock depends upon the organic carbon content of the source rock, the oil generative capacity of the kerogen in the source rock which is indicated by the kerogen type, and the thermal maturity achieved by the organic material. All these parameters affect the quantity of hydrocarbons that have already been generated. The basic equation used to calculate hydrocarbon volumes from these data is -

$$\text{Volume of HC} = (k) \times (TOc) \times (HI) \times (f)$$

where k, is the conversion constant depending upon the source rock density, TOC is expressed in weight percent, hydrogen index (HI) is mg HC/g TOc when the source rock was at its immature state, and f is the fractional conversion factor indicating the present day maturation state of the source rock.

Samples for this study were selected from Chasnala, Bhaunra and Phulwaritand areas. The organic matter in the sediments is mainly terrestrial- kerogen of type III. It is matured to various levels in Chasnala and Bhaunra areas. However, it is immature at Phulwaritand area. Besides the maturation of organic matter during burial of sediments due to basement heat, the igneous intrusions while burning the sediments close to their margins, have also further enhanced the maturity of these organic sediments in their vicinity (Table 5.7).

In Chasnala area, of the three sampled locations for volumetric study, 6 million barrels of oil along with 1285174.3 million cubic metre of gas, from each cubic kilometer of source rock was expelled from the location situated about 200 m north of Dhanbad Sindri bridge over Domohani nala (river) (Sample No. 82-93) alone. However in the other two locations, negligible amount of gas insufficient for expulsion was generated. From these three locations due to igneous intrusions 30 million barrel additional oil and oil equivalent hydrocarbons were generated.

In Bhaunra area, four locations were investigated. In the first location which is situated SE of Joraphokar, the maturity was not enough to generate gas or oil although it has genetic potential of 8 kg of hydrocarbons per ton of source rock. Second location situated NNW of Gorkhuti, generated 23.294 million barrels of oil and oil equivalent from each cubic kilometer of source rock. Third location, about 22 km south west of previous location generated negligible amount of gas and since the amount was not enough to cross the threshold of 12 million barrels of oil and oil equivalent hydrocarbon could not be expelled from the

TABLE 5.7 Petroleum Hydrocarbons Generated due to Burial of Sediments and Igneous Intrusions

Location	HYDROCARBONS			GENERATED			DUE TO		
	Burial			Burial + Intrusion			Intrusions		
	Oil	Gas	Oil + Oil Equi.	Oil	Gas	Oil + Oil Equi.	Oil	Gas	Oil + Oil Equi.
				CHASNALA AREA					
A	--	1506946.7	8.870	--	2595401.6	15.278	--	1088454.9	6.408
B	11.836	1606467.9	21.292	26.921	4193602.2	51.606	15.085	2587134.3	30.314
C	--	Neg.	Neg.	-	221018.84	1.301	--	221018.84	1.301
Total	11.836	3113414.6	30.162	26.921	7010022.6	68.185	15.921	3896608.0	38.023
				BHAUNRA AREA					
A	-	-	-	-	-	-	-	-	-
B	11.873	1940193.8	23.294	26.544	5552522.7	59.228	14.671	361232.8	35.934
C	-	796798.04	4.690	52.880	12013120	123.593	52.880	11216312.0	118.903
D	15.967	1488423.7	24.728	17.241	2183251.7	30.092	1.274	694828.00	5.364
Total	27.840	4225415.5	52.712	96.665	19748894.4	212.913	68.825	15523478.9	160.201

Oil in Million Barrel per kilometer cube of source rock.
Gas in Million cubic meter per kilometer cube of source rock.
Oil equi. - Oil equivalent - Gas volume multiplied by 1/169884.86, may be cracked to form gas totally or partially.

source rock. The fourth location, about 10 km northwest of third location is again very important since its maturity is comparatively more than the other three locations. It generated about 16 million barrels of oil and 1488423.7 million cubic metre of gas for each cubic kilometer of source rock, out of which 7.984 million barrel of oil along with 1190738 million cubic metre of gas is estimated to have been expelled. An additional amount of 69 million barrel of oil and $16x10^6$ million (16 billion) cubic metre of gas was generated from the shales in the vicinity of igneous intrusions in the area from these four locations.

Phulwaritand area though having a moderate source rock potential due to their low level of maturity did not generate or expel oil or gas.

It is observed that in the vicinity of igneous intrusions the immature organic matter witnessed enough thermal maturity to generate additional oil and gas. The thicker the intrusive body, more is the effect and hence more the generation of oil and gas.

As mentioned in chapter-1, in Jharia coalfield there are a number folds and faults as well as sandstones in the Barakar Formation to act as traps and reservoir rocks. Shales forming about 60-65% of more than 1250 m thick Barakar sediments in more than 50-60 cycles of shale-coal-sandstone sequences, may form cap rocks. Therefore this area holds promise for hydrocarbon prospects, especially in the southeastern part in and around Bhaunra and Chasnala.

CHAPTER - 6

CLAY MINERALOGY AND SPECTRAL SIGNATURES OF SHALES

6.1 INTRODUCTION

The influence of mineral matrices on organic matter during thermal maturation has been studied during the last three decades and the results showed that some clay minerals catalyze certain reactions during heating experiments of pure compounds (Jurg and Eisma, 1964; Henderson et al., 1968; Shimoyama and Jhons, 1971; Jhon, 1979 and Goldstein, 1983) kerogens and bitumens (Espitalie et al. 1980; Horsfield and Doglas, 1980; Davis and Stanley, 1982; Tannenbaum and Kaplan (1985). Clay minerals also seem to adsorb hydrocarbons (Eltantawy and Arnold, 1972; Espitalie et al, 1980 and 1984). Tannenbaum et al. 1986, further emphasized on the adsorption and catalytic effect of clay minerals.

As is observed in chapter-3 through microscopic examination of the organic matter rich sediments of Jharia coalfield, there exists an abundant amount of clay minerals. Therefore, the detailed study of these clay minerals was felt a crucial need.

On the other hand, physical properties are also expected to change through the process of maturation besides the chemical properties of organic matter rich sediments studied in chapter 3. Spectral signatures of shales were studied for these changes.

As these organic rich sediments are intruded by igneous intrusions of various thicknesses these, therefore, provide an excellent opportunity to study the changes in crystallinity of clay and the spectral response of shales of the same age, same type and at the same pressure having same type of organic matter.

6.2 CLAY MINERALOGICAL COMPOSITION OF SHALES

Pyrolytic organic compounds will be adsorbed by mineral matrix. This adsorption capacity generally decreases from illite to montmorillonite, then to calcite and finally to kaolinite. Since the organic matter in all the areas under investigation in Jharia coalfield is found to be of type III kerogen and this particular kerogen is most prone to this phenomenon, as it generates less pyrolyzate per gram of organic matter than do type I or II, therefore identification of the clay minerals in these argillaceous sediments becomes critical. With this in view, shales from the Barakar Formation of Jharia coalfield were analyzed for the clay mineralogical composition by using X ray diffraction.

6.2.1 Preparation of Clay Mineral Slides

A total of 58 samples were selected for clay mineralogical studies from Chasnala, Bhaunra and Phulwaritand. For that about 10 grams of each sample which was previously crushed and ground to pass through 200 mesh sieve (ASTM) was mixed with deionised distilled water in 1000 ml glass cylinder. The mixture is stirred thoroughly and kept for soaking for 24 hours. The clear water containing excess salts was decanted and mixture was brought to 1000 ml and again stirred and kept undisturbed. In case the suspension settled down too fast, again the clear supernatant water is decanted and fresh distilled water is added, and in this process no deflocculating agents was added at any stage. After removing the excess salts the suspensions is again diluted to 1000 ml, stirred and kept for settlement for about 225 minutes (this time changes with atmospheric lab temperature).

The top 5 cm of suspension (around 170 - 200 ml) which would supposedly contain particles of size less than two microns was removed by siphoning. Siphoning off the suspension containing mostly <2 μ size fraction can be easily done by clamping a glass tube with a 5 cm mark into the settling column and attaching an E-tube to it to facilitate suction at the end of 225 minutes.

Recovery of the <2 μ size fraction was done by centrifuging at 2000 RPM for 10 to 15 minutes, and the clear water at the top was decanted. From this paste three oriented clay slides were prepared for scanning by X-ray diffractometer as:

1) Untreated

2) Heated to 550° C, and

3) Ethylene Glycol treated samples, if needed to confirm the presence of montmorillonite, corrensite or any peak at 17 A° or 14 A° minerals such as vermiculite or chlorite.

These oriented clay slides were scanned from 3° to 40° 2θ angle by P.W 1140/90 Phillips X-ray diffractometer (XRD) under following operational conditions.

1. Voltage	35 kv.
2. Target	Cu kα
3. Chart Speed	1cm/min.
4. Goniometer Speed	1° /min.
5. Filter	Ni
6. Current	20 mA
7. Gain	32

8. Window	1.1%
9. Lower Level	0.45%
10. Angle of 2θ	3-40°
11. Range	2 Kc/sec.

The basal plane (OOl) reflection, whether of first order or higher order peaks is used for clay mineral identification. Therefore, the clay mineral slides were prepared with orientation of their C-axis perpendicular to the glass slide surface.

6.2.2 Clay Mineral Identification

A variety of minerals are found to occur in sediments or sedimentary rocks, but the dominant minerals which are common in less than 2 μ size fractions are few and are mostly clay minerals which can be identified using the following criteria employing Bragg's equation $n=2d \text{ Sin } \theta$ where ‘θ' is diffraction angle, ‘d' is molecular plane repeat distances (d-spacing) for any ‘n' multiple of any X-ray wavelength.

Clay mineralogical study using X-ray diffraction methods, performed on oriented clay slides reveals that the main clay minerals in Barakar Formation are kaolinite, illite and chlorite, the predominance being that of the kaolinite (Fig. 6.1)

a) Kaolinite: This particular mineral forms the dominant fraction and is characterized by a number of basal X-ray diffraction peaks at d-spacing of 7A°, 3.58 A° and 2.38 A°. These peaks generally collapse at 550°C. It is commonly adopted as the product of a tropical paleoclimate or terrestrial, near shore environment. Burial diagenesis can cause the kaolinite group of minerals to be neoformed, transformed, or destroyed.

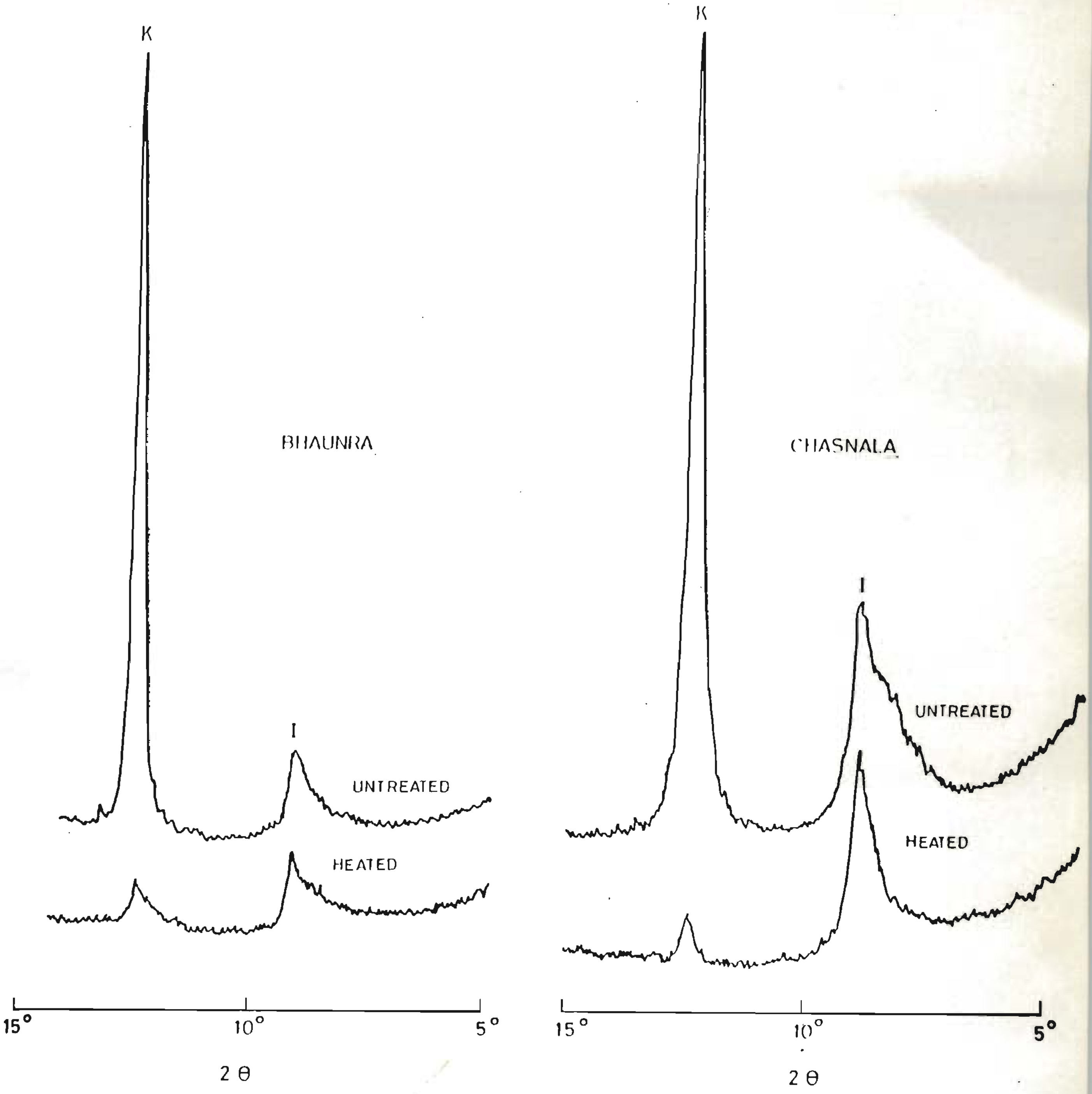

Fig. 6.1 X-ray diffraction patterns of clay samples from Barakar Formation, K-Kaolinite and I- Illite.

