9th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2012"

P-065

Source Organofacies in Tertiary and Pre-Tertiary sequences of Ganga Basin and their hydrocarbon exploration significance

Trilok Chand, Sapna Sethi, Sanjeev Kaushal, Neha Rawat, Harvir Singh and R.R.Singh

Summary

The Ganga Basin is a poly-history sedimentary basin in northern India, with four main phases of geological evolution. Basement tectonics played an important role during the sedimentation and deformation of the basin. Search for hydrocarbons in Ganga Basin was started by ONGC as early as 1956. So far fifteen exploratory wells in the structures namely Mohand, Saharanpur, Tilhar, Sahajhanpur, Puranpur, Matera, Tisua, Banda and Ujhani, have been drilled to evaluate the hydrocarbon prospects of Tertiary and Pre-Tertiary sequences in Ganga Basin. For the first time, 45m thick effective source rock sequences (2715-40m and 2770-90m) have been identified in the Pre-Tertiary (Ujhani Formation) in Tisua-A and 35m thick potential source rock with very good source characteristics in Tertiary (Siwalik Formation) in Banda-A through geochemical evaluation.

Source rock assessment of Pre-Tertiary (Ujhani Formation) indicate mature source rock sequences (SS_1: 2715-2740m and SS_2: 2770-2790m) having good/very good organic richness (TOC: 1.72-5.8%) and poor to fair remaining hydrocarbon generation potential (S2:0.86 -2.38 mg HC/g rock) in Tisua-A. These source rock layers are in the late peak oil window as inferred by Tmax (460-470^oC)values. In Banda-A Tertiary sequence(Siwalik Formation) at 2310-2345m possess very good to excellent source rock with very good hydrocarbon generation potential (S2: 81.86mgHC/g rock) and organic richness (TOC: 7.82%) in early stage of maturation (Tmax:433^oC).

GC and GC-MS based biomarker studies performed on the identified source rock units in well Tisua-A revealed two different source facies though the hopane and sterane fingerprints are alike. The studies performed on the bitumen extract of the hydrocarbon show observed in the organic-rich interval at 2160-85m, indicate good correlation with the source sequence SS_2 2770-2790m extract. More or less similar hopane distributions indicate a siliciclastic/calcareous shale source rock with mixed organic matter input deposited in well preserved marine environmental conditions. The organic matter in Tertiary sequence is predominantly marine deposited in marginal marine to shallow marine environment.

Thermal maturation model indicates that good organic rich layers in the Ujhani Formation in well Tisua-A have attained 93-94% kerogen conversion as on present-day. Potential source sequence identified in Banda-A is expected to be mature in the deeper basinal part and might have entered into oil window. The sand layers present in the vicinity of these source rock sequences are worthy for future exploration.

Introduction

Petroleum geochemistry is an established science that improves hydrocarbon exploration success and production efficiency. The petroleum geochemistry increases exploration efficiency by accounting for many of the variables that control the volumes of petroleum available for entrapment (charge), including source rock quality, richness, thermal maturity, and the timing of generation-migration-accumulation relative to trap formation (Murris,1984 and Hunt,1996) respectively. The integrated hydrocarbon exploration activities in Ganga Basin by ONGC since early-sixties of the last century with drilling fifteen exploratory wells so far proved futile. However, some indications of minor oil/gas shows were observed in Terminal Proterozoic-Lower Paleozoic (Madhubani Group) and Neogene (Siwalik) sediments in some exploratory wells (Sahajhanpur-A & Puranpur-A). But, the commercial occurrence oil and gas is yet to be established. Recently, two exploratory wells Tisua-A and Banda-A of Ganga Basin were drilled to evaluate the Pre-Tertiary hydrocarbon prospects in the Ganga Basin.

KDM Institute of Petroleum Exploration, Oil & Natural Gas Corporation Limited, Dehradun-248 195, Uttarakhand, India
E-mail: dogra_tc@rediffmail.com

Geological Setting and Stratigraphy

The Ganga Basin (Fig.1) is a poly-history sedimentary basin in northern India, with four main phases of geological evolution. Basement tectonics played an important role during the sedimentation and deformation of the basin. A thick succession (500-1500m) of Neogene (Siwalik) sediments underlies the Ganga Alluvium as established from a number of exploratory wells, and also exposed as a narrow linear belt towards the northern margins of the basin.

