Int. J. Econ. Environ. Geol. Vol. 9(1)01-06, 2018
Journal home page: www.econ-environ-geol.org

Open Access
ISSN: 2223-957X

Microfacies Analysis and Source Rock Potential of Nammal Formation, Western Salt Range, Pakistan

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Received: *20 June, 2017* ***Accepted:*** *26 March, 2018*

Abstract: The present study investigates the microfacies and source rock potential of the Eocene Nammal Formation in the Nammal Gorge Section, western Salt Range, Pakistan. The Nammal Formation consists of light grey to creamy color limestones, olive green to grey shales and light grey marls. Twelve rock samples of limestone were collected for microfacies analysis and nine samples of limestone and shale were analyzed for determination of Total Organic Carbon (TOC) content and source rock potential of the Nammal Formation. Thin section studies of rock samples revealed four microfacies, i.e., mudstones, wackestones, wackestones to packstones and packstones. Microfacies analysis showed that intraclast, planktons and some small benthic foraminifera, pelecypods and opperculina are present in the Nammal Formation. The type of microfacies and abundance of planktons suggest deposition on a carbonate ramp platform within outer neritic to distal shelf environment in the study area. The Nammal Formation presents a coarsening upwards trend and rise in sea level during its deposition. The average TOC value of nine samples of shale is 0.0812 which shows very little organic matter and poor source rock potential of the Nammal Formation.

Keywords: Microfacies analysis, source rock evaluation, Nammal Formation, western Salt Range, carbonate ramp.

Introduction

The facies analysis of carbonate rocks helps in understanding the past depositional environment and sea level changes (Wells and Gingerich, 1987). The Tertiary carbonates deposits in the Indus Basin provide important clues about the past history of the region. The Eocene carbonate rocks of the Indus Basin show good outcrop exposures for the sedimentological studies in the Salt Range (Afzal etal. 2011).

The Nammal Formation represents the Eocene succession of the Salt Range and it is widely distributed in the Cis-Indus Salt Range and Surghar Range in the Trans Indus Ranges (Gee and Gee, 1989). The present study was carried out to identify the microfacies, depositional environments and source rock potential of the Nammal Formation in the Nammal Gorge section, western Salt Range. Few studies have been carried out on the Eocene carbonate deposits in the Salt Range, Upper Indus Basin, Pakistan. Differences in paleontological assemblages of western and eastern Tethys Ocean during the early Eocene period were identified by Afzal et al. (2011). They studied the Paleocene to Eocene carbonate succession of Indus Basin and recognized eight bio-zones based on larger benthic foraminifera. Early Cenozoic strata of Kohat provide insight about the closure of the Tethys Sea and formation of a restricted marine basin (David and Wells, 1996). The terrigenous sediment deposition dominated the western margin of Tethys in early Eocene while the eastern margin was acting as a carbonate shelf (Pivnik and Wells, 1996). Haque (1956) reported the occurrence of the Planktonic Foraminifera Morozovella Velascoensis in the lower part of the Nammal Formation in Nammal Gorge. Based on the occurrence of dinocysts in Nammal Formation of Dhak Pass section, Edward (2007) suggested an early Eocene age of the Nammal Formation. The study on microfacies and foraminiferal assemblages of the Nammal Formation in the Central Salt Range by Ghazi, et al. (2004) indicated deposition in the neritic environment. The source-reservoir relationship of Patala and Nammal formations in Potwar Plateau was studied by Wandrey, et al. (2004) and concluded that source rock quality shales of Eocene in the Kohat-Potwar geologic domain is fair to good. However, there is a need for a composite study of microfacies and source rock potential of Nammal Formation in the western Salt Range. This study aims to address the gap in research of source rock evaluation and microfacies of Nammal Formation.

Geology of the Study Area

The Nammal Gorge Section of western Salt Range was selected for microfacies and source rock evaluation of Nammal Formation. It is located approximately 200 km south of Islamabad with coordinates of 32°39'25.5" North and 71°47'49.6" East. The area can be accessed by road and rail network. The study area of Nammal Gorge is located in the district Mianwali of Punjab province (Fig. 1).