The formation of kaolinite during diagenesis takes place via dilute acidic formation waters reacting with feldspars and other aluminosilicates, including pre- existing clay minerals. If the pore water environment remains non-alkaline the kaolinite will be preserved and with increasing temperature and depth of burial it may be transformed to the more lightly ordered polymorphs dickite and more rarely, nacrite. However, often the kaolinite is destroyed before such transformations take place. It seems possible that the organic matter, which intimately envelopes and shields the mineral grains, prevents reactions between the mineral and the surrounding solutions (Spiro, 1979). Organic compounds with hydrophobic properties may result from decomposition of kerogen during pyrolysis of the bituminous shales improving the shielding efficiency of the original organic matrix. Being sensitive to heat the degree of crystallinity, as measured from diffraction peak of kaolinite at d-spacing of 7A°, is an excellent tool to measure the crystallite size of the kaolinite at this particular peak (This will be discussed in detail successively).

b) Illite: It is characterized by a series of basal plane peaks at 10A°, 5A° and 3.3 A° which are not appreciably affected by either glycolation or heat treatment. Its importance in oil industry is established because during burial diagenesis the clay minerals also undergo a number of diagenetic changes, one of which is the transformation of smectite to illite in the interstratifed clays. This process is accompanied by dehydration which has been satistically correlated with the depths of oil production (Burst, 1969; Foscolos, 1976). Illite is a three layer composite (2:1) clay mineral abundant in diocatahedral form, though occasionally its trioctahedral form also occurs. The principal interlayer component is K^+ ion. The sharpness of 10A° peak for samples close and away from intrusions indicate that the sharpness ratio is around 2.5 and not much difference is observed in different samples.

c) **Chlorite:** It is a three layer composite (2:1) clay, like illite but occurs only in triocatahedral form with principal interlayer components as $[(Fe^{2+}, Mg^{2+}) (OH)_6]^{4-}$. It is identified by basal plane peaks at 14A°, 7A°, 4.75 A° and 3.5 A°. No change after glycolation. The peak shifts to 13.8A° after heating to 550° C.

6.3 EFFECT OF IGNEOUS INTRUSION ON CLAY MINERALS

Of all the clay minerals found in the shales of the Barakar Formation, kaolinite is found in almost all the 58 samples and occurs as a well-developed peak in the X ray differactograms.

It is known to be unstable at high temperatures. In sedimentary sequences subjected to deep burial, hydrothermal activity and igneous intrusions above 190° C, illite and chlorite occur but kaolinite is rarely formed (Danoyer de Segonac, 1970; Spiro, 1979; and Awasthi and Alizadeh, 1991). Since kaolinite is sensitive to temperature, an attempt has been made to investigate the effect of igneous intrusions on it.

It is observed that kaolinite is destroyed in the samples very close to intrusive bodies (Fig. 6.2, a). Its crystal structure collapses at about 550°C. The degree of crystallinity of kaolinite indicated by sharpness and narrowness of peaks

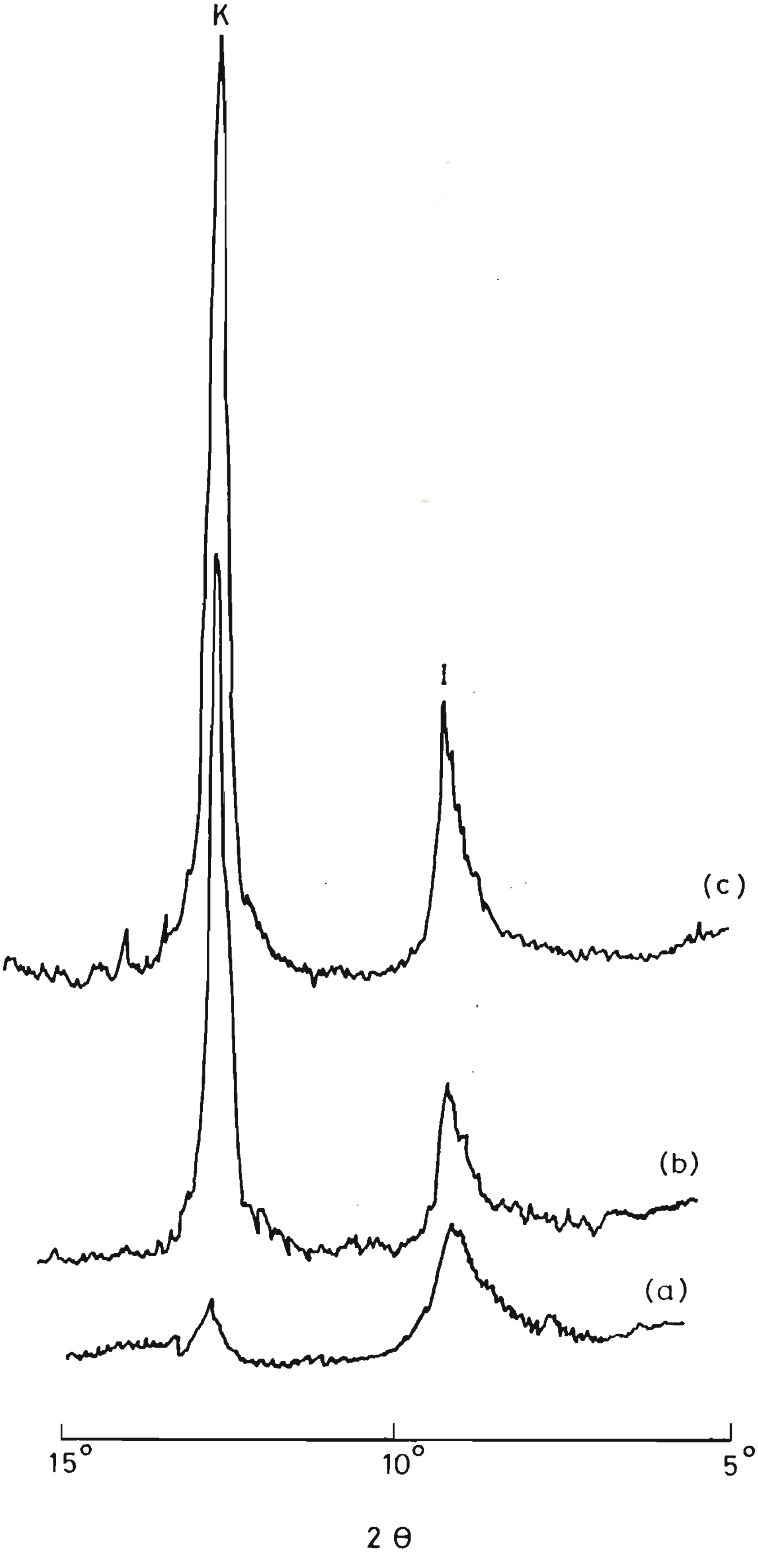

Fig. 6.2 Effect of intrusive body on crystallinity of kaolinite.

a. closer to igneous intrusion
b. kaolinite crystallinity a little away
c. kaolinite is well crystallised away from intrusion

decreases towards the intrusive body indicating its thermal degradation due to mica-peridotite intrusions (Fig. 6.2 b and c).

6.3.1 Average Crystallite Size of Kaolinite

Crystallinity of kaolinite is determined as crystallite size, measured at half the height of its peak. In general, the width of diffraction peaks indicates the average size of the tiny crystallites in the analyzed specimen. Large crystallites produce narrow peaks; small crystallites produce broad ill-defined peaks (Carver 1971).

Rau (1963) has developed a series of correction curves which shorten the process of correcting peak width for instrumental factors, he has simplified further the process by use of a curve that allows observed peak widths to be converted directly into an approximate measure of average crystallite size. Carver (1971) has recomputed and extended Rau's curve for use with broad peaks often produced by the fine grained components of sediments (Fig. 6.3)

Kaolinite is first identified in the X-ray diffractograms. A base line and a perpendicular to the apex of peak is constructed. At half height point between the base line and apex of the (001) peak, width is measured in terms of degree 2θ. The peak width observed, is entered in the Figure 6.3 by Carver (1971) and the average crystallite dimension perpendicular to 001 refracting plane is read.

Relation between Average Crystallite size of Kaolinite and Igneous Intrusions

Bivariate plot (Fig. 6.4) between the avarage crystallite size of kaolinite and its distance from intrusive bodies brings

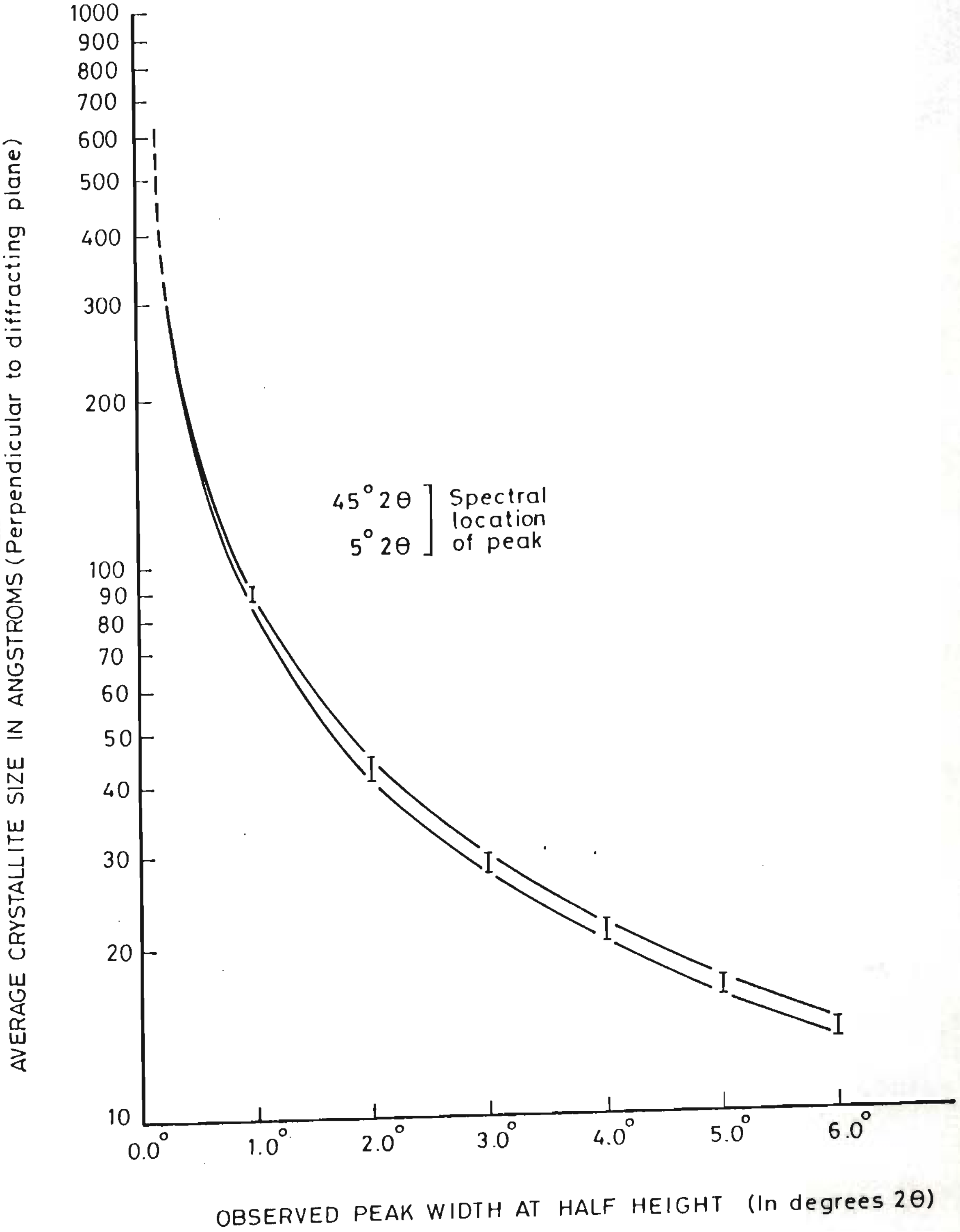

Fig. 6.3 Average crystallite size as a function of peak width at half height (After Carver, 1971).

