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Gas potential of Proterozoic and Phanerozoic shales from the NW Himalaya, India: Inferences from pyrolysis

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ABSTRACT

Organic richness and kerogen properties of sixty-seven shales, obtained from the outcrops and underground mines of Jammu, Kashmir and Ladakh regions of Northwest Himalaya, India, have been studied to evaluate their gas generation potential using Rock Eval pyrolysis. Ranging in age from the Proterozoic to Tertiary, organic matter content and characteristics of the carbonaceous and coaly shales vary widely, indicating that sedimentary and burial history significantly affected the preservation and maturation of organic components in rocks.

The total organic carbon (TOC) content ranges from 0.01 to 1.2% in the Permian–Jurassic and Paleozoic–Tertiary shales of Ladakh to as high as 32.5% in the Eocene shales/coaly shales from Jammu. The thermo-labile hydrocarbons (S1) and those from cracking of kerogen (S2), released from the pyrolysis of Eocene Subathu shales, are observed to be high (from 0.1 to 2.6 and from 0.5 to 15.5 mg HC/g rock, respectively). Rock Eval thermal maturity parameters, indicated by T_{max} (temperature at highest yield of S2; >490 °C) and calculated vitrinite reflectance (1.5 to 3.7 Ro %), suggest a post-mature, dry gas stage for the hydrocarbon generation. Based on hydrogen index (HI) and T_{max} correlations, organic matter in the Subathu shales is characterized by a late metagenetic gas prone Type III kerogen and a fair to excellent gas potential is exhibited by these shales.

The interbedded shale units in the Proterozoic Sirban Limestone Formation, occurring as an isolated inlier in Jammu, show TOC values from 0.1 to 1.4% with quite low S1, S2 and HI values. Thermal maturity of shales within the stromatolitic Sirban succession indicates a post-mature and/or already spent hydrocarbon stage. The Plio-Pleistocene carbonaceous clays, lignites and mudstones from the Lower Karewa Group of Kashmir basin are organically rich with TOC content ranging from 5.86 to 29.4%. A thermally immature, Type II/Type III kerogen is indicated by the HI (109 to 278 mg HC/g TOC) and T_{max} (399 to 427 °C) plots of the Karewa samples. The exposed Lower Triassic Black shales from the Permian–Triassic boundary sections in Kashmir are comparatively lean in organic matter, with TOC values ranging from 0.18 to 0.93%, whereas the Permian–Jurassic and Paleozoic–Tertiary shales from Ladakh have a TOC content ranging from 0.01 to 1.22%. The pyrolyzable organic carbon is <0.1% and the residual organic carbon contributes significantly to the TOC content of these shales. The other Rock Eval parameters (S1, S2, HI) are quite low and indicate a poor source potential. The majority of shales from the Tethys and Trans Himalayan regions appear to have undergone metamorphism and exhumation of organic carbon associated with the Himalayan orogeny.

1. Introduction

The significant amount of natural gas trapped in organic-rich, fine grained sedimentary shale rocks has emerged as an unconventional energy resource in recent times globally (Boyer et al., 2006). Shale gas, primarily methane, is generated in place from the buried organic matter within the sediments under influence of heat and pressure. The shale acts as a source as well as reservoir where the generated gas remains stored within the intra- and inter-particle mineral pores and organopores (Loucks et al., 2012; Ross and Bustin, 2009); natural fractures in the shale, or adsorbed onto the organic matter (Boyer et al., 2006). Advanced exploration technologies such as horizontal drilling and hydraulic fracturing have allowed access to large volumes of shale gas that were earlier uneconomical to produce (EIA, 2013; Horsfield and Schulz, 2012; USGS, 2012). Shale gas technology has been largely pioneered in the United States of America and the gas production from several plays such as the Barnett, Haynesville, Fayetteville, Woodford, and Marcellus offer an answer to the growing demand of clean energy.

Ahead of drilling and production, shale gas plays spur a closer look at shale rocks in terms of its organic matter distribution, richness and

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properties that contribute largely to the gas generation potential, evaluation of energy resource and delineation of target horizons (Boyer et al., 2006). Compositional characteristics of organic matter provide useful insights onto the variations in depositional environments that prevailed during sedimentation (Romero and Philip, 2012). Geochemical attributes of sedimentary organic matter such as the TOC content, kerogen type and thermal maturity are important parameters for the assessment of gas shale potential toward hydrocarbon generation (Horsfield and Schulz, 2012; Jarvie et al., 2007; Romero and Philip, 2012). Open system pyrolysis of shales using Rock Eval is one of the basic organic geochemical methods for characterization of the sedimentary organic matter. The pyrolysis technique is based on the steady heating of rock samples so that the total evolved hydrocarbons can be monitored as a function of temperature (Behar et al., 2001; Espitalie et al., 1987; Lafargue et al., 1998). Released hydrocarbons and the carbon di and mono oxides generated from the organic/mineral sources are monitored by flame ionization (FID) and infrared (IR) detectors, respectively (Behar et al., 2001; Lafargue et al., 1998).