Salt Range is formed as a result of an ongoing collision between Indian and Eurasian plates (Lillie et al., 1987; Kazmi and Jan, 1997). It is the most recent and outermost expression of Himalayan shortening and represents the surface manifestation of decollement along the Eocambrian Salt horizon and exposed the Paleozoic and Mesozoic strata on young Tertiary deposits (Gee and Gee, 1989). The Salt Range is characterized by broad shallow folds and gentle monoclines on the northern slope and tight folding with faulting, formed on the southern slope of Salt Range (Baker et.al., 1988). The superimposition of salt diapirism along the southern scarp has created north-south salt-cored anticline ((Lillie et. al., 1987).EWE-WSW style of Salt Range is constrained via Hazara Kashmir Syntaxis in the East and the right lateral Kalabagh fault in the west (Gee and Gee, 1989). Due to the presence of Eocambrian evaporite sequence, there is a weak coupling between the sedimentary rocks and the basement (Crawford, 1974). The Salt Range Thrust carries Phanerozoic divisions above late Quaternary fanglomerates and alluvium of Jehlum River (Yeats et al., 1984). In the western Salt Range the alignment of the layers sharply changes to N-W from E-W in the central part. A conflicting style of distortion happens in the structural reentrant of the western Salt Range involved by Indus River (Baker et al., 1988).

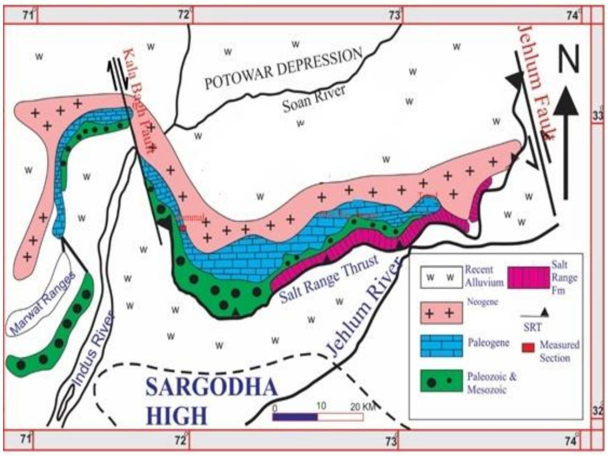

Fig. 1 Geological map of Salt Range with location of measured section of the Nammal Formation, western Salt Range, Pakistan (after Afzal and Butt, 2000).

Materials and Methods

Detailed fieldwork and laboratory methods were used in the present study. A stratigraphic section of the Nammal Formation having 70 m thickness was measured using Brunton compass, Jacob staff, measuring tape, hammer and hand lens. Twelve samples of limestone were taken for microfacies analysis and nine samples of shale and limestone were collected for determination of Total Organic Carbon (TOC) content. For microfacies analysis, the Dunham (1962) classification was adopted. Thin sections were studied and TOC tests were conducted by using Carbon-Sulphur Determinator (CS-300).

Results and Discussion

Litho-stratigraphic units of the Nammal Formation

In the study area, Nammal Formation has a well-developed sequence of approximately 70 m thickness. The formation consists of light grey to creamy color limestone, olive green to grey shale and light grey marl (Fig. 2). The Nammal Formation was assigned Eocene age on the basis of fossil record (Edward, 2007; Afzal etal., 2011). It has conformable lower and upper contacts with Patala Formation and Sakesar Limestone respectively (Fig. 3). On the basis of field observation the Nammal Formation is divided into four distinct units (Fig. 4).

Fig. 2 An outcrop view of the measured section of Nammal Formation, Nammal Gorge section, western Salt Range, Pakistan.

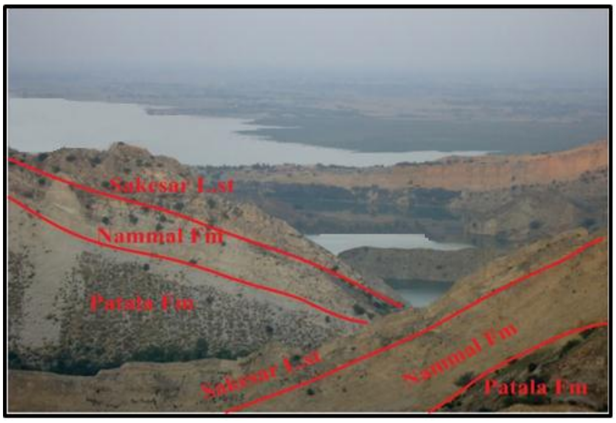

Fig. 3 Field photograph showing lower and upper contacts of Nammal Formation with the Patala Formation and Sakesar Limestone respectively in study area.