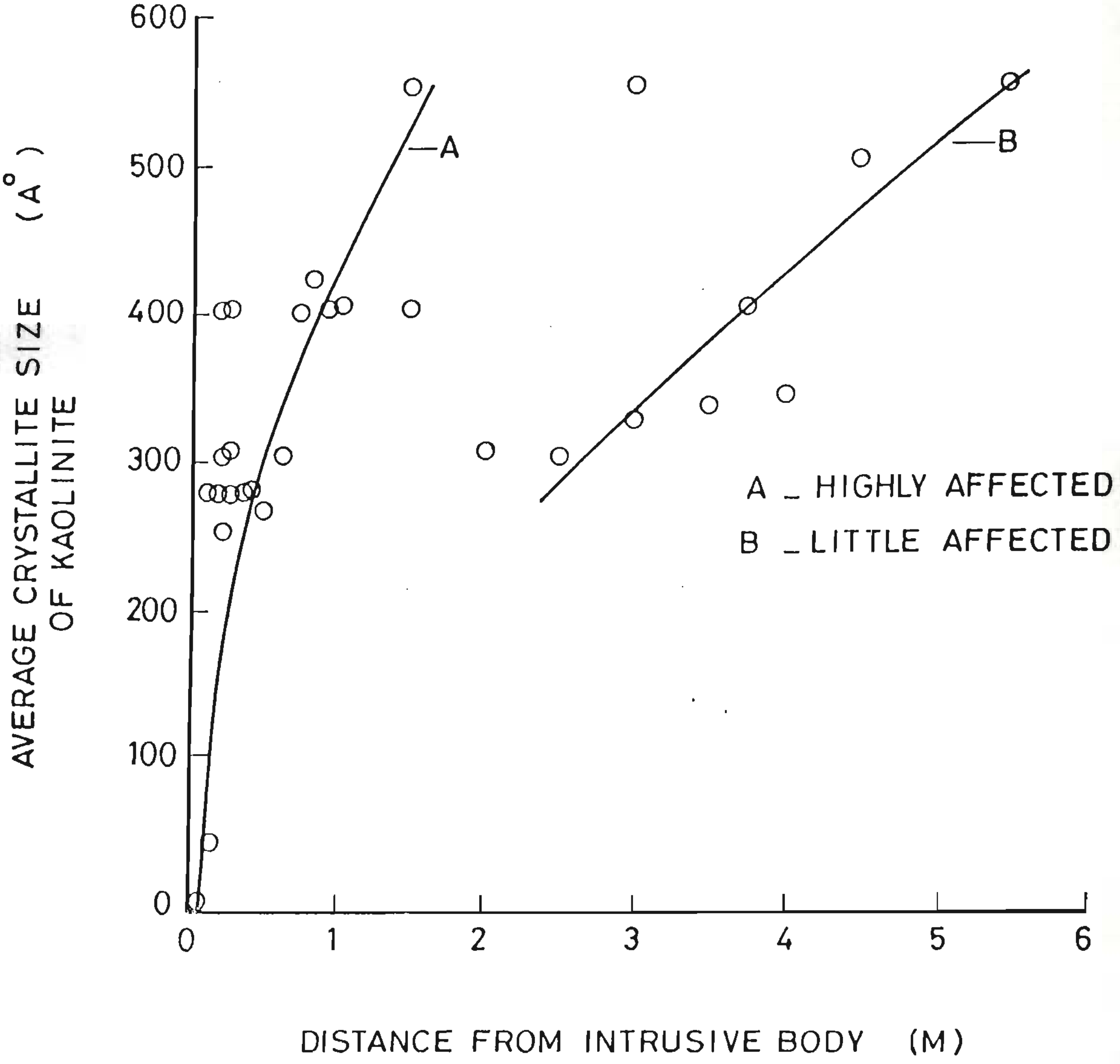

Fig. 6.4 Variation of crystallite size with distance from intrusion.

out the following generalization :

With increasing distance from the igneous bodies, the crysallite size tends to increase with steeper gradient for samples highly affected by thermal effects of igneous body (`A' in Fig. 6.4). It varies from almost neglegible size near the contact to almost 550 A° away from it. Similar trend (`B' in Fig. 6.4) but with gentler gradient also appears for samples little affected by igneous intrusions. It increases from about 300 A° to about 575 A° with increasing distance from the igneous body.

In view of these observations, it is inferred that the crystallite size indicating the crystallinity of kaolinite, in general, decreases towards igneous intrusions of mica-peridotite. This decrease in the crystallinity is due to increasing disorder in the crystal lattice due to the thermal effects of igneous bodies.

Relationship between Crystallinity Index and Igneous Intrusion

Crystallinity index, defined by Jacob (1974) was determined as the ratio of width of 001 peak of kaolinite at mid height above the background to the peak height. The basis of such determination is that a sharply resolved peak of high intensity indicates good crystallinity for a small values of crystallinity index.

Crystallinity index of kaolinite, when plotted against the distance of sample from the igneous body (Fig. 6.5) indicates that with increasing distance, crystallinity index decreases. Since crystallinity index has inverse relationship with decrease crysallinity, it indicates that near the igneous body,

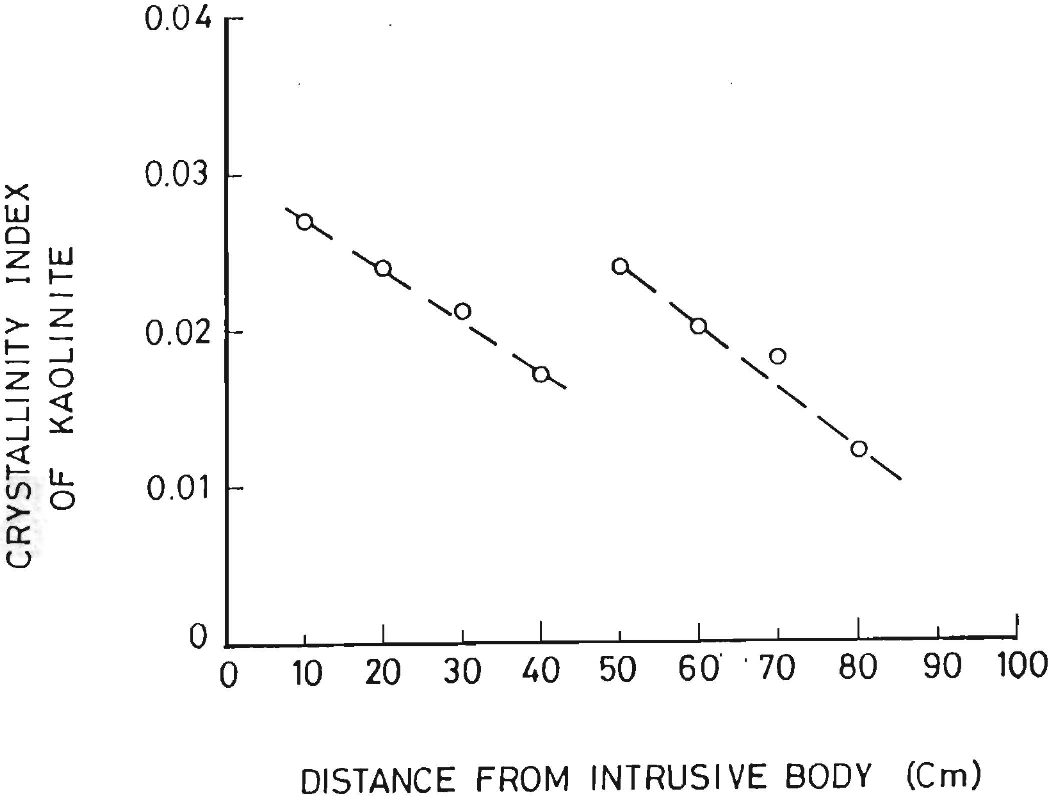

Fig. 6.5 Effect of intrusion on crystallinity index of kaolinite.

crystallinity of kaolinite is also decreasing implying increase in disorder in the crystals of this mineral.

6.3.2 Crystallite Size as a Possible Measure of Maturity of Source Rock

Igneous intrusions have generated different zones of maturation of organic matter found in the argillaceous sediments of the Barakar Formation. As mentioned in Chapter-4, these intrusions have affected these zones upto about twice their thickness. Also, these intrusions have affected the crystallinity of kaolinite found in these sediments. If this is so, then clay mineral crystallinity may be correlated with the organic matter maturation stages.

Vitrinite reflectance, which is considered as a good parameter for determining the maturity of organic matter, when plotted against the crystallite size of kaolinite of shales (Fig. 6.6) brings out the following-

1. The zone of catagenesis (VR_o between 0.6 to 2.0 %) is characterized by crystallite size between 250 A° to about 450 A°.
2. Samples in metagenetic stage (VR_o between 2.0 to 4.0 %) have almost negligible crystallite size of kaolinite.
3. In the metamorphic zone (VR_o > 4%), kaolinite is destroyed.
4. Samples in diagenetic stage or in early catagenetic stage (VR_o about 0.5-0.75) have higher average crystallite size. Crystallite size above 550 A° may be taken as indicative of a diagenetic stage.

Variation in crystallite size of kaolinite is more apparent for the thicker intrusions as observed in sampled areas of

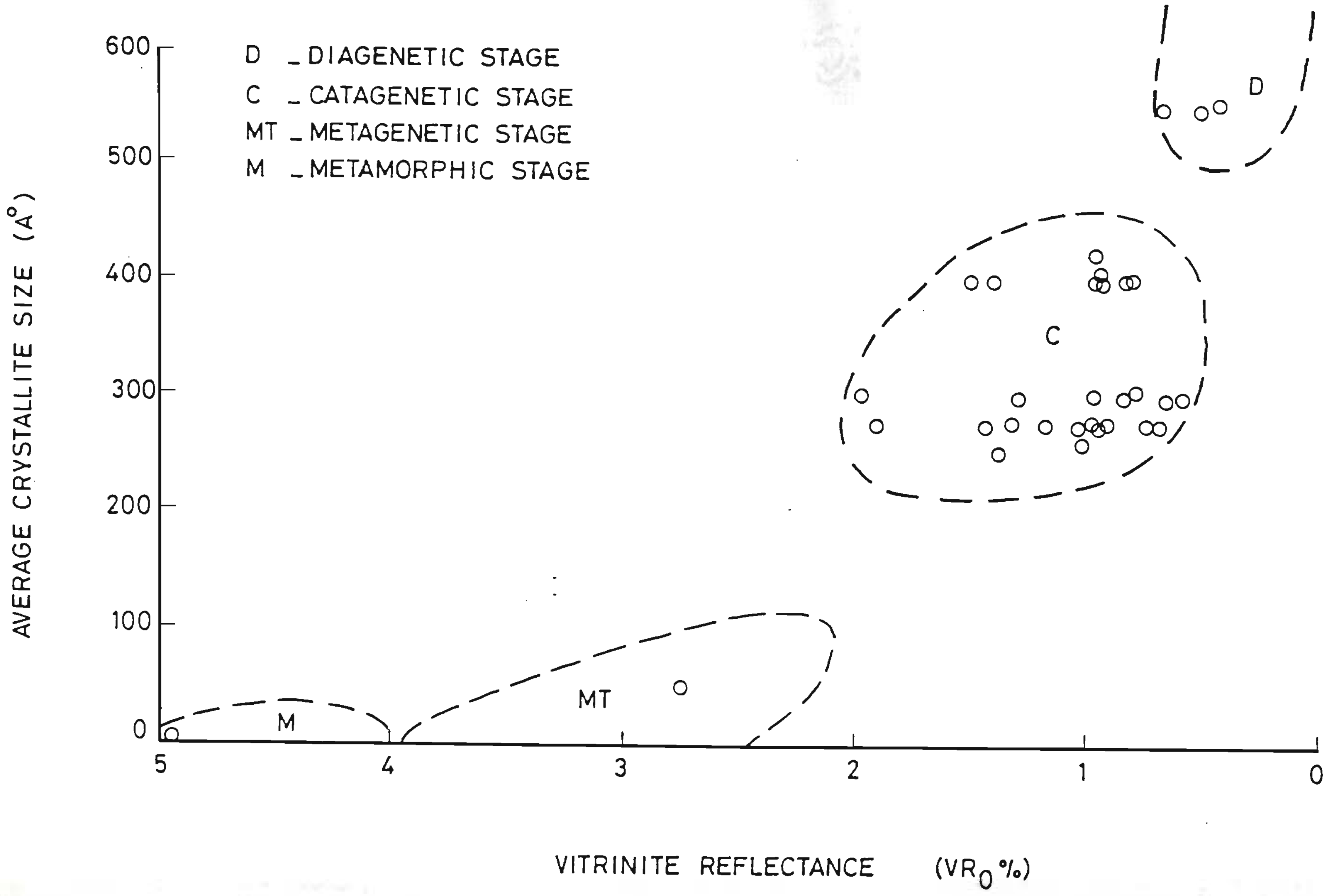

Fig. 6.6 Relationship between crystallite size and vitrinite reflectance.

Bhaunra. This effect is not perceptible in the case of the thinner intrusions found in Chasnala. Spiro (1979), has also reported that in the vicinity of "Mottled Zone" in the Nebi Musa Basin, the Infrared spectra of samples at varying distance from the Mottled Zone indicate thermal destruction of the kaolinite close to it and away from it the kaolinite will be well developed.

6.4. SPECTRAL SIGNATURE OF SHALES AS AN INDICATOR OF MATURITY:

Application of reflectance spectrometry in mineral exploration and remote sensing is well known, but its application in source rock studies is little known. As mentioned above, the pyrolytic heat due to igneous intrusions have affected both the organic matter and crystallite size of kaolinite found in shales. If this is so then these intrusions must have affected physical properties of these shales. Therefore, an attempt was made to study the spectral responses of these shales to electromagnetic radiation, in the wave lengths 350, 400, 450...850 nm for samples collected at varying distances from the igneous intrusions of mica-peridotite.

6.4.1.Experimental Set Up :

For the present study a spectroradiometer of model IL21700/760D/785 Research Radiometer/Photometer manufactured by International Light Inc., Newburyport, MA, USA was used Photomultiplier is used to magnify the signals, especially for low level detection. The photometer gain is roughly 500,000 times of a vacuum photodiode. The net result is about 100 times more detectivity. The components used in this model are :

Input optics : S1W
Monochromator : GM1100
Blaze : 500 nm
Detector : PM2271E
Power supply : IL760
Photometer : IL1700
Conditions : Slit width in nm or
Band width in nm-5 nm

The light source used was of constant wavelength and intensity. A halogen lamp, model KL 1500 manufactured by Schott, West Germany, was used. This gives five intensity levels each for half illumination and full illumination of light which has a frequency of 50 to 60 Hz.

6.4.2. Experimental Work :

Samples collected at different distances from the intrusive bodies were cut to small chips and polished thereafter.

