Bulletin of Earth Sciences of Thailand

Fluvial stratigraphic architecture in outcrop and its gamma-ray response

Shahidul Islam

Petroleum Geoscience Program, Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand

*Corresponding author email: shahidul_79@yahoo.com

Abstract

The assumptions in determining sub-surface lithology to interpret specific depositional environments from vertical logs are based on an unambiguous relationship between gamma-ray geometry and sedimentary processes. These assumptions are suspect with respect to interpreting fluvial stratigraphic architecture. This study focuses on outcrop gamma-ray data and sedimentological/ stratigraphic observations for a better understanding of the relationship between log shape and fluvial architecture as a model for the sub-surface. The study shows that gamma-ray logs are helpful in defining the vertical trend of sedimentation but not correlable to facies based on sedimentary structures. Overlaps occur between facies which may pose problems for interpretation of sub-surface well-log data. Correlation between gamma-ray data and architectural elements shows that determining stratigraphic variability from sub-surface gamma-ray log is not so reliable. Gamma-ray log can only differentiate sandstones from siltstone or mud, but cannot distinguish sandstone-dominated architectural element types. Thin beds, their extension and small-scale sedimentary features which have a great impact on reliable interpretation of depositional system and reservoir properties are not possible to determine by gamma-ray log. Comparison of outcrop spectral gamma-ray data to nearby core data would help to determine variations in the spectral gamma-ray signature, which may help to interpret architectural elements in the sub-surface from gamma-ray logs.

Keywords: Fluvial Architecture, Gamma-ray, Stratigraphy

1. Introduction

It is common practice to use gamma-ray logs to determine lithology in the subsurface, with finer grained sedimentary rocks generally displaying higher gamma-ray values and coarser strata having lower gamma-ray values. The assumptions in this practice are to interpret specific depositional environments from vertical logs based on an unambiguous relationship between log geometry and sedimentary processes. Both of these assumptions are suspect with respect to interpreting fluvial stratigraphic architecture. This study focuses on outcrop gamma-ray data and sedimentological/stratigraphic analysis for a better understanding of the relationship between log shape and fluvial architecture as a model for the sub-surface.

2. Methods

The datasets used in this research come from outcrop study in Loei-Phetchabun Folded Belt under Loei province, north-east Thailand. A detailed outcrop study of sedimentology and stratigraphy was carried out in a meandering channel deposit to determine depositional environments and stacking patterns. Spectral gamma-ray measurements were integrated with the outcrop study to determine and to see how well the lithofacies and their stacking patterns are represented by a gamma log signature.

3. Results

3.1 Facies description and interpretation

Eight facies were defined from the outcrop:

Laminated muddy sandstone

The laminated muddy sandstone is the bottom most facies of the studied section. It is fine-grained grey to dark grey sandstone and is interpreted as low energy channel-fill i.e., abandonment of channel deposit. The facies shows erosional basal contact with sharp and abrupt contact at top.

Planner cross-bedded sandstone

This medium to coarse-grained quartzitic sandstone facies is interpreted as channel-fill deposit which is characterized by plannar and trough cross-beds, cross-laminations and mud pebbles as dominant sedimentary features. Erosive basal surfaces also occur within this facies.

Cross-bedded and rippled sandstone

This medium to fine-grained, moderately sorted, grey to brownish grey facies with small-scale cross-beds, asymmetrical ripples and lateral accretion surfaces has been interpreted as point bar deposits. Erosional contacts are found at bottom while the top contacts are abrupt and sharp.

Rippled sandstone with silt interbed

About 2.0m thick medium to very fine-grained rippled sandstone is interpreted as crevasse splay deposit. The dominant sedimentary structures are found as climbing ripples with mud-filled laminations.

Tabular sandstone with silt interbed

This facies consists of medium to coarse-grained moderately sorted brown to reddish brown sands. The sandstones are massive with some disorder mud clasts. The silty layers contain mud-filled cross-laminations and sandy lenses. The bedding contacts with above and below is sharp and abrupt. This facies is also interpreted as crevasse splay deposit.

