# Preliminary Investigations on the Hydrocarbon Potential of a Recently Discovered Black Shale Deposit in the North-East of Sri Lanka

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## ABSTRACT

A faulted sedimentary basin in the area of Kinniya near Trincomalee, North-east of Sri Lanka was discovered during a routine geotechnical investigation. Two boreholes were drilled and a black shale deposit was encountered which continued to exist even at a depth of 50m, as indicated by drilling and geophysical investigations. Analyses of some samples proved that it has an organic carbon content ranging from 6-11 % with a hydrocarbon potential. Even though the initial analysis showed that the sample plots near the type-IV field in a modified Krevelen diagram as an immature source rock, the extent of the deposit as indicated by structural and tectonic studies covering tens of square kilometres warrants much larger geophysical and geochemical investigations.

## INTRODUCTION

Although petroleum exploration activities in Sri Lanka has been mainly concentrated in two offshore sedimentary basins namely, the Cauvery Basin and the Mannar Basin in the North and west of Sri Lanka, the eastern sector of Sri Lanka however, has not been investigated significantly for occurrences of sedimentary basins. In 2007, the first author with the Foundation and Water-well Engineering Limited, Sri Lanka, in a routine drilling project for an engineering construction, discovered a black shale deposit in the Kinniya close to Trincomalee (Fig. 1). Initial investigations revealed that this black carbonaceous shale deposit extends to an unknown depth with a possible extent of over 10 sq km. This study has as its main objective, the understanding and evaluation of the hydro-carbon potential of this black organic shale that was found in the Kinniya region. The geological setting, mineralogy, organic chemistry and trace metal contents and the geophysical nature of the deposit were also investigated.

Sri Lanka, a tropical island, located in the southern continuation of the Indian sub-continent is composed mainly of Precambrian metamorphic rocks, divided into three units namely Highland Complex, Wanni Complex and the Vijayan Complex (Fig. 1). The Highland Complex is made up of granulite grade rocks and the other two consist partly of amphibolite grade rocks. The north western and northern parts of the island are overlain by Miocene sedimentary deposits and only a few scattered igneous bodies are recorded.

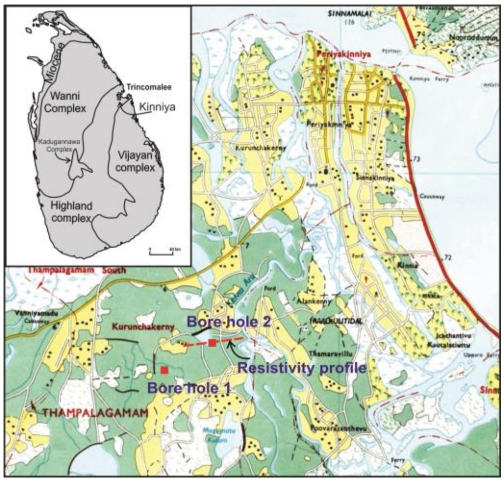


**Figure 1**: Location of the newly discovered shale deposit near Kinniya.

The recently discovered shale deposit is found at Kinniya, a village located about 7 kms from the eastern coastal line of Sri Lanka. The most prominent metamorphic rock type in the region is quartzite and charnockites (Wijayananda, 1985) while the other rock types in the area include calciphyres, pink feldspar granulitic gneiss and garnet-biotite gneiss. The rocks trend towards the north-east and are deformed into typical synformal and antiformal structures. The study region in Kinniya is a flat terrain with less than 10 m from the msl and covered by metasedimentary outcrops.

## MATERIALS AND METHODS

Shale samples were collected from two boreholes drilled by the Foundation and Water-well Engineering Ltd in the study area to a depth of 10m and 18m. A resistivity survey was also carried out across the area, particularly in the low relief terrain where the sedimentary sequence had been identified in dug wells and bore holes. The resistivity profile was 400 m long and lying approximately in the direction EW (Fig. 1). Shale samples were collected from boreholes and washed with distilled water to remove surface contaminants and air dried before carring out the mineralogical observations. Textural studies were carried out using a binocular microscope. X-ray diffractometry (XRD) analysis was also carried out to obtain the mineralogical composition of shale samples. Subsamples of shale that were powdered using an agate ball mill were used to obtain the chemical composition using the XRF techniques. Powdered shale was weighed into a crucible and dried at 110° C until a constant weight was obtained and then fused in a muffle furnace for 6 hours at 450° C to obtain the organic matter content. The powdered shale samples were extracted with dichloromethane ($CH_2Cl_2$) three times using the sonicator for the qualitative determination of organic compounds. The extraction was then filtered and the solvent was removed using a rotary evaporator and the crystalline organic extract was obtained. The extracts were then analysed with Thin Layer Chromatography (TLC), High Performance Liquid Chromatography (HPLC) and Nuclear Magnetic Resonance (NMR) methods. The hydrocarbon potential of samples was measured by pyrolysis and the measuring was done at United States Geological Survey (USGS) laboratories.