To study the spectral responses of the samples at different stages of maturity, the shale samples were fixed on a sample holder, designed and fabricated in the department of Earth Sciences, University of Roorkee, India. The halogen lamp was kept at full illumination with a highest intensity level of 5. The light was at the normal position to the surface of the sample at a distance 7.5 cm. The longest diameter of the light reflected from the sample was 3cm. The distance of the sensor to the sample surface was fixed at 8.5 cm (Fig. 6.7).

Power Selection: The IL1700 can be operated from seven different sources of power, out of which stabilized alternating current

Fig. 6.7 Experimental set up for Spectroradiometric studies.

FIG. 6.7

(AC) of 230 volt was selected (extreme care was taken to get stabilised light, because a 1% change in the lamp current, often produces a 3% change in the light output).

Radiometer/Photometer: The radiometer/photometer measures the photon flux and gives the value in optical units or amperes. The radiometer was programmed to read the electrical current in amperes. 1.000 x 10^0 was stored as the factor for this purpose by putting the instrument in `FACTOR' mode using 'DISPLAY' button and bringing 0 in `FACTOR SELECT', and feeding the desired factor with the help of `MSD', `LSD' and `EXP'.

Zeroing: One of the most important controls on this instrument is the `Zero' display. It subtracts the present reading from itself and from all future readings. It also remembers this condition even if the unit is turned off. The `Zero' level was stabilised by covering the detector extremely well to seal all light leaks, and waiting for the full 10 seconds before the `zero' button is pressed. This helps is making certain that all available light is measured.

Percent Mode: To make the display reading equal 100.0, and referencing all subsequent readings to this original value. These readings are a percentage of that original value. This is very useful for making reflectance measurements directly. For that a reference for the 100% value is established by using a white reflectance standard for the 100% condition. Barium sulfate coated plate was used as the standard plate and the source light was placed at full lamp illumination with intensity 5, and 100% button was pressed.

Changing Wavelength : The micrometer is used for the desired wavelength. Each rotation of the micrometer handle changes the wavelength by 50 nm. For automatic scanning in IL785, the 4 RPM monochromator wavelength drive produces a scan of 100 nm per minute. The micrometer was set to the shortest wavelength desired (350 nm) and a reading was taken. The motor is switched on and after full 30 seconds the grating monochromator (micrometer) is advanced by 50 nm where it is stopped and next reading is taken. The order sorting filters are slide mounted on the spectroradiometer. For wave lengths upto 400 nm no filter is used, between 400 to 600 nm, SC365 (clear) filter and beyond 600nm, SC562 (Orange) filter is used.

As the selected sensitivity factor dialed into the IL785 was 1.000×10^{0}, therefore, the current was read in amperes. This current data is then divided by each sensitivity factor provided with the instrument (Table 6.1) to obtain the final reflectance in optic units in W/Cm^{-2} nm.

Spectral Signatures of Shale

Under the above mentioned experiment conditions, spectral responses to electromagnetic radiation, in the wavelengths 350,400,450...850nm for 40 samples collected at varying distances from the igneous intrusions, were measured. These responses could be best studied in the Bhaunra area, as there the intrusions are thicker and are of the order of 0.75 to 2.25m. The spectral response of shales (Fig. 6.8), in general, shows that first the reflectance increases with increase in wavelength in the range of 350 to 600 nm and then decreases with increase in wavelength in the range from 600 to 850 nm. This trend remains

Table 6.1 Sensitivity factor for conversion of Ampere to optic units.

WAVELENGTH (nm)	SENS FACTOR A*cm2*nm/W	
300	5.6153805e-04	NO FILTER
310	8.89403453e-04	
320	1.40186866e-03	
330	1.84351032e-03	
340	2.30929877e-03	
350	2.73491158e-03	
360	3.15163621e-03	
370	3.52010236e-03	
380	3.77074421e-03	
390	4.08501349e-03	
400	4.49471282e-03	
400	4.07455532e-03	SC 365 (CLEAR) FILTER
410	4.44742582e-03	
420	4.8134673e-03	
430	5.06115594e-03	
440	5.31109396e-03	
450	5.62904999e-03	
460	5.85360388e-03	
470	6.04793217e-03	
480	6.24445236e-03	
490	6.43142522e-03	
500	6.59028021e-03	
510	6.70179235e-03	
520	6.77103325e-03	
530	6.84795261e-03	
540	6.91548071e-03	
550	6.96047599e-03	

SC 365 FILTER

560	6.97060725e-03
570	6.93344776e-03
580	6.86864488e-03
590	6.85781017e-03
600	6.70541439e-03

SC 562 (ORANGE) FILTER

600	6.55146355e-03
610	6.47798229e-03
620	6.34689804e-03
630	6.19499919e-03
640	6.04896762e-03
650	5.88456831e-03
660	5.73679791e-03
670	5.58866998e-03
680	5.42723084e-03
690	5.2704108e-03
700	5.08506065e-03
710	4.9225265e-03
720	4.74278794e-03
730	4.57386182e-03
740	4.39241328e-03
750	4.21400611e-03
760	4.07065371e-03
770	3.92272575e-03
780	3.76673956e-03
790	3.60649777e-03
800	3.44211797e-03
810	3.3150478e-03
820	3.18494628e-03
830	3.0553553e-03
840	2.92275469e-03

850	2.76610044e-03
860	2.57151956e-03
870	2.30776406e-03
880	1.9473186e-03
890	1.48029654e-03
900	9.24698274e-04

SC 562 FILTER

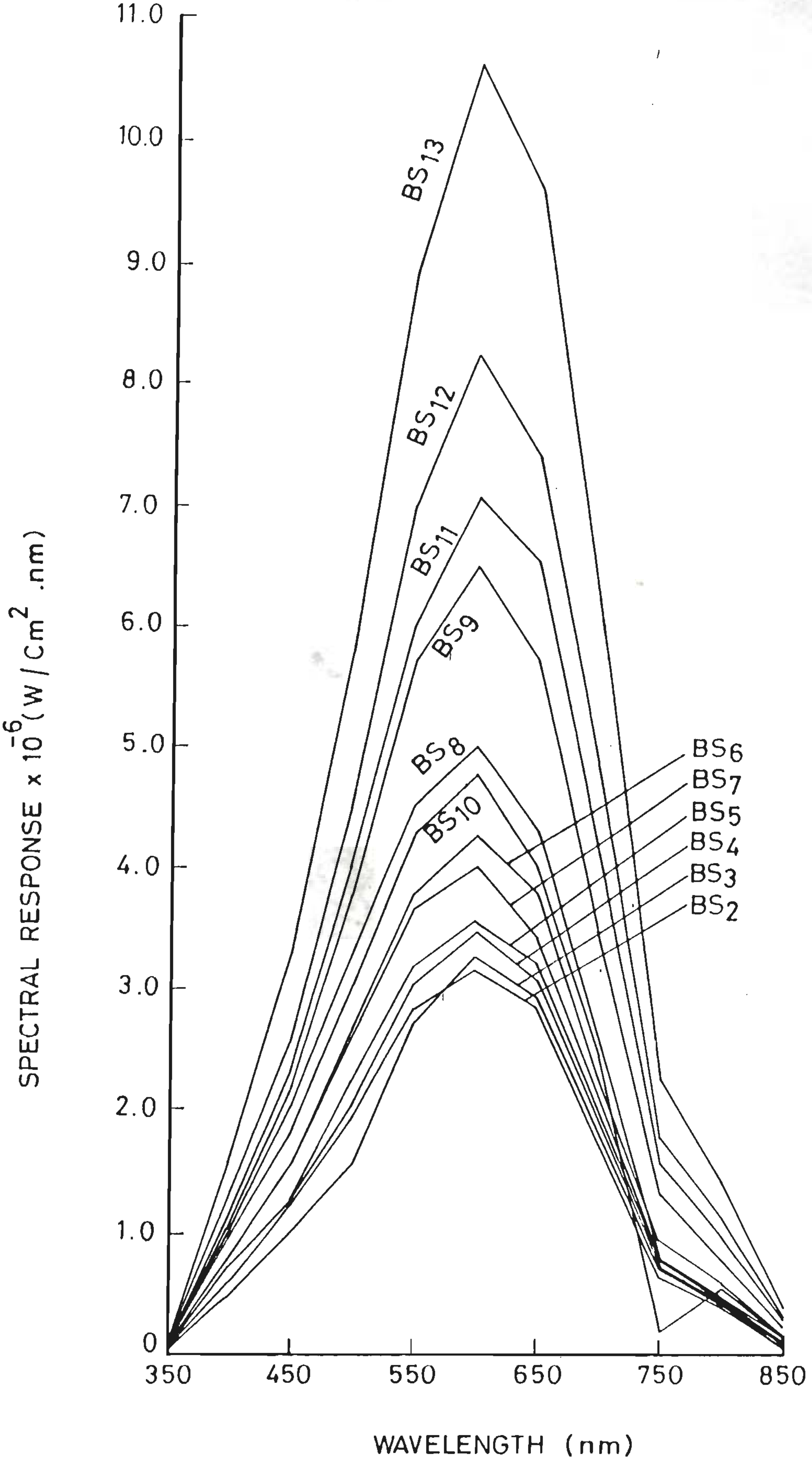

Fig. 6.8 Variation of spectral response with change in the wave length of electromagnetic radiation (Bhaunra area).

same for all samples, irrespective of their location in relation to igneous intrusions. However, for any given fixed wavelength the reflectance increases with increase in the distance of samples from the intrusions. It is best manifested at the wavelength 600 nm (Fig. 6.9). Similar spectra is also found in Chasnala area but because of complexities of sills and dykes this trend has become complex (Fig. 6.10). Conversely, the reflectance decreases with increase in nearness of samples to the intrusion. This decrease in reflectance may be attributed to the continual increasing disorder in the crystal lattice of clays in the clay shales of the Barakar Formation. This is also corroborated by decrease in the crystallinity of kaolinite of shales discussed earlier.

The spectral response of shales appears to be inversely related with vitrinite reflectance. The relationship of spectral responses and the vitrinite reflectances at 600 nm is demonstrated in Fig. 6.11 It is observed that the samples with high vitrinite reflectance have low spectral response. It does not show much variation in metamorphic and metagenetic zones. Relatively sharper increases in spectral response is observed in catagenetic stage of maturation.

At 600 nm, the zones of metamorphism, metagenesis, catagenesis and diagenesis are maximally discriminated and fall in the reflectance of 3.18 x 10^{-6}W/cm^2 nm, between 3.18 and 3.25 x10^{-6}W/cm^2.nm, between 3.25 and 14.05x10^{-6} W/cm^2. nm and >14.05x10^{-6} W/cm^2 nm, respectively (Fig. 6.11).

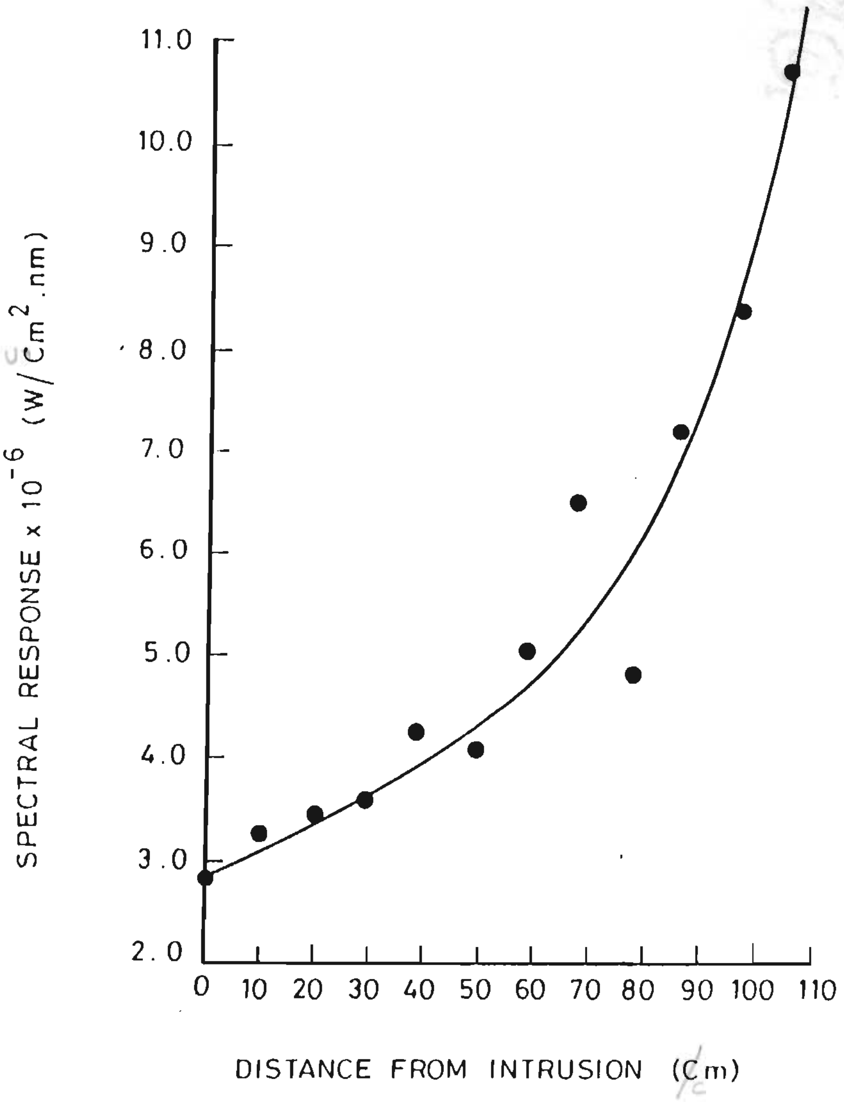

Fig. 6.9 Increase of spectral response away from the intrusion at wave length 600 nm.