Sheet sandstone with mud interbeds

The sheet sandstone with mud interbed facies occurs in two intervals of the studied section. Both intervals are followed by thick mud deposits. Brown to reddish brown sheet sandstone facies is fine to medium-grained, moderate to well sorted. The facies contains climbing ripples and laminations as dominant sedimentary structure. This facies is interpreted as over bank crevasse splay.

Tabular and blocky rippled sandstone

About 4m thick sandstone containing climbing ripples as the dominant sedimentary structures has been interpreted as sandy crevasse splay deposit. Layers of mud pebbles (lag deposits) are observed at the base of the sand beds. Rippled sandstone is typically blocky in nature and fine to very fine-grained, moderate to poorly sorted and brown to reddish brown in color. The contacts with above and below are sharp and abrupt.

Thick massive mud

The thick massive mud which is interpreted as floodplain deposit also occurs in two intervals in the studied section. The facies is typically grey to bluish grey or brown in color with silt-sized grains. This facies commonly contains nodules and layers. Some horizontal calcite veins and small-scale carbonate nodules (pedotubles) are also found.

3.2 Stratigraphic architecture and depositional environments

Stratigraphic architecture

Based on facies and facies association, four architectural elements were identified in studied section: single-story channel body

(SC), multi-story channel body (MC), crevasse splay (CS) and floodplain (FP).

The term channel body is used to refer any rock whose sediments were initially deposited within a channel, regardless of channel type (Gibling, 2006). Types of channels within the study area include fluvial and crevasse. Point bars are included in the multi-story channel body architectural elements because they occur within the channels. This differs from Miall's (1985) architectural element scheme, as he proposes a separate architectural element for lateral accretion deposits. He also proposes separate architectural element for sandy bed forms like channel fills, crevasse splays, and minor bars. But Bridge (1993) says it is not possible to make one architectural element for channel-fills and crevasse splays because they occur in different depositional processes and pose different confinement criteria.

Single-story channel body

Single-story channel body includes medium to fine-grained organic-rich laminated silty sandstone. The scale of single-story channel bodies cannot be determined due to very small portion of exposed area. The maximum thickness measured from the exposed area is 2.2m. Upper contact is sharp and abrupt while basal contact is erosional.

Multi-story channel body

Multi-story channel bodies are the most common sandstone-dominated architectural element in the studied outcrop. Facies associated with this channel body include planner and tabular cross-bedded and rippled sandstone. Multi-story channel-fills are typically lenticular and tabular with erosional bases. The scale of multi-story channel bodies is not possible to determine. Only the thickness is measured as 7.2m. Multi-story channel bodies differ from single-story channel bodies most significantly due to the presence of multiple internal scours and contain more complex channel-fills.

Crevasse splays

Facies associated with crevasse splays include rippled sandstones, tabular blocky rippled sandstone, tabular stacked sandstone with silty interbeds and sheet sandstone. Crevasse splays are generally found as tabular, with thicknesses ranging from 2.5m to 5m. Vertical contacts are sharp and abrupt while lateral contacts are mostly abrupt, but occasionally appear pinched out. Significant vertical variation in facies is present with little lateral variations.

Floodplain

As the floodplain deposit lacks geometrical data, it is considered as facies association not architectural element. This facies association contains nodular mud and structureless siltstone. It is laterally continuous within the study area and thickness varies from 8m to 13m. Contacts with above and below are sharp and abrupt.

Depositional environment

Based on the characteristics of facies, facies associations and architectural elements, environment of deposition for this outcrop section is interpreted as meandering fluvial channel with broad floodplain area.

Because channels are stacked vertically and laterally, and also because many of the rocks within these sandstone bodies contain lateral accretion surfaces, it is likely that multi-story channel-fills were deposited by meandering fluvial channels.

Single-story channel bodies do not contain lateral accretion surfaces but have prominent erosional basal surfaces with laminations and organic-rich muddy fine sand. Depositional environment for this single-story channel body is also interpreted as meandering fluvial rivers which became abandoned.

