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Elemental and organic geochemistry of Gondwana sediments from the Krishna–Godavari Basin, India

Devleena Mani[a,*], B. Ratnam[b], M.S. Kalpana[a], D.J. Patil[a], A.M. Dayal[a]

[a] National Geophysical Research Institute, Hyderabad, India
[b] Oil and Natural Gas Corporation Ltd., Rajahmundry, India

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ABSTRACT

Elemental and organic geochemical studies have been carried out on the Gondwana sediments, collected from the outcrops of Permian and Jurassic–Cretaceous rocks in the Krishna–Godavari basin on the eastern coast of India, to understand their paleo and depositional environment and its implications for hydrocarbon generation in the basin. Amongst the studied formations, the Raghavapuram, Gollapalli and Tirupati form a dominant Cretaceous Petroleum System in the west of the basin. Raghavapuram shales and its stratigraphic equivalents are the source rock and Gollapalli and Tirupati sandstones form the reservoirs, along with basaltic Razole formation as the caprock. Major element systematics and X-ray diffraction study of the sandstones indicate them to be variably enriched with SiO_2 relative to Al_2O_3 and CaO, which is associated, inherently with the deposition and diagenesis of the Gondwana sediments. Post-Archean Average Shale normalized rare earth elements in shales show enrichment in most of the samples due to the increasing clay mineral and organic matter assemblage. A negative europium and cerium anomaly is exhibited by the REE's in majority of rocks. Composed primarily of quartz grains and silica cement, the Gollapalli and Tirupati sandstones have characteristics of high quality reservoirs. The shales show a significant increase in the concentration of redox sensitive trace elements, Ni, V, Cr, Ba and Zn. The total organic carbon content of the shales ranges between 0.1 and 0.5 wt%. Programmed pyrolysis of selected samples show the Tmax values to range between 352–497 °C and that of hydrogen index to be between 57–460 mgHC/gTOC. The organic matter is characterized by, mainly, gas prone Type III kerogen. The *n*-alkane composition is dominated by n-C_{11}–C_{18} and acyclic isoprenoid, phytane. The aromatic fraction shows the presence of naphthalene, anthracene, phenanthrene, chrysene and their derivatives, resulting largely from the diagenetic alteration of precursor terpenoids. The organic geochemical proxies indicate the input of organic matter from near-shore terrestrial sources and its deposition in strongly reducing, low oxygen conditions. The organic matter richness and maturity derived from a favorable depositional setting has its bearing upon the Gondwana sediments globally, and also provides promising exploration opportunities, particularly in the Raghavapuram sequence of the KG basin.

1. Introduction

The Indian Shield forms a fragmented part of the unified Gondwanaland (Veevers and Tiwari, 1995; Veevers, 2004). The Gondwana sediments of Late Paleozoic to Mesozoic age are preserved in several Indian rift valleys such as the Mahanadi, Damodar, Rewa, Son, Narmada and Krishna–Godavari (Gombos et al., 1995; Bastia, 2006). These regions are known for their profuse coal and hydrocarbon reserves. The Krishna–Godavari (KG) on the east coast is an important basin that evolved from the rifting of Gondwanaland along the eastern continental margin of India during the Early Mesozoic (Sastri et al., 1973, 1981; Veevers, 2004) (Fig. 1). Gondwana sediments along with the Tertiary sequences form rich source rocks, making KG one of the most promising petroliferous provinces of India.

KG is a northwest-southeast trending pericratonic, passive margin basin (Fig. 1). It evolved in the 'rift phase' which was active during the Jurassic-Lower Cretaceous and the 'drift phase', which continued from Upper Cretaceous to Holocene (Gupta, 2006). The basin is divided into three sub-basins, the Krishna, West Godavari and the East Godavari, separated by the Bapatla and Tanuku horsts, respectively (Fig. 2). The West Godavari is further subdivided into the Gudivada and Bantumilli grabens, which are separated by the Kaza–Kaikaluru horst (Rao, 2001). The basin's characteristic fea-

* Corresponding author.
E-mail address: devleenatiwari@ngri.res.in (D. Mani).