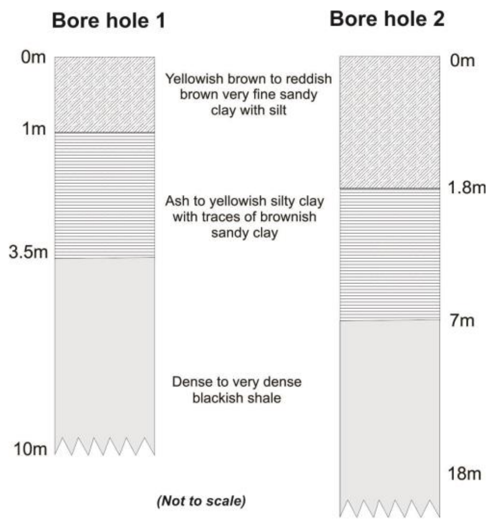


**Figure 2**: Generalized stratigraphical profiles of two boreholes drilled at Kinniya.

## RESULTS AND DISCUSSION

The stratigraphic profiles of the two bore-holes are illustrated in figure 2. It is evident that the thickness of the black shale is not known as yet but estimated to be over 100 m considering the structural geology of the area and the information obtained from the geophysical investigations. Drilling investigations carried out by a private organization also have recorded black shale layers at even 100 m depth. Faulted basins are very common in this terrain and a sizeable deposit of carbonaceous shale is therefore possible especially in the areas of low relief. The general geological profile consists of a ferruginous cap followed by a ferruginous gravel layer, a lateritic formation and a whitish-mottled clay layer. The cumulative thickness of these layers is about 6 m. A dark gray to black mudstone to shale formation is present below these formations. Nearly 85 % of the shale is composed of clay sized particles with the content of fine sand and coarse sand being 10 % and 1 %, respectively. The remainder consists mainly of mica minerals. Montmorillonite, quartz, pyrophyllite, microcline, rutile, pyrite, illite, hematite, zircon, scapolite, gypsum and malachite are the main minerals found in black shale from Kinniya as illustrated by the XRD analysis.

Table 1 shows the major oxides and trace elements that were measured in black shale samples. In view of their relatively simple and homogeneous mineralogical composition which includes sheet silicates, sulphides and organic matter, black shale acts as a host to a variety of elements. Hence in general, black shales are enriched in trace metals. When the sulphides contained within the black shale undergo oxidative weathering, a large amount of iron-rich secondary minerals with a large surface area are formed. Hu et al. (2008) studied the distribution of trace elements in a black shale deposit from China and showed very similar metal contents to those in the black shale samples investigated in this study; however Ni, Cr, V, Zn and Zr are in the higher range (Hu et al., 2008; Shpirt and Punanova, 2007), probably due to accumulation of heavy mineral phases. The Chinese back shale samples had an average Total Organic Carbon (TOC) content of 8.54 %. The trace element contents probably indicate partitioning between the inorganic fraction and the organic matter. The organic content as indicated by the loss on ignition values were in the range of 7 and 10 % which is in the range of typical black shale.

Figure 3 illustrates the resistivity image along the selected profile. The profile shows a thin overburden (about 10 m) in the western segment. The eastern segment of the image shows a much thicker overburden which is thicker than 40 m. In this segment, a thick sedimentary sequence which probably extends to a greater depth can be expected. The abrupt change of the depth to bed rock at ~40 m in the profile indicates an eastward dipping fault boundary. Even though the geographic extent of the formations is yet to be investigated, it appears to cover at least several tens of square kilometres indicative of a sizeable black shale deposit. Geophysical investigations also reveal the possibility of a deep existence of the deposit, probably in association with faulted basins in the crystalline basement. Such an occurrence can be of immense importance when considering the sedimentary formations that trap hydrocarbons. Systematic investigation of these formations may reveal information that may be of great significance both scientifically and economically.

