A Simplistic Approach in Estimating Paleo-Bathymetry by Using Seismic Stratigraphic Features in Fluvial-Dominated Delta

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Abstract

The advance of high resolution 3D seismic technology has enabled much detailed imaging not only for structural features, but also for detailed stratigraphic features. If we squeeze a little bit more out of seismic data, it can provide us some important information. Seismic stratigraphy analysis in a prograding delta setting can deliver simple yet useful tool in understanding the geological and depositional aspects from seismic data. Recognizing unique seismic stratigraphic pattern of each part of delta and their chronostratigraphic correlative unit will allow us to understand the depositional relief of ancient delta sequence observable in seismic. This article discusses how to do simple estimation of paleo-bathymetry in a fluvial-dominated delta and its limitation. This is a little effort to make seismic interpretation more meaningful and much more fun.

Background

Seismic interpretation has been the back bone of oil and gas exploration since many years. The advance of high resolution 3D seismic technology has enabled much detailed imaging not only for structural features, but also for seeing some detailed stratigraphic features. For a geophysicist, seismic interpretation could be a routine job. Much of the time is spent interpreting seismic reflectors, seeking a continuity to build nice smooth maps. Sometime seismic interpreter are trapped in this routine, skipping an important step in interpreting seismic data, which is to relate the seismic features to their geological aspects beyond the structural information.

Seismic reflections are chronostratigraphic in nature, which means we are following bedding or time plane while tracing the seismic reflector and not following lithology. Interaction of seismic reflections will reflect the timing of deposition and their relative position from one sequence to another, forming a geometry that will be unique for each depositional and geological setting. In other words, geometry of seismic reflections will be reflecting the geological processes that formed them. Therefore, it is important to think geologically while interpreting our seismic data. However, is there any way to get a geological or depositional setting sense while we are interpreting seismic data? When seismic data have enough details and areal coverage, we may have the chance to evaluate its geological aspect through seismic stratigraphy.

"Seismic Stratigraphy" is one of the branches of geological science. Seismic stratigraphy is the study of stratigraphy and depositional facies as interpreted from seismic data (Mitchum *et al.*, 1977a). A seismic sequence is a depositional sequence identified on a seismic section (Mitchum, 1977). A depositional sequence is a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by uncorformities or their correlative conformities (Mitchum *et al.*, 1977b).

The most studied depositional setting in seismic stratigraphy study is deltaic depositional setting, which provides a range of depositional setting changes that can be identified by good seismic data. Delta is a contiguous mass of sediments, partly sub-aerial, deposited around the point where a stream enters a standing body of water (Galloway, 1975). Galloway (1975) also subdivided deltas into three end members, based on the energy source which dominates the seaward edge of the delta, which include: (1) fluvial-dominated, (2) wave-dominated and (3) tide-dominated deltas. The interaction of fluvial flow, wave action and tidal current are the main energy source in which one of them may be the dominant energy at the leading edge of the delta.

For the simplicity of this article, it will only discuss the quick interpretation technique of paleo-bathymetry using seismic stratigraphy approach without discussing extensively on the deltas typing and their detailed seismic characteristics. This article will also focus on fluvial-dominated deltas because this type of delta is the most ideal type to be evaluated by using this technique.

Some typical characteristic of fluvial dominated delta are summarized below:

Delta plain setting

Dominated by parallel reflection patterns with some channel scours indication, some bright amplitude of coal beds in upper delta plain, small scale carbonate build-up reflections, and small scale prograding clinoforms which may occur when the slope changes within the transition from upper to lower delta plain area.

Delta front setting

In a fluvial-dominated delta, the delta front is characterized by upper offlap or toplap, large prograding clinoform and downlap expression at the bottom of the packages which enter into prodelta setting. Sometimes, at the leading edge of a delta front there are onlap expressions of younger beds onto the delta front packages.

Pro delta setting and Basin floor setting

The prodelta setting is dominated by downlap seismic reflections and

parallel reflections at the leading edge of the delta front. This setting may also sometimes exhibit subsequent parallel reflectors on-lapping onto the prograding prodelta package slope, which may be an indication of turbiditic stratigraphic unit.

