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Thermal history of the Krishna–Godavari basin, India: Constraints from apatite fission track thermochronology and organic maturity data

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ABSTRACT

The Krishna–Godavari (KG) basin, a passive margin Late Carboniferous to Holocene basin along the rifted east coast of India, includes the deltaic and inter-deltaic regions of the Krishna and Godavari rivers onshore and extends into the offshore. It is one of India's premier hydrocarbon-bearing basins. In an attempt to better understand the thermal history of the basin, apatite fission track (AFT) data has been obtained from six exploration wells (five onshore and one offshore). AFT thermal history models as well as other thermal indicators e.g. vitrinite reflectance (VR), Rock–Eval T_{max} data reveal that the host rocks are currently at their maximum post-depositional temperatures and that any possible heating related to small-scale tectonism or rifting episodes in the basin bears little significance on the maturation of the sediments. In the case of one borehole (M-1) however, the organic maturity data reveals a period of Oligocene cooling across an unconformity when ~1000 m of section was eroded due to falling sea-level. This information offers the potential for improved basin modeling of the KG basin.

1. Introduction

Sedimentary basins on the east coast of peninsular India have gained significance in the last decade due to the discovery of hydrocarbons in both their onshore and offshore settings (Lal et al., 2009). Amongst these basins, the Krishna–Godavari (KG) basin (Fig. 1) has in particular gained central importance because of giant gas field discoveries in the offshore and the earlier discovery of liquid hydrocarbon in both the onshore and offshore areas. This northeast-southwest oriented polycyclic basin was initiated during the Late Jurassic as an intracratonic rift along a divergent margin setting superimposed on the Pranhita–Godavari (PG) rift basin, a NW–SE oriented Gondwana graben (Bastia, 2004; Padhy, 2009). Later the KG basin acquired a pericratonic character evolving through characteristic syn-rift and post-rift phases in the Cretaceous (Rao, 2001). The basin forms a unique province characterized by depositional systems resulting from Krishna and Godavari river delta progradation, tectonic processes, igneous activity and relative sea level changes. The relatively high basinal geothermal gradient (4 °C/100 m in the onshore to 7 °C/100 m in deep water) and a thick sedimentary package (up to ~5 km) create an environment conducive for source rock maturation (Rao, 2001; Gupta, 2006). Based on previous work, four major regional unconformities have been identified across the basin during Jurassic, Paleocene, Oligocene and Mio-Pliocene time (Raju et al., 1994; Aswal et al., 2001; Singh et al., 2003). However, no absolute information with respect to maximum burial depths and thicknesses of eroded sedimentary rocks at the unconformities are available, limiting a proper understanding of the thermal evolution record of the basin.

Among the controlling parameters of the chemical reactions leading to conversion of organic matter into hydrocarbon, temperature is the most sensitive (Tissot et al., 1987). A detailed understanding of sedimentary basin thermal evolution is therefore important as it controls the maturity level of source rocks and helps in evaluating potential petroleum exploration targets. The annealing behaviour of fission tracks in apatite with increasing temperature, particularly within partial annealing zone (PAZ) at ~60–110 °C, enables the AFT technique to act as a thermochronometer, often allowing thermal histories to be calculated in geologic settings of interest (e.g. Gleadow et al., 1986, 2002; Gallagher et al., 1998). In the absence of any tectonic disturbances, temperature can often be used as a substitute for depth within the upper crustal environment and thus valuable information on rock exhumation can be derived from thermochronometer data. One of the most important aspects for understanding the thermo-tectonic evolution of a sedimentary basin is to identify whether periods that are not represented in the basin stratigraphy are associated with significant heating episodes during burial followed by cooling due to uplift and erosion. AFT data may provide important constraints on the timing and duration of heating/cooling events as

