A Petroleum System in the Gulf of Mannar Basin, Offshore Sri Lanka

D.M.U.A.K. Premarathne¹, Noriyuki Suzuki¹, Nalin Prasanna Ratnayake², and E.K.C.W. Kularathne³

(1). Division of Earth and Planetary Sciences, Graduate School of Science, Hokkaido University, Kita 10, Nishi 8, Kita-Ku, Sapporo, 060-0810, Japan.
(2). Department of Earth Resources Engineering, University of Moratuwa, Katubedda, Sri Lanka.
(3). Petroleum Resources Development Secretariat (PRDS), No. 80, Sir Ernst De Silva Mawatha, Colombo 07, Sri Lanka.
*E-Mail: premarat@yahoo.com

1. Introduction

History of oil exploration in Sri Lanka dates back to 1957. During 1972-1975, Soviets drilled three exploration wells (Pesalai-1, 2 and 3) in the Pesalai area on the Mannar Island of Sri Lanka (Fig. 1). Later, Palk Bay-1 and Delft in 1976 and Pedro-1 and Pearl -1 in 1981 were drilled by different consortia. However, all these wells were plugged and abandoned as dry holes, leading oil exploration in Sri Lanka into dormancy. Most of these wells had drilled into structural highs of the Cauvery Basin, of which the adjacent Indian Jurisdiction is productive for both oil and natural gas now. Geology of the Cauvery Basin has been addressed in detail by Cantwell et al. (1978) and Chandra and Venkataraman (1988).

After a hiatus of 16 years, oil exploration in Sri Lanka resumed in 2001 with TGS-NOPEC, a Norwegian geophysical company acquiring 1,050 km two dimensional (2D) marine seismic data in the Sri Lankan side of the Gulf of Mannar Basin, located immediately to the south of the Adam’s Bridge, between the Southeastern coast of India and the western coastline of Sri Lanka. Interpretation of seismic data showed the Gulf of Mannar Basin, frequently referred to as the Mannar Basin, to have a higher petroleum potential (Baillie et al., 2003).
2. Recent Exploration Drilling in the Mannar Basin

Cairn’s first exploration well, referred to as CLPL-Dorado-91H/1z (Dorado), was drilled in a water depth of 1,354 m, which penetrated a gross 25 m hydrocarbon column in a sandstone between the depth of 3,044-3,069 m, measured depth (MD). Total depth of the well was 3,288 m, MD. It is the first exploration well to discover hydrocarbons in Sri Lanka as well as in the Gulf of Mannar.

CLPL-Barracuda-1G/1 (Barracuda), the second exploration well, located 68 km off the western coastline of Sri Lanka and 38 km west of the Dorado well, drilled up to a total depth of 4,741 m, MD in 1,509 m water depth. It penetrated 24 m of three hydrocarbon bearing sandstones between the depths of 4,067-4,206 m, MD. Both discoveries were predominantly natural gas. Third and the final well, drilled 2.5 km north of the Dorado well, was plugged and abandoned as a dry hole.

3. Geology of Mannar Basin

Baillie et al. (2003) has suggested the Mannar Basin to have been developed during, at least, two periods of rifting and associated continental breakup as part of the multiphase breakup of Gondwanna during the Mesozoic. Due to similarities in origin, geological structure and stratigraphy, Baillie et al. (2003), Rao et al. (2010) and Premarathne (2011), have considered it to be a sub basin of the Cauvery Basin. The area of the Mannar Basin under the Sri Lankan jurisdiction is around 45,000 km². Bathymetry of the basin ranges 20 m to in excess of 4,000 m. Mannar 1-1A, drilled in 1977, was the first exploration well drilled in the Indian side of the Gulf of Mannar, while the Pearl-1, drilled in 1981 by Cities Services Company of USA, was the first and the only exploration well drilled in the Sri Lankan side of the Mannar Basin until 2011. Both these wells were subsequently plugged and abandoned as dry holes. Stratigraphic section of the Pearl-1 well shows the existence of around 2,902 m thick Upper Cretaceous to Recent sediments. Stratigraphic section of the Pearl-1 well lies on an igneous rock leading to a hypothesis that the Mannar Basin was overlain by an oceanic crust. Baillie et al. (2003), based on interpretations of the seismic data, have not only suggested the occurrence of sediments beyond igneous rocks, but also have identified four discrete tectono-stratigraphic packages in the Mannar Basin that are consistent with the tectonic history of the region.