A thick sequence, mainly dominated by calcareous and argillaceous successions, occurs below the Upper Cenozoic sediments in a number of exploratory wells which is referred to as the Lower Palaeozoic. Many workers (Shukla *et al.*, 1993, 1994; Jokhan Ram *et al.*, 1996; Pramanik *et al.* 1996) opined that the pre-Tertiary Sequence of the Ganga Basin is the northern subsurface extension of the Proterozoic Vindhyan sediments. The basin is divided into three sub-basins, viz. Sarda, Gandak and Madhubani depressions. These sub basins are separated by two subsurface basement highs, viz. Shikohabad- Lucknow - Farenda Ridge which separates the Sarda depression from the Gandak depression and Allahabad - Sitamarhi Ridge separates the Gandak depression from the Madhubani Depression (Shukla et al., 1993 and Pramanik *et al.*1996)

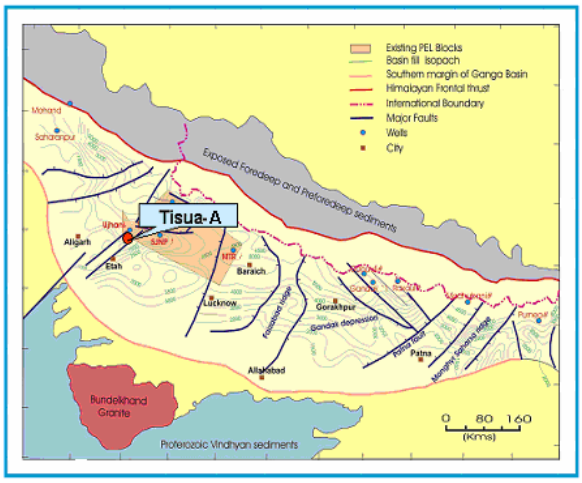

Fig.1: Location map of Ganga Basin (after Bijai Prasad, 2007)

Samples and Methods

All the sediment samples and core samples were pyrolysed on RE-VI by the methods of Espitalie et al. (1977) and Lafargue et al. (1996). Total Organic Carbon measurements were performed on multi EA 2000C carbon analyser after decomposing inorganic carbon with 4N HCl. The EOM of the selected samples were extracted and concentrated. The saturated and aromatic hydrocarbons fractions of EOM were separated by column (50 cm length and internal diameter 0.75cm) chromatography. These fractions were concentrated under reduced pressure and dried by blowing nitrogen. The saturate fractions were analyzed for normal and isoprenoid alkanes distribution on Varian CP3800 Gas Chromatograph. After removal of n-alkanes by urea adduction, the branched and cyclic hydrocarbons in the saturated hydrocarbon fractions of EOM were analysed on a Quattro II triple quadrupole mass spectrometer. Selective Ion Recording (SIR) for hopanes (m/z 191) and steranes (m/z 217) carried out in EI+ Ionization mode at 70 e.v in the mass range: m/z 50 to 650.

Thermal Maturation and Hydrocarbon Generation Modeling

Generation, migration and accumulation of petroleum are very complicated geological processes. The organic matter buried during basin subsidence under goes increased thermal stress with time and generates hydrocarbons. Once saturation is reached, the hydrocarbons expulsion starts from the source rocks and migrate through carrier beds to accumulate in traps having a proper cap rock. In this context, 1D thermal maturation modeling studies were carried out with Genex software in Tisua-A well.

The reconstructed thermal and maturation model of Tisua-A well was based on observed VRo and Rock Eval Tmax data. In the present study kinetic parameters of 100% Type-III in Siwalik Formation and mixed kinetic (95% Type II and 5% Type I) for the source rock layers present in Ujhani Formation were used for hydrocarbon generation modeling.

Results and Conclusions

Out of fifteen wells drilled in Ganga Basin, only the well Tisua-A has about 45m mature source in Lower Cambrian to Lower Ordovician (Ujhani Formation) sequence as shown in Fig.2&4. The Rock-Eval data of studied sediments of Ujhani Formation from 2715-2740m and

2770-2790m intervals (Table-1) shows fair mature source rock sequences (TOC%: 1.72-5.8).