Unit-1 consists of an 18m thick sequence of alternate limestone and shale. The weathering color is light yellowish and fresh color is light grey. Limestone is medium bedded and fractured.

Unit-2 consists of 17m thick layers of shales. The shale is calcareous and greyish in color and yields, abundant fossils.

Unit-3 comprises thin to medium bedded fractured limestone with small intercalations of light grey marl. Marl is calcareous and contains abundant fossils. It is 14m thick.

Unit-4 consists of 21m thick and richly fossiliferous limestone. The weathering color of limestone is light creamy to brownish and fresh color is light grey to whitish grey.

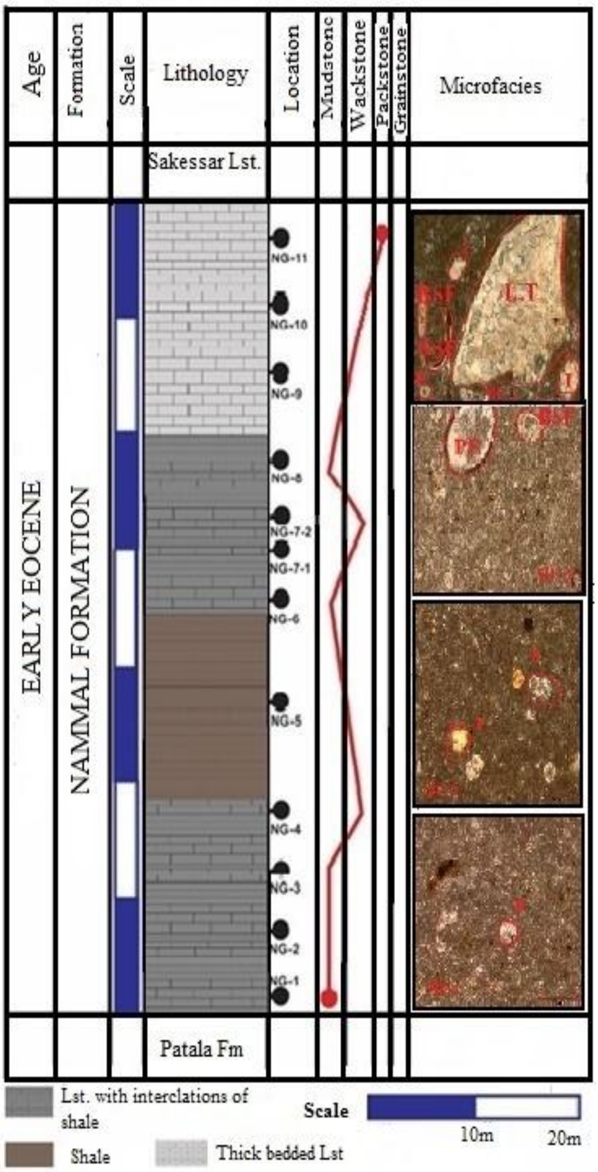

Fig. 4 Microfacies synthesis log of the Nammal Formation, Nammal Gorge section, western Salt Range

Microfacies analysis

A total number of four microfacies have been identified from the Nammal Formation, Nammal Gorge Section, western Salt Range, Mudstones, Wackestones, Wackestones to Packstones and Packstones.

Mudstones (MF-1)

Microfacies, MF-1, consists of 5-7% skeleton grains and about 5% planktons are present. Most shell fragments are of planktons and no benthic foraminifera were observed (Plate 1a). The mud matrix along with broken shells of planktons show low energy environment of deposition under wave base through deep water conditions in the outer ramp to open shelf (Barbieri, et al., 2006).

