Significance and Laboratory Characterization of High Gamma Clay Markers:Examples from Pasarlapudi Formation, Pasarlapudi Field, KG Basin

N. Pendkar[1] and K.C. Vig[2]
[1]RGL, A&AA Basin, ONGC Ltd., Sivasagar, Assam –785697
[2]Mumbai Region, ONGC Ltd., Mumbai

Summary

To recognize the significance of high gamma markers within Pasarlapudi Formation in Krishna Godavari Basin, laboratory investigations were undertaken to understand the relationship of high gamma signature with mineralogy, organic matter, and depositional environments. The content of U, Th, and K were determined using Natural Gamma Spectroscopy. Amongst U and Th, the latter is present in abundance. The relationship between GR value and Th has a correlation coefficient of 0.92, followed by U (0.80) and K (0.41). There is also a good correlation between the presence of organic matter and GR (0.45). Based on these analyses, it is inferred that Th followed by U is contributing to the high gamma-ray signature. A quantitative examination of clay minerals indicates that chlorite followed by kaolinite is the dominant clay minerals along with montmorillonite and illite. The formation of high gamma shales present in Pasarlapudi Formation was due to intermittent basinal scale transgressive episodes of sea-level changes.

Introduction

High gamma markers play a key role in evaluating stratigraphic analysis by allowing correlation between different horizons both at outcrop level (Sharma et al, 1994; Aigner et al, 1995), but mostly in subsurface where electrlogs provide an important analytical tool. Key markers have a great significance in comprehending the regional variation of various litho units, especially as it relates to the regional distribution of source rock and reservoir facies in a producing field (Davies and Elliott, 1996). The present study was undertaken to understand the significance of clay mineralogy, mineral chemistry, organic matter, and gamma ray signatures present in sediments of Pasarlapudi Formation of Krishna Godavari basin from four different wells (Figure 1). This formation has a key role in making of several hydrocarbon-bearing fields in KG basin (Rao, 2001). The recognition of this phenomenon at a fundamental formation level will greatly help in understanding the stratigraphic significance of these local markers, not only for this formation, but similar such litho units aiding accurate correlation in the basin.

Pasarlapudi Formation mainly consists of sandstones and shales with thin limestone bands. The shales are gray, moderately hard and compact, splintery, fissile, with pyrite and mica and thin bands of argillaceous sandstones at places. Minor load structures are seen at their

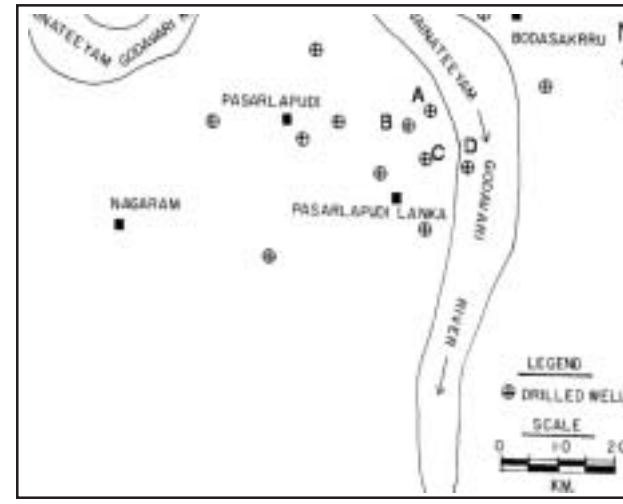

Fig. 1: Location of the study wells in Pasarlapudi Field, KG basin

contact with sandstone. The thickness of this formation in type well is 870 m. The formation thickens towards coastal tract basin and laterally changes to Vadaparru Shale (Venkatrangan et al., 1993). The Pasarlapudi Formation is predominantly arenaceous in the Chintanpalli area but towards the northeast and southwest part of Godavari Trough, it becomes predominantly argillaceous with organic matter (Venkanna et al, 2000). The top of the formation can be clearly demarcated by the presence of an overlying limestone section of middle Eocene age. The bottom of this formation is marked by presence of a major argillaceous

sequence termed as Palakollu Shale (Figure 2). The age of the formation ranges from Late Paleocene to Early Eocene. The formation has been interpreted to be deposited in open marine conditions based on paleontological data.