Crevasse splays are typically tabular or lenticular with erosional bases and tops, and can grade into floodplain siltstone (Miall, 1985). Typically two crevasse-splay deposits were found in studied section: sandy crevasse splays and silt/mud interbedded crevasse splays. Sandy crevasse splays are fine-grained blocky and dominated by climbing ripples with lag deposits which is deposited in proximal crevasse channel. Mud interbedded crevasse splays might be deposited due to inundation of water flow at the distal part of floodplain.

Floodplain facies association is located within inter-channel environments and is typically structureless. The occurrence of pedotubles (carbonate nodules) may suggest semi-arid environment of deposition.

3.3 Interpretation of spectral gamma-ray profile

A thorough gamma-ray measurement was carried out in the studied section by a portable handheld gamma spectrometer. Based on the measured values, synthetic gamma logs are prepared for total gamma and compared with the lithologic column. Figure 1 is a representative log profiles showing the sedimentology and gamma-ray log for the whole studied section. The profile encompasses the facies and architectural elements observed in the outcrop section. Note that due to the steep slope and highly weathered surface, it was not possible to measure the gamma values in the top most mud intervals. Only few readings were taken at the base of this mud.

The overall pattern of gamma-ray log shows increasing upward trend which is very common in most fluvial system deposits. But identification of individual facies from gamma-ray pattern is quite difficult because no unique signature was found in gamma-ray log for any specific facies. Most of the cases, overlapping occur in gamma-ray log. For example in figure 1, contacts of laminated muddy sandstone with planner cross-bedded sandstone and massive mud with tabular blocky rippled sandstone show the overlapping in gamma-ray log. Moreover, in tabular and blocky rippled sandstone, the gamma-ray shows decreasing upward trend which means that the grain size is increasing upward but sedimentological analysis shows the fine-grained blocky nature. So, the gamma-ray may not be a good indicator for grain size iedentification.

In terms of architectural elements, it is also quite difficult to define the channel system from the gamma-ray log. Single-story channel body almost matches with gamma log shape. In multi-story channel body, it is difficult to distinguish the channel-fill and point bar deposits. But it is important to know the channel system for assessing the sub-surface reservoir quality because porosity and lateral connectivity of sand body varies with the different channel systems.

In crevasse splay architectural elements, from the gamma-ray log shape it could be misinterpreted as channel sand because the gamma log does not show the interbedded thin silt and mud. Although the upper crevasse splay part shows the serrated shape of gamma-ray which may indicate the alternation of sand and mud beds. But there are some thin sand beds and thin lenticular

