Chapter 1: Introduction

Preamble

In today's world, shale gas is rapidly substituting conventional fuel to suffice the growing energy requirements. The fluctuating oil price, high input cost in exploration and production of hydrocarbons and the relative abundance of natural gas resources have changed the bearing towards unconventional shale gas exploration. The numerous applications of natural gas and its green environmental conditions imply that shale gas will play an important role in meeting the energy demand. The United States of America and Canada are contributing commercial shale gas production up to 20% of total natural gas produced (including both conventional and unconventional). The success of the Barnett Shale play in Texas has activated in search for shale gas resources across the United States, Canada, Europe, Asia and Australia. India has the immense potential of unconventional natural gas resources i.e. coal bed methane (CBM), tight gas, shale gas, etc (Mishra, 2009; Mani *et al*, 2014; Varma *et al*, 2015; Baruah and Ganapathi, 2015).Commercial exploration of these resources can effectively make the natural gas curve more elastic.

India is looking for the development of alternative energy resources, which point towards unexplored shale gas resources. Oil & Natural Gas Corporation (ONGC) Limited has started shale gas pilot project and discovered the world's third (after US and Canada) and the country's first shale gas reserve in the Raniganj field. Since, it being a new area for exploration of shale gas, the author has conceived after going through the literature to look for the shale gas in Gondwana sediments of Raniganj Field. Initial review has made positive shale gas potential in Damodar valley, particularly the lower Gondwana shales of Permian age. Coal resources are explored from Raniganj and Barakar Formations since 17th century except the Barren Measures Formation, which is barren of coal. The Barren Measures Formation has thick shale with high organic matter content which may be the potential reservoir for shale gas. However, the fabric anisotropy, gas generation potential and reservoir quality of the Barren Measures shale were not assessed by earlier researchers in correlation to geological characters and processes which may cause great impact to hydraulic fracturing and production of shale gas. Over viewing all previous literatures of Indian Gondwana geology and shale gas exploration, the author has oriented the research target towards the Barren Measures Formation of Raniganj Field to know its gas potential and possibility of future exploration.

Objective

In order to achieve the above problem addressed, the following objective was identified:

To study the geology of the area, its organic geochemistry of the sediments, and reservoir characterization of the Barren Measures shale of Permian age in Chalbalpur- Mahishmura area of Raniganj Field, Damodar Valley Gondwana Basin was selected. This study is an effort to highlight the mineral composition, organic richness, maturity, gas generation potential, fluid flow mechanism of Barren Measures shales, including pore system and fabric anisotropy study at different scales in order to assess the reservoir quality. Integrated studies were aimed to understand mineralogical, geochemical and petrophysical factors and correlating with key geological factors and processes to validate shale gas prospects in Raniganj Field.

Study Area

To work on the mentioned objective, the study was focused on Barren Measures Formation of Late Permian age belonging to the north-north-west part of the Raniganj coal field in Burdwan district of West Bengal (Figure 1.1). Since this study requires the subsurface sample of shales, an area of approximate 55 km^2 was selected, which lies at the Chalbalpur-Mahishmura region where numbers of boreholes were penetrated through Barren Measures Formation by CMPDI (a subsidiary of Coal India Limited) and Geological Survey of India targeting the Barakar coal seams. The study area is located between latitudes 23º46´00˝ N & 23º43´00˝ N and longitudes 86º 52' 00"E & 86º55' 30" E, covered by the Survey of India toposheet no. 73I/13 & 73I/14. It extends from Chalbalpur village in the west to Mahishmura village in the east which is marked by the Barakar- Barren Measures contact while the southern limit is marked by the Raniganj- Barren Measures contact on the surface. The outcrop of the Barren Measures Formation is exposed here along the Nunia rivulet.

Physiography of the Area

Topography

The area is more or less a flat terrain with gently rolling topography with low humpy elevations and wide shallow depressions. The regional slope is towards south.

Drainage

The Damodar River is the main river in the area and arises from the Chotanagpur hill (606m above Mean Sea Level). Dharma Nala is flowing from north to south and its few tributaries which constitute the main drainage system of the area.