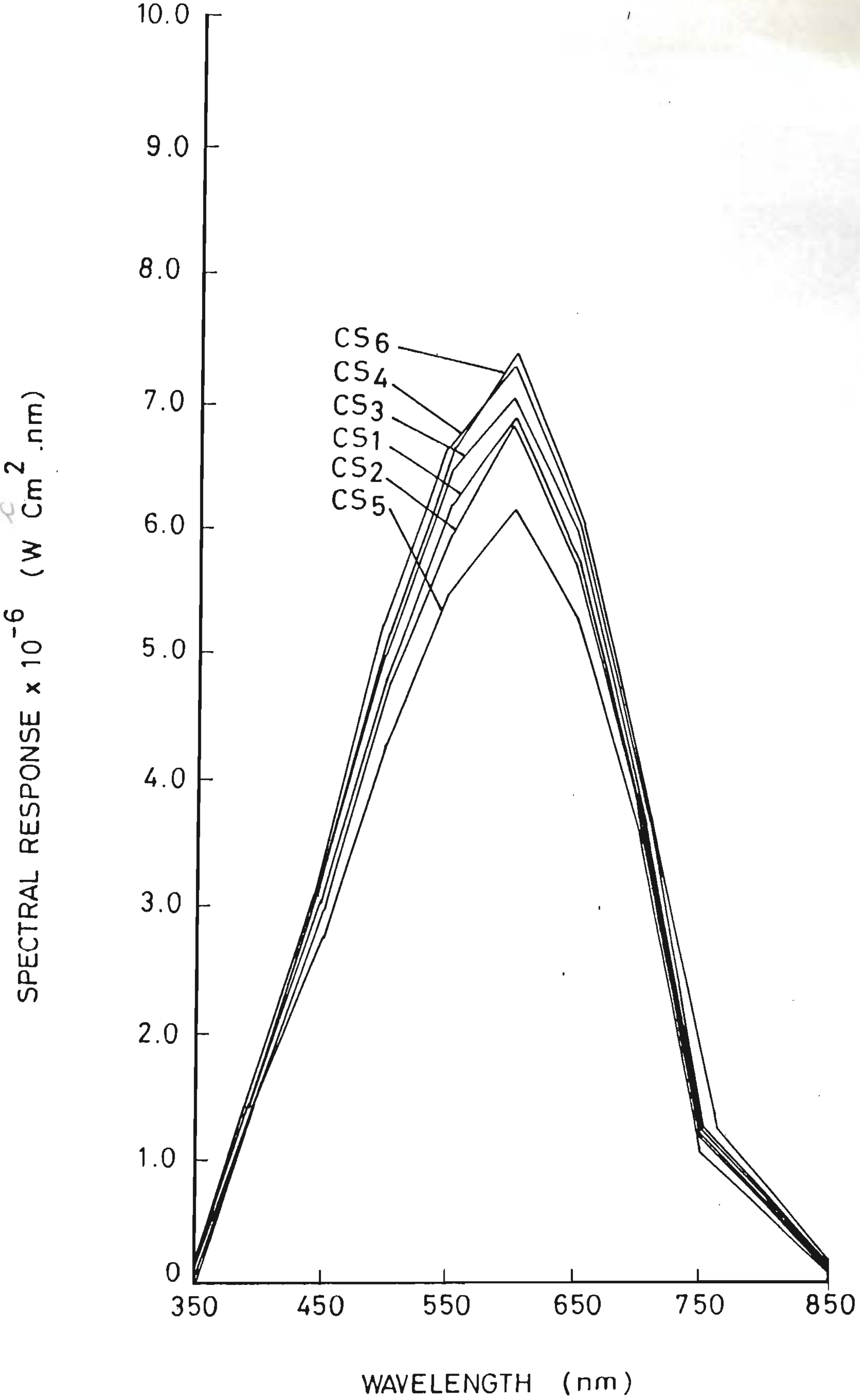

Fig. 6.10 Variation of spectral response with change in the wave length of electromagnetic radiation (Chasnala area).

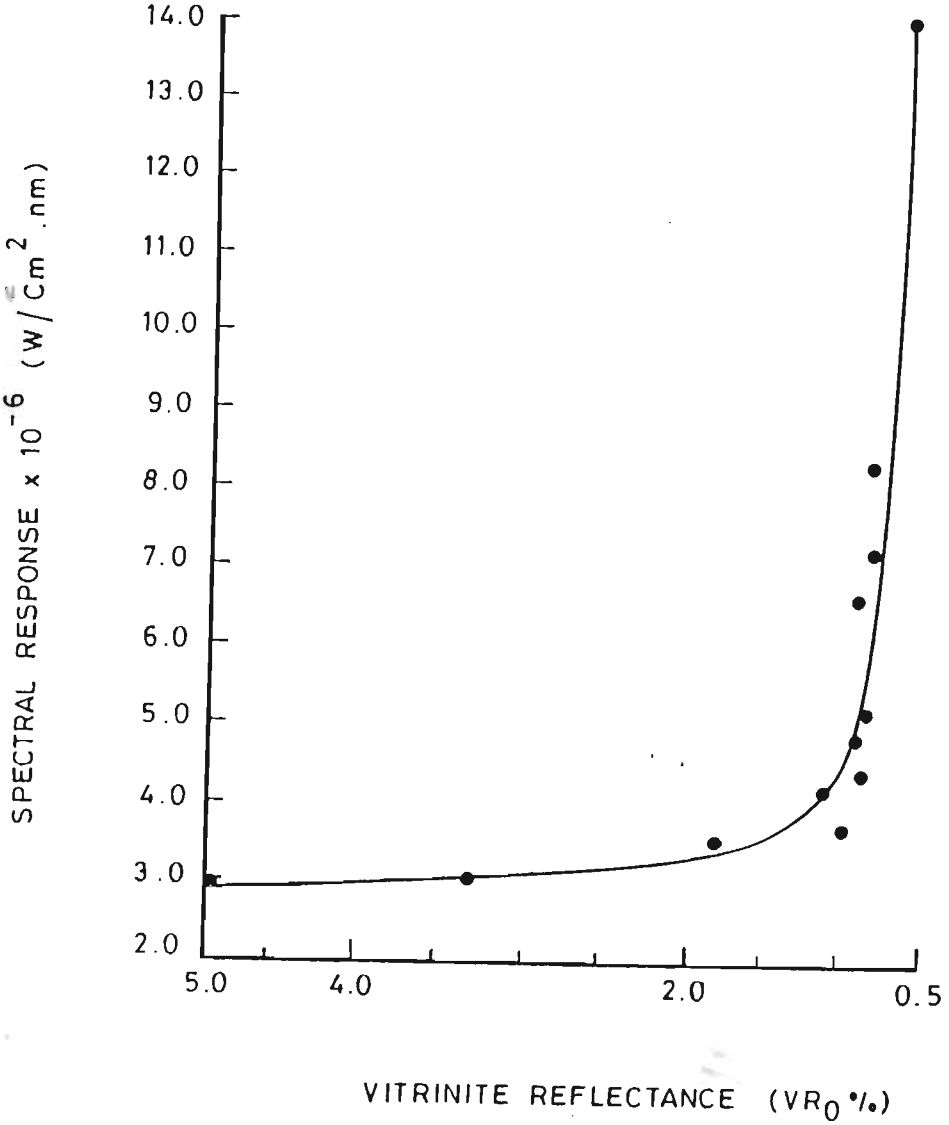

Fig. 6.11 Relationship between vitrinite reflectances and spectral responses of shale at wave length 600 nm.

It is therefore inferred that spectral signatures of shales offer promise for use as a screening method for maturity of sediments.

6.5 SUMMARY

Physical properties of sediments as well as organic matter are changed during the process of maturation, inaddition to the changes in chemical properties. Since the organic matter in the Barakar Formation of Jharia coalfields is mainly of type III kerogen and it generates less pyrolyzate per gram of organic matter, therefore, besides thermal studies the catalytic effect of clay minerals to this type of kerogen should also be investigated.

Clay mineralogical study reveals that the main clay minerals Barakar Formation are kaolinite, illite with little chlorite, the predominance being that of the kaolinite. Catalytic and adsorption effect of kaolinite is little as compared to expandable clays. However, kaolinite is sensitive to temperature changes and therefore can be used as maturity indicator. It has been destroyed in the samples very close to intrusive bodies (having temp. above 550 C). However, the degree of crystallinity of kaolinite decreases towards the intrusive body. Using crystallite size an attempt has been made to identify various zones of maturation. The zone of catagenesis is characterized by crystallite size between 250 A° and 550 A°. Values above 600 A° may be taken as indicative of diagenetic stage. Variation in crystallite size of kaolinite is more apparent for the thicker intrusions as observed in sampled areas of Bhaunra.

To study the spectral responses of the samples at different stages of maturity, spectroradiometer was used. Spectral responses to electromagnetic radiation in the wavelengths 350 to 850 nm with 50 nm interval were measured. Reflectance response increases with increase in wavelength in the range of 350 to 600 nm and then decreases with increase in wavelength in the range from 600 to 850 nm, Also, the reflectance response for any given wavelength increases with increase in the distance of samples from igneous intrusions and it is best exemplified at the wavelength 600 nm.

The reflectance responses of shales appear to be inversely related with the vitrinite reflectance. At 600 nm, the zones of metamorphism, metagenesis, catagenesis and diagenesis are maximally discriminated, and fall in the reflectance of $<3.18 \times 10^{-6}$ W/cm^2.nm, between 3.18 and 3.25×10^{-6} W/cm^2.nm, between 3.25 and 14.05×10^{-6} W/cm^2. nm and $>14.05 \times 10^{-6}$ W/cm^2 nm, respectively.

The study demonstrated that the clay mineral crystallite size and the spectral responses of shales to electromagnetic radiations shales appear to hold promise as new valuable simple tools to gauge the degree of maturity of organic matter in the argillaceous rocks.

CHAPTER - 7

SUMMARY AND CONCLUSIONS

With the findings of commercial accumulations of petroleum of non-marine origin in various parts of the world (Hedberg, 1964; Demaison, 1984; Snowdon, 1991; and Hunt, 1991 etc.), the non-marine sediments of the Gondwana Supergroup (Upper Carboniferous to Jurassic/Middle Cretaceous) in India have assumed great importance. Their status has further been upgraded because their equivalents in the Cooper Basin in Australia (Patchawara and Toolachee formations of Permian age) are producing commercial petroleum hydrocarbons (Smyth, 1983; and Clark and Cook, 1987). Despite this, little studies have been made to assess their petroleum prospects. The present investigation is an attempt in this direction with an aim to study source rock characters of these sediments. With this in view the Barakar Formation of Jharia in the Damodar Basin, Bihar, India, have been investigated in this study because it is in this basin, the Barakar Formation has attained maximum thickness of more than 1250 m of sediments characterised by as many as 50 to 60 cycles of shale-coal-sandstone sequences containing rich amount of organic matter. Also, since it contains large number of coal seams, it has been extensively mined and thus offers excellent object for investigating source rock characters of these non-marine sediments of Lower Permian age.

Verma and Singh (1979) have recognised three sets of fold (1) Early folds: Early folds along NW-SE axes oriented parallel to the lineament of the depositional valley in which paleodrainage has been recently established to be north-westerly (Casshyap, 1973). (2) Cross folds: Cross folds along E-W axes, which are parallel to the alignment of present Gondwana outlines in the Damodar valley coalfields and (3) Later folds: Later folds along NNE-SSW axes, which have formed smaller warps within the coalfields and are larger,coeval to the cross folds.

The sandstones are profusely cross bedded showing northerly unidirectional paleocurrents at outcrop level. It is northwesterly in the western segment, towards north in the central part and northeasterly towards eastern part. Also, the occurrence of ripple marks, erosional channels, pebble and grain imbrication in conglomerates, sandstones and embedded fragments of vegetal debris in fine grained sandstone and siltstone owe their deposition to streams. The shales are rich in kaolinite and contain terrestrial plant fossils such as Schizoneura Gondwanensis, Glossopteris indica, Barakaria dichotoma etc.

Shales of the Barakar Formation found in the Jharia form the major object of source rock studies. These investigations are based on 146 samples collected systematically across the trend of intrusions from Bhaunra, Chasnala and Phulwaritand - Maheshpur areas.

Organic Matter Richness

The organic matter richness of these sediments was determined in terms of their total organic carbon (TOC) content by high temperature combustion of pulverized samples. The TOC, as expected, varies from higher values in coal rich sediments to lower values in shales. The coal samples have TOC values, at times, as high as 61.46%. In Chasnala area, TOC values of coaly shale samples range from 0.94 to 57.8% with an average of 32.01%, whereas the TOC of shale samples in this area varies from 4.09 to 49.86% with an average of 13.19%. In Bhaunra area, TOC values of coaly samples range from 13.58 to 61.46% with an average of 44.63% and the shales in this area have wide range of TOC ranging from 0.22 to 36.08% with an average of 10.97%. In Phulwaritand a TOC range of 1.91 to 53.98% with 33.23% as an average for coaly shale samples and 0.22 to 3.85% with an average of 1.55% for shale samples were determined. Maheshpur area shows a TOC range of 0.11 to 6.81% with 0.21% as an average of shale samples collected from this organic matter lean area.

These sediments have TOC invariably more than the threshold value of 0.5% (especially in Bhaunra and Chasnala) and are therefore, of interest from the point of view of source rock investigations. These sediments have varying levels of organic matter richness - moderate to good to rich.

It is observed that TOC increases towards south and southeastern part of the area of study (towards Bhaunra and Chasnala). It is also important to note that the thickness of the Barakar Formation also increases towards south and southeast, implying thereby higher prospects of these sediments in Bhaunra and Chasnala.

Quality of Organic Matter

The quality or type of organic matter present in the sediments indicates its proneness to generate petroleum hydrocarbons. It was determined using Rock-Eval pyrolysis, analysis of extractable organic matter, gas chromatography of

C_{15+} alkane fractions and optical methods of transmitted and reflected light microscopy.