Methodology

The goal of the present study is to evaluate the parameters that are contributing to the high gamma signature in Pasurlapudi Formation of Lower Eocene age.

Quantitative mineralogical studies were carried out on samples that had been measured for Natural Gamma Spectrometry (Wells A, B, and C; Table 1). Natural Gamma Spectrometry (NGS) is a laboratory technique offering powerful approach to evaluate the quantitative signature. In addition, samples from Well D, where NGS log was available was also utilized for study (Table 1). Laboratory analyses on samples include semi-quantitative clay and bulk mineralogy using x-ray diffraction and bulk chemistry of the sediments by x-ray fluorescence methods to resolve the role played by major and minor elements. Both these methods offer quantitative insights to the mineralogical and chemical factors controlling the high gamma signature. Clay mineral determinations were used in conjunction with NGS data to evaluate and pinpoint the most likely adsorbed element in the particular type of clay mineral. Bulk XRD data was utilized in understanding the distribution of overall mineralogy of the sample.

Factors Causing High Gamma Signatures

Natural gamma radiation in rocks is almost entirely attributable to potassium-40 and the radioactive isotopes of the uranium and thorium families. A conventional gamma ray log records a pooled summation of counts from all radioactive sources. According to Adams and Gasparini (1970) uranium and thorium are chemically stable in the tetravalent ion state under reducing conditions, have similar ionic radii, equal coordination number (8) with respect

Table 1 List of Wells and Studied Intervals for examination of High Gamma Markers

Well No	Sampled Intervals Examined during present study for mineralogical and NGS Spectrometry studies
A	2558.06-2562.50 m
B	2731.24-2737.99 m
C	2511.37-2668.24 m
D	2137.50-2802.5 m

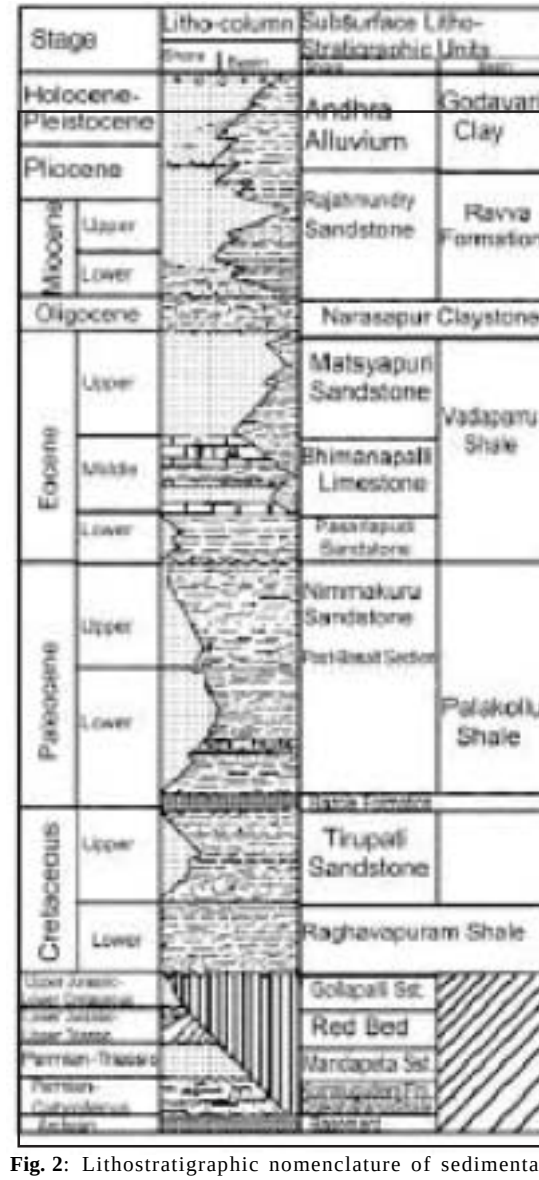

Fig. 2: Lithostratigraphic nomenclature of sedimentary sequences penetrated in the KG basin (after Rao, 2001).