Wackstones (MF-2)

This microfacies consists of 8-12 % shell fragments of planktons and intraclasts (Plate 1b). Shells are rounded and of similar sizes. The shells are composed of calcite and show occasional signs of dissolution. This facies was deposited in a calm environment below fair-weather base. The presence of micrite and planktonic foraminifera indicates open water marine conditions in outer ramps setting (Pomar et al., 2004).

Wackstones to packstones (MF-3)

It consists of 10-15% grains which include intraclast, planktons and some small benthic foraminifera, pelecypods and opperculina were observed in this facies (Plate 1c). Some calcite was also present which may have formed during the digenetic processes. The presence of pelecypods and opperculina and some other benthic forams indicate deposition in shallow water conditions with low energy (Flugel, 2010).

Packstones (MF-4)

This facies comprises 20-30% fossils shells of benthic foraminifera and some planktons. Intraclasts and calcite veins are present. Recrystallized shells of Lockhartia tipper and calcite veins show effects of dissolution during diagenesis (Plate 1d). The presence of benthic forams supports the interpretation of well aerated, low turbidity and shallow marine conditions (Suchy and West, 2001).

Environment of deposition

The distinctive features and characteristics of a rock unit indicate physical, chemical and biological conditions of the depositional environment. Foraminifera is abundantly found in the epipelagic and outer ramp marine environments. They serve as an important tool to establish the depositional setting of a rock unit (Barbieri, et al., 2006). Presence of abundant forams and broken shells with a lesser amount of mud point towards deposition in high energy environment, such as inner neritic and shallow water condition. Larger benthic foraminifera shows adequate energy settings, thus depositional environment stands to be a shallow shelf (Akhtar and Butt, 1999). The presence of planktonic forams along with mud designate depositional environment under wave base in open shelf through deep water environments (Ghazi, et al., 2004).

The microfacies analysis indicates deposition of the Nammal Formation mainly in deeper water at shelf slope and adjacent basin areas as evident by an abundance of planktonic foraminifera (Fig. 5). The facies analysis suggested that facies of inner to middle ramp setting indicate shallowing uptrend in the Nammal Formation.