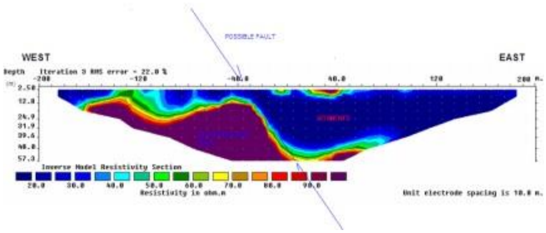


**Figure 3**: Resistivity profile carried out in E-W directions in Kinniya.

## Organic matter in shales

TLC analysis of the organic extract with n-hexane as the eluent indicated the presence of highly low polar UV active compounds. The extract was chromatographed over a column of silica gel with n-hexane-ethyl acetate to give three major fractions A, B and C. A yellow coloured crystalline material was observed in both fractions A and B. TLC indicated a presence of highly low polar compounds in the n-hexane extract which

**Table 1**: Major and trace element contents in black shales from Kinniaya as determined by XRF (*weight loss at 1100° C).

| Major elements | % | Trace elements | mg/kg |
|---|---|---|---|
| $SiO_2$ | 41 | As | 16 |
| $TiO_2$ | 1.01 | Ba | 396 |
| $Al_2O_3$ | 22.11 | Ce | 120 |
| $Fe_2O_3$ | 10.04 | Co | 29 |
| MnO | 0.044 | Cr | 146 |
| CaO | 1.17 | Cu | 82 |
| MgO | 0.62 | Ga | 26 |
| $Na_2O$ | 0.07 | Hf | 12 |
| $K_2O$ | 1.42 | La | 87 |
| $P_2O_5$ | 0.078 | Nb | 14 |
| LOI* | 26.41 | Ni | 58 |
| | | Pb | 30 |
| | | Rb | 82 |
| | | Sr | 114 |
| | | Th | 19 |
| | | V | 192 |
| | | Y | 45 |
| | | Zn | 132 |
| | | Zr | 162 |

moves in TLC with n- hexane as the eluent (20 mg). The $^1$HNMR indicated the presence of only hydrocarbons in this fraction. The $^{13}$CNMR of the same fraction in $C_5D_5N$ indicated the presence of only four peaks at 14.23, 22.88, 29.55, 29.86, 29.93 (high intense peak), 32.07 which are typical signals of long chain hydrocarbons such as $CH_3CH_2(CH_2)_nCH_2CH_3$. It is possible that there is a mixture of long chain hydrocarbons in this fraction.

It is important to note that the yellow crystalline material obtained from fractions A and B is not soluble in n-hexane as in other hydrocarbons. However it elutes through the column of silica with a mixture of solvents of n-hexane and ethyl acetate. Although an extraction method for normal organic compounds has been followed in this study, the elemental analysis indicated the absence of C, H and O in this fraction. The crystalline compound is probably sulphur due to its colour and the nature of the compound. Finally the melting point of this crystalline compound nicely tallies with the reported melting point of sulphur. Further purification of the fraction C, yielded a high intense UV active compound in minor quantities (< 1 mg) which is an aromatic compound, confirmed by the $^1$HNMR analysis.

## Hydrocarbon Generating Potential

A sample from one of the cores was subjected to pyrolysis to determine the hydrocarbon generating potential (table 2). Commonly, rocks containing <0.5 wt % TOC are considered to have negligible hydrocarbon generating potential. Rocks with TOC between 0.5 and 1.0 have marginal hydrocarbon generating potential and those with TOC between 1.0 and 2.0 have a moderate potential and those with TOC > 2.0 have excellent hydrocarbon generating potential. The sample analyzed from Kinniya Shale has a TOC value of 5.77 wt % and therefore should have excellent hydrocarbon source potential. However, rocks with high TOC values could have little source potential because the organic matter (kerogen) may be woody or oxidized. Therefore, high TOC values alone cannot be taken as indicative of prolific hydrocarbon source rocks. In a modified Krevelen diagram the sample plots near the Type IV field (Fig. 4). Therefore the likely kerogen type would be Type IV- gas prone. This is supported by HI < 50 (table 2) and the $S_2$ vs. TOC plot (Fig. 5). The $T_{max}$ value indicates that the sample is immature and has not produced hydrocarbons. This is supported by the low $S_1$ and the PI values and the analyses indicate an immature source rock with potential to generate gas.

## Structural Evolution of the Faulted Basin

Desa et al. (2006) studied the sea floor spreading magnetic anomalies in south of Sri Lanka. They obtained results from compilation and re-interpretation of about 21000 line km of bathymetry, magnetic and satellite gravity data between 10º N latitudes and 75º to 90º E longitudes south of Sri Lanka. Their data revealed the presence of a Mesozoic anomaly sequence, the oldest (134 Ma) occurring between 110 and 140 km south of Sri Lanka. The formation of the fracture zones and faulted basins are probably a result of the break up of eastern Gondwana and the subsequent rifting.