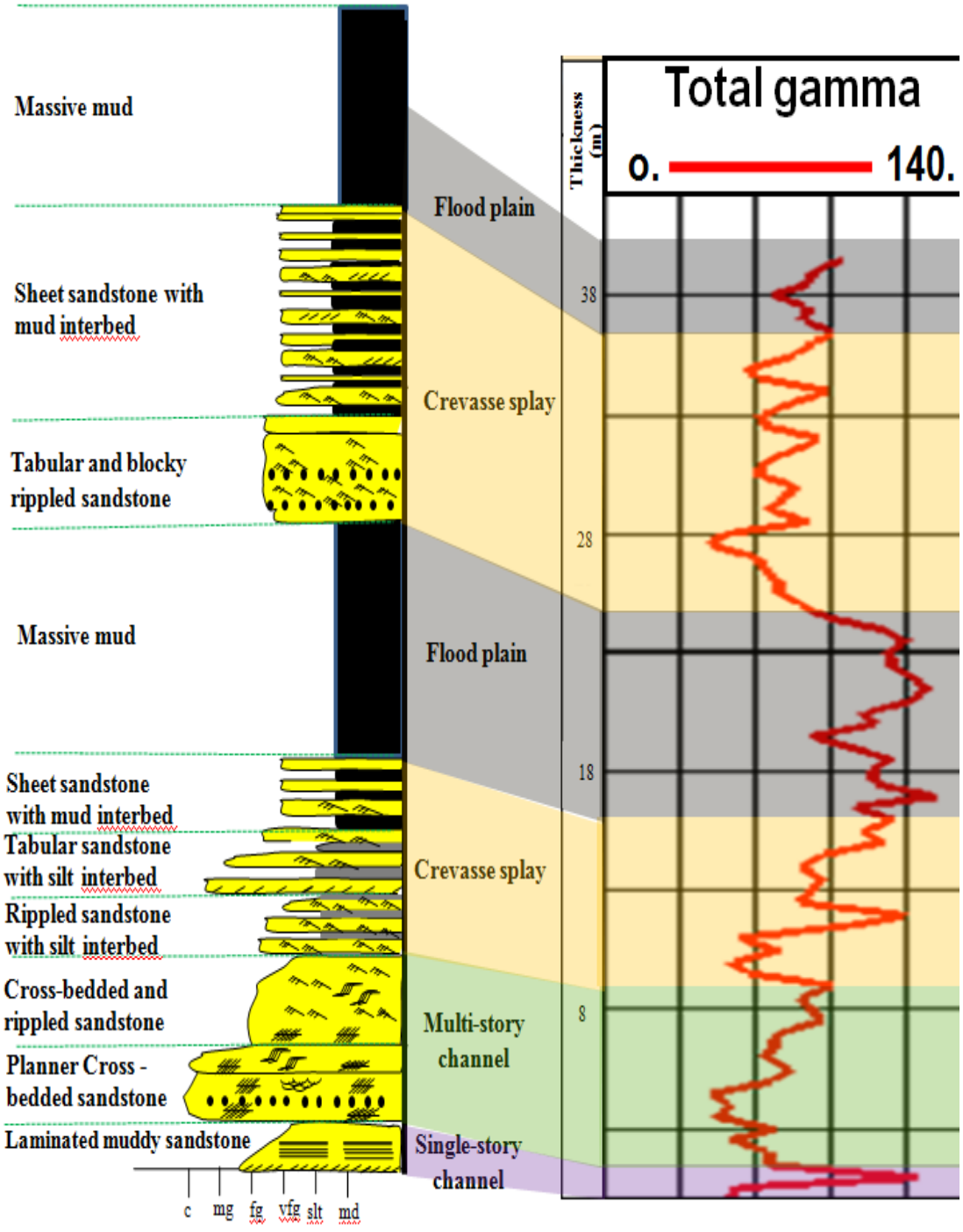

Figure 1. Representative relationship between sedimentological log and gamma-ray profiles for the whole studied section. The profile encompasses eight lithofacies and four stratigraphic t architectural elements that were interpreted in this study.

The floodplain interval can be easily identified from gamma-ray log with its high porosity. Although a point of low gamma values is seen within the thick mud which may happened due to the variation of internal mineralogical constituents or due to the presence of calcite veins.

Therefore, from gamma-ray log alone, it is quite difficult to map the sub-surface channel system and sub-surface interpretation of this channel system based only on the gamma-ray log might bear little or no relation to the geologic reality.

4. Discussion

Interpretation of architectural elements from gamma-ray log is not so reliable because gamma-ray log can differentiate sandstones from siltstone or mud, but distinctions between sandstone-dominated architectural element (point bar, channel-fill, etc) types are not quite clear. The depositional processes have great impact in sub-surface reservoir quality assessments because porosity distribution and lateral connectivity of sand bodies differ with depositional systems.

In addition, it is difficult to map the sub-surface multi-story channel body by gamma-ray log data because sub-surface gamma-ray can encounter an array of sandstone and mud which could represent a number of different channel systems. The application of sub-surface mapping based only on gamma-ray data would misinterpret the system which could bear little or no relation to the sub-surface geologic reality.

From outcrop, it can easily distinguish the sandstone thickness and their geometries and can compare them with gamma-ray signature. But in sub-surface, we only have gamma-ray data and this gamma-ray alone cannot provide true indication for sand body geometry and its lateral and vertical continuity and connectivity. For example, many lenticular shaped and pinching out of sandstone beds were found in the outcrop which is not possible to determine by gamma-ray log. On the other hand, some homogenous mud beds were noticed to have well lateral extend which could make obstacles for vertical connectivity of sandstone beds. Based on the gamma-ray data alone, it is quite difficult to identify this lateral extends which plays a vital role in sub-surface reservoir quality. We, therefore, need help from outcrop study to make a correlation between outcrop and spectral gamma from which we can make a better prediction for sub-surface reservoir potentiality as well as field development techniques.

