Application of Micro Computer Tomography (µ CT) in Resolving Barren Measures Shale Properties

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Abstract—The microstructure of Barren Measures Shales of Raniganj Field has been investigated using micro-computed tomography (µ CT). The results show fabric anisotropy and complex pore structure among the different shale samples imaged. The shales of Barren Measures are primarily composed of varying amounts of clay minerals, quartz, and kerogen with a range of porosity 3 to 5%. Pores are isolated and interconnected including intergranular, matrix hosted and/ or organic matter hosted in nature. Three-dimensional internal structures of the shales were generated from serial sectioning and imaging of the samples and it depicted kerogen and pore connectivity across the volumes. The internal microstructure of shales is essential in understanding the micro scale reservoir heterogeneity. It controls the key aspects of reservoir development and fluid flow through the shales.

Index Terms— Micro Computer Tomography; shale gas; reservoir characterization; Barren Measures, pore, micro scale, shales

1 INTRODUCTION

Rocks and fluid properties are key parameters for the development of petroleum reservoirs. In contrast to the conventional reservoirs, unconventional shale gas reservoirs have micro scale reservoir heterogeneity and complex pore systems. Micro-computed tomography (µCT) is an advanced technology for micro scale geological investigations. It is a fast and nondestructive technique to generate images that correspond to serial sections through an object. Successive contiguous images are assembled to create three dimensional depictions. Visualization of µCT data allows the imagining of internal structure and flow media in petroleum reservoir rocks. Petrophysical applications, fluid migration, fractures in rock, etc., with the help of x-ray CT were studied earlier by different researchers [1] [2] [3] [4] [5]. The fractures in shale and internal structure of gas shale core samples investigations were discussed in earlier literatures [6] [7]. This paper is to assess the petrophysical properties and fabric anisotropy of Barren Measure shales from Raniganj Field using micro computed tomography. Raniganj field is located in West Bengal and partly in Jharkhand state. It is situated about 185 Km North-West of Kolkata. The present study area is the part of the Raniganj Coalfield, between latitudes 23°46ˈ00˝ N & 23°43ˈ00˝ N and longitudes 86°52'00"E & 86°55'30" E. Here, the Permian Gondwana sediments are represented by Talchir, Barakar, Barren Measure and Raniganj Formations. As the early researchers have reported the shale gas generation potential of Barren Measures [8] [9], it is crucial to understand the internal microstructure and fluid flow mechanism within the rock.

2 MATERIALS AND METHOD

2.1 Sample Preparation

Shale core samples were collected from the organic rich Barren Measures Formation of Raniganj Field in India. Within the study area, the Barren Measures Formation is comprised of a thick sequence of monotonous grey to black micaceous and often carbonaceous shales, with thin sand-shale intercalation at the base. Thin bands of hard and tight ironstone layers are encountered in the boreholes of the area. Small irregular sand patches are often seen within the black shales and these are presumed to have originated by biogenic activities filled with angular to sub angular coarse sand. The samples were selected from conventional core of Barren Measures shale unit, from a borehole located in north western part of Raniganj Coal field, for µCT investigation. Two cylindrical samples of 10mm diameter and 12mm length were taken out using 10mm drill bit cutter from the conventional cores for µ-CT study. The samples were dried and cleaned using acetone.

2.2 Image Acquisition and Processing

To produce a three-dimensional CT image of a rock, a whole set of such two-dimensional projections need to be acquired. In µCT, these projections are usually taken in a setup in which

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the source and detector are at a fixed position and the object is rotated around its long axis. The source is a micro focus X-ray tube and the detector is normally based on a CCD camera with a phosphor layer to convert X-ray to visible light. The basic physical principal of computed tomography is the interaction of ionizing radiation. Thus, the actual attenuation not only depends on the material but also on the energy spectrum of the X-ray source. CT measures the linear attenuation coefficient. The linear attenuation coefficient is defined by Beer's law and it measures the fraction of X -rays that pass through the shale sample. The linear attenuation coefficient is related to other physical properties by the following equation: $\mu = pb\ (a + bZ^{3.8}/E^{3.2})$. Where pb = bulk density (electron density), a and b = constants, Z=effective atomic number, and E=X-ray energy. At low energies, μ will be primarily a function of Z; and at high energies μ will be primarily a function of pb. Therefore, an X-ray projection (or X-ray image) represents an image of the sum of all local attenuations along the X-ray beam. Images were acquired at 2048^3 voxels and no. of projections was 2880. The projections were linearized and reconstructed using Feldkamp method in Q-MANGO (Medial Axis and Network Generation) software to get the tomogram (2048^3 voxel size). The tomogram (3D representative of the rock) was segmented into two-phase (pore and grain) and three-phase (pore, grain and intermediate). Different noise reducing filters are applied before segmentation for better visualization of the tomogram. Image processing was run by Q-MANGO. The images were achieved by acquiring a series of radiographs at different viewing angles. Based on system generated tentative values of pores and grains, segmented images (Figure 1) were analysed with the help of Q-Mango software and pore network of the rock samples were extracted [9] [10] [11]. 3D visualization of the pore-network was developed using visualizing software Paraview. Different filters such as eluclidean distance, smooth distance map, watershed transform, cluster region mergin etc were used to enhance the resolution quality of the tomogram images to analyse texture and the pore & pore throat network [10] [11].