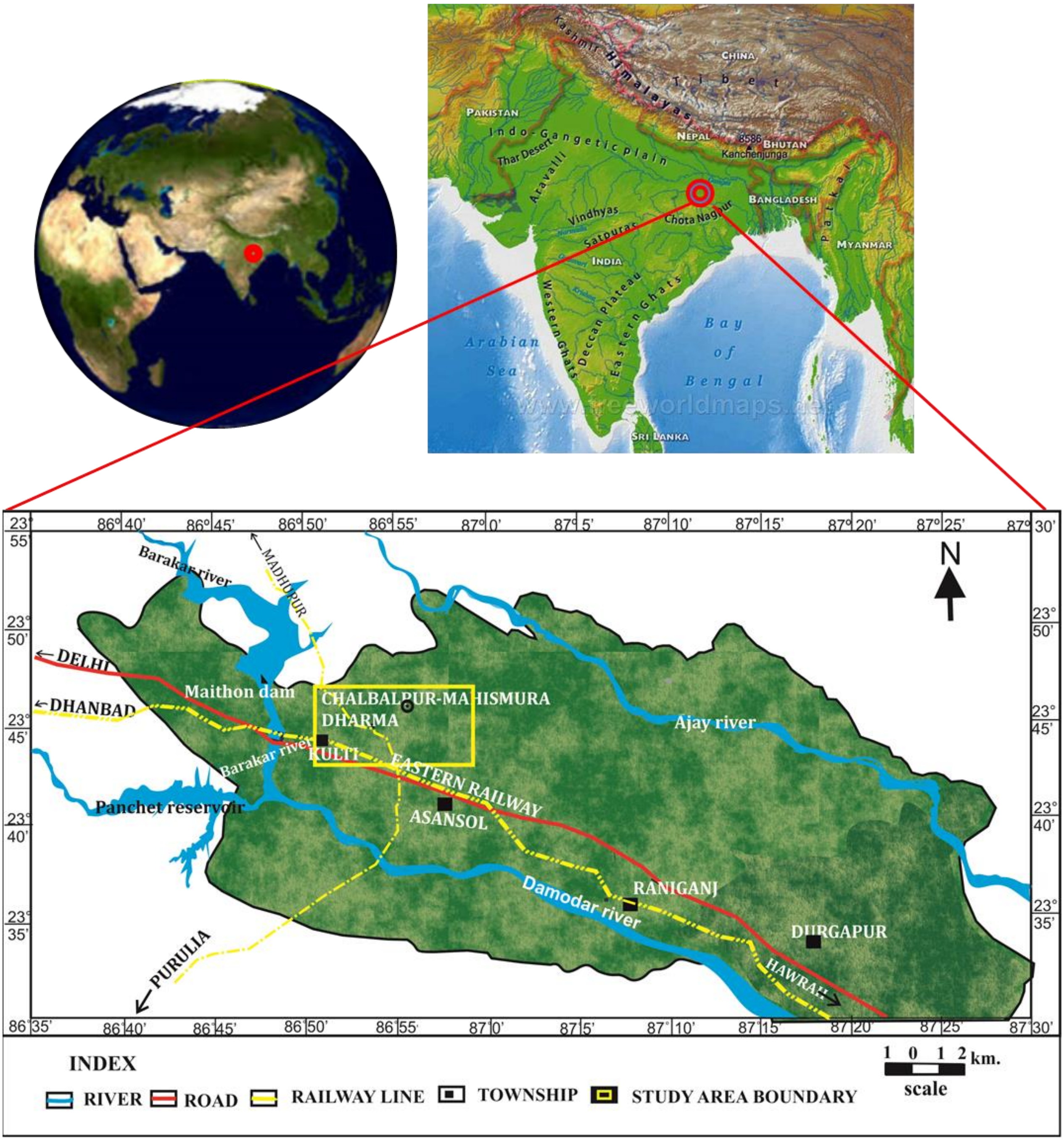

Figure 1.1 *Location map of Study Area in Raniganj Coal Field, West Bengal, India (modified after CMPDI report, 1993).*

Climate

The area experiences a humid sub-tropical climate where the summer lasts from the month of March to June and winter from the month of November to February. Mean annual rainfall is about 1200 mm. the rainy season generally begins from July and lasts up to October. The average annual temperature is 26.5ºC. The warmest month of the year is May with average temperature of 32.3ºC. In January, the average temperature is 19ºC. Predominant of wind direction is from southeast and northeast during post monsoon and from north and north east during winter.