tooxygen, and complete outermost electron shells. As a result they strongly tend to remain together in geologic processes that occur under reducing conditions. Because of their large atomic size, high valence and electronegativity, uranium and thorium cannot form isomorphic series that involve major rock forming minerals and occur mostly in accessory minerals. Uranium is a soluble element that is transported in solution, and rarely in suspension. It is dissolved out during the alteration or leaching of source minerals, which are mainly from felsic igneous rocks. Leaching is active in the presence of water rich with organic acids. Uranium will precipitate and accumulate in sediments in presence of organic matter, platy minerals, by bacterial

action of anaerobic bacteria in reducing conditions, as phosphate, in acidic environments, in presence of adsorptive materials like amorphous silica, alumino-silicates, and coals. Under oxidizing conditions, thorium remains stable in the tetravalent state but uranium is oxidized to the hexavalent state and is soluble in aqueous solutions. Unlike uranium, thorium is relatively insoluble, and therefore the dominant mechanism of thorium for transportation is in suspension form, and is mostly found in detrital material (Gableman, 1977). The small amount of thorium that goes in to solution is adsorbed on to clay minerals. In fine-grained sediments, thorium is found in detrital clay minerals, where it is adsorbed on the platelet surfaces. Some of the accessory minerals that often contain uranium and/or thorium are apatite, sphene, zircon, allanite, monazite, pyrochlore, thorite, uraninite, and xenotime. Thorium is found in natural state in felsic igneous rocks like granites, which are inferred as provenance using petrography for the studied formation.

Potassium is an alkali element and is one of the major rockforming elements of the Earth's crust (Fairbridge, 1972). It is present in almost all crustal rocks and is enriched in the last stage of magmatic differentiation. During weathering of crystalline rocks, potassium is readily dissolved but is also easily removed from solution. Potassium in solution is readily adsorbed on clay minerals or may contribute to the formation of glauconite and sericite. Under certain conditions, potassium can precipitate from seawater as a chloride or sulfate (carnallite, kainite, sylvite). Common potassium minerals found in igneous and metamorphic rocks are potassium feldspar, leucite, muscovite, and biotite. The provenance for the studied formation has been derived from mostly felsic plutonic and metamorphic rocks.

Results and Discussion

To understand the significance of high gamma with various factors like organic matter content, enrichment of different radioactive elements, chemistry, and clay minerals correlation coefficients were used to determine the relationship between them.

For samples from wells A, B, and C the distribution of clay minerals indicates that chlorite followed by kaolinite is the dominant minerals. Illite is present at times in traces, and montmorillonite is present in traces (Figure 3). However, for samples from Well D, montmorillonite is present in addition to chlorite, illite, and kaolinite (Figure 4 and 5). The conventional and NGS logs for a part of studied interval of Well D is depicted in Figure 6.

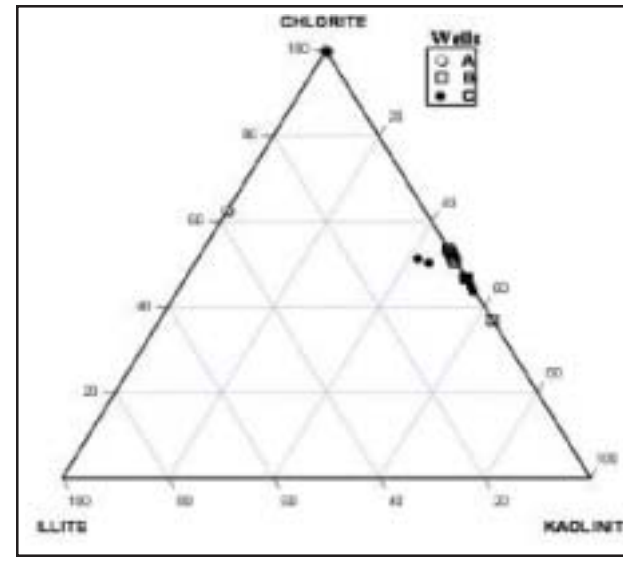

Fig. 3: Clay mineralogical distribution for Wells A, B, and C. Montmorillonite is present in traces, and has not been depicted in the plot.