Plate 1

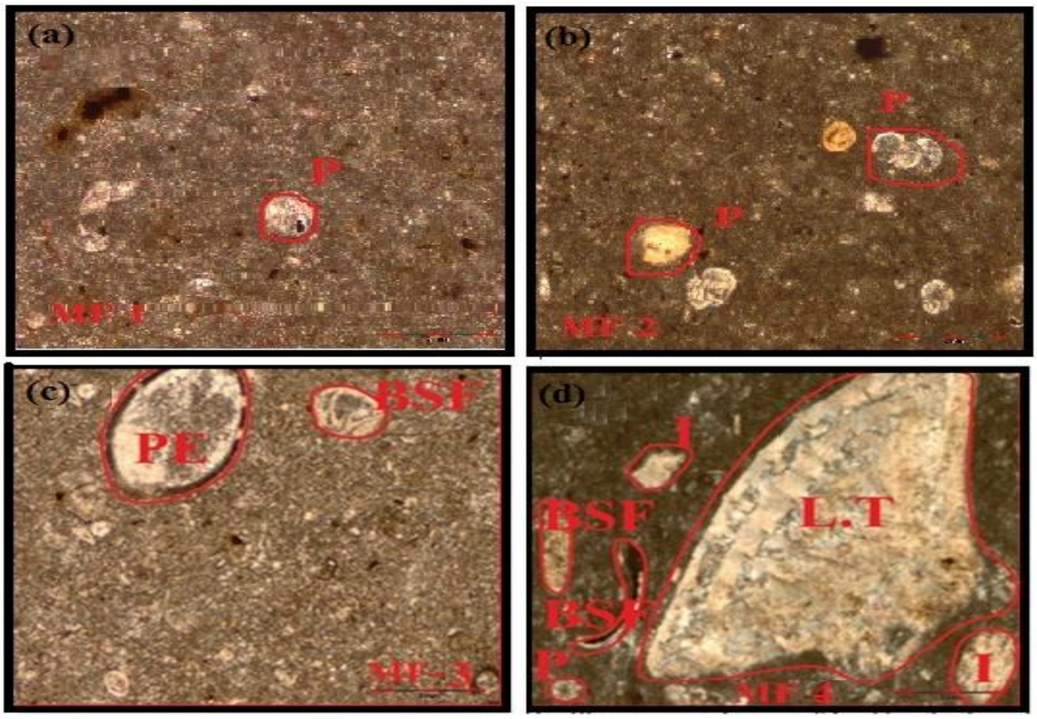

Plate 1 Photomicrographs showing 4 X PPL views of thin sections, (a) Mudstone facies, (b) Wackestone facies. (c) Wackstone to Packstone facies, (d) Packstone facies. (PE= Pelecypods, BSF= Benthic small forams, Op = Opperculina DAVIES and PINFOLD, L.T=Lockhartia tipper, P= Planktons, I= Intraclast, N.S= neomorphosed shell, Cal.V= calcite veins).

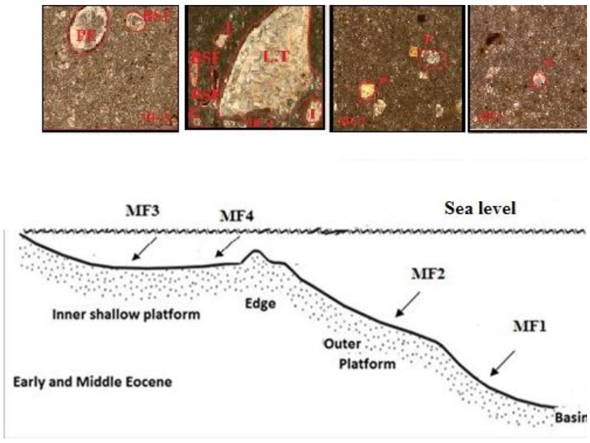

Fig. 5 Depositional environment of Nammal Formation based on microfacies analysis of the measured section in study area.

Source rock potential of the Nammal Formation

The TOC analysis was carried out using outcrop samples of shales and limestones. Rock samples were decarbonized by adding 5-10% concentrated HCL in order to remove inorganic carbon content and then in oven dried at 40 ^{0}C. The carbon-sulphur determinator instrument was used to determine the organic carbon content of rock samples (Fig. 6)

Fig.6 Displaying the CS-300 instrument used for determination of organic carbon content of rock samples procured from the measured section of the Nammal Formation.

Total organic carbon (TOC) results

Total 9 samples were selected for TOC analysis. Five samples (S1, S2, S3, S4, and S5) were selected from shales and four samples of limestone (NG-4, NG-6, NG-7, and NG-8) from the Nammal Formation. The results of TOC analysis are shown in Table 1. The TOC values indicate that the Nammal Formation has poor source rock potential in the studied area. These results could be attributed to unfavorable depositional environment for the preservation of organic matter in the basin. The low values of TOC may have, also, been caused by the factor that rock samples were collected from outcrop, which is prone to oxidation of organic matter from water and air.

Table 1 Results of Total Organic Carbon Content (TOC) of rock samples from the measured section of Nammal Formation, Nammal Gorge, Western Salt Range.

Sample Number	TOC %	Descriptive Term
S1	0.08	Poor
S2	0.009	Poor
S3	0.012	Poor
S4	0.05	Poor
S5	0.06	Poor
NG-4	0.03	Poor
NG-6	0.08	Poor
NG-7	0.03	Poor
NG-8	0.006	Poor

Conclusion

The Nammal Formation consists of four microfacies, i.e., mudstones (MF-1), wackestones (MF-2), wackestones to packstones (MF-3) and packstones (MF-4) in the study area. The microfacies yield planktonic and some of the small benthic foraminifera. Diagenetic features, such as recrystallized shells and calcite veins were also observed. Based on the results of microfacies analysis, it is concluded that deposition occurred in outer to distal shelf environment with shallowing upward trend. The source rock analysis of the formation showed poor values of TOC, which do not support the generation of hydrocarbon from the rock contents of Nammal Formation in the study area.

Acknowledgement

Authors would like to thank the concerned authorities of Higher Education Commission (HEC) of Pakistan, who supported this study through access to Scientific Instrumentation of Hydrocarbon Development Institute of Pakistan and Pakistan Museum of Natural History, Islamabad.

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