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Depositional Facies Analysis from Seismic Attributes: Implication of Reservoir Characterization

Park, Yong-Joon

Korea National Oil Corporation,
1588 Kwanyang-dong, Dongan-gu, Anyang, Kyungki-do, Korea

ABSTRACT

This study includes structural analysis of the northern Pattani Basin, areal description of depositional facies, and their spatial relationships using 3-D seismic and well data. Well log data indicate that the representative depositional facies of the studied intervals are sandy, fluvial, channel-fill facies encased in shaly floodplain deposits. Seismic responses were predicted from a synthetic seismogram using a model of dominant depositional facies. Peak-to-trough amplitude and instantaneous frequency seismic attributes are used in depositional facies interpretation.

Three intervals A, B and C are interpreted on the successive stratal surfaces. The shallowest interval, A, is the Quaternary transgressive succession. Each stratal surface showed flow pattern variation of fluvial channel facies. Two transgressive cycles were identified in interval A. Interval B also indicated fluvial facies. Depositional facies architectures are described by interpreting seismic attributes on the successive stratal surfaces.

1. Introduction

The Gulf of Thailand consists of a series of north-south trending Tertiary rift basins. The Pattani Basin is the largest basin among them, covering approximately 10000 square kilometers, and located in the central part of the Gulf of Thailand. This study investigates the variation of depositional facies for several intervals of Upper ~ Middle Miocene and Quaternary fluvial depositional facies in the northern Pattani Basin.

High-resolution depositional facies analysis is possible by interpreting 3-D seismic horizon slices as well as well logs. Spatial distribution of depositional facies and their variation throughout geologic time are recognized by seismic attribute analysis of successive stratal slice surfaces. Three-dimensional seismic attribute analysis is especially useful in understanding the evolution of fluvial depositional facies. It could be analogy examples for deeper hydrocarbon reservoirs of similar depositional environments because depositional facies interpreted from seismic attributes are not apparent in deeper horizons.

2. Structural setting and sedimentary environments

Basins of the Gulf of Thailand are controlled by two major strike-slip fault systems (Fig. 1). They are the NW-SE trending Three Pagodas fault zone in the east and the NE-SW trending Ranong and Klong Marui fault zone in the west. A series of north-south trending extensional faults bounding the Tertiary basins are between the two major faults systems.

There are three grabens in the seismic survey area one main graben on the right side and two small northwest and southwest grabens on the left side of the survey area. The graben-bounding master faults of the main graben are N-S in strike and dip east or west. Graben structures are clearly visible in the 3-D view of the fault planes (Fig. 2).

The sedimentary evolution of the Pattani Basin was a response to rifting which began in the Late Eocene. The sedimentary succession is divided into syn-rift and post-rift sequences. Syn-rift sequences correspond to rifting and extension of southeast Asia including block faulting and rapid subsidence. The main controls of syn-rift sequences are a high subsidence rate and large sediment influx resulting from rifting. Post-rift sequences correspond to a period of slow thermal subsidence and reduced sediment influx. Therefore, Chonchawalit (1993) suggested that eustatic sea-level fluctuation played a more important role in post-rift sequences. Areal distribution of depositional environments during Oligocene to Miocene time indicates that the northern part of the Pattani Basin was mostly a fluvial environment.

3. Interpretation Concepts

The basic assumption of seismic stratigraphic interpretation is that coherent seismic events seen on seismic a record are reflections from acoustic impedance contrasts in the subsurface. The next assumption is that the primary seismic reflections follow chronostratigraphic (time-stratigraphic) correlation patterns rather