The illustration in Figure 1 describes that theoretically, each part of delta will have unique seismic stratigraphic signatures. By knowing specific seismic signature to its depositional setting and then tracing it outboard toward its genetically related unit down to the basin in the same chronostratigraphic interval, the geographic position of each location and relief difference between them at the time of deposition can be drawn. For ancient deformed delta, the reconstruction sometime will require structural restoration.

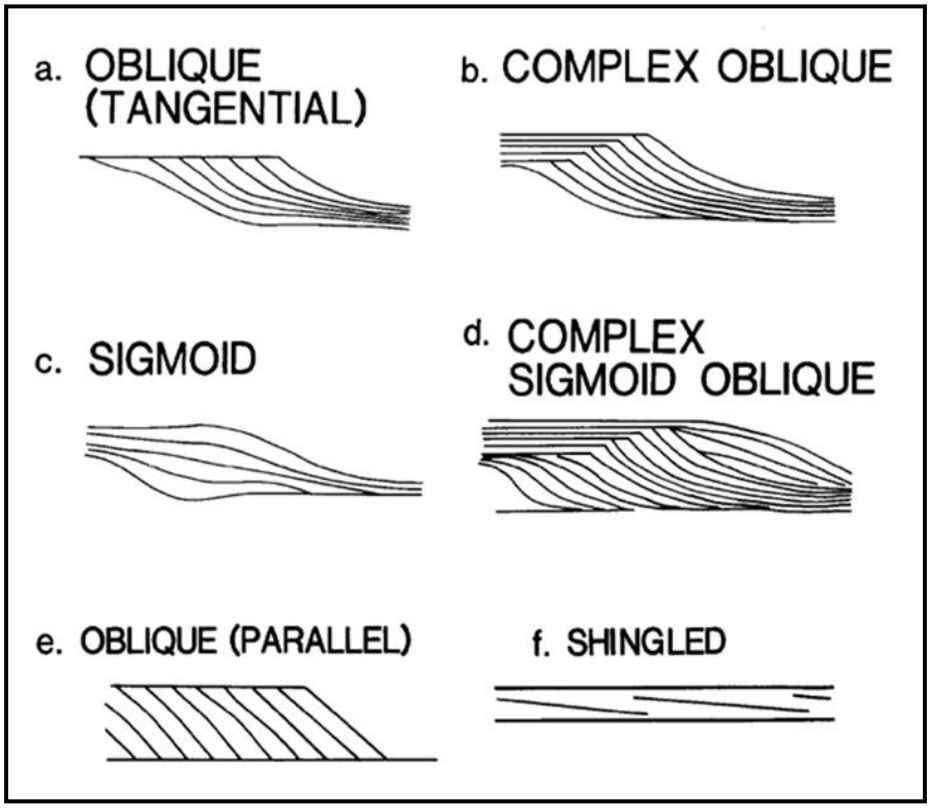


Figure 1. Model of seismic reflection pattern in fluvial-dominated delta and wave-dominated delta (modified from Mitchum *et al.*, 1977a)

Modern Analog and Test Case

The key is to find areas that have delta plain seismic signature in shallow setting, which continues to the genetically related basin floor setting indicated by downlap surface that reflects deeper setting. In an ideal undeformed stratigraphic unit, the seismic time elevation difference between those two depositional settings will represent water depth difference in time. To get it in depth domain (meters), we have to multiply seismic interval velocity on the particular section with the time difference.

It has to be noted that the bathymetric difference will not be directly a real bathymetric depth but it will only be a minimum water depth difference between the shallow and deeper locations. We have to realize that the shallow package had minimum water depth when it was deposited. This depth will be added to the residual depth between the shallow and deeper stratigraphic packages. The paleo-bathymetry of shallow packages ideally can be inferred from biostratigraphy by using benthic foram fossil assemblage, but if we do not have it, seismic pattern association indicating unique depositional setting can be a hint to estimate water depth by comparing them to its modern analog. Another thing to be considered is compaction factor that have to be corrected with decompaction calculation. The later correction will have to be applied in the academic world but in the practical fit for purpose use, it can be simplified by using some factor or even disregard it for the sake of simplicity.