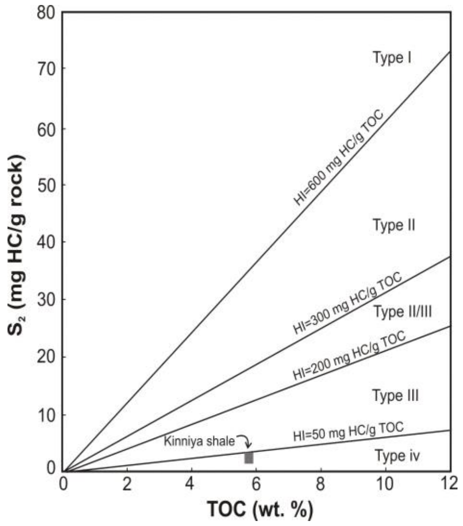


**Figure 4**: Plot of TOC vs $S_2$ (see the text for details).

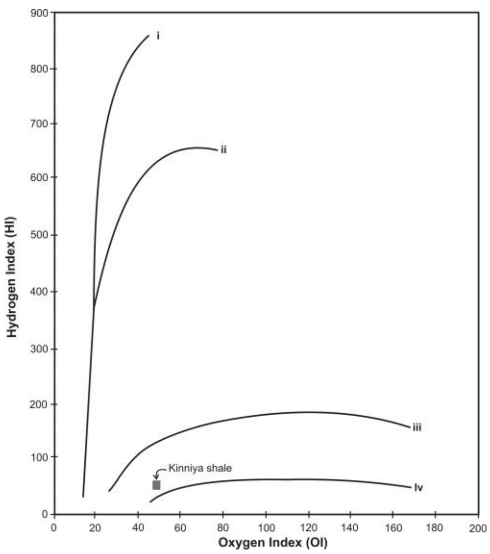


**Figure 5**: Modified van Krevelen diagram showing that the shale from Kinniya falls on the type III and IV boundary.

The continental shelf of Sri Lanka is narrow (< 30 km) and has a steep slope beyond the 500 m isobaths. As illustrated in figure 3, there are six major and some minor NNW-SSE to NW-SE trending fracture zones inferred from the offsets in the magnetic anomaly sequence. The disposition of the anomalies by the fracture zones resulted in the formation of an arcuate shaped sea floor mosaic in the south of Sri Lanka (Desa et al., 2006). Watkinson et al. (2007) have reported that normal fault-bounded basins have been identified from seismic lines from offshore basins of the southeast Indian continental margin. Basin restriction coupled with deposition during two Ocean Anoxic Events led to the deposition of over 90m of organic-rich marine black shales (Govindan, 1982 & 1993). The juxtaposition of black marine shale with syn-rift shallow marine carbonates and siliciclastic turbidites has significant potential for future petroleum exploration in southeast Indian basins (Watkinson et al., 2007). From a local concept, we do need to emphasise that Sri Lanka lies on the same continental shelf as that of south India. Today along the southern coast of India there are wells producing petroleum which contributes to their national economy.

**Table 2**: Results obtained from the pyrolysis

| | |
|---|---|
| Total organic carbon content (TOC) – wt % | 5.77 |
| Amount of free hydrocarbons volatilized below 300° C ($S_1$) mg/g | 0.25 |
| Amount of hydrocarbons produced between 300° and 600° C ($S_1$) mg/g | 2.36 |
| Amount of $CO_2$ produced ($S_3$) mg/g | 2.68 |
| The temperature at which maximum release of hydrocarbons occurs ° C | 403 |
| Vitrinite reflectance (ρ) | 0.47 |
| Hydrogen Index (HI) | 41 |
| Oxygen Index (OI) | 46 |
| Productivity Index (PI= $[S_1/(S_1+S_2)]$) | 0.1 |

## CONCLUSIONS

A potentially large black shale deposit that has been discovered in the north-eastern sector of Sri Lanka indicates a promising hydrocarbon potential. Eventhough the limited number of samples investigated does not indicate a true estimate of the hydrocarbon potential, the geological and tectonic features of the terrain are highly conducive for the existence of economically important shale deposits of potential hydrocarbon generating capacity. However more detailed studies are necessary to evaluate the extension of the deposits and its hydrocarbon potential.

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