Abstract

Shale is considered as an excellent hydrocarbon source rock as well as an effective cap rock that can stop the fluid migration. During last few decades, the increasing global energy demand and the advancement of technology shifted the focus of hydrocarbon industry from conventional sandstone reservoirs to the unconventional shale reservoir systems. Due to the presence of thick shale sequences in various sedimentary basins, India has significant potential to explore and produce from its shale reserves. The present research work analysed shale samples collected from three different shale sequences, Barren Measure Formation (Raniganj basin), Cambay Shale (Cambay basin) and Raghavpuram Shale (Krishna-Godavari basin) in India. This thesis is an attempt to thoroughly investigate the properties of those three major shale sequences by applying multi-technique approach and to produce one concise document compiling source rock potential, mineralogical and elemental properties and pore properties. The recommendations made by this research work can directly be applicable for the hydrocarbon exploration purpose of the shale formations.

The kerogen types, thermal maturity and organic content influence the quantity and types of hydrocarbon generated in shale. Analysis of rock eval pyrolysis data reveals that the Barren Measure shale contains high TOC, Type II and Type III kerogen and thermal maturity range of this shale can make it as oil producing or oil with thermogenic gas producing source rock. The Cambay Shale contains Type III kerogen and high volume of organic content and can produce gas. Thermally over-matured Raghavpuram Shale samples contain mostly Type IV kerogen and are identified as non- producers.

2D FESEM, SEM and 3D micro-CT scan image analysis of the studied samples identify abundance of mesopores, and presence of microcracks and fractures in these samples. The pores are present as intra- particle pores or inter-particle pores within shale matrices. The pores are of different shapes such as sub-rounded, slit, wedge and bottle-neck types. Micro CT scan images reveal the good interconnectivity among macropores present in Barren Measure and Raghavpuram Shale, whereas macropores in Cambay Shale show comparatively less connectivity.

Low pressure N_2-adsorption method was used to calculate pore volume and surface areas of the pores. Adsorption data shows the abundance of mesopores in the

samples. Low pressure CO_2- adsorption was used for three Barren Measure samples to estimate micropore volume and surface area. The t-plot method was used to calculate micropore volume and surface area for Cambay and Raghavpuram Shale samples. High volumes of pores indicate good storage capacities in Barren Measure and Cambay Shale samples. Raghavpuram Shale has comparatively less pore volumes. Porosities of the samples were measured using helium porosimetry for Cambay and Raghavpuram samples and mercury intrusion capillary porosimetry (MICP) for Barren Measure samples.

Occurrence and distribution of pores are closely associated with the organic matter and inorganic minerals present in shale. Mineralogical variations are estimated using XRD. Major minerals present in these samples are kaolinite and quartz. Also, illite, smectite, feldspar, mica, siderite and pyrite are present. The samples become silica-poor and clay-rich at deeper depths. The brittleness index is higher in quartz-rich samples than carbonate or clay-rich samples. The fracturing is easier for shale with higher brittleness.

The minerals in shale are consisted of different elements and oxides. XRF method was used to estimate concentrations of major oxides. ICP-MS technique was used to estimate the concentrations of trace elements (including REE). The variable oxide contents and trace element concentrations are used to infer the provenance composition, paleo-tectonic settings, paleoclimate, weathering intensity and paleo-redox conditions. The data shows that the sediments of Barren Measure samples were derived from granitic or granodioritic provenance and were deposited in a passive margin or transition between passive and active margin setting in a dry arid climate with reducing condition. The highly weathered and matured sediments of Cambay Shale were deposited in active continental margin or oceanic island arc region with arid climatic condition. The provenance was granitic or granitic to basaltic in composition. The moderate to highly weathered sediments of Raghavpuram Shale were derived from granitic source rocks and were deposited mostly on the transition zone between passive and active continental margin in an arid climate and in anoxic or reducing environment.

Attempts to check the influence of source rock and mineralogical assemblage on pore volumes reveal that the source rock properties can have variable effects on pore characters of shale from different formations. Every shale sequence needs to be

investigated separately to infer any conclusion. The clay content does not show any clear relation with pore volumes indicating that the clay minerals are not major host of pores in these samples.

One of the major limitations of this study is the less information available on micro- and nano- size pores. Also limited low pressure CO_2 adsorption data was available to analyse the size distributions of the micropores. Another limitation is the number of samples per basin. More number of samples could have provided better relations among parameters. Despite of these limitations, this study is strongly recommended to be consulted as a guide to understand the source and reservoir characters for the three major shale sequences, during the future shale hydrocarbon exploration projects in Raniganj, Cambay and Krishna-Godavari basins.

Keywords: Barren Measure Formation, Cambay Shale, Raghavpuram Shale, source rock potential, clay mineral, trace elements, adsorption, pore volume