In terms of scale of beds, the role of gamma-ray logs is restricted as much of it occurs in a scale below the resolution of gamma tools. In the outcrop, it is possible to see fining upward in beds which is too small scale to show in a gamma-ray log. Sometimes the lithofacies variations are also very small in scale and it is not possible to show in gamma-ray log. For example, in the silty mud interval there is a lenticular shaped thin layer of sand which stacked as too small to be recognized by the gamma-ray. There are some thin mud beds which are lenticular in shape and the measured section shows the very thin pinching out point of these mud beds. These small scale mud beds are not possible to distinguish from the gamma log signature. Though sometimes it can be shown as thin mud but the lateral extends are still impossible to define by gamma-ray logs. But such types of small scale variations allow the more reliable interpretation of depositional system and have a great impact on reservoir properties. These types of heterogeneities are not possible to identify only from the gamma-ray logs. Therefore, gamma-ray log data need to be cross checked and calibrated by outcrop data and/or by core.

Facies were classified based on internal sedimentary structures and sand-body geometry which reflect their depositional environments. Gamma-ray log can only show the grain distribution and thickness but cannot define sedimentary structures. Thus, no well defined correlation was observed between gamma-ray log and facies. Moreover, overlaps occur in gamma-ray signature within the facies which might pose problems for interpretation of sub-surface data.

This study, therefore, reveals that gamma-ray logs are helpful in defining the vertical trend of sedimentation and are useful in developing lithology-based understanding of relationships between gamma-ray log patterns. But it cannot distinguish architectural elements in multi-story channel body which is one of the prime target in sub-surface reservoir delineation and field development in fluvial system. So, gamma-ray alone is not a very good tool to define sub-surface fluvial architectures and lithofacies distribution for assessing reservoir potentiality and planning field development. It also suggests that great care must be taken in drawing conclusions from small outcrop and limited data because channel geometry and hydraulics can change very quickly in space and time. Comparison of outcrop spectral gamma-ray data to nearby core data would help to determine variations in the spectral gamma signature, which may help to interpret architectural elements in the sub-surface from gamma-ray logs. If specific gamma-ray signature can be defined for every particular architectural element, sub-surface interpretation of fluvial architecture could be more accurate.

5. CONCLUSION

This study leads to the following conclusions:

a. Gamma-ray logs are helpful in defining the vertical trend of sedimentation and are useful in developing lithology-based understanding of relationships between gamma-ray log patterns. But it does not show any specific signature for lithofacies identification.

b. Gamma-ray log alone is not so reliable to identify the sub-surface fluvial architectural elements and lithofacies distribution for determining reservoir potential and field development techniques.

c. Small scale variations in lithofacies like thin sandy lenses and thin lenticular silty mud layers are not possible to distinguish from gamma-ray log.

d. Gamma-ray log across the sub-surface equivalent would not always be a true indicator to identify the grain size.

e. Sub-surface gamma log interpretation should be checked and calibrated by core and/or near-by outcrop data.

6. Acknowledgements

The author would like to thank Prof. Joseph Lambiase for his patient guidance and supervision during this research and for editing of the manuscript. The author wants to thank PTTEP, Thailand and Petrobangla, Bangladesh for granting the scholarship and funding this research project.

7. References

Bridge, J. S., 1993, Description and interpretation of fluvial deposits: a critical

perspective: Sedimentology, v. 40, p. 801-810.

Gibling, M. R., 2006, Width and thickness of fluvial channel bodies and valley fills in the geological record; a literature compilation and classification: Journal of Sedimentary Research, v. 76, p. 731-770.

Miall, A. D., 1985, Architectural element analysis: a new method of facies analysis applied to fluvial deposits: Earth Science Reviews, v. 22, p. 261-308.