Sl. No.	Depth (m)	Formation	S1 mg.HC/g rock	S2 mg.HC/g rock	S3 mg.CO_2/ g rock	HI mg.HC/g TOC	PI	Tmax °c	S2/S3	TOC %	MINC %	VRo %
1	2160-2165	Ujhani	2.2	2.74	3.64	183	0.45	284	0.75	1.50	0.44	-
2	2165-2170	Ujhani	1.31	1.95	3.03	186	0.40	282	0.64	1.05	0.54	-
3	2170-2175	Ujhani	0.85	1.44	2.24	162	0.37	410	0.64	0.89	0.51	-
4	2175-2180	Ujhani	1.38	1.86	2.9	166	0.43	283	0.64	1.12	0.53	-
5	2180-2185	Ujhani	2.22	3.96	6.3	148	0.36	408	0.63	2.68	0.63	-
6	2715-2720	Ujhani	0.23	1.95	0.36	66	0.11	470	5.42	2.96	0.76	-
7	2720-2723	Ujhani	0.65	2.7	0.39	47	0.19	472	6.92	5.8	0.38	-
8	2723-2725	Ujhani	0.58	2.38	1.12	42	0.20	455	2.13	5.63	0.37	-
9	2725-2730	Ujhani	0.48	2.3	1.11	41	0.17	455	2.07	5.6	0.62	-
10	2730-2735	Ujhani	0.45	1.49	0.59	26	0.23	440	2.53	5.71	0.29	-
11	2775-2780	Ujhani	0.29	1.1	0.6	39	0.21	460	1.83	2.84	0.62	1.1
12	2780-2785	Ujhani	0.22	0.9	0.6	29	0.20	453	1.50	3.09	0.48	-
13	2785-2790	Ujhani	0.19	0.94	0.85	37	0.17	449	1.11	2.55	0.48	-

Table-1: Rock Eval data of Pre Tertiary (Ujhani Formation) Sediments of well Tisua-A

The Tmax data in general ranges from 440-456oC suggests that these intervals have attained middle catagenic stage and VRc (0.72-0.84) a calculated maturity parameter (Table-4) based on MPI1 data are also consistent with maturity stage of the source rock layers. Vitrinite like formed with poor hydrogen by benthonic plants (A.Maende, et al., 2000) was observed only in the cutting samples of the interval 2775-80m. The VRo (%) of the sample is 1.1, which correlates with the maturity corresponding to the Tmax. (460^{o}C). In Banda-A (Siwalik Formation) sediments pyrolysis indicate 35m thick (2310-2345m) excellent source rock (Table-2&Fig.3) in early stage of maturation (Tmax 433^{o}C).

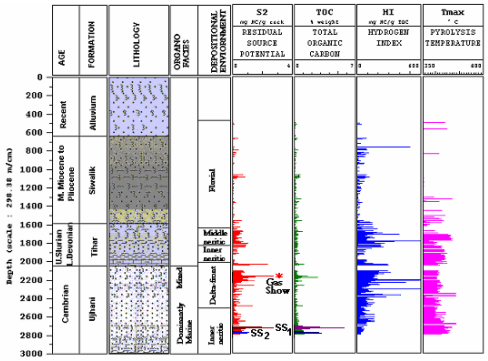

Fig.2: The source rock analysis in well Tisua-A has indicated the presence of 45m thick mature source rock sequences in Ujhani Formation.

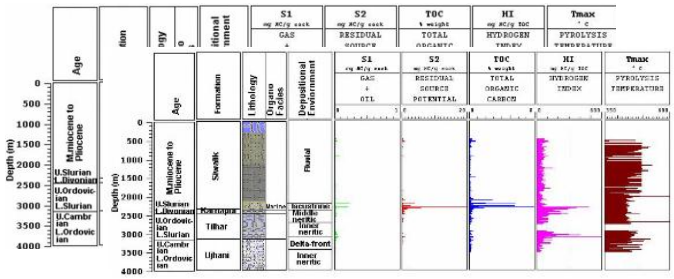

Fig.3: The source rock log of Banda-A well indicates 35m thick (2310-2345m) excellent source rock in early stage of maturation.