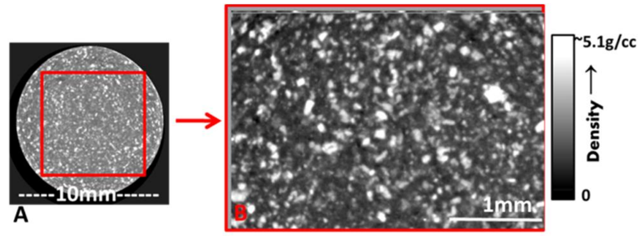

Figure 1 CT images of Barren Measures shale along with density scale (sample no 2). A. Tomogram image; B. Segmented image of tomogram (A)

3 RESULTS AND DISCUSSION

Figure 2 shows 2-D segmented images of a shale sample (sample 1) of Barren Measures shale. The width of each image is almost 5mm, and each image represents the variations along the bedding plane while the sequence of images (Figure 2) illustrates the heterogeneity perpendicular to bedding plane. The images reflect differences in grain size distribution, matric percentage and porous spaces at micron scale along the bedding plane and also perpendicular to the bedding plane. The mineral grains in the images are sub rounded to rounded and moderately sorted. Organic matters (dark grey) are seen dispersed within the matrix. Because of the low atomic number of carbon compared with higher atomic number elements in the matrix minerals (e.g., Si, Fe, Ca, and Al), the kerogen is discernible by its darker gray scale value. The lighter gray matrix is composed of variable amounts of clay mineral, quartz, feldspar etc. The heavy minerals are differentiated by bright white colour. The amount of the organic matter (kerogen) in the samples varies from 4 to 19%. The studied shale samples of Barren Measure Formation are highly heterogeneous, moderate to well sorted and tight (Figure 2). The computed porosity range is 3 to 5% while porous media in Barren Measures shales were resolved in the segmented CT images such as interparticle pores (Figure 3), intraparticle pores, micro fractures, (Figure 4) etc. The Barren Measures shale has complex pore structure and multi scale pore dimensions. Within each of these three categories, the pores are isolated, connected and partially or completely filled with organic matter and/or detrital clay. Unfortunately, it is very difficult to analyse the presence of features with intermediate attenuation (e.g. clay domains), features at scales below image resolution and also a significant number of solid/pore-interface voxels leads to an overlap in the density signal. The analysed images show that the samples are moderate to well sorted, grains are sub rounded to round which indicate the maturity of the sediments and long distance of provenance [12]. From image 4, two different microfacies were identified based on petrographic properties of the rocks. The sample 1 is carbonaceous shale with >50% clay matrix (Figure 4A) while sample 2 is silty shale with tight matrix (<30%). A fracture of al-most 2mm length was observed perpendicular to the bedding (Figure 4c). Pores of different morphologies were identified such as pinpoint, spherical, elongated. In the 3D pore network study, minimum pore and throat radius are resolved up to 0.468 micron for samples where most of the pores are with less than 20 micron pore radius, and more than 50% of pore throat radius ranges between 0 to 5 µm (Figure 5). The number of individual pore-body sizes was estimated from the reconstructed volumes. The histograms of the pore-size distribution and pore throat radius for Barren Measures shale (sample no 2) reconstruction is shown in Figure 5B and 5C respectively. The sizes of the pores have been given as the radii of spheres of equivalent volume to each pore. The histogram suggests that smaller pores dominate the distribution with the smallest and most numerous pores having a radius of approximately 0.5 to 6 µm. The analysed images help in investigation of the microstructural details which illustrates the moderate to good reservoir quality of Barren Measures shale. However, the generalizations about the reservoir on larger scales require adequate statistical sampling.