The seismic on Figure 2 is the modern analog in lower delta plain near self edge of the northern Mahakam delta.

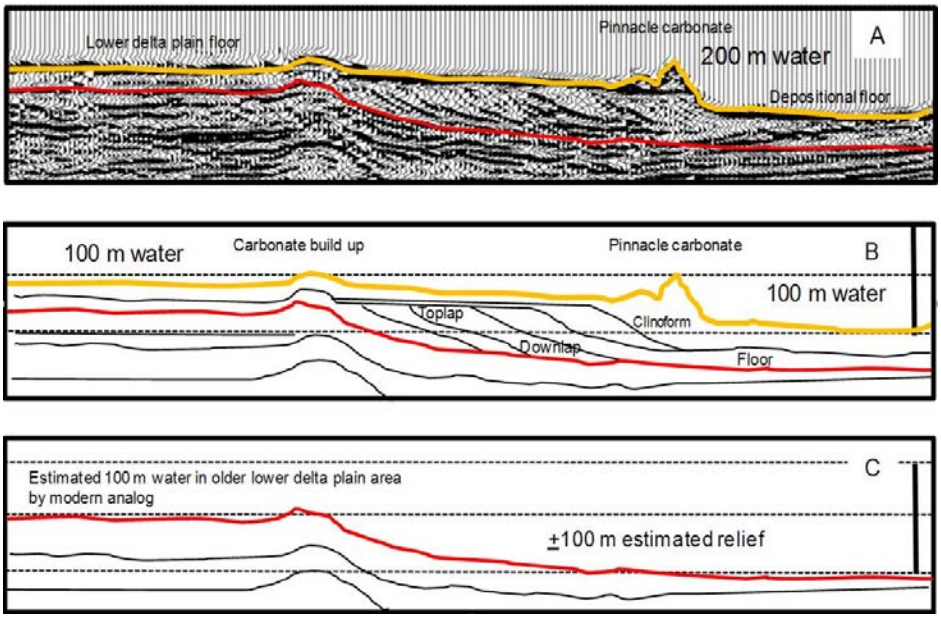


Figure 2. (A) Seismic image of modern sea bed on a lower delta plain near the shelf edge in northern Mahakam Delta shows flat delta plain on the left, carbonate build up and pinnacle reef, prograding clinoform complex, and near shelf edge depositional floor at about 200 meter water depth. (B) Schematic drawing of important seismic reflectors, the Yellow horizon is water bottom elevation at present-day. The Red horizon is the older water bottom. (C) Graphical estimation of older water bottom Red horizon.

At water bottom level (Orange horizon), it exhibits lower delta plain flat area, carbonate mound and pinnacles, break of slope and a basinal flat area with some bumps of what appear to be carbonate build up. Beneath the water bottom (Orange) horizon, it is observable parallel flat reflection patterns at the left side that continues to prograding clinoform complex stacking laterally to the right end. The top of the prograding complex exhibits toplap features as a sign of the top stratigraphic body. The deeper flat area consists of downlapping stratal pattern and parallel reflector which eventually conformably stacked at the far end of the section. The shallow and deeper delta plain settings at this location can be used as modern analog to do simple paleo-bathymetry estimation. On the Orange horizon in Figure 2, water depth estimation is simply done by measuring the depth of water bottom reflection on the seismic section then multiplied by seismic velocity of the water. To do similar estimation to the older strata is little bit tricky, since the paleo water bottom reflector might have been distorted or eroded. We will not be able to do an accurate estimation but we can do an educated guess of the paleo-bathymetry.