Depth (m)	Formation	S1 mg.HC/g rock	S2 mg.HC/g rock	S3 mg.CO_2/ g rock	HI mg.HC/g TOC	PI	Tmax °C	S2/S3	TOC (%)	MINC %
2310-2315	Siwalik	0.74	81.86	1.49	1047	0.01	432	54.94	7.82	1.62
2315-2320	Siwalik	0.38	63.01	1.12	644	0.01	432	56.26	9.78	1.22
2320-2325	Siwalik	0.43	45.86	0.91	627	0.01	431	50.40	7.31	0.5
2325-2330	Siwalik	0.09	26.26	0.63	565	0.00	436	41.68	4.65	0.67
2330-2335	Siwalik	0.1	30.54	0.67	570	0.00	435	45.58	5.36	0.71
2335-2340	Siwalik	0.1	24.01	1.29	435	0.00	434	18.61	5.52	1.36
2340-2345	Siwalik	0.17	26.34	0.61	552	0.01	433	43.18	4.77	0.62

Table-2: Rock Eval data of 2Tertiary (Siwalik Formation) Sediments of well Banda-A

SL NO	Depth (m)	Formation	TOC %	EOM %	Saturate %	Aromatic %	NSO %	Saturate/ Aromatic	β	Pr/Ph	Pr/nC17	Ph/nC18	Pr+nC17 / Ph+nC18
1	2160-85	Ujhani	1.45	0.15	27.18	18.22	40.85	1.49	0.11	1.48	0.84	0.28	0.7
2	2720-40	Ujhani	5.14	0.12	29.69	17.19	46.88	1.73	0.02	4.34	1.18	0.27	1.7
3	2770-90	Ujhani	2.83	0.07	23.36	13.39	54.13	1.74	0.02	1.50	0.55	0.22	0.76

Table-3. Compositional data of EOM of Sediments of Tisua-A well,Ganga Basin

SL NO	DEPTH (m)	Formation	Ts / Ts+Tm	TS / TM	$C_{29}H$ / C30H	$C_{30}M$ / $C_{30}H$	C_{31} Hopane 22S/(22S+22R)	C_{32} Hopane 22S/(22S+22R)	C_{33} Hopane 22S/(22S+22R)	C_{34} Hopane 22S/(22S+22R)	C_{29} Sterane 20S/(20S+20R)	C_{29} Sterane ββ/(αα+ββ)	VRc (based onM PI_1)
1	2160-85	Ujhani	0.44	0.78	1.23	0.11	0.54	0.60	0.60	0.62	0.36	0.75	0.72
2	2720-40	Ujhani	0.45	0.83	1.19	0.09	0.57	0.61	0.59	0.63	0.43	0.74	0.78
3	2770-90	Ujhani	0.49	0.98	1.16	0.09	0.57	0.61	0.61	0.6	0.28	0.78	0.84

Table -4. Biomarker distribution in EOM of sediments of Tisua-A,Ganga Basin.

GC and GC-MS based biomarker studies (Table-3, 4& Fig.5) enabled to distinguish the two source rock layers. More or less similar hopane distributions indicate a siliciclastic/calcareous shale source rock for these extracts (29H/30H > 1.0) with mixed organic matter input deposited in well preserved environmental conditions.

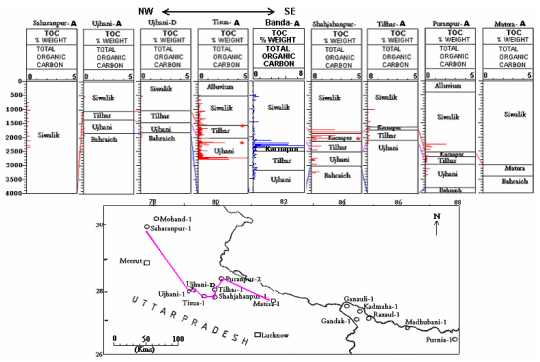

Fig.4: source potential of sediments encountered in different wells of Ganga Basin. Tisua-A well has about 45m fair mature source rock in Lower Cambrian to Lower Ordovician (Ujhani Formation) and 35m potential source rock in Middle Miocene to Pliocene in Banda-A.

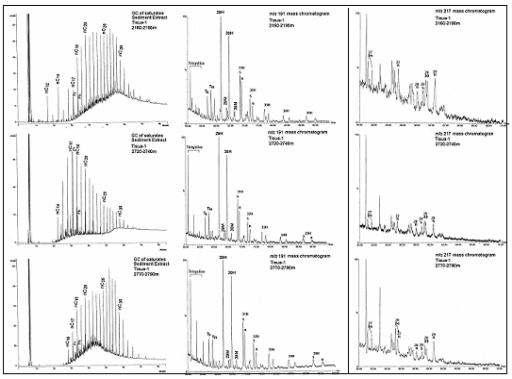

Fig.5: GC and GC-MS of bitumen extracts of source rocks units (2715-40m and 2770.90m) and hydrocarbon show (2160-85m) reveal that both source facies are different though the hopane and sterane fingerprints are alike. The Hydrocarbon show observed in the organic-rich interval, 2160-85m, indicates a good correlation with the source rock extract of 2770-2790m in Tisua-A.