Flora and fauna

The general vegetation is tropophilous. The flora of the area is characterized by the arborescent species such as Simul, Neem, Amlaki, Narikel, Khejur, Tal, Bat, Asvattha, Palas, Krishnachuda, and shrubby species such as ashsheoda, Pianj, Rasun, Rajanigandha, Tulsi,etc. Trees of economic importance are like fruit-bearing trees, trees for timber and flowering trees. Low lands of the area are cultivated by mainly Paddy and Maize. Vegetables like Brinjal, Tomato, Potato, Chili, Bean, Jhinga, and Parol are cultivated. The carnivora of the area comprise mainly jackal, hyenas, mongooses and other smaller species. Poisonous snakes include several kinds of cobra, karait and russell viper. Various types of pigeon and dove, goose, duck, teal, lapwing, white necked stork and some varieties of egret and heron are present.

Communication

The study area is located in the north western part of the Raniganj Coalfield about 15 km. northwest of Asansol town in Burdwan District of West Bengal. It is well located in respect of accessibility and communications by roads and railway lines. The Eastern Railway Main line passes through the western part of the area. Eastern Railway grand chord & Grand Trunk Road (NH-2) passes on the south of the block. The railway track from Kolkata to Delhi passes through the south of area and bifurcates into the main line and the grand chord line, at Sitarampur railway junction, to the west of Asansol.

Brief Geology

The study area is covered with alluvium while a few scattered exposures of grey shales of Barren Measures Formation are present in the eastern part of the area near Mahishmura Village. The Gondwana sediments in the study area represents the Permian age at the base overlying large areas of pre-Gondwana metamorphic rocks unconformably. Barakar and Raniganj Formations succeed the Talchir deposits and comprise fluviatile sediments with discontinuous thick coal seams. The Iron Stone Shale or Barren Measures Formation of Permian age separates the two coal measures. The Barren Measures Formation is comprised of thick sequences of grey to black micaceous and carbonaceous shale with rare occurrence of thin sand intercalation. The regional strike of the bed is ENE-WSW with 5^{o}-10^{o} southerly dip. The rocks of Barren Measures Formation are exposed in a small area near Mahishmura village along Nunia nala whereas Barakar Formation is exposed in a small area to the north of Mahishmura village along Dharma nala. Thickness of Barren Measures is ranging from 80 m to 399 m in the study area. However, it is expected to be thicker (750-850m) towards the southern margin of the study area as compared to the northern margin, best developed (>1000m) in the southern part of the Raniganj field. Barakar lithology is characterized by conglomerate, sandstone and siltstone, interbedded with grey shale and thick coal seams. The ENE-WSW trending Begunia- Petanna strike fault is extending in the western part of the area with 120m to 180m southerly downthrow. A stratigraphy of the study area is furnished in the table 1.1.

Table 1.1 *General Stratigraphy of the study area, Chalbalpur- Mahishmura in Raniganj Field (after Das, 1992)*

AGE	FORMATION	THICKNESS (m)	LITHOLOGY
Quaternary	Alluvium	11-20	Alluvium and residual soil
Late Permian	Barren Measure	400	Grey to black micaceous and often carbonaceous shale, shale sandstone intercalation with thin bands of ironstone
Early Permian	Barakar	500	Sandstone, carbonaceous shale and coal seams
Late Carboniferous To Early Permian	Talchir	93	Green silty shale, mudstone, sandstone
Pre- Cambrian		Not Known	Metamorphic granite, gneiss, schists with pegmatite and intrusive of metadolerite, dolerite, lympophyre.