For the Indian subcontinent, about 63 trillion cubic feet of recoverable shale gas has been estimated from the sedimentary basins of Cambay, Krishna–Godavari, Cauvery and Damodar Valley (DGH, 2013; Klett et al., 2012). Among other frontier basins, those of the Himalayan region appear prospective for the hydrocarbon resources (Bhattacharya and Chandra, 1979; DGH, 2013). The Himalayan Foreland basin has no significant oil and gas shows, however; owing to favorable geological conditions for hydrocarbon generation and entrapment, it is considered prospective. The Karewa and Spiti–Zanskar basins are categorized potentially prospective due to their analogy with similar hydrocarbon producing basins of the world (DGH, 2013; Jokhan Ram, 2005). The Himalayan orogeny has been associated with the continental collision and active tectonic prevails in the region (Molnar, 1986; Powell and Conaghan, 1973). Plate junctions and major tectonic features have been related to some of the largest oil and gas fields of the world (Bullard, 1973; Nair et al., 1979). Studies have revealed that the level of organic metamorphism in Himalayan foreland basins is favorable for the occurrence of mainly thermo-catalytic gaseous hydrocarbons (Bhattacharya and Chandra, 1979; Verma et al., 2006). The exploratory knowledge, specifically for shale gas, in the tectonically active Himalayan region is in the knowledge building stage due to the constraints of complex structure and tectonics of the fold and thrust belts and logistics.

In the present work, organic geochemical characterization of shales from Jammu, Kashmir and Ladakh regions of Northwest Himalaya has been carried out using Rock Eval pyrolysis. Sixty-seven Proterozoic and Phanerozoic shales were collected from the outcrops and underground mines, which are physiographically located within the Outer, Tethys and Trans Himalaya (Fig. 1). The sampled areas include the Cenozoic Foothills belt of Outer Himalaya, comprising of the Eocene Subathu and interbedded shales of Proterozoic Sirban Formations, carbonaceous clays, mudstones and lignites of Karewa Group and the Black shales of Permian–Triassic boundary sections of Kashmir basin along with the Permian–Jurassic shales from the Zanskar basin of Tethyan Himalaya and the Paleozoic–Tertiary shales from the Indus–Shyok and Karakoram zones of Ladakh, Trans Himalaya (Figs. 1–4). Organic richness and kerogen properties of the varied age shales studied here provide useful insights onto the abundance, distribution and thermal maturation of

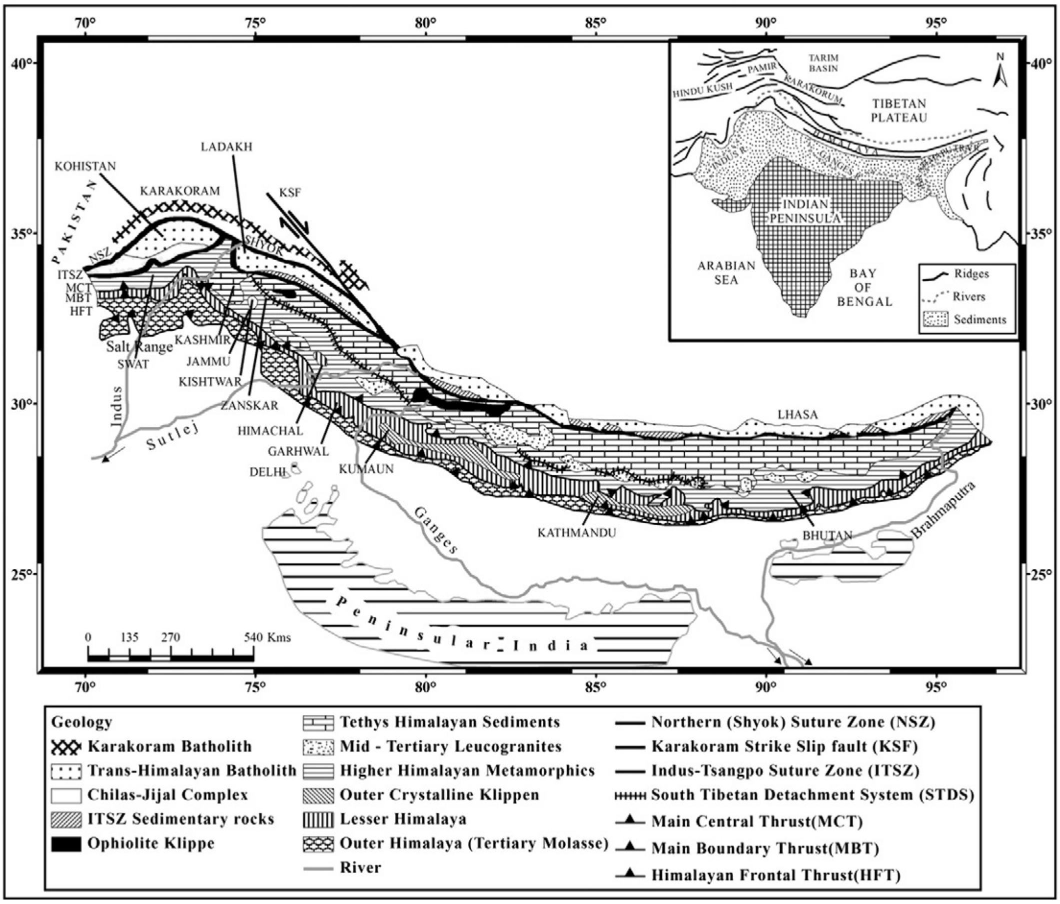

Fig. 1. Geological map of Himalaya showing the different tectonic features along with the present study regions of Jammu, Kashmir and Ladakh. Modified after Sorkhabi and Macfarlane (1999).