Presence of tricyclic compounds in m/z 191 and significant presence of C29H and higher homolog of hopane (Fig.5) also suggest dominant marine source organofacies of the organic-rich layers. The hydrocarbon show observed at 2160-2185m interval of Ujhani Formation indicates migrated bitumen that correlates with deeper source rock extract (2770-2790m).

In well Banda-A the Pristane/Phytane ratios (1.66), β (0.02) and napthenic hump after nC27 indicate that the source rock layer 2310-2315 is in immature stage. Tmax data (433°C) and petrophysical studies also corroborated the findings. C maxima at nC18 and even n-alkane dominance show predominantly marine input. The GC-MS-MS, MRM studies (Fig.6) shows that both C27 and C30 steranes are present in significant abundance. The organic matter is predominantly marine deposited in marginal marine to shallow marine environment .Further presence of gammacerane is m/z191 mass chromatograms indicates that the depositional environment ultimately became lacustrine-lagoonal type.

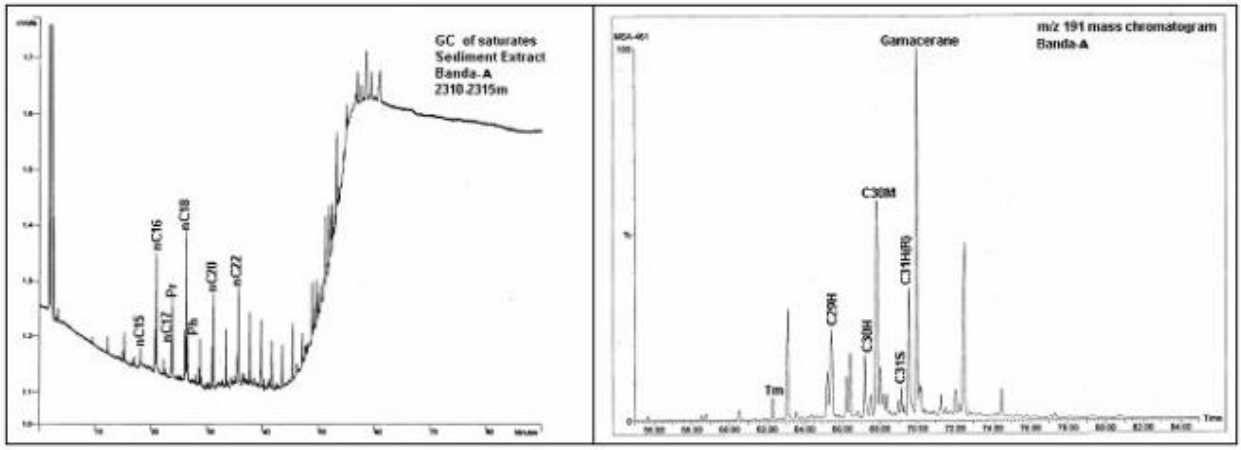

Fig.6: GC fingerprints and mass chromatograms of EOM of sediment samples of Middle Miocene to Pliocene(Siwalik Formation) of Banda-A well, Ganga Basin indicate that the source rock layer 2310-2315 is in immature stage and organic matter is predominantly marine deposited in marginal marine to shallow marine environment. The presence of gamaserane indicates lcustrine-lgoonal type deposinal environment

Attempt has been made to reconstruct the burial and thermal history model of the Tisua-A well based on geochemical inputs derived from lab analysis. The control on thermal model was achieved by obtaining close fit between observed and computed VRo and Tmax of Rock Eval data. The modeling was performed under the following two scenarios based on certain assumptions:

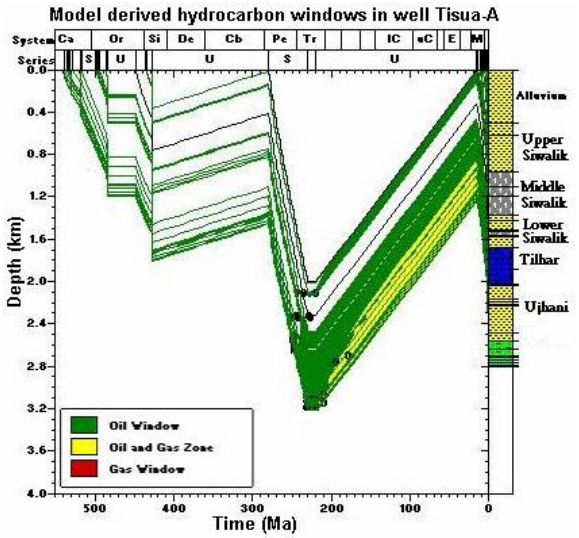

Fig.7: The hydrocarbon windows of Tisua-A showing maturity Levels of source rock sequences