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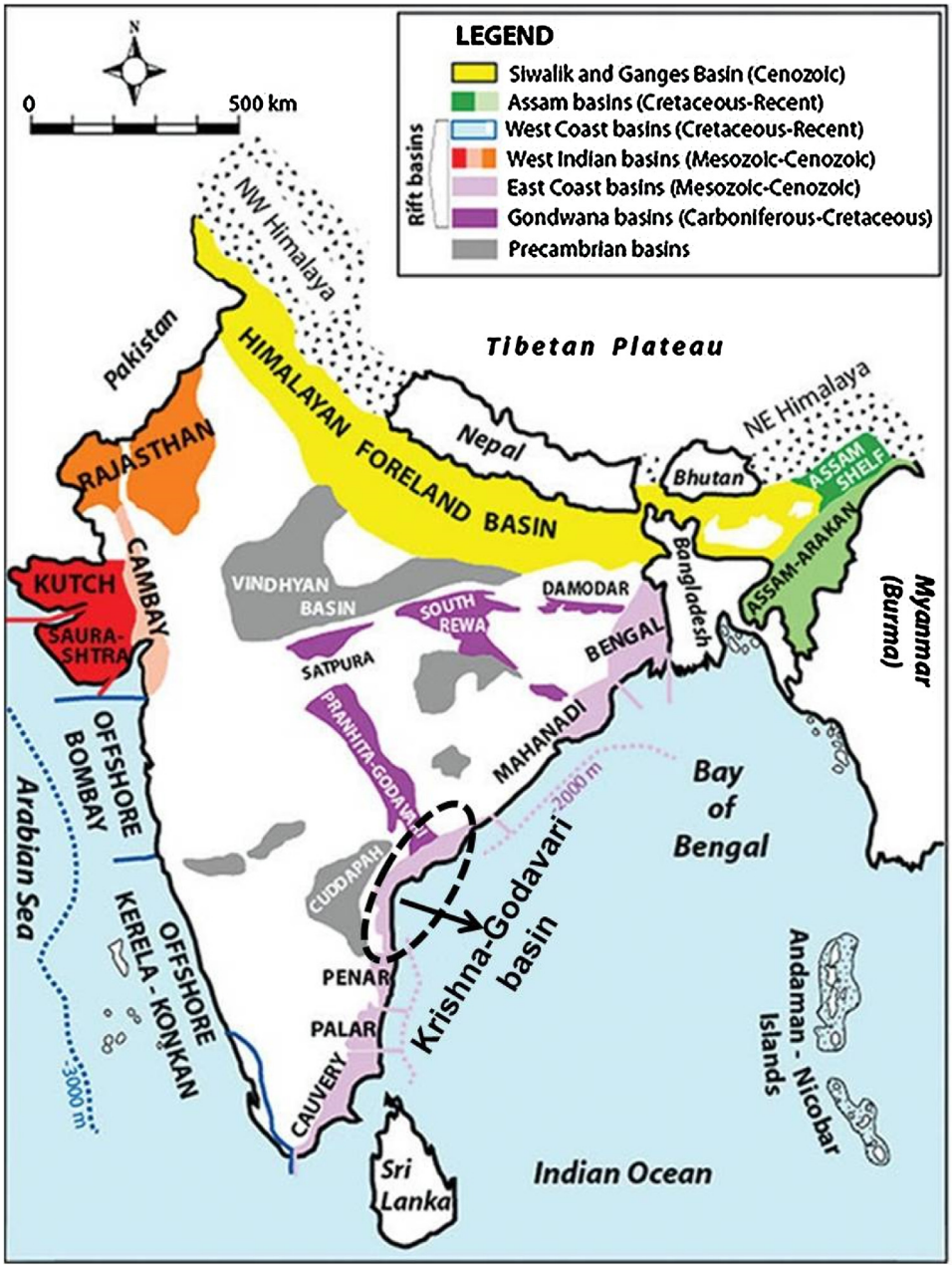

Fig. 1. Sedimentary basin map of India highlighting the study region- the Krishna–Godavari basin, on the eastern coast (after DGH, 2012).

ture is its en echelon horst and graben system. The stratigraphic successions, ranging from the Late Carboniferous to Holocene, are more than 5 km thick (Sastri et al., 1981; Biswas, 1992, 1999; Gupta, 2006).

Of the four petroleum systems existing in the basin, Gondwana sediments form part of the Permo – Triassic, Kommugudem – Mandapeta – Red Bed and the Late Jurassic—Early Cretaceous, Raghavapuram – Gollapalli – Tirupati – Razole (R–G–T–R) Petroleum Systems (DGH, 2012). Exposures of Lower Gondwana (Permian-Carboniferous) exist mainly within the Pranahita–Godavari graben, abutting the KG basin in the northwest. Outcrops in the basin margin area include the Permian Chintalapudi sandstone (Rao, 2001; Gupta, 2006). The Upper Gondwana (Jurassic–Cretaceous) sediments are represented by the Gollapalli sandstone, Raghavapuram shale and the Tirupati sandstone (King, 1880), and are exposed on the northeastern margin of the basin (Rao, 2001; Gupta, 2006). The Gondwana sediments in KG have been classified as the continental and coastal Gondwana based on the litho-assemblage and palynoflora (Lakshminarayana, 1995; Lakshminarayana, 2002). The sedimentary sequences of the Raghavapuram – Gollapalli – Tirupati – Razole Petroleum System are part of the coastal Gondwana lithic fill; however, the Gollapalli sandstones in the West Godavari form part of the continental Gondwana (= Kota formation) (Lakshminarayana, 1995; Lakshminarayana et al., 1992).

Sedimentation in the Gondwana basin was initiated during the Early Permian over Archean crystalline basement, forming the Draksharama/Kommugudem formation (Table 1) (Lakshminarayana, 2002; Gupta, 2006). Sediments of Triassic age are absent. Early synrift sediments (Gollapalli equivalents during Tithonian–Barremian) were deposited during early extensional subsidence accentuated by the earlier basement rifted fault systems. The top of Gollapalli sandstone (King, 1880) forms the southeastern continuation of the Kota formation of the Chintalapudi graben (Lakshminarayana et al. 1992). Differential basin