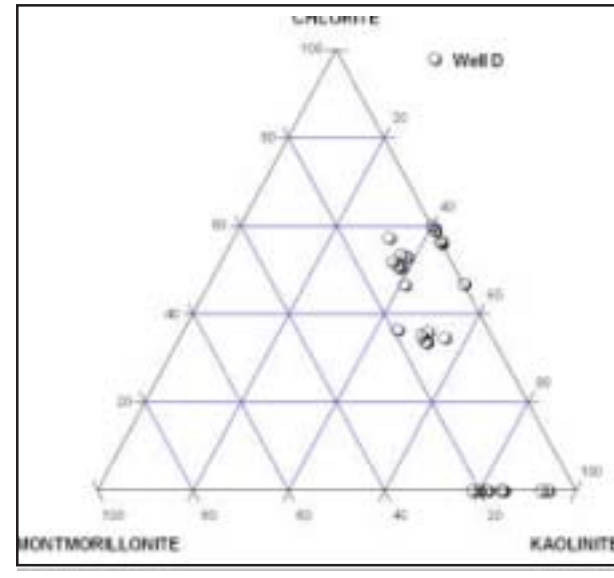

Fig. 4: Clay mineralogical distribution For Well D. Illite is present in minor amount, and has not been depicted in the plot.

The detrital fraction of the examined sediments was depleted in feldspar content. This was concluded after representative samples were examined by petrography and bulk XRD analysis. The bulk mineralogy of coarser sediments shows presence of dominant quartz, with traces of plagioclase feldspar and orthoclase. The chemical composition shows significant enhancement of iron (Figure 7).

Plots of TOC against GR (API) units were made to understand the significance of organic matter versus the

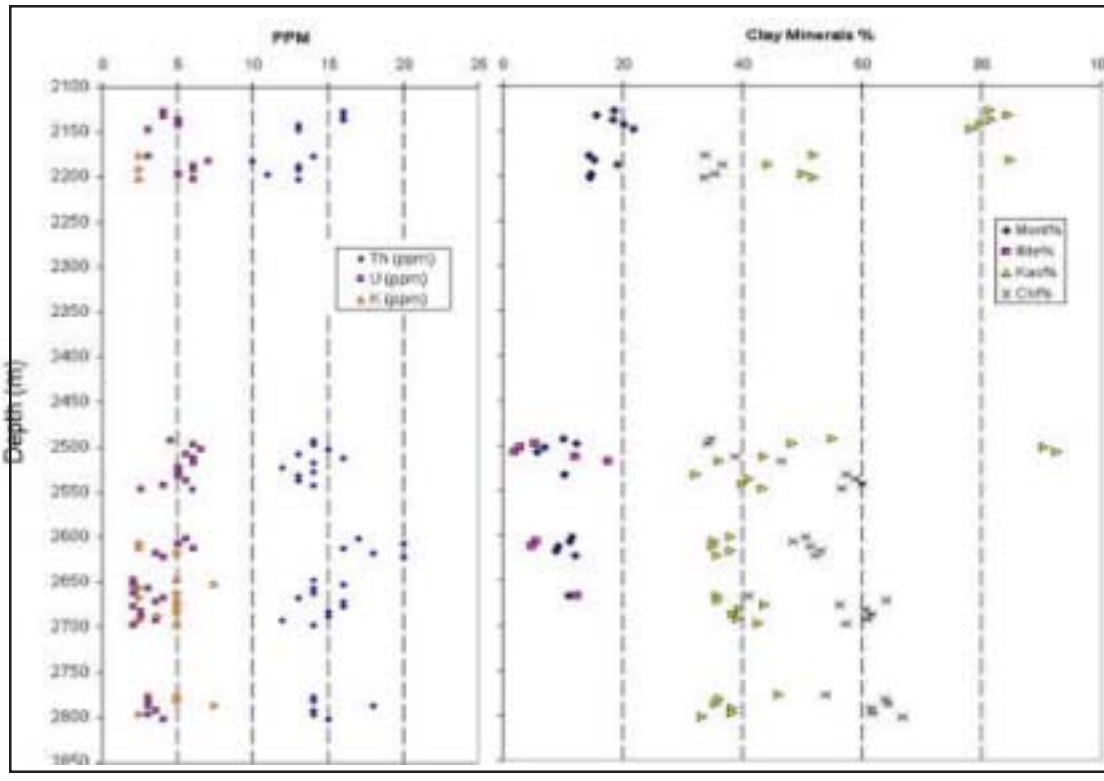

Fig. 5: Composite log showing values of Th, U, and K (as ppm) derived from NGS log and a plot of various clay minerals (as %) determined from XRD analyses for Well D.