The three major tectonics (upheaval) during Pre-tertiary are; Rifting during Mesoproterozoic and Late Neoproterozoic, Deposition of shallow marine sediments in Ediacaran – Early Devonian and Passive margin during Late Eocene – Oligocene. The model has been discussed under two scenarios. (1) Approximately 2000m (2km) sediment got deposited between 280-230Ma during Gondwana period that subsequently eroded due to immense tectonic activity associated with upliftment in the study area. This scenario offered the best fit model with the observed thermal maturity parameters.(2) The second scenario, assumes the absence of Gondwana sediments, if the eroded stratigraphic column belongs to Vindhyan sediments, then an additional 4.2Km missing section of Vindhyan sedimentation has to be invoked to fit the observed thermal maturity of the source rock layers deposited in the Ujhani Formation.

Thermal maturation modeling (Fig.7) in the first scenario indicates that in the Tisua-A well, the organic rich source rock layers in the Ujhani Formation attained kerogen conversion to a maximum of 93-94% as on present-day with significant oil generation (20% TR) began 241Ma before present with peak expulsion between 240-205Ma. Alternately peak expulsion was in Devonian age (400-370Ma) in the case of second scenario. Hence the sand layers present in the vicinity of these source rock sequences are worthy for future exploration.

Acknowledgements

The authors are indebted to Sri P.K.Bhaumick, ED-HOI-KDMIPE for his inspiration and suggestions. The gratitude are due to Shri Harindar Upadhyay, General Manager (Geology) and Dr. Bijai Prasad, Dy. Gen. Manager (Paly.), for fruitful discussions and valuable suggestions from time to time. The views expressed in this paper are solely those of the authors and, in no way, reflect the views of the organization they represent.

References

Espitalie J.M., M. Madec, B.Tissot, J.J.Menning, P.Leplar, 1977, Source rock characterization method for Petroleum Exploration: Annual offshore Technology Conf., Vol.3, pp. 439-448.

Bijai Prasad, L.Phor, R.Asher, T.C.Saikia,S.Sinha and N.Pendkar, (2007). Integrated geological and geochemical studies of samples from well Tisua-1, Ganga Basin, Unpublished Report, KDMIPE.

Hunt, M., 1996, Petroleum Geochemistry and Geology: 2nd Edition. , W.H. Freeman and Company, New York (1996).

Jokhan Ram, S.N. Shukla, A.G. Pramanik, B.K. Verma, G. Chandra, and M.S.N. Murty, 1996, Recent investigations in the Vindhyan Basin: Implications for the basin tectonics. Mem. Geol. Soc. India, no. 36, pp. 267-286.

Lafargue E., J.M. Espitalie, F.Marquis and D, Pillot, 1996, Rock Eval-6 applications in hydrocarbon exploration, production and in soil contamination studies: Presented at the 5th Latin American Congress on Organic Geochemistry, Cancun, October 6-10.

Murris, R.J., 1984, Petroleum Geochemistry and Basin Evaluation In: Demaison, G.,Murris, R.J. (Eds.), American Association of Petroleum Geologists Memoir 35, Tulsa, Oklahoma, pp. x–xii.

Maende,A.F, M. Mbatau and P.K.Thuo, 2000, Source rock potential of two shales of Lodwar South sub basin,Tertiary Rift Valley,Kenya: Petroleum Geochemistry & Exploration in the Afro-Asian Region 5th Intl.Conf.&Exbn.25-27 Nov., page 147-74.

Pramanik, A. G., J. Ram, and G.C. Katiyar, 1996, Ganga Basin-Geologic evolution and hydrocarbons prospectivity: Ind. Journ. Petrol. Geol, vol. 5 (1), pp. 1-33.

Shukla, S. N., B.Mudiar, and M.M. Misra, 1994, Lithostratigraphy of Ganga Basin, India: Indian Journ. Petrol. Geology, vol. 3 (No. 2); pp. 69-90.