Methodology

A series of systematic procedures were accomplished to investigate the study area in order to achieve the objectives.

Field Investigation and Sample Collection

Field study was carried out along the exposed section of Barren Measures Formation in Chalbalpur-Mahishmura areas, the lateral and vertical continuity of the formation was observed and measured. The various litho units were identified and vertical litho sections were prepared. Fresh samples were collected from the surface exposure section. A total of 13 borehole lithologs were aided to the lithologs correlation to depict the subsurface geology of the study area. Cores of four boreholes (B#1, B#2, B#3, B#4) were studied at the drill sites, litho units were identified, and core samples were collected from Barren Measures shale units for laboratory investigations. The approximate sizes of each core plug were 4.5cm in diameter and 7 to 9cm in length. The samples were air-dried at room temperature. Extraneous matter was removed. Due to the different requirements of each analytical method, samples were preserved as whole core, crushed and powdered fractions. Part of the samples was crushed to a maximum size of -2 to -3 phi (4-8 mm). They were then powdered in a TEMA (tungsten carbide) swing.

To achieve the desired results, the following methodology has been designed and executed. The flow chart (Figure 1.2) depicts the methods. A brief discussion on each analytical technique has been given in the proceeding paragraphs.

a. Megascopic study

A general study on surface exposures and subsurface core samples were done to identify the major features such as lithology, colour, bedding thickness, nature of bed contacts, sedimentary structures, texture, composition (grain, cement and fossils), porosity, fracture etc. The core samples of Barren Measures Formation were collected from four boreholes i.e. B#1, B#2, B#3 and B#4 and their litho units were identified and studied.

b. Thin Section Analysis

Thin section study of both surface samples and core samples were done with the help of the polarizing microscope to obtain petrographic characters such as mineral constituent, texture, porosity, diagenesis, provenance to certain extent and inferred the depositional environment. Samples were prepared for thin section analysis with epoxy to augment sample cohesion and to prevent loss of materials during grinding. Each sample was mounted on a frosted glass slide and then cut and ground in water to an approximate thickness of 30 microns. The thin sections of samples were analysed using standard petrographic techniques.