The cross plot of HI and OI on modified van Krevelen type diagram indicates that the organic matter is characterized by kerogen type III, although a few samples from Phulwaritand area have very low HI and high OI, suggesting type IV kerogen.

Plots of hydrogen index versus T_{max} when used as an indicator of type of organic matter suggests that about 90% of the samples are characterized by kerogen of type III and only 10% of them have organic matter comprising 20 to 40% type II kerogen. This, therefore, also indicate that organic matter is of terrestrial origin and, therefore, is favourable for mainly gas generation.

Extracts of bitumens from 91 samples (49 from Bhaunra, 34 from Chasnala and 8 from Phulwaritand - Maheshpur) reveal their variation from 0.01 to 1.16% in Bhaunra, 0.01 to 0.66% in Chasnala and 0.02 to 0.60% in Phulwaritand - Maheshpur, indicating thereby that these rocks can be classified mainly as `rich to adequate' in terms of source rock potential.

The degree of bituminization (ß), measured as extractable bitumen per unit TOC, in almost all the samples of these three areas, is less than 5% confirming further that the source rocks are mainly gas prone and are syngenetic in nature. Organic matter of humic type and the kerogen mainly of Type III are considered to be mainly gas prone.

Aromatics form the dominant component as compared with saturates in the extracts. The ratio of saturates/aromatics which is very low and is of the order of 0.11 to 1.69 confirms the previous observations regarding the terrestrial origin of organic matter and the kerogen of type III.

Gas chromatography of C_{15+} normal alkane fraction (saturates) of 39 selected samples from Bhaunra, Chasnala and Phulwaritand-Maheshpur areas were also used to determine the type of organic matter. Bivariate plot, of Pristane/nC_{17} against Phytane/nC_{18}, indicates that all the samples fall in the humic organic matter, suggesting thereby Type III kerogen deposited under peat-swamp environment and intermediate between peat swamp and open water.

The ratio of Pristane to Phytane used to find oxidizing/reducing environments, is generally less than 3 indicating thereby mainly reducing environment of deposition.

Transmitted light studies exhibit a mixed type of organic matter, but with the domination of humic matter. Fusinite matter is also dominant in some samples, whereas sapropelic matter though present is recorded in few samples. It is, therefore concluded that the sedimentary organic matter in the area of study is mostly land derived and is prone mainly to gas and little oil.

Optical studies under reflected light reveals that vitrinite and inertinite (with its characteristic "Bogel structure") dominate. It indicates terrestrial biota as the source of organic matter. Also, the cross plot of VR_o against HI, corroborates type III Kerogen.

On the basis of all these studies, pertaining to quality of organic matter and environment of deposition, the following conclusions can be drawn.

(i) The biogenic matter is mainly humic and land derived. It is characterized by mainly type III kerogen and traces of type II and type IV in all the three areas.

(ii) The deposition of the organic matter took place in reducing environment.

(iii) The physical environment worked out to be ranging from peat swamps to open water with an intermediate type.

(iv) These organic matter has proneness to generate mainly gas with little oil.

Maturity of Organic Matter

Kerogens of suitable quality such as Types I, II and III when undergo optimal thermal maturation produce petroleum hydrocarbons. Undercooked and overcooked kerogens do not yield petroleum. Hence maturity parameters were determined and evaluated based on optical examination of kerogen, physicochemical analysis of kerogen, and chemical analysis of extractable bitumen.

The most consistent and reliable technique for estimating the stages of thermal maturations of organic matter is the reflectance of vitrinite (Dow, 1977). The studies are based on 93 samples (51 from Bhaunra, 34 from Chasnala & 8 from Phulwaritand-Maheshpur area). Sediments unaffected by intrusions have vitrinite reflectance ranging from 0.4 to 1.60% with mean of 0.95% in Bhaunra area; 0.43 - 1.30% with a mean of 0.74% in Chasnala area and 0.40 - 1.50% with a mean of 0.69% in

Phulwaritand area. These reflectance values indicate that these sediments are well within the petroleum window (VR_o between 0.5 to 2.0%).

Thermal alteration index (TAI), of Staplin (1969), was also used in the present study. Visual examination of 92 samples recovered organic matter slides from these three areas show TAI value of 2.75 indicating adequate or moderately matured facies.

Fluorescence measurement of organic matter, gives the spectral maximum numerical values of the order of 8.46% at 530 nm thereby indicating maturation of organic matter just above the onset of oil window.

The temperature T_{max}, obtained from the pyrolysis of samples, varies from 330° C to 458° C for sediments unaffected by igneous intrusions in Bhaunra and Chasnala areas. These also indicate that the sediments are moderately mature and only in Phulwaritand they are immature as indicated by lower values of T_{max} (330 to 431).

Plot of samples on modifiedvan Krevelen diagram clearly indicates that OI in most of the samples from these three areas is about 50 mg CO_2/g TOC, and therefore fall in the moderately matured level of thermal evolution of organic matter.

The bitumen extracted from these sediments, containing mainly kerogen of Type III, varies from 0.01 to 1.2% and the degree of bituminization (ß) varies from 0.01 to 12.8%. These values together with lower oxygen index (OI), indicate the maturation in an early stage of principal zone of oil genesis.

The mean ratio of saturate/aromatic is about 0.7 which indicates moderately matured organic matter.

The carbon preference index (CPI), the parameter relevant to gas chromatography (GC) analysis of total alkanes, originally proposed by Bray and Evans (1961), for the Barakar sediments is observed to be either around 1 or less. This also shows that the samples are matured corroborating thereby previous inferences about the maturity of organic matter found in these sediments.

Thus, all these studies indicate that the organic matter found in these sediments have undergone maturation to generate mainly gas with little oil.

Time of Generation of Hydrocarbons

Lopatin model, based on the burial history curves and geothermal gradients was applied to determine Time - Temperature Index (TTI). The TTI of 15 at which petroleum begins to generate from kerogen of Type III was attained at about 235 million years before present. These sediments reached maximum maturity level corresponding to TTI of about 79 at about 200 million years ago. It is therefore inferred that these sediments with increasing burial had undergone maturation to produce petroleum during a period ranging from about 235 to 200 million years.

Effect of Intrusion on Organic Matter

The Barakar Formation of Jharia coalfield has been intruded by high fluidity and high temperature mica peridotite and also dolerite; these sediments, therefore, provide excellent opportunity for studying the effect of temperature on the rocks of same age, type, and the same pressure. Because of the steep thermal gradient across the intrusion body, the organic matter in the rocks close to the intrusive has been exposed to high temperatures while the organic matter farther away has been heated only a little above the normal temperature of the country rock.

Effect of igneous intrusions on organic matter, dispersed in these sedimentary rocks, has been studied in terms of variation of vitrinite reflectance (VR_o), thermal alteration index (TAI), fluorescence, pyrolytic parameters, and the content of bitumen and its componental elements, based on 18 intrusions (12 dykes and 6 sills).

Reflectance measurements performed on vitrinite maceral indicate that VR_o for samples just at the contact with the igneous intrusions, is high (as much as 6.27%) and decreases away from the intrusive bodies till it attains a ground value varying between 0.50 to 0.9% in general, where the effect of intrusions is negligible.

These intrusions affected various zones of maturity across them. The width of these thermally affected zones varies with the thickness of intrusive body. It is generally twice the thickness of igneous body. The thermally affected zone is characterized by contact metamorphism, metagenetic and catagenetic zones, depending upon the thickness of igneous body. In general, the widths of the metamorphic, metagenetic and catagenetic zones are about 15%, 32% and 180% (nearly twice the thickness of the intrusive body), respectively. As the thickness of igneous intrusions increases, the width of various maturity zones also increases. However, if the thickness of intrusion is 30 cm or less, the effects are not perceptible.

Thermal Alteration Index (TAI) measurements were made on the kerogens, microscopically.The darkening of kerogen particles with increasing thermal maturity can be used as an indicator of maturity and igneous intrusion effect. It is well illustrated by these sediments. At the contact with igneous intrusions the kerogen is in darkest state and the colour fades away from the contact. The TAI values from the Barakar Formation of Jharia coalfield are, all, around 2.75. It becomes as high as 4.5 for sediments close to the contact with the igneous body and decreases to its ground value of about 2.75 away from the intrusions. This is in corroboration with the VRo results.

Measurements of the intensity of the fluorescent light given off after irradiation of the microscopic slide with ultraviolet light, were made over a range of wavelengths. It is observed that the samples at the contact show maximum fluorescence of 168.44% at 730 nm wavelength and the maxima decreases to 8.46% and the wavelength, at which the maxima is obtained, shifts to 530 nm in case of the samples from intrusions.

Higher temperatures imposed by the intrusions in the study area cracked some of the more labile hydrocarbon side chains from the kerogen. This increased the Tmax upon Pyrolysis (T_{max} is as high as 554°C at the contact and decrease to ground value of about 330°C away from these contacts), and the products became part of the free compounds (increasing the PI). Depending on the permeability of the rock, some of these thermally generated products migrated and some remained near their place of origin.

However, in most of the samples, production index (PI) increases towards the intrusion and reaches its maximum, approaching at times to 1, at the contact. In some beds the hydrocarbons thus produced have migrated some distance to form what are known as microreservoirs.

Igneous intrusions have also affected the amount of extractable organic matter content of the sediments. At the contact or very close to intrusive bodies volatiles appear, to have been lost, in general. This suggests that pyrolysis products from organic sediments of Barakar Formation in Jharia coalfield, at or near contacts of intrusions, got diffused and were collected in the so called microreservoirs. The collection of bitumen in these microreservoirs is as high as 1% bitumen (i.e. about 10% of the organic matter present), whereas the average of extractable organic matter in these sediments is about 0.2% or less).

The aromaticity (A/S) ratio is greater than one. It increases to 4 near the contact and it again decreases, away from the intrusions. This also explains why fluorescence is observed at higher wavelength near the contact of intrusions.

The gas chromatograms of the saturates from these three areas also indicate that in some sediments the nC_{max} is as low as nC_{18} at or near their contact with intrusions.It gradually increases away from the contact, reaching sometimes as high as nC_{22} or even nC_{24} and occasionally upto nC_{25}. This clearly shows the effect of the intrusions on cracking of the higher molecular weight normal alkanes to lower ones. Although the sediments are already in matured state, still this effect is clearly discernible.

Fluorescence is a useful measure of organic matter type and maturity and the presence of non-indigenous hydrocarbons (Waples, 1985). Longer wavelengths of fluorescent emissions indicate higher maturity because of greater delocalization of energy (and therefore greater stability).

From what has been inferred above, it is concluded that the igneous intrusion especially the mica-peridotites have enhanced the maturity of sediments and have generated additional petroleum hydrocarbons when they were emplaced around 100 my back during Lower Cretaceous.

Genetic Potential and Petroleum Hydrocarbon Yield of Shales

The amount of hydrocarbons generated by a given volume of source rock depends upon the organic carbon content of the source rock, the oil generative capacity of the kerogen in the source rock which is indicated by the kerogen type, and the thermal maturity achieved by the organic material. All these parameters affect the quantity of hydrocarbons that have already been generated. The basic equation used to calculate hydrocarbon volumes from these data is -

$$HC = (k) \times (TOC) \times (HI) \times (f)$$

where HC is the volume of hydrocarbons generated, k, is the conversion constant depending upon the source rock density, TOC is expressed in weight percent, hydrogen index (HI) is mg HC/g TOC when the source rock was at its immature state, and `f' is the fractional conversion factor indicating the present day maturity state of the source rock.

Samples for this study were selected from Chasnala, Bhaunra and Phulwaritand areas. The organic matter in the sediments is mainly terrestrial- kerogen of type III. It is matured to various levels in Chasnala and Bhaunra areas. However, it is generally immature in Phulwaritand area. Besides the maturation of organic matter during burial of sediments due to basement heat, igneous intrusions have also further enhanced the maturity of these organic sediments in their vicinity.

In Chasnala area, volumetric estimation of hydrocarbon yield was made at three sampled locations. Of these three locations, the sediments from the area B, situated about 200 m north of Dhanbad Sindri bridge over Domohani nala (river) (Sample No. 82-93) expelled 6 million barrels of oil along with 1285174.3 million cubic metre of gas, from each cubic kilometer of source rock. However, in the other two areas, negligible amount of gas (insufficient for expulsion) was generated. From these three locations, due to igneous intrusions, 30 million barrel of additional oil and oil equivalent hydrocarbons were generated.

In Bhaunra area, four locations were investigated. In the first location which is situated SE of Joraphokar, the maturity was not enough to generate any gas or oil, although these sediment have genetic potential of 8 kg of hydrocarbons per ton of source rock. Second location(B) situated NNW of Gorkhuti, generated 23.294 million barrels of oil and oil equivalent from each cubic kilometer of source rock. Third location(C) about 22 km south west of previous location generated negligible amount of gas and since it was not enough to cross the threshold of 12 million barrels of oil and oil equivalent, it could not be expelled from the source rock. The fourth location, about 10 km north west of third location is again very important since its maturity is comparatively more than all the other three locations. This site generated about 16 million barrels of oil and 1488423.7 million cubic metre of gas for each cubic kilometer of source rock, out of which 7.984 million barrel of oil along with 1190738 million cubic metre of gas was expelled. Besides this, from these two locations, an additional average of 16.5 million barrel of oil and 5.9×10^6 million (6 billion) cubic metre of gas was estimated as generated from each kilometer cube of shales in the vicinity of igneous intrusions of the area.

Phulwaritand area though having a moderate source rock potential, due to their low level of maturity have generated little oil or gas.

It is observed that in the vicinity of the igneous intrusions the immature organic matter has witnessed enough thermal maturity to generate additional oil and gas. The closer the distance to the intrusions, more is the maturity of sediments and hence more the generation and expulsion of hydrocarbons. Also the thicker the intrusive body the more is the effect to generate more oil and gas.