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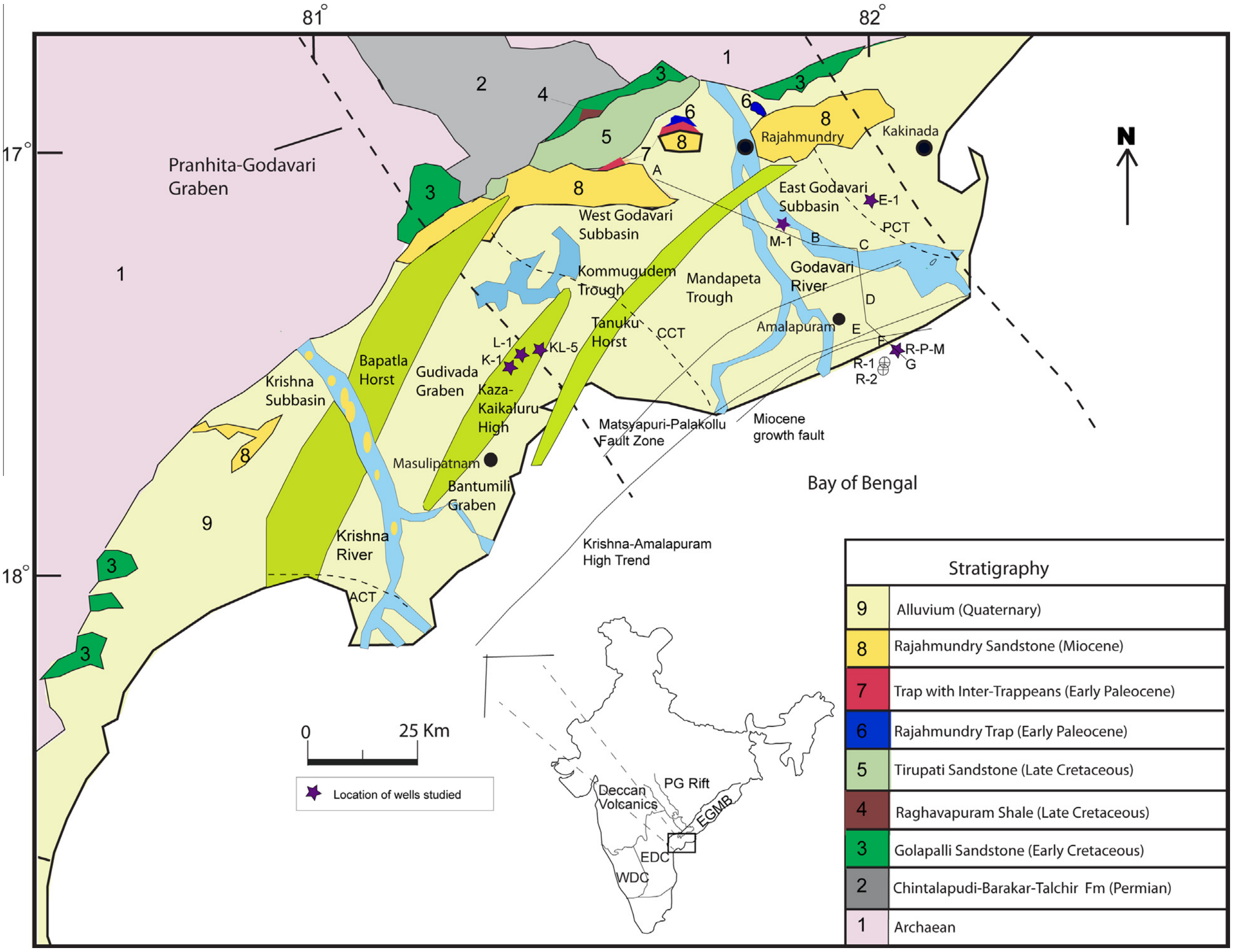

Fig. 1. Geological map of Krishna–Godavari basin (modified after Rao, 2001 and Gupta, 2006) showing location of the wells studied. Extension of Pranhita–Godavari (PG) basin beneath the Krishna–Godavari basin into the offshore is shown by dashed line. ACT = Avanigudda cross trend, PCT = Pithapuram cross trend, CCT = Chintalapudi cross trend, EDC = Eastern Dharwar Craton, WDC = Western Dharwar Craton.

well as maximum paleotemperatures and all this information can be used as an aid in evaluating hydrocarbon systems as well as structural and basin-forming mechanisms (e.g. Bray et al., 1992; Green et al., 1995; Kamp et al., 1996). AFT data in combination with other thermal indicators e.g. vitrinite reflectance (VR), Rock–Eval T_{max} data, thermal alteration index (TAI) data can therefore be used to reconstruct detailed thermal histories for basins.

This study aims to examine the basin wide thermal history of the KG basin using integrated apatite fission track analysis and organic maturity data. For this purpose, 36 samples (both cores and cuttings) from six representative boreholes located in different geologic settings across the basin were analysed. The results allow a comprehensive thermal history of the basin to be reconstructed as well as providing information on provenance and amount of erosion across main unconformities.

2. Regional geology

The KG basin, located along the central part of the eastern Indian peninsula trends NE–SW parallel to the Eastern Ghats Mobile Belt (EGMB) (Fig. 1). Archaean basement of the EGMB and Cretaceous sedimentary outcrops of the Pranhita–Godavari (PG) basin demarcate the northwest basin margin. To the southwest, in the vicinity of the Krishna river system, the KG basin overlies metamorphic basement while to the northeast in the vicinity of Godavari river system, it overlies the NW–SE trending PG graben (Fig. 1). Combined with the sedimentary successions of the underlying PG graben, the KG basin comprises several sedimentary cycles ranging in age from Late Carboniferous to Holocene (Fig. 2a and b) (Biswas, 1992; Rao, 2001; Gupta, 2006).

The basin has been broadly divided into three sub-basins (Krishna, West Godavari and East Godavari) separated by two basement horsts (Bapatla and Tanuku) (Fig. 1). The sediment thickness in these sub-basins is >5 km (Rao, 2001). The KG basin stratigraphy and depositional environment is described in detail by Sikka, 1990; Rao and Mani, 1993; Venkatarangan and Ray, 1993; Rao, 2001 and Gupta, 2006. Permo-Triassic sediments are restricted to the NE part of the basin and were deposited in a fluvial environment (Rao, 2001). This includes Permo-Carboniferous strata (Kommugudem/Barakar Formation) and the Late Permian-Early Triassic Mandapeta Sandstone. Based on paleocurrent studies of the basin margin, the provenance for these sediments has been established to be from Antarctica (Kent, 1991; Lakshminarayana, 2002). Most of Triassic and Jurassic time is marked by a hiatus and a prominent red claystone bed separating Cretaceous sediments from pre-Cretaceous sediments (Rao, 2001).

The Cretaceous sediments were deposited mostly in a marine environment, but their provenance is still debated. The Golapalli Sandstone (Aptian/Albian) also named the Kanukollu Sandstone in the Krishna graben, is considered to mark the initiation of a change of provenance from an easterly to a westerly source (Raza