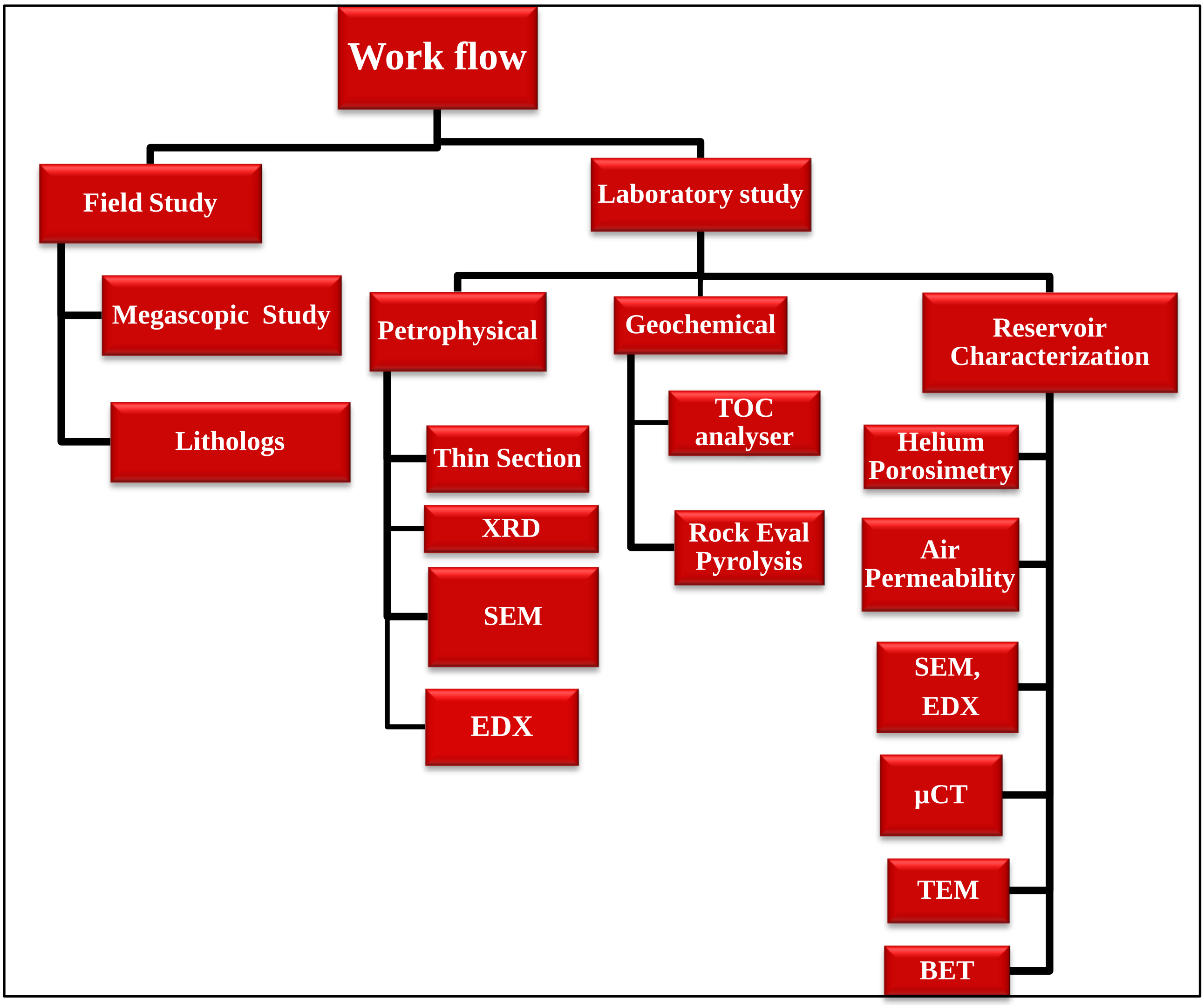

Figure1.2 *Flow chart on Methodology*

c. X-Ray Diffraction (XRD)

Qualitative and semi quantitative mineralogical analyses of 32 core samples of different depth intervals were done using X-Ray Diffractometer. The samples were powdered and passed through the ASTM # 300 mesh using Fritsch Micro Pulverisette-7 machine. The powdered samples were scanned from 3° to 90º 2ϴ in a Rigaku X-Ray Diffractometer (Model Ultima-IV) with Ni-filtered Cu Ká radiation. The data were interpreted using JCPDS cards.

d. Total Organic Carbon Analyzer

The TOC of 32 samples was determined by direct combustion using LECO EC-12 carbon analyzer. Approximately 0.2grams of the sample was carefully weighed, treated with concentrated hydrochloric acid to remove carbonates, and vacuum filtered on glass fiber paper. The residue and paper were placed in a ceramic crucible, dried, combusted with pure oxygen in a LECO EC-12 carbon analyzer at about 1000 centigrade. A laboratory standard was run every five minutes. "Total carbonate" was determined from differences in weight of the original sample and residue that remained after acid treatment or by LECO combustion (%TOC) differences before and after the acid digestion.

e. Rock Eval Pyrolysis

The samples from 34 different depth intervals of four borehole locations were studied using Rock Eval-6. Pyrolysis analysis provides four important parameters: (1) the total free hydrocarbons (S1 peak); (2) the amount of remaining hydrocarbon or amount of hydrocarbon obtained by heating during pyrolysis (S2 peak); (3) the amount of carbon dioxide (CO_2) released through heating organic matter (S3 peak); and (4) the highest temperature for generating a maximum amount of hydrocarbon during pyrolysis (Tmax). Based on the Rock Eval parameters, hydrogen index (HI), oxygen index (OI), production index (PI), genetic potential (GP), maturity (Vro), etc. were calculated using standard empirical methods. This experiment was performed to assess the organic richness, gas generation potential, kerogen type, maturity, etc. of Barren Measures shales.