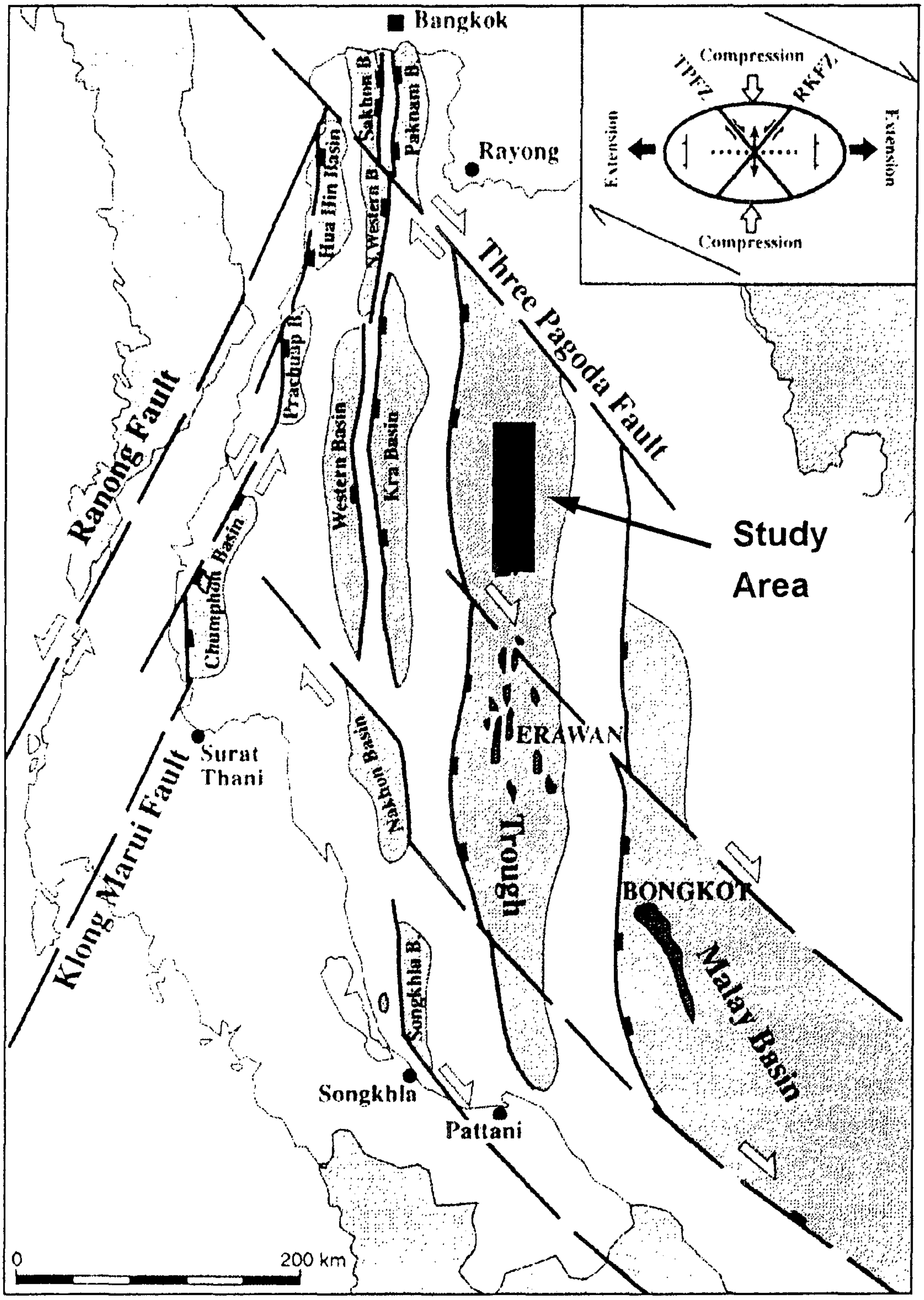

Fig. 1. Simplified structure map of the Gulf of Thailand (after Polachan and Sattayrak, 1989)