The Barracuda well, the deepest exploration well drilled in the Sri Lankan side of the Mannar Basin, has penetrated around 760 m thick basaltic rock in the depth interval of 3,500-4,260 m (Figs 2 & 3). Three hydrocarbon beading sandstone reservoir rocks are interbeded with the igneous rock suggesting several episodes of volcanisms in the Mannar Basin. The igneous rock is overlain by light to dark gray coloured shales, which continue down to the bottom of the Barracuda well. This bears out the existence of sediments beyond igneous rocks and disproves the previous hypothesis that Mannar Basin was overlain by an oceanic crust. Seismic data as well as gravity and magnetic maps show the igneous rocks to have wider extension over the Mannar Basin.

Krueger Enterprises Inc., on behalf of Cities Services Group, has determined the age of igneous rocks from the Pearl-1 well to be 76.8 ± 4.5 million years (Ma), the Campanian age, on K⁴⁰/Ar⁴⁰ method. Torsvik et al. (2002) has suggested that Late Cretaceous of Madagascar was characterised by magmatism created due to its separation from India around 85 million years before present. Accordingly, igneous rocks in the Mannar Basin may have been the
result of volcanisms created due to onset of rifting and subsequent northward drifting of India from Madagascar during Late Cretaceous.

4. Petroleum System

Discovery of hydrocarbons in Sri Lanka, for the first time, confirms the existence of an active petroleum system in the Gulf of Mannar Basin. Study of well logs and seismic data shows that igneous rocks act as traps and seals for hydrocarbon deposits penetrated by the Barracuda well. For the discovery made by the Dorado well, tilled fault blocks act as the trap while claystone act as the seal. Sandstones have been the reservoir for both discoveries.

Knowledge on source rocks for hydrocarbons discovered in the Mannar Basin is limited. However, Kuldeep et al. (1991), based on analysis of Mesozoic sediments from Ariyallur-Pondicherry, Thanjavur and Nagapattinam sub basins in the Cauvery Basin, has shown that Middle to Late Cretaceous shale deposited in marine environment regime has a good source potential. Pear-1 well section does not show any sufficiently thick fine grained sediments having source rock potential. However, the fine grained dark greenish gray shales underlain by igneous rocks of the Barracuda well may have source rock potential at least for the hydrocarbons discovered in that well.

De Silva (2006) has suggested that anticlinal closures appear on seismic data from the Mannar Basin to be flower structures associated with NE trending transform faults which could be traced to transform faults related to the mid oceanic ridge in the Indian Ocean east of Madagascar. De Silva (2006) has further suggested that minor faulting and fracturing associated with the transform faults could pave the way for hydrocarbon migration from source rocks to overlying reservoirs and traps. In this scenario, it could be assumed that hydrocarbons generated by organic rich shales below igneous rocks could have migrated upward through fractures and faults into
sandstones interbeded with igneous rocks penetrated by the Barracuda well making a vertical drainage system in the Mannar Basin. Oil exploration in Sri Lanka is still at its early stage to fully understand the total petroleum system in the Mannar Basin. Further studies, more exploration wells and new hydrocarbon discoveries, in future, will show as to whether the Mannar Basin has one or more petroleum system/s or the petroleum system in the Mannar Basin is just the southern extension of the petroleum system in the Cauvery Basin.

5. Conclusions

Mannar Basin has wider extension of igneous rocks, which may have formed by several episodes of volcanism created due to onset of rifting and subsequent northwards drifting of India from Madagascar during Late Cretaceous. Occurrence of an active petroleum system in the Gulf of Mannar Basin is established by recent natural gas discoveries in offshore Sri Lanka. Sandstones act as the reservoir for both discoveries. Tilted fault blocks and igneous rocks act as taps, where as claystone and igneous rocks act as seals. Dark greenish gray colored shales underlain by igneous rocks in the Mannar Basin could be a potential source rock, at least for hydrocarbons discovered in the Barracuda well. Facies systems in igneous rocks may have paved the way for hydrocarbon migration into overlying reservoir rocks making a vertically drainaged system in the Mannar Basin.

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7. References