f. Scanning Electron Microscope (SEM)

The samples were analysed under scanning electron microscope to understand the mineralogy, pore geometry, clay structures, diagenetic effects, pore size & structure, lamination, micro fractures and micro scale reservoir heterogeneity. The rock samples were mounted on aluminium stub with double side metallic tape so that fresh broken surface was exposed. The samples were coated with Gold (Au) using a Polaron Sputter Coating Unit. The SEM photomicrographs were taken using JEOL, JSM-6460 LV Scanning Electron Microscope operating at 10 to 20 kV to bring out the desired features under high magnification up to 20,000X.

g. Energy-dispersive X-ray spectroscopy (EDX)

EDX technique was used for the elemental analysis and chemical characterization of Barren Measures shale samples. This analysis usually implicates the generation of an X-ray spectrum from the complete scan region of the SEM image. Two basic types of X-rays are produced on interaction of the electron beam with the specimen atoms in the SEM. Characteristic X-rays result when the beam electrons eject inner shell electrons of the specimen atoms. The energy of the X-ray is characteristic of the specimen atomic number from which it is derived Continuum (Bremsstrahlung) X-rays result when the beam electrons interact with the nucleus of the specimen atoms. As each element has a unique atomic structure, unique set of peaks appears on its X-ray emission spectrum. These permit to analyse the elemental composition of the specimen. The number and energy of the X-rays emitted from a specimen can be measured by an energy-dispersive spectrometer. It depends on the interaction of X-ray source and the sample.

h. Micro Computer Tomography (m CT)

Micro Computer Tomography of selective samples were done to understand the pore distribution, porosity, fractured zone and micro scale vertical heterogeneity of the cores. The m CT tomogram images are acquired at a total 64 blocks of 2048 voxel with a setup of ≤4.01 micrometer resolution and the total number of projection is 2880. The projections or raw images are linearized and reconstructed using Feldkamp method in Q-MANGO (Medial Axis and Network Generation) to get the tomogram (20483 voxel size). The tomogram (3D representative of the rock) is segmented into two-phase (pore and grain) or three-phase (pore, grain and intermediate). Before segmentation different noise reducing filters are applied for better visualization of the tomogram. Image processing is again run by ‘Q-MANGO’. Pore network of the rock sample was extracted using ‘Q-MANGO’ and the 3D visualization of the pore-network was developed using visualizing software ‘Paraview’. Different filters i.e. eluclidean distance, smooth distance map, watershed transform, cluster region mergin and network from lebels were used to resolve the good quality image of pore & pore throat network.

i. Helium Porosimetry

Porosity of 20 core samples was determined using Ultrapore-300 helium pycnometer system. This equipment determines the porosity and grain density based on Boyles law and is used in conjunction with the ABACUS-200 work station for automated mercury bulk volume, calipered bulk volume and weight determination.

j. Air Permeability Measurement

Air permeability has been determined using Ultraperm 400 based on Darcy's law to determine permeability by measuring the steady state flow rate through the sample under a given pressure gradient. This apparatus combine data acquisition and real time graphical display with mass flow determinations so as to provide more accurate, valid and precise permeability data. Absolute air permeability of core samples was corrected automatically for flow slippage effect to derive Klinkenberg corrected permeability.

k. Transmission Electron Microscopy (TEM)

To identify the nano pores in shale rocks, the samples were analyzed by using TEM Tecnai 20 at high magnification of 750,000x operating at 200KV.

l. Brunauer-Emmett-Teller (BET)

BET technique was used for low pressure adsorption and desorption analysis. The specific surface area, pore size distribution and pore volume of shale samples were determined by using nitrogen multilayer adsorption technique using Micromeritics ASAP 2010™ instrument. The technique involves external area and pore area evaluations to determine the total specific surface area in m^2/g yielding important information on surface area availability for storage of gas, pore size distribution such as micro, meso and macro and average pore volume at relative pressure (P/Po).

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