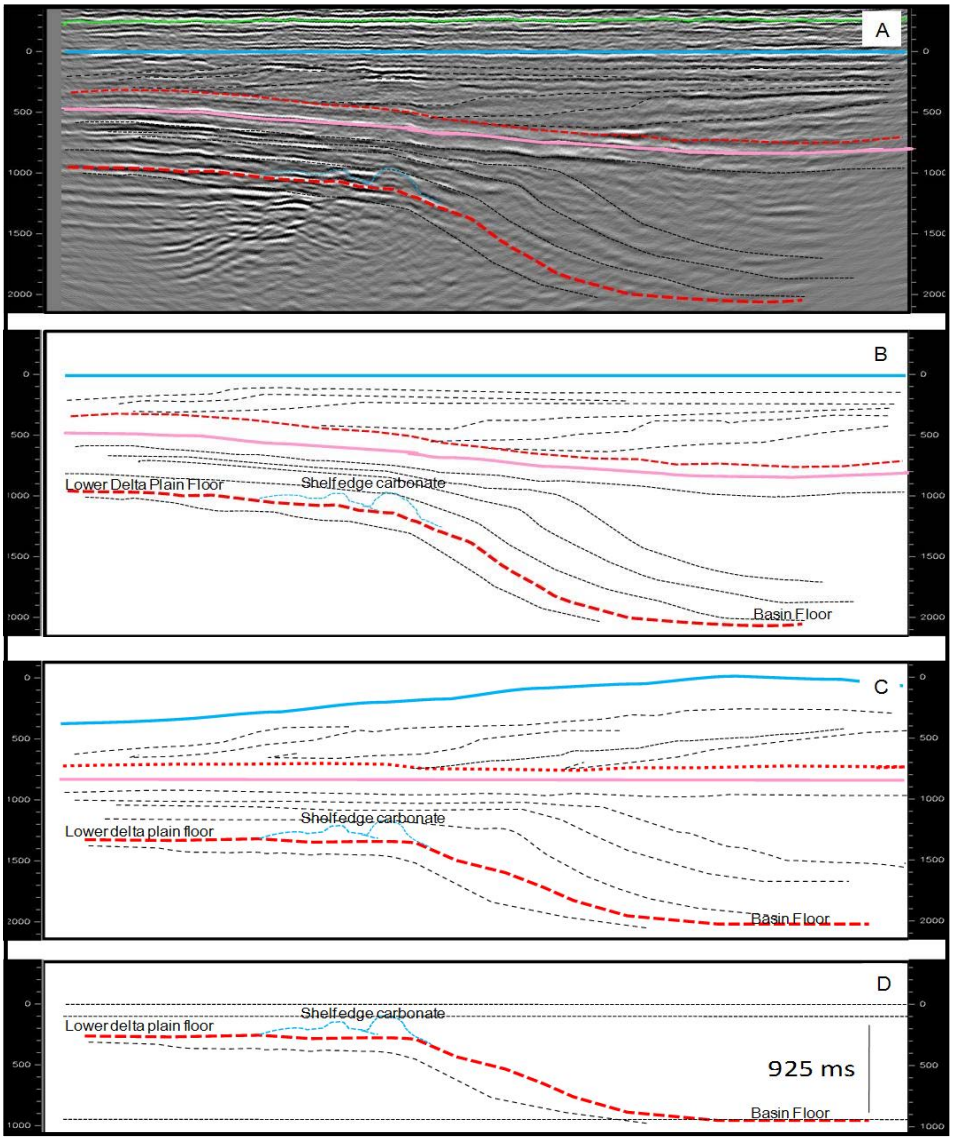


Figure 3. **Simple application of seismic stratigraphy to estimate paleo-bathymetry in Late Oligocene stratigraphic unit. (A) Seismic interpretation flattened on Early Miocene Blue horizon. The Late Oligocene Pink and Oligocene lower dashed Red horizon in deformed state. (B) Schematic drawing based on seismic reflector tracing shows possible shelf edge setting with carbonate build up below Pink horizon. (C) Section flattened on Pink horizon shows a clearer flat reflector on delta plain above dashed Red horizon, clinoform complex and possible basin floor downlap surface. Lower dashed Red horizon is the chronostratigraphic surface. (D) Delta plain to basin floor relief graphical measurement indicates 925 ms time relief equivalent to +1,110 meters.**

The steps are:

1. Identification of shallow part of delta setting which can be traced to its correlative deeper part of delta by observing key seismic stratigraphic reflection pattern.
2. Graphically estimate time difference between those shallow and deeper part of ancient water bottom reflector.
3. Estimating seismic interval velocity of the evaluated seismic stratigraphic unit.
4. Calculate the depth difference by multiplying time relief by seismic interval velocity.
5. Estimate the minimum possible paleo-bathymetry of the shallow part of delta by evaluating benthic foram biostratigraphic data when available, or by evaluating sedimentary structure of core when we have it in hand. If those benthic foram and core data are not available, we may develop and use seismic stratigraphic pattern analog to its modern cousins as described in Figure 2.