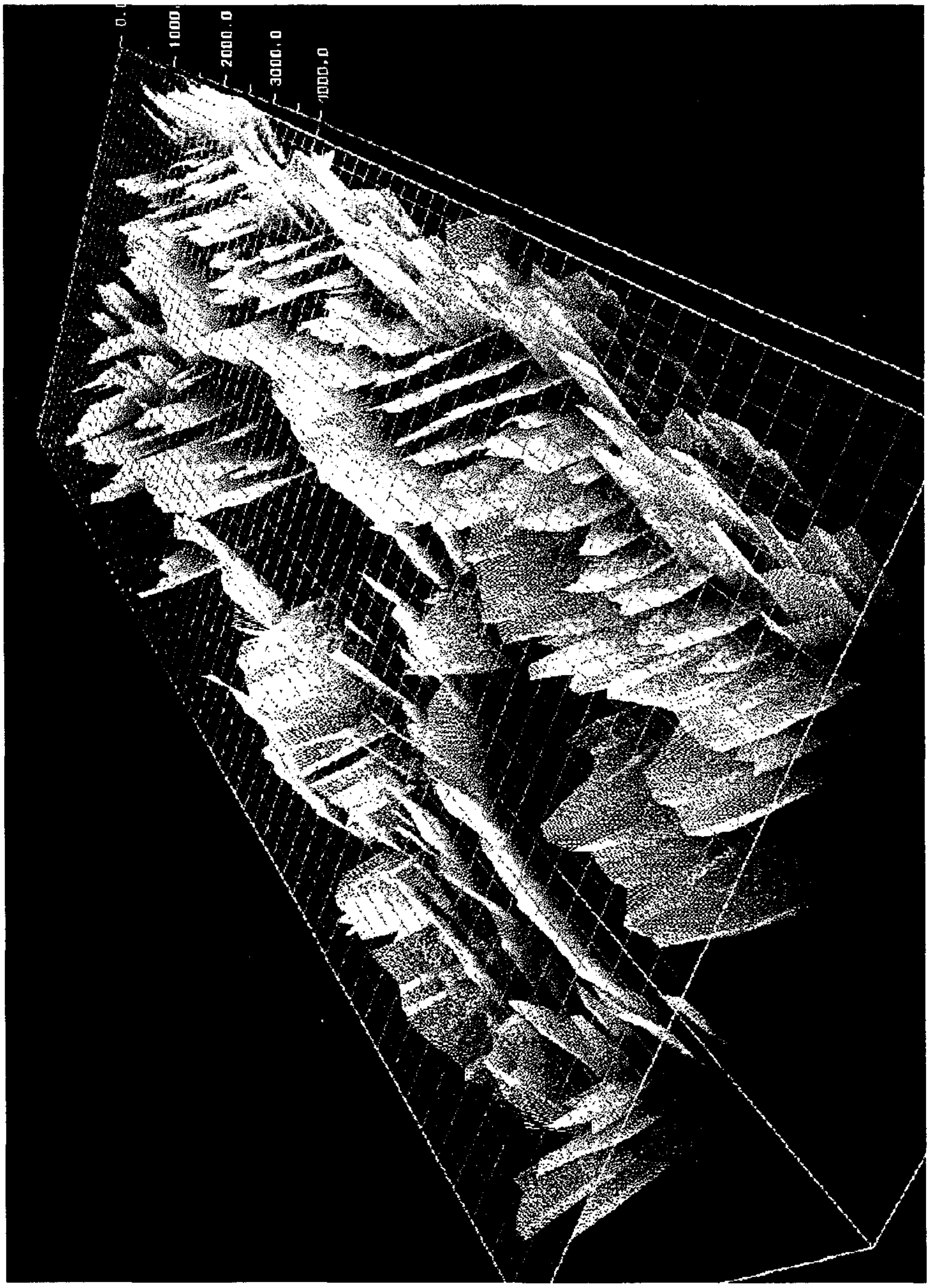

Fig. 2. Three dimensional view of fault structures.

than time-transgressive lithostratigraphic (rock-stratigraphic) units. Physical surfaces that cause primary seismic reflections are stratal surfaces and unconformities. Stratal surfaces are major bedding surfaces, and therefore represent ancient depositional surfaces (Vail *et al.*, 1977). In some situations, however, seismic reflection events do not follow chronostratigraphic surfaces. If bed boundaries are gradational and discontinuous, recognizable continuous reflections can be parallel to diachronous lithostratigraphic units, depending on thicknesses and vertical and horizontal separations of thin beds (Tipper, 1993). If bed thicknesses and vertical separations are very small, less than a quarter of the dominant wavelength, reflections may follow diachronous lithostratigraphic units. Therefore, seismic stratigraphic interpretation requires caution, especially when interpreting thin layers.