Clay Mineral Crystallinity as Possible Indicator of Maturity

Physical properties of sediments as well as organic matter are changed during the process of maturation, besides changes in chemical properties. Therefore an attempt has been made to correlate crystallinity of clay mineral with the maturity of organic matter.

Clay mineralogical study reveals that the main clay minerals of Barakar Formation are kaolinite, illite and chlorite, the predominance being that of the kaolinite. Catalytic and adsorption effect of kaolinite is less as compared to expandable clays and it is also sensitive to temperature changes, therefore, its crystallinity has been used to correlate with the maturity of organic matter. It has been destroyed in the samples very close to intrusive bodies. However, the degree of crystallinity of kaolinite appears to decrease with decreasing nearness of sample to the intrusive body. Using crystallite size, an attempt has been made to identify various zones of maturation. The zone of catagenesis is approximately characterized by crystallite size between 250 A° and 550-600 A°. Values above 600 A° may be taken as indicative of diagenetic stage. Variation in crystallite size of kaolinite is more apparent for the thicker intrusions as observed in sampled areas of Bhaunra.

Spectral Reflectance of Shales as Possible Indicator of Maturity

With increasing temperature, the maturity of organic matter increases within petroleum window. This increase in temperature may also change mass properties of shales. If this is so, then a correlation between the maturity of organic matter with the mass property is expected. With this premise, the spectral reflectance of the samples at different stages of maturity, were studied. Spectral responses to electromagnetic radiation in the wavelengths 350 to 850 nm with 50 nm interval were measured. Reflectance response increases with increase in wavelength in the range of 350 to 600 nm and then decreases with increase in wavelength in the range from 600 to 850 nm. Also, the reflectance response for any given wavelength increases with the increase in distance of the samples from igneous intrusions and it is best exemplified at the wavelength 600 nm.

The reflectance response of shales appears to be inversely related with the vitrinite reflectance. At 600 nm, the zones of metamorphism, metagenesis, catagenesis and diagenesis are maximally discriminated, and fall in the reflectance of <3.18 x 10^{-6} W/cm^2.nm, between 3.18 and 3.25 x 10^{-6} W/cm^2.nm, between 3.25 and 14.05 x 10^{-6} W/cm^2. nm and >14.05 x 10^{-6} W/cm^2 nm, respectively.

The study demonstrated that the clay mineral crystallite size and the spectral responses to electromagnetic radiations, of shales appear to hold promise as new valuable simple tools to gauge the degree of maturity of organic matter in the argillaceous rocks.

Petroleum Prospects

In conclusion, this study indicates that the shale of the non-marine Barakar Formation are rich in organic matter which is mainly of a kerogen type III with little type II and IV and have undergone adequate maturation to generate petroleum, mainly gas with little oil. These hydrocarbons were generated in two separate phases by two distinct sources of heat. In the first phase, petroleum hydrocarbons were generated during Permo-Triassic (235-200 my) period due to `basement heat' while the sediments were undergoing burial. In the second stage, igneous intrusion specially the mica peridotite further matured these initially matured sediments during Lower Cretaceous time (100 my), slightly away from their contacts with these sediments.

These hydrocarbons were expelled as they had crossed the Momper's (1978) threshold value of 12 m bbl.

The Barakar Formation as mentioned earlier forms a thick pile of sediments consisting of more than 50-60 cycles of shale-coal-sandstone sequences. The sandstone can act as good reservoir rocks and the shales both as source rocks and cap rocks. If the traps in the form of anticline and syncline were formed before the generation and expulsion of hydrocarbons, then these could form a good prospects.

Mukherjee (1977) and Verma et al. (1989) studied the chronology of geological events in the Jharia coalfield. According to them major structures in the form of folds, faults were developed in two stages - the first generation of major folding took place at about 100 my during Lower Cretaceous time with NW - SE axis and the second generation cross folds at about 65 m years or so during Paleocene. If this is so, then the oil/gas generated due to burial process at about 235 - 200 my had little traps available and therefore from this angle, the prospects of getting this petroleum are poor. However, since the area falls in a rift basin, some structures specially the growth faults, roll over anticlines might have been formed during or just after the deposition of these sediments. Under such conditions there may be some prospects for petroleum generated around 235-200 my ago. In view of this, detailed basin evolution and structural studies are required to be done to evaluate the prospects of these sediments more objectively.

Due to the intrusion of mica peridotite around 100 my the organic matter was matured. As the major folding, faulting and intrusion took place more or less contemporaenously, the petroleum thus generated due to intrusion could have got accumulated into these trap forming structure provided there are good cap rocks. In this connection this may be mentioned that the shales of the shale-coal-sand sequences (more than 50-60) if found to be extensive, can also serve as good cap rock. The TOC and maturity of these sediments show increasing trends towards south and southeastern part (Bhaunra and Chasnala) of Jharia basin where these sediments have also attained maximum thickness (+1250m). Thus the areas around Bhaunra and Chasnala holding high potential, have formed petroleum kitchens.

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DETAILS OF SAMPLES COLLECTED FROM THE SEDIMENTS OF BARKAR FORMATION

Sl. No.	Sample No.	Dist.from Intrusion (Cm)	Location	Thickness of Intrusion (Cm)	Lithology
1	2	3	4	5	6
			MAHESHPUR AREA		
1	1	00	A	250	Shale
2	2	50	A	250	Shale
3.	3	100	A	250	Shale
4.	4	150	A	250	Shale
5.	5	200	A	250	Shale
6.	6	250	A	250	Shale
7.	7	300	A	250	Shale
8.	8	350	A	250	Shale
9.	9	400	A	250	Shale
10.	10	450	A	250	Shale
11.	11	500	A	250	Shale
12.	12	550	A	250	Shale
1.	13	000	B	150	Shale
2.	14	20	B	150	Shale
3.	15	40	B	150	Shale
4.	16	60	B	150	Shale
5.	17	80	B	150	Shale
6.	18	100	B	150	Shale
7.	19	120	B	150	Shale
8.	20	140	B	150	Shale

Contd....

1	2	3	4	5	6
9.	21	160	B	150	Shale
10.	22.	180	B	150	Shale
11.	23.	200	B	150	Shale
12.	24.	220	B	150	Shale
		PHULWARITAND AREA			
1.	25	--	C	50	Mica-Peridotite
2.	26	00	C	50	Shale
3.	27	5	C	50	Shale
4.	28	10	C	50	Shale
5.	29	15	C	50	Shale
6.	30	20	C	50	Shale
1.	31	-	D	130	Mica-Peridotite
2.	32	10	D	130	Shale
3.	33	20	D	130	Shale
4.	34	30	D	130	Shale
5.	35	40	D	130	Shale
6.	36	50	D	130	Shale
7.	37	60	D	130	Shale
8.	38	70	D	130	Shale
1.	39	00	E	130	Shale
2.	40	10	E	130	Shale
3.	41	20	E	130	Shale
4.	42	30	E	130	Shale
5.	43	40	E	130	Shale

Contd...

1	2	3	4	5	6
1.	44	25	F	300	Jhama
2.	45	100	F	300	Jhama
3.	46	200	F	300	Coal
4.	47	250	F	300	Siliceous Shale
5.	48	300	F	300	Carbonaceous Shale
6.	49	400	F	300	Siliceous Shale
7.	50	500	F	300	Siliceous Shale
8.	51	650	F	300	Coal

CHASANALA AREA

1	2	3	4	5	6
1.	52	00	F	275	Jhama
2.	53	50	F	275	Jhama
3.	54	100	F	275	Carbonaceous Shale
4.	55	250	F	275	Siliceous Shale
5.	56	300	F	275	Siliceous Shale
6.	57	350	F	275	Carbonaceous Shale
7.	58	450	F	275	Siliceous Shale
8.	59	750	F	275	Coal
1.	60	00	A	200	Jhama + Mica-Peridotite
2.	61	25	A	200	Jhama
3.	62	50	A	200	Jhama
4.	63	75	A	200	Jhama
5.	64	100	A	200	Jhama

Contd...

Contd...App.I

1	2	3	4	5	6
6.	65	125	A	200	Carbonaceous Shale
7.	66	150	A	200	Carbonaceous Shale
1.	67	00	B	200	Jhama + Mica-Peridotite
2.	68	50	B	200	Jhama
3.	69	100	B	200	Jhama
4.	70	150	B	200	Jhama
5.	71	200	B	200	Jhama
6.	72	250	B	200	Carbonaceous Shale
7.	73	300	B	200	Carbonaceous Shale
8.	74	350	B	200	Carbonaceous Shale
9.	75	400	B	200	Shale
10.	76	450	B	200	Shale
11.	77	500	B	200	Shale
12.	78	550	B	200	Shale
13.	79	600	B	200	Shale
1.	80	00	C	--	Mica-Peridotite
2.	81	00	C	--	Carbonaceous Shale
3.	82	00	C	135	Shale
4.	83	10	C	135	Carbonaceous Shale
5.	84	20	C	135	Carbonaceous Shale

Contd....

Contd...App.I

1	2	3	4	5	6
1.	85	-	D	30	Carbonaceous Shale
2.	86	00	D	30	Carbonaceous Shale
3.	87	10	D	30	Carbonaceous Shale
4.	88	20	D	30	Carbonaceous Shale
1.	89	-	E	5	Mica-Peridotite
2.	90	00	E	5	Carbonaceous Shale
3.	91	5	E	5	Shale
4.	92	10	E	5	Shale
5.	93	15	E	5	Shale

BHAUNRA AREA

1.	94	0	C	75	Burnt shale + mica peridotite
2.	95	25	C	75	Siliceous Shale
3.	96	50	C	75	Shale
4.	97	75	C	75	Shale
5.	98	100	C	75	Carbonaceous Shale
6.	99	125	C	75	Shale
7.	100	150	C	75	Carbonaceous Shale
8.	101	175	C	75	Siliceous Shale
9.	102	200	C	75	Coal
1.	103	00	D	100	Jhama + Mica-Peridotite
2.	104	20	D	100	Jhama

Contd...

1	2	3	4	5	6
3.	105	40	D	100	Jhama
4.	106	60	D	100	Jhama
5.	107	80	D	100	Jhama
6.	108	100	D	100	Siliceous Shale
7.	109	120	D	100	Silicious Shale
8.	110	140	D	100	Siliceous Shale
9.	111	160	D	100	Siliceous Shale
10.	112	180	D	100	Siliceous Shale
1.	113	00	E	225	Jhama
2.	114	50	E	225	Burnt Shale
3.	115	150	E	225	Carbonaceous Shale
4.	116	200	E	225	Carbonaceous Shale
5.	117	250	E	225	Carbonaceous Shale
6.	118	300	E	225	Carbonaceous Shale
7.	119	350	E	225	Carbonaceous Shale
8.	120	450	E	225	Carbonaceous Shale
9.	121	550	E	225	Carbonacesous Shale
1.	122	25	A	215	Burnt shale with Carbonate
2.	123	75	A	215	Burnt Shale with Carbonate
3.	124	150	A	215	Siliceous Jhama
4.	125	250	A	215	Siliceous Shale
5.	126	300	A	215	Siliceous Shale

Contd....

Contd...App.I

1	2	3	4	5	6
6.	127	375	A	215	Siliceous Shale
7.	128	450	A	215	Carbonaceous Shale
8.	129	550	A	215	Coal
1.	130	-	F	75	Mica-Peridotite
2.	131	00	F	75	Jhama + Mica-Peridotite
3.	132	10	F	75	Siliceous Shale
4.	133	20	F	75	Siliceous Shale
1.	134	-	B	225	Mica Peridotite
2.	135	00	B	225	Jhama
3.	136	10	B	225	Burnt Shale
4.	137	20	B	225	Burnt Shale
5.	138	30	B	225	Carbonaceous Shale
6.	139	40	B	225	Carbonaceous Shale
7.	140	50	B	225	Carbonaceous Shale
8.	141	60	B	225	Carbonaceous Shale
9.	142	70	B	225	Carbonaceous Shale
10.	143	80	B	225	Carbonaceous Shale
11.	144	90	B	225	Shale
12.	145	100	B	225	Shale
13.	146	110	B	225	Shale