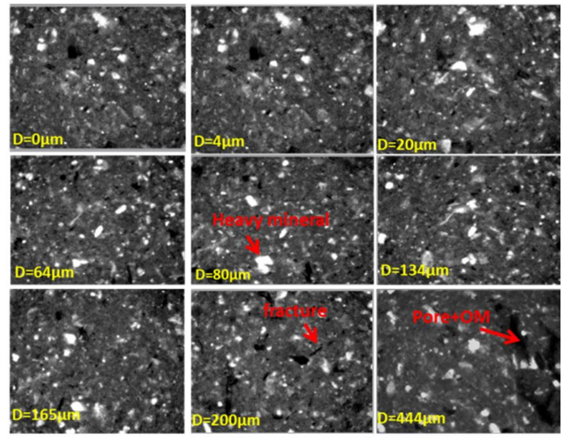

Figure 2 Segmented Images of micro computed tomography (Sample no 1) of Barren Measures. It is showing fabric heterogeneity (both in vertical and horizontal direction) at micron scale. "D" is the vertical distance from the first image.

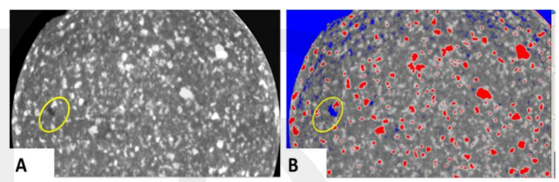

Figure 3 Pores in tomogram image. B is showing analysed colour image where red is indicating heavy minerals, blue is indication pores+ organic matter and white to grey colour is indicating find grains+ matrix.

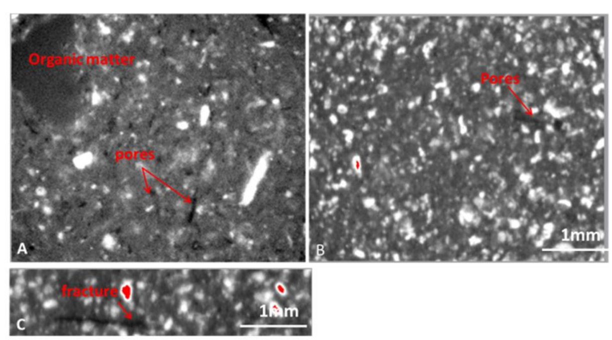

Figure 4 Segmented images of Barren Measures shale. A. Organic matters and pinpoint + elongated pores are seen. The matrix is >50% and rock type is carbonaceous shale (Sample no 1). B. The matrix is (<30%) sub rounded to rounded, moderate to well sorted, pores are rarely seen,

gains contacts are floating and point. The rock type is silty shale (sample no 2). C. Micro fracture in XZ direction (sample no 1).

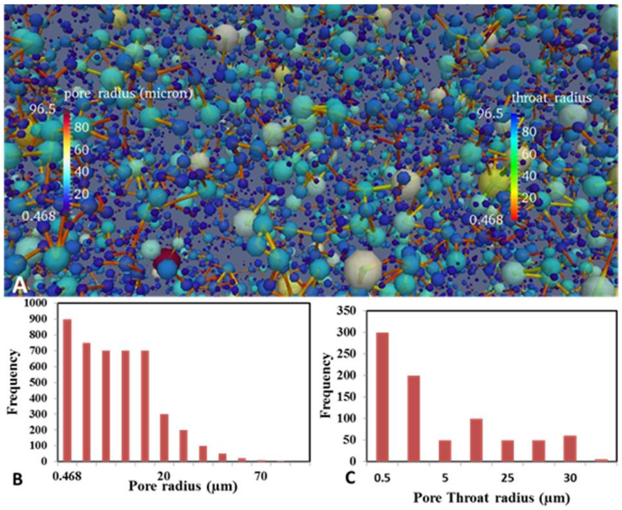

Figure 5A.3D image of sample no 2 of Barren Measures depicting pore radius and pore throat radius. B. Pore radius ranging from 0.468 to 96.5µm. C. Pore throat radius showing most of the values <5µm.

4. CONCLUSION

Micro computed tomography has a unique ability in resolving pores and grain structures as well as both vertical and horizontal heterogeneity. Present study reveals the fabric anisotropy of Barren Measures shale at micron scale. The rock type is identified as clay rich shale and silty shale, rich in organic matter, composed of moderate to well sorted, sub rounded mineral grains with tight clay matrix. µCT calculated the porosity of Barren Measures as 3 to 5%, where porous media consists of isolated pores, connected pores and micro fractures. Such observations are crucial in understanding and modeling the shale gas reservoirs. The results obtained from this research showed that micro computed tomography is a useful technique to study multi-phase flow mechanisms in porous media.

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