If horizon interpretation and correlation is carried out correctly after structure interpretation, stratal surfaces approximating chronostratigraphic surfaces are acquired over the 3-D seismic survey area. Seismic attributes including amplitude, frequency, phases and waveshape are measurable both from vertical seismic sections and horizontal stratal surfaces and are used in interpreting seismic sequences and depositional facies. Patterns and variations of seismic attributes are closely related to geological features because changes in seismic attributes result from variations of lithology, depositional facies, porosity, and fluids in pore space. The purpose of seismic attribute analysis from vertical sections is to identify vertical depositional units and seismic stratigraphic sequences. Individual depositional facies are better identified from stratal surface horizons than vertical seismic sections. Depositional facies are identified from vertical sections if facies have distinct amplitude or waveshape that distinguishes them from surrounding facies. On the other hand, if reflection amplitudes of the target depositional facies are very weak, it is difficult to distinguish them using vertical seismic sections. However, they are generally easily detected on stratal surfaces because their depositional geometry can be seen from stratal surfaces. Therefore, the basic idea of this study is that it is possible to describe continuous depositional facies variations throughout successive increments of geologic time using stratal surfaces acquired from 3-D seismic data.

Hardage and Remington (1998) showed that a series of stratal surfaces is acquired by incremental time-shifting from a reference stratal surface and that continuously sliced stratal surfaces improve imaging of thin-bed sequences. Most depositional features are commonly discontinuous and tend to pinch out, especially when bed thickness is thin such as fluvial channel facies. The time-shifted stratal surface concept is applied not only to imaging a thin layer, but also to describing depositional facies architecture, when a series of successive stratal surface slices are acquired from continuous time-shifting above and below the reference stratal surface.

4. Seismic attribute analysis from synthetic seismogram

After creating stratal surfaces, depositional facies are analyzed from seismic attributes. The most useful seismic attribute in interpreting depositional facies was peak-trough amplitude. The advantages of utilizing peak-trough amplitude are that each peak and trough of a reflection event represents acoustic impedance changes that allow correlation of interpretations from vertical sections to time slices and stratal surface slices.

In addition to the peak-trough amplitude, which is an attribute of ordinary seismic traces, attributes of complex seismic traces, such as instantaneous amplitude, instantaneous phase, and instantaneous frequency, can also be applied to interpret depositional features from 3-D seismic data. Taner and Sheriff (1977) introduced use of seismic attributes of complex seismic traces for the purpose of seismic interpretation. Robertson and Nogami (1984) showed that instantaneous frequency reaches an anomalously high value when the layer thickness is seismically thin, less than a quarter period, and that the instantaneous frequency section is a sensitive analytical tool for investigating stratigraphic sequences composed of very thin layers. Instantaneous frequency is particularly sensitive to slight distortions of the reflection wavelet because anomalous high frequencies commonly occur when the wavelet shape is distorted, even slightly (Bureau of Economic Geology, 1996). Therefore, instantaneous frequency is useful for interpreting geologic features affecting distortions of the reflection waveshape such as seismically thin beds, stratigraphic pinch-outs, lateral changes of depositional facies, and fault zones.

Well log data provided information concerning lithology and one-dimensional depositional facies succession (Fig. 3). The representative depositional facies of the studied intervals were sandy fluvial channel fill facies encased between shaly floodplain, backswamp, and lacustrine deposits. The channel facies have distinct seismic responses because the channel fill sand has much lower impedance than the