Could this technique be applied to estimate paleo-bathymetry of much older and deformed strata? First, it will be ideal to have the seismic section in un-deformed state by restoring the section through balanced cross section, but in less faulted area simple horizon flattening in some cases will do the job. Simple horizon flattening may provide enough vertical restoration to have the correct impression of which end is the shallow and the deeper depositional setting. The illustration in Figure 3 is the schematic section of sequentially restored seismic section example using simple horizon flattening technique from southern Mahakam delta area.

Seismic section displayed on Figure 3 originally deformed as an anticline, therefore to do seismic stratigraphic interpretation on the lower part is almost impossible. Sequential flattening technique started from Blue horizon to Pink horizon helps us to properly

observe some seismic stratigraphy features and determine which area is the shallow and the deeper deltaic setting. When the section was flattened on Pink horizon, we start to see some familiar pattern related to deltaic setting including parallel reflections on the left, offlap, clinoform complex in the middle and possible downlap pattern and basin floor parallel pattern on the right end.

With the same technique as previously discussed, we can estimate the minimum water depth at the time the dashed Red horizon stratigraphic unit was deposited. In this case we use top of carbonate build up growing on top of Red horizon as the shallow marker and break of slope as the shallow area indicator and while downlap and parallel pattern as the deeper basin location indicator. The structural difference between those two features is about 925ms (OWT). Having interval velocity at this package of about 1,200m/s, the relief between the two locations will be about 1,110m.

Mounded shape at the left end may be shelf edge carbonate build up in which normally carbonate forming organism live in photic zone in 50-100 meters water where sun light can penetrate into the water. Adding up carbonate water depth 50-100 meters to 1,110 meters relief, the paleo-bathymetry of sedimentary basin was at least 1,160-1,210 meters deep. When a more accurate estimation is needed, decompaction calculation must be taken into account, but even without it, we already got a sense of how the depositional setting once looked like.

Conclusion

Seismic interpretation is not all about creating smooth structural maps. If we squeeze a little bit more out of seismic data, it can provide us some important information. By knowing the range of water depth of particular stratigraphic package we can think of what geological processes might have occurred within that particular interval during its deposition or estimating possible lithological facies variation within the stratigraphic unit. This simple step of paleo-bathymetry estimation technique will drive the interpreter to think in geological sense and have better understanding of scale aspect while interpreting seismic data. Other advantages of doing such approach are: Seismic Interpreter will have the sense of depositional scale and basin configuration. Correct sense of landward, seaward direction, basin slope angle and depositional relief can be achieved. We will also have a better sense of how deep the water was and how much the minimum accommodation space available. Seismic interpreters will have the ability to infer what type of transport system and associated reservoir geometry within each depositional setting. When it is combined with complete biostratigraphic analysis, the evaluation of lateral accretion or progradation rate of delta deposition evaluation will be possible to do. As a closing note, this simple paleo-bathymetry estimation using seismic stratigraphic features alone will not be quantitatively accurate but it can make seismic interpretation work more geologically meaningful and much more fun.

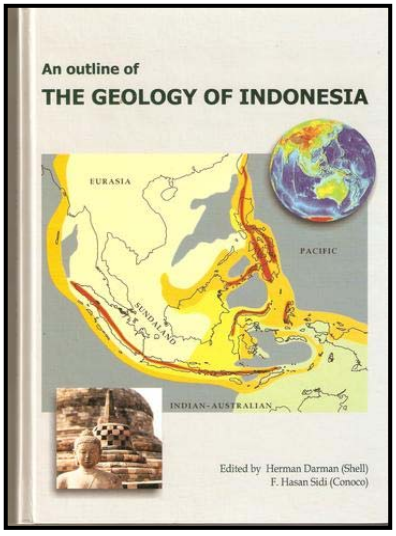
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