APPENDIX - II

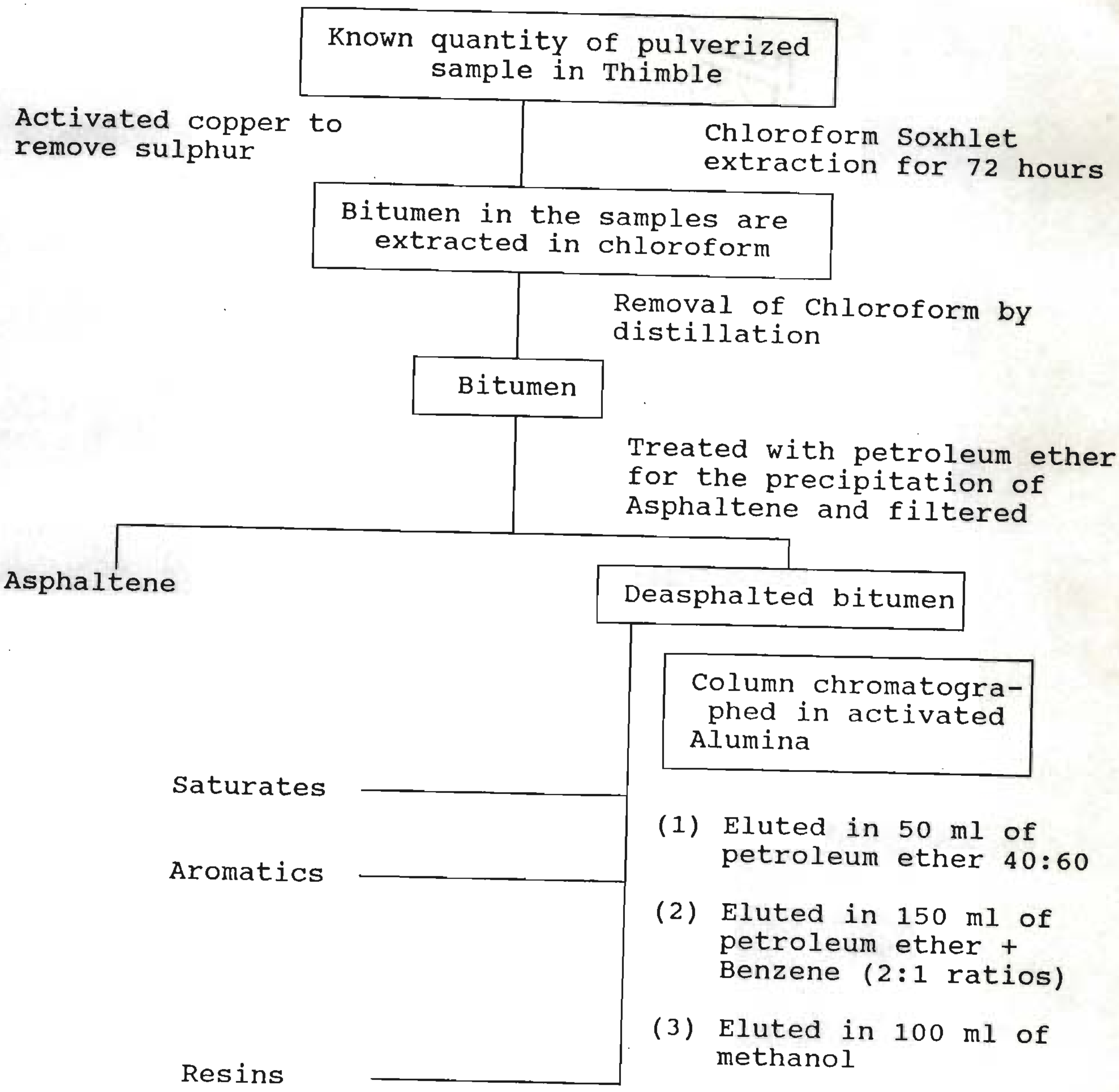
Determination of Total Organic Carbon Content

The out crop samples were handpicked and pulverized. Then the weighted quantity was treated with 4 N hydrochloric acid and kept over night for the removal of carbonates. This was filtered through Watman filter paper and washed throughly with water for the removal of chlorides. The residue free of chlorides and carbonates were over dried at 40° C was weighed again to measure the percentage of carbonates. Known quantity of the residue is combusted in oxygen atmosphere at an elevated temperature and the carbon dioxide coming out is measured in carmograph percentage of total organic carbon is reported on total sample basis.

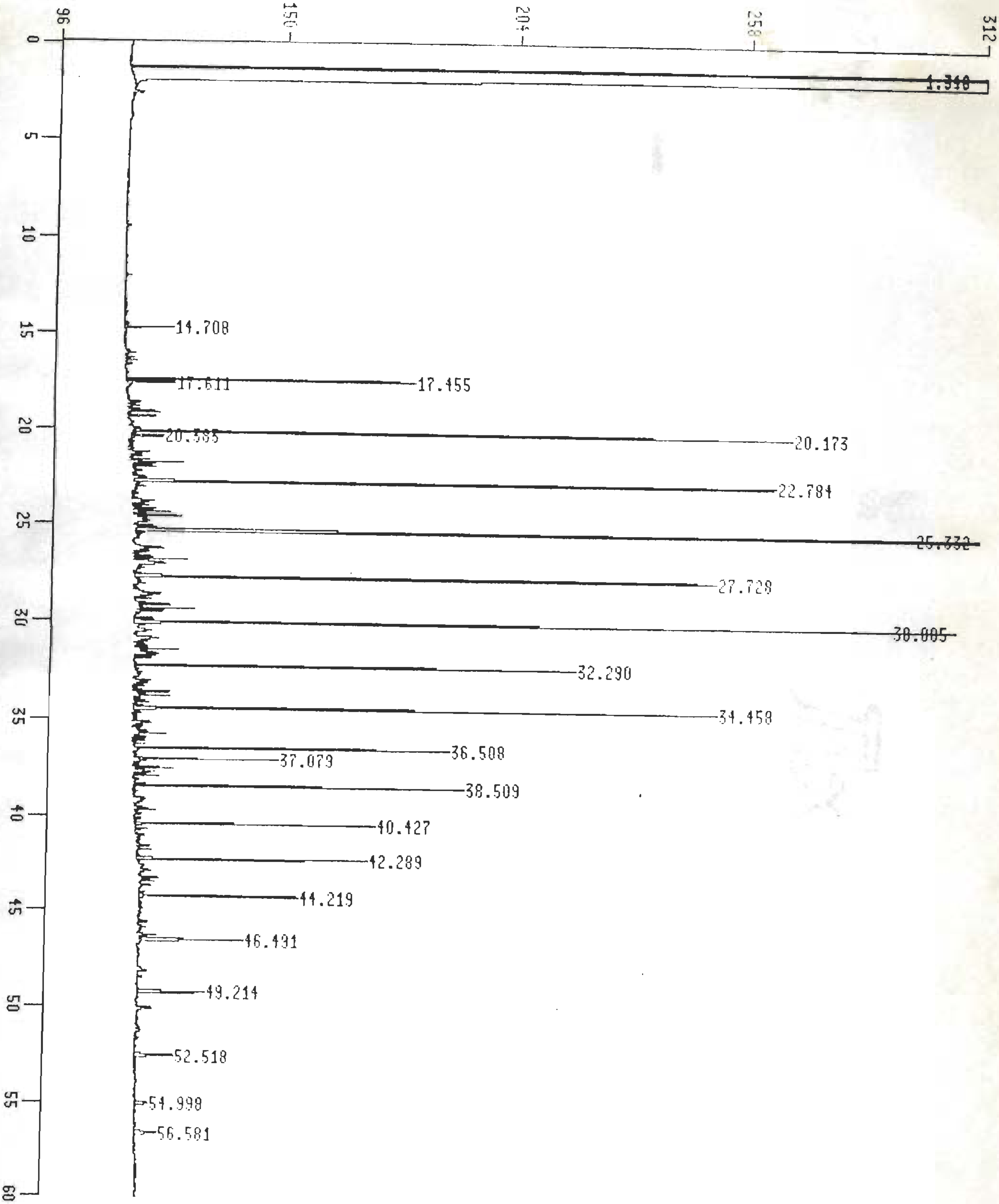
APPENDIX - III

Extraction of Bitumen and componental Analysis

The extraction of Bitumen and the componental analysis was carried out as mentioned in the following chart.



APPENDIX-IV



End of plot. Time = 0.00 to 60.00 minutes Chart speed = 0.33 cm/min

```
Peak#  Ret Time   Type   Width        Area      Start Time    End Time
   1     1.310    BV     0.041      137347          1.193       1.325
   2     1.346    VB     0.246     7258839          1.325       2.250
   3    14.708    BB     0.048        352.59       14.603      14.790
   4    17.455    BV     0.045        1972         17.343      17.520
   5    17.611    PB     0.065        456.64       17.520      17.720
   6    20.173    BV     0.049        5226         20.000      20.227
   7    20.383    PB     0.078        380.31       20.306      20.557
   8    22.784    VV     0.050        5045         22.667      22.840
   9    25.332    VV     0.059        8743         25.185      25.420
  10    27.728    PV     0.050        4559         27.607      27.820
  11    30.085    VV     0.060        7931         29.938      30.163
  12    32.290    VB     0.052        3543         32.167      32.357
  13    34.458    VV     0.057        5145         34.336      34.623
  14    36.508    PV     0.054        2539         36.343      36.567
  15    37.079    PV     0.053        1086         36.893      37.137
  16    38.509    VB     0.052        2628         38.410      38.587
  17    40.427    BB     0.052        1872         40.243      40.503
  18    42.289    BB     0.052        1826         41.983      42.450
  19    44.219    VB     0.061        1485         44.103      44.410
  20    46.491    BB     0.070        1069         46.360      46.630
  21    49.214    BB     0.086         885.83      49.000      49.380
  22    52.518    BB     0.102         604.18      52.323      52.667
  23    54.998    BB     0.123         271.30      54.797      55.180
  24    56.581    BB     0.119         415.73      56.233      56.773
  25    61.593    BB     0.171         479.94      61.320      61.867
```

Sampling method for palynological analysis

Crushed samples

Treatment with 4 N HCl for the removal of carbonates and washed free of chlorides

Acid treated samples

Treatment with 40% HF in plastic beaker removal of silica. Repeated washing with water for removing acid.

Silica free sample

Mixed with heavy liquid of Sp.gravity 2.3 and centrifuged for 1/2 an hour at 1200 RPM and decant.

Kerogen concentrate

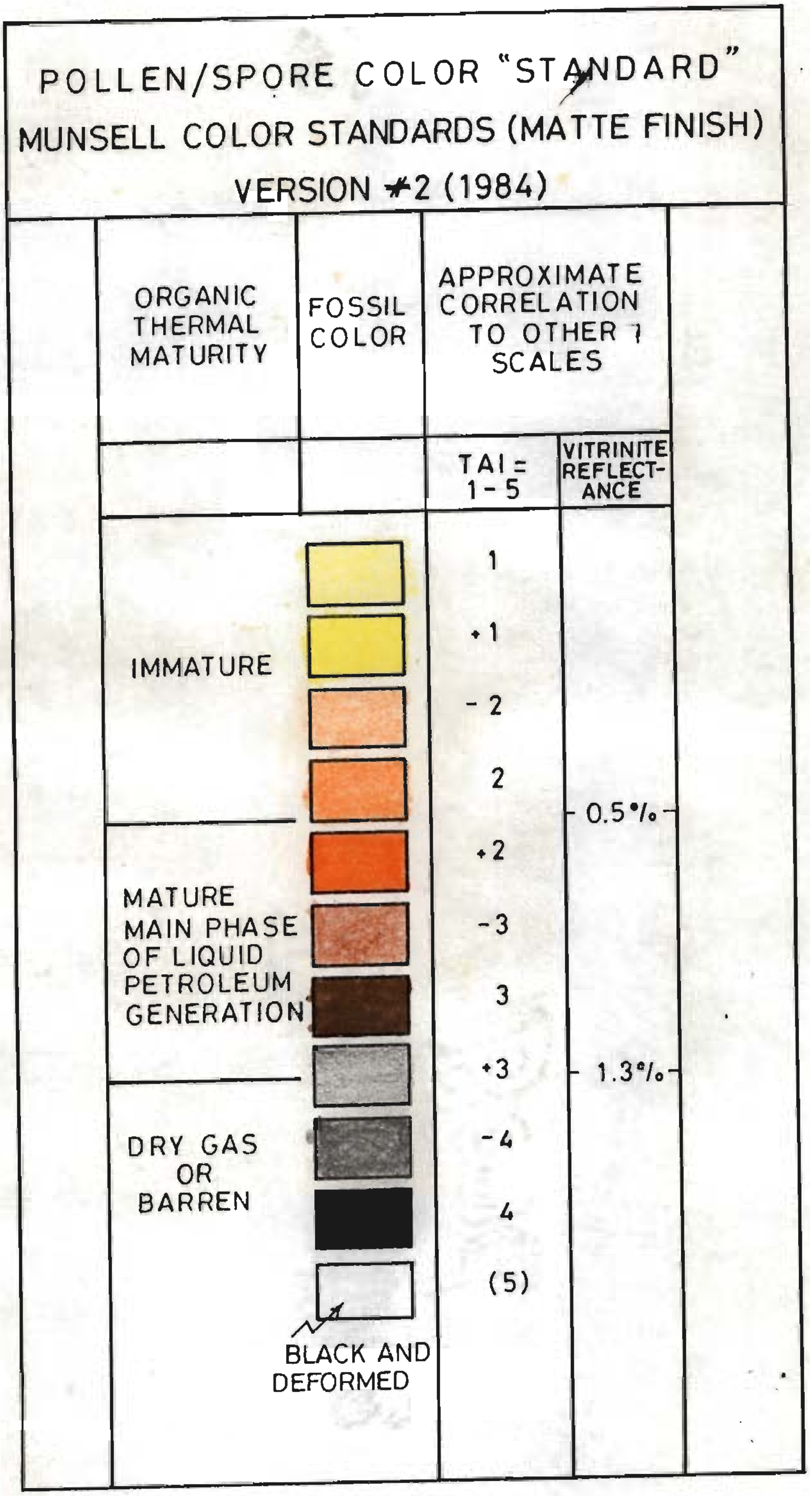
Mix with poly vinyl alcohol

Spread the material on cover slip

Mount it on glass slide with Can~~n~~ada Balsam and dry up on hot plate and clean the slide with xylene.

Plate mounted with organic matter ready for palynological analysis

APPENDIX _ VI



POLLEN/SPORE COLOR "STANDARD"
MUNSELL COLOR STANDARDS (MATTE FINISH)
VERSION #2 (1984)

ORGANIC THERMAL MATURITY	FOSSIL COLOR	APPROXIMATE CORRELATION TO OTHER SCALES	
		TAI = 1 - 5	VITRINITE REFLECTANCE
IMMATURE	🟨	1	
	🟨	+1	
	🟧	- 2	
	🟧	2	
MATURE MAIN PHASE OF LIQUID PETROLEUM GENERATION	🟧	+2	0.5%
	🟫	-3	
	🟫	3	
DRY GAS OR BARREN	▨	+3	1.3%
	▨	-4	
	⬛	4	
	☐ BLACK AND DEFORMED	(5)	