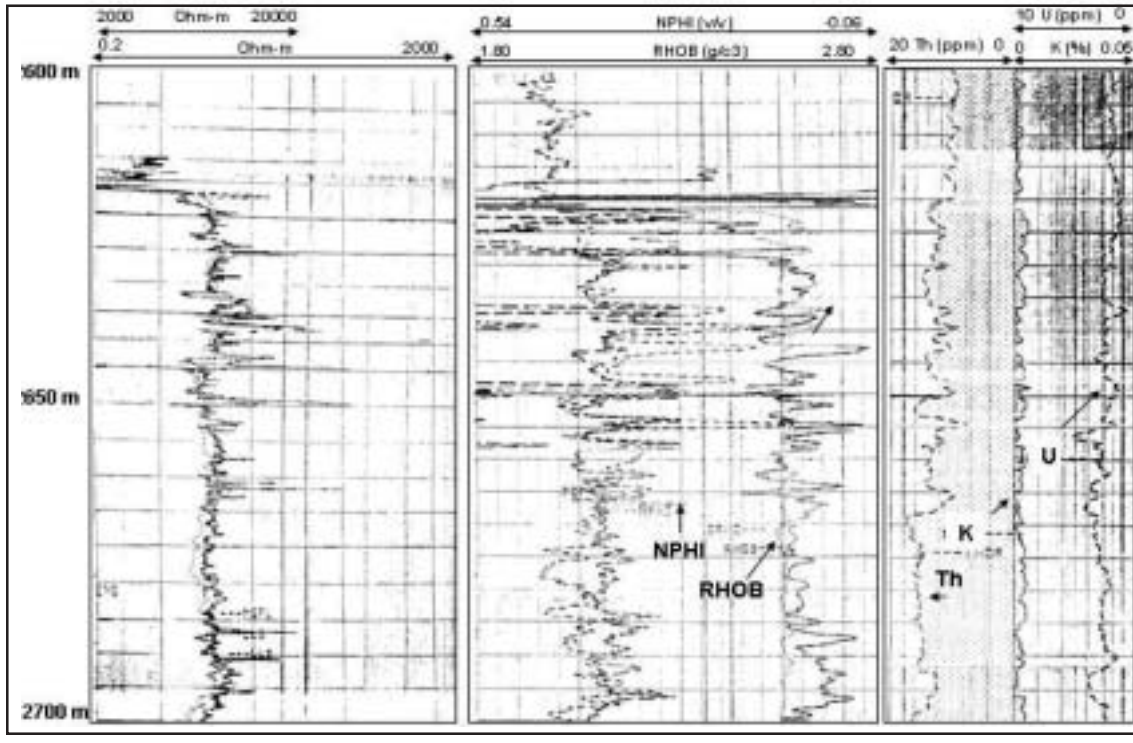

Fig. 6: Logs (resistivity, porosity and NGS) for a part of studied section of Well D.

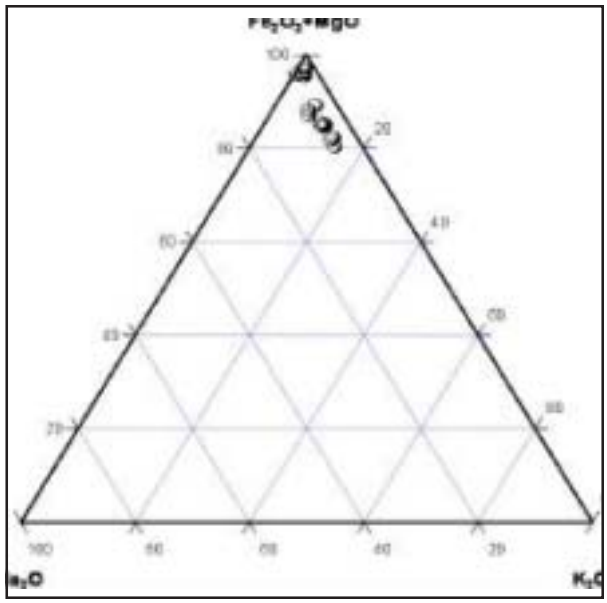

Fig. 7: Geochemical plot for shale samples from Wells A, B, C, and D. The plot significant enrichment of Fe2O3+MgO component compared to Na2O and K2O.

gamma ray enhancement. The plots show a fair correlation (linear r2=0.45 and exponential r2=0.68) showing that the organic matter played a key role in the enhancement of the gamma ray value (Figure 8).

The percentages of the main radioactive elements that give ise to gamma ray like K, U, Th were examined for their significance (Figure 9). It was found that the Th has the best statistical significance and correlate well with the GR (r2=0.92), followed by U (r2=0.80), and K (r2=0.41).

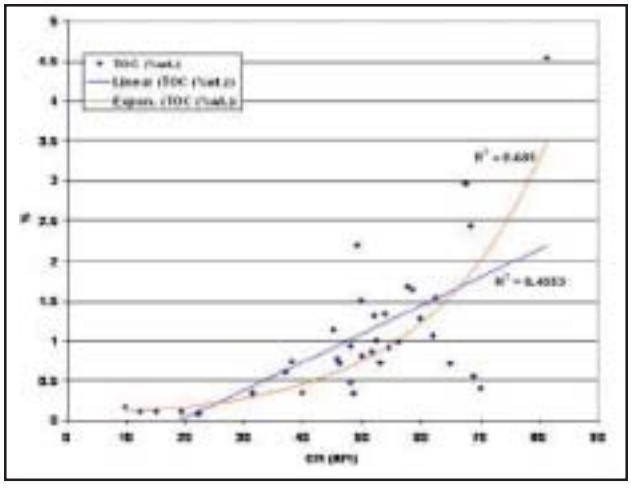

Fig. 8: Plot of TOC content versus GR API units for studied wells from Pasarlapudi field.

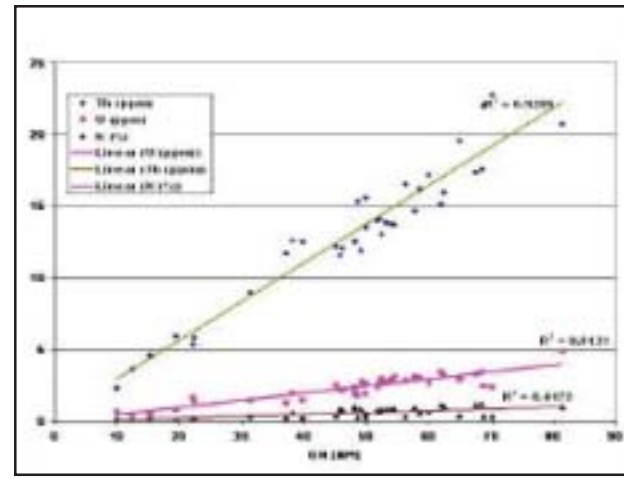

Fig. 9: Plot of GR API units versus concentration of various radiactive elements for studied wells from Pasarlapudi field.

It can therefore be interpreted that Th was significant radioactive element for contribution towards GR, followed by U. NGS measurements for Wells A, B, and C also determined the dominance of Th.

Kaolinite is a 1:1 phylosilicate composed of a Si thetrahedral sheet and a A1 octahedral sheet (dioctahedral) combined so that the oxygen at the apex of the Si tetrahedrons extend into and are part of the octahedral sheet. There is very little ionic substitution in kaolins, except for small amounts of Fe3+. The fundamental 14A**0** unit layer of the trioctahedral chlorite consists of negatively charged 2:1 mica like layers that alternate regularly with positively charged hydroxyl sheets. The negative charge is created largely by the substitution of Al**3+** in the tetrahedral sheets. Many chlorites formed under low temperature conditions have incomplete interlayer sheets. Illite is a 2:1 phyllosilicate and has composition close to mica, with substitution of Mg2+ and Fe2+ to give it a tetrasilic character. Montmorillilonite is a dioctahedral clay mineral and have interlayer water at normal values of humidity. They are characterized by disorder with respect to the way in which 2:1 layers are stacked. They have high cation exchange capacity, due to low layer charge, and therefore weak bonds holding the interlayer cations (Weaver, 1988).

The cation exchange capacity for smectite, illite, kaolinite, and chlorite is 80-150, 10-40, 10 meq/100g respectively. Clay surfaces have a negative charge, so when clays are placed in solution, cations from solution are attracted to clay surfaces to maintain electrical neutrality. An additional factor that enhances the adsorbtion of cations is the large surface area of clay minerals due to their platy

habit (Eslinger and Pevear, 1988); some clays therefore have large internal or intercrystalline surface area. According to van Olphen and Fripiat (1979), smectite has a surface area (both internal and external) of 800 m2/gram, with chlorite, kaolinite, and illite, having a surface area of 20, 15, and 30 m2/gram respectively. A plot of Th versus kaolonite and chlorite for the studied samples shows that there is a positive trend associated with chlorite and Th content of the samples (Figure 10).

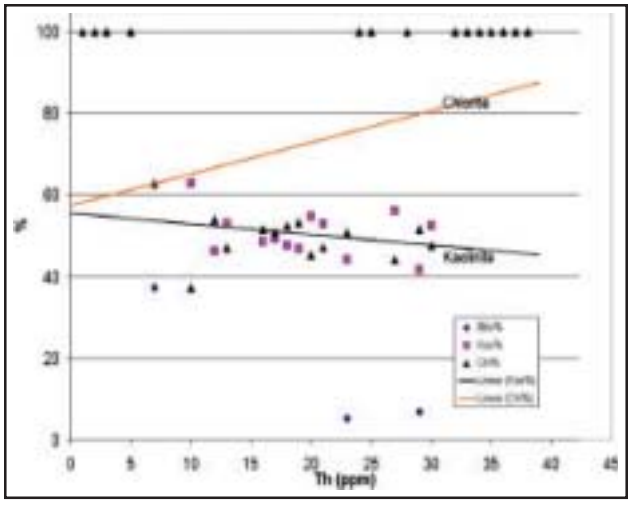

Fig. 10: Plot of Th versus percentage of illite, chlorite, and kaolinite for samples from wells A, B, and C. Chlorite shows a positive trend. Event though montmorillonite may have significant effect, it could not be plotted due to estimation uncertainties.

In a pioneering paper, Adams and Weaver (1958) concluded that the Th/U ratio was often strongly linked with depositional environment, based on their laboratory analysis of many samples of differing lithologies. They suggested that when the ratio was computed to be <2 (i.e., uranium-rich), the depositional environment had promoted uranium fixation under probable reducing conditions and was most commonly marine. For the present study, it was observed that sandstones have fairly low radioactivity because they consist mainly of quartz, and have only minor contents of clay, feldspars, and other accessory minerals. By contrast, the interbedded shales have moderate radioactivity caused by thorium adsorbed on the clay platelets, potassium in the composition of some clays, and variable amounts of uranium generally associated with organic matter and fixed under reducing conditions.

Conclusions

The concentration of radioactive elements on clay minerals was facilitated in the presence of organic matter. The high gamma intervals are characterized by mainly thorium and subordinate uranium; the clay minerals associated are montomorrilonite, chlorite, kaolinite and illite. Even though montmorillonite is not predominant clay mineral, its crystalline properties facilitate a large role in the enhancement of gamma ray signature. XRF analysis shows that the sediments are rich in silica and alumina with significant enhancement of iron. The presence of iron may be related anoxic environment present with preservation of organic matter.

It has been found that the preservation of organic matter in marine conditions is best associated with periods of marine transgression, where because of rising sea level associated with plate tectonic activity, the oceans become mildly to strongly anoxic leading to preservation of organic matter (Adams and Weaver, 1958). A small-scale event similar to this would be relative sea level associated with basin level tectonics.

It is thus inferred that the high gamma shales present in Pasarlapudi Formation were deposited during basin level sea level fluctuations that were ultimately linked to global scale sea level oscillations during Late Paleocene/ Early Eocene times (Leckie et al 1990). These changes were responsible for enrichment of thorium and uranium during transgressive episodes in the presence of organic matter.

Acknowledgments

The authors are thankful to Shri D. P. Sahasrabudhe, GGM & Basin Manager, A&AA Basin for his kind permission to publish this paper. We also gratefully acknowledge our thanks to Dr. Dewakar, Head, RGL, for all encouragement. Mr. James Peters, GM (Geology) and then Head of Geological Laboratories gave keen insight to this study carried out during the tenure of authors at KDMIPE, Dehradun. We are thankful to Mr. N. C. Gupta of NGS Laboratory, KDMIPE for discussions and samples. The views expressed here are of authors and do not represent the organizational viewpoint.

Views expressed in this paper are that of the author(s) only and may not necessarily be of ONGC.

References

Adams, J.A., and Weaver, C.E., 1958. Thorium to uranium ratios as indicators of sedimentary processes; example of concept of geochemical facies. Bull. Am. Assoc. Pet.

Geol., 42.

Adams, J.A.S. and Gasparini, Paolo, 1970, Gamma-ray spectrometry of rocks: New York, Elsevier Publishing Company, 295 p.

Aigner, T., Schauer, M., Junghans, W.D., and Reinhardt, L., 1995, Outcrop gamma-ray logging and its applications—

examples from the German Triassic: Sedimentary Geology, v. 100, p. 47-61.

Davies, S.J., and Elliott, T., 1996, Spectral gamma ray characterization of high resolution sequence stratigraphy— examples from Upper Carboniferous fluvio-deltaic systems, County Clare, Ireland, in Howell, J.A., and Aitken, J.F., eds., High resolution sequence stratigraphy; innovations and applications: Geological Society [London] Special Publication No. 104, p. 25-35.

Eslinger, E., and Pevear, D., 1988, Clay Minerals: SEPM Short Course Notes No. 22.

Fairbridge, R.W., ed., 1972, The encyclopedia of geochemistry and environmental sciences: Encylopedia of Earth Science Series Volume IVA, Van Nostrand Reinhold

Company, New York, 1321 p.

Gableman, J.W., 1977, Migration of uranium and thorium - exploration significance: Studies in Geology No. 3, The American Association of Petroleum Geologists, Tulsa, Oklahoma, 168 p.

Leckie, D. A., Singh, C., Goodarzi, F., and Wall, J. H., 1990, Organic rich radioactive marine shale: A case study of a shallow water condensed section, Cretaceous Shaftsbury Formation, Alberta: Journal of Sedimentary Petrology, v. 60, p. 101-117.

Rao, G. N., 2001, Sedimentation, stratigraphy, and petroleum potential of Krishna-Godavari basin, East Coast of India: Bulletin American Association of American Geologists, v. 85, p. 1623-43.

Sharma, S.K., Mallik, S., and Gupta, S.S., 1994, Analysis of gamma ray spectrometry (GST) surveys in Ankleshwar field, India: Indian Journal of Petroleum Geology, v. 3, no. 1, p.45-63.

van Olphen, H., and Fripiat, J. J., 1979, Data book for clay materials and other non-metallic minerals: Pergamon Press, New York

Venkanna, P., Rao, BVS., Srivastava, TB, Mehrotra, KL, and Guha, B, Source potential assessment in the Island and Amalapuram areas in East-Godavari sub-basin, KG Basin

India: Proceedings of Petroleum Geochemistry in Afro- Asian Regions, 5th Inter. Conf. And Exbn., 25-27 Nov 2000, New Delhi

Venkatrangan, et al., 1993, Lithostratigraphy of Indian Petroliferous Basins: Document VIII

Weaver, C. E., 1989, Clays Muds, and Shales: Developments in Sedimentology, V. 44, Elsevier, Amsterdam.