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RESEARCH PAPER

Geological features, hydrocarbon accumulation and deep water potential of East Indian basins

QIN Yanqun[1,*], ZHANG Guangya[1], JI Zhifeng[1], LI Zhi[1], WU Yiping[1], WANG Xinglong[2], LIANG Xu[2]

1. PetroChina Research Institute of Petroleum Exploration & Development, Beijing 100083, China;
2. CNOOC Research Institute, Beijing 100028, China

Abstract: Based on the tectonic evolution, sedimentary filling and hydrocarbon geological characteristics, this paper establishes a variety of deep water fan models and accumulation patterns and analyzes exploration potential of deep water area in East Indian basins. Due to the breakup of East Gondwana, the passive continental margins of East India are evolved. The basins in these margins experienced four evolution stages, which include intracratonic rift (P_1-T), East Gondwana rift (J_1-K_1), post-rifted thermal subsidence (K_2), and passive continental margin (K_3-N). There are three obvious unconformities which were formed in the end stages of post-rift thermal subsidence and first and second phases of passive continental margin. Four sets of structural layers were formed, rift stage, and the first, second and third stages of passive continental marginal structural formation. The main deposition of these basins is the sediments evolved during the passive continental margin stage. Two prolific fan systems were developed: superposition fans are complicated in near shore and delta; low fans are located at fault slope-break while turbidity fans are located in front of delta. Four sets of proven source rocks were developed, the Lower Permian, Lower Cretaceous, Upper Cretaceous and Paleogene. There are many middle porosity reservoirs and lowstand permeability reservoirs, such as sandstone and local carbonate in rift period, sandstone of delta and deep water gravity flow in the rifted thermal subsidence and passive continental margin stages. Many seals were developed in the basins, regional seals in drifted stage and local seals in other stages, and the seals thickness change are enormous. There are eight plays in these basins which include Upper Cretaceous sandstone, Paleogene sandstone, Neogene sandstone, etc. The hydrocarbon exploration of deep water area during the passive continental margin stage should focus on Krishna and Cauvery river delta on the plane, and delta sandstone related to fault, lowstand fan located at fault slope-break and near shore fan complex in vicinity of 85°E ridge and south offshore of Cauvery basin vertically.

Key words: passive continental margin; deep water petroleum exploration; deep water fan; delta; Mahanadi basin; Krishna-Godavari basin; Cauvery basin; East India

1. The study background

Oil and gas discoveries in passive continental margin deep-water zones take a considerable portion of the new discoveries globally in the past few years[1–2]. The golden deep-water exploration zones including Gulf of Mexico, Central West Africa and Eastern Brazil emerged in the early 21st Century has expanded to NW Australia continental shelf, East Africa, North Sea, Eastern Mediterranean, Nova Scotia, South China Sea, Northwest Africa, East India and other offshore zones[3–5]. Successful hydrocarbon exploration practices in deep-water passive continental margin zones in the above-mentioned areas provide valuable references for expansion of new fields around the world[3,6–7].

Basins in the East India can be classified as passive continental margin basins. These basins include Mahanadi, Krishna-Godavari and Cauvery. They stretch in NE direction along the continental shelf margin, covering a total area of approximately 30.9×10^4 km^2, with over 80% being offshore (Fig. 1). Strike, lateral dislocation and other geometric feature changes of basement faults in these basins suggest that the structures in these basins are controlled jointly by rifting in early stage and transform faults in later stage. Crossing of transform faults and continental margins show that the northern part of the Cauvery basin and the southern part of the Krishna-Godavari basin have continental margin structure of shear type, whereas other areas have continental margin structure of rift type (Fig. 1). According to IHS data[1], the concerned area is low or extremely low in exploration degree with only 2.1 exploration wells per 10 000 square kilometers by the end of 2016. In total, the area has proven + probable oil reserves of 97.7×10^6 t and natural gas reserves of 7.12×10^{10} m^3, showing very uneven distribution of oil and gas. The present

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*** Corresponding author.** E-mail: yqqin@petrochina.com.cn
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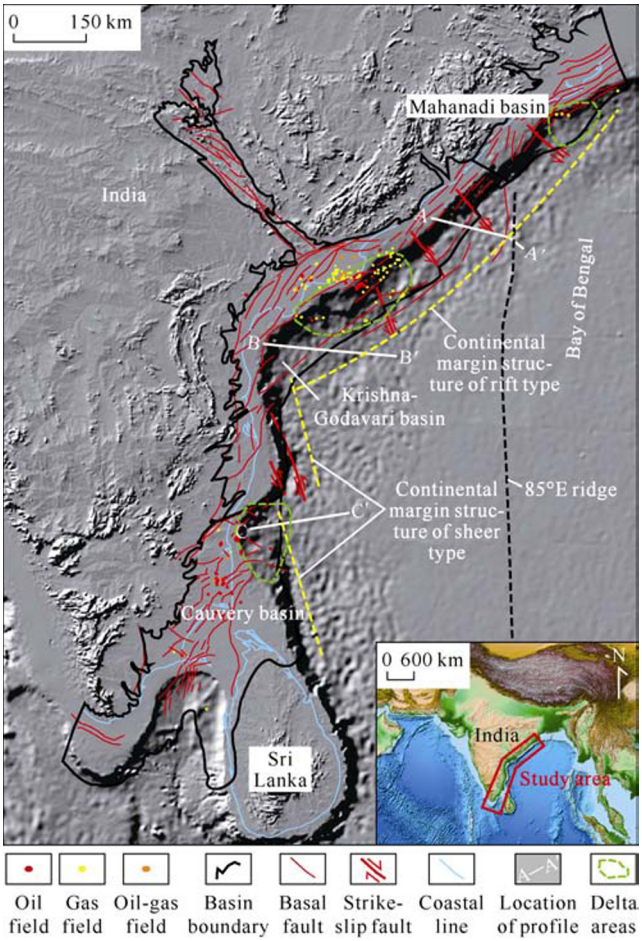

Fig. 1. Distribution of discoveries and basement faults in the East India basins (Data related to basement faults, oil and gas fields originated from references [1-2]).

discoveries dominated by natural gas are distributed mostly in the two continental margin delta zones in the central part of the Krishna-Godavari basin[1–2]. In the past few years, with more and more seismic and drilling data collected in offshore zones of the Bay of Bengal, and especially with the beginning of deep-water operations of Chinese "HYSY-981" drilling platform in this area, deep-water exploration in the area has attracted extensive attentions of multiple domestic and international oil companies and explorers[8–10]. Previous researches on geologic evolution[10–14], sedimentary filling[10,15–17], petroleum geology[8–9,18] and other aspects of the Bay of Bengal are concentrated on a specific aspect or basin. There are few reports on deep-water exploration in the western part of the Bay of Bengal, or the East India area. Systematic study of overall geologic evolution and hydrocarbon features in the East India basins based on the International Commercial Oil/Gas Field Database is a key means to further deepen understanding on resource potentials in the area. Moreover, the study may provide valuable reference for comparison of differences in hydrocarbon accumulation and identification of optimal deep-water zones under similar tectonic evolution background[4,19].

2. Regional tectonic and sedimentary evolution

Formation and evolution of the East India passive continental margin basins are closely related to the breakup of India, Antarctica and Australia plates from the East Gondwana Paleocontinent into the closure of Meso-Tethys and the Neo-Tethys since the Jurassic[10,20]. According to existing data related to plate re-construction, together with sedimentary filling and development of unconformities in the basins in the Commercial Database[1–2,10], tectonic evolution of the East India passive continental margin basins can be divided into four stages, i.e. intracratonic rift (Early Permian–Triassic or P_1-T), East Gondwana rift (Early Jurassic–Early Cretaceous or J_1-K_1), post-rift thermal subsidence (Middle Cretaceous or K_2), and passive continental margin (after Late Cretaceous or K_3-N). Due to the sequence of the palaeocontinental blocks, different basins have different specific times of evolution stages (Figs. 2 and 3).

(1) Intracratonic rift stage. India, Madagascar, Antarctica, Australia, Lhasa and other blocks were a whole during the Permian and a part of the East Gondwana land[10,21]. In the Early Permian (approximately 270 Ma), a long and narrow rift in nearly S-N direction developed in the central and eastern parts of the India block, and expanded to the northern margin of the Antarctica, which was filled by fluvial and lacustrine sediments. The Meso-Tethys was in the northern part of the India block, where continental shelf shallow-water sediments developed extensively on margins, with discontinuous N-W grabens and half-grabens in local parts. Sediments of this stage currently can be found in the Krishna-Godavari basin only, and have not been found in residual formations of the Mahanadi basin. During the same period, the Cauvery basin was in an uplifting and denudation environment (Figs. 2a and 3).

(2) East Gondwana rift stage. During the Late Jurassic (approximately 152 Ma), with the gradual closure of the Meso-Tethys and opening of the Neo-Tethys, a long and narrow ocean basin occurred to the northwest of the India and Madagascar block. The southwestern part of the block, or the southern part of the present Cauvery basin, was a restricted sea environment, where continental sediments deposited in the early stage and shallow sea shale in the late stage (Figs.2b and 3). The southern part of the Indian continent, or the present eastern part, had a trifurcate rift in nearly EW and NE directions, which was connected with the Neo-Tethys to the east, this area was dominated by littoral-neritic sea sediments in continental shelf zones (Fig. 2b)[10].

(3) Post-rift thermal subsidence stage. With the gradual weakening of rifting, a narrow oceanic basin was formed between the eastern edge of the Indian continent and the Antarctica and Australia to the Middle Cretaceous (approximately 112 Ma). At the same time, the Sri Lanka landmass was still connected with the Antarctica (Fig. 2c). The East Indian continental margin zone developed basement faults of early rift stage in nearly SN direction[10,20]; this area was dominated by littoral neritic–abyssal sediments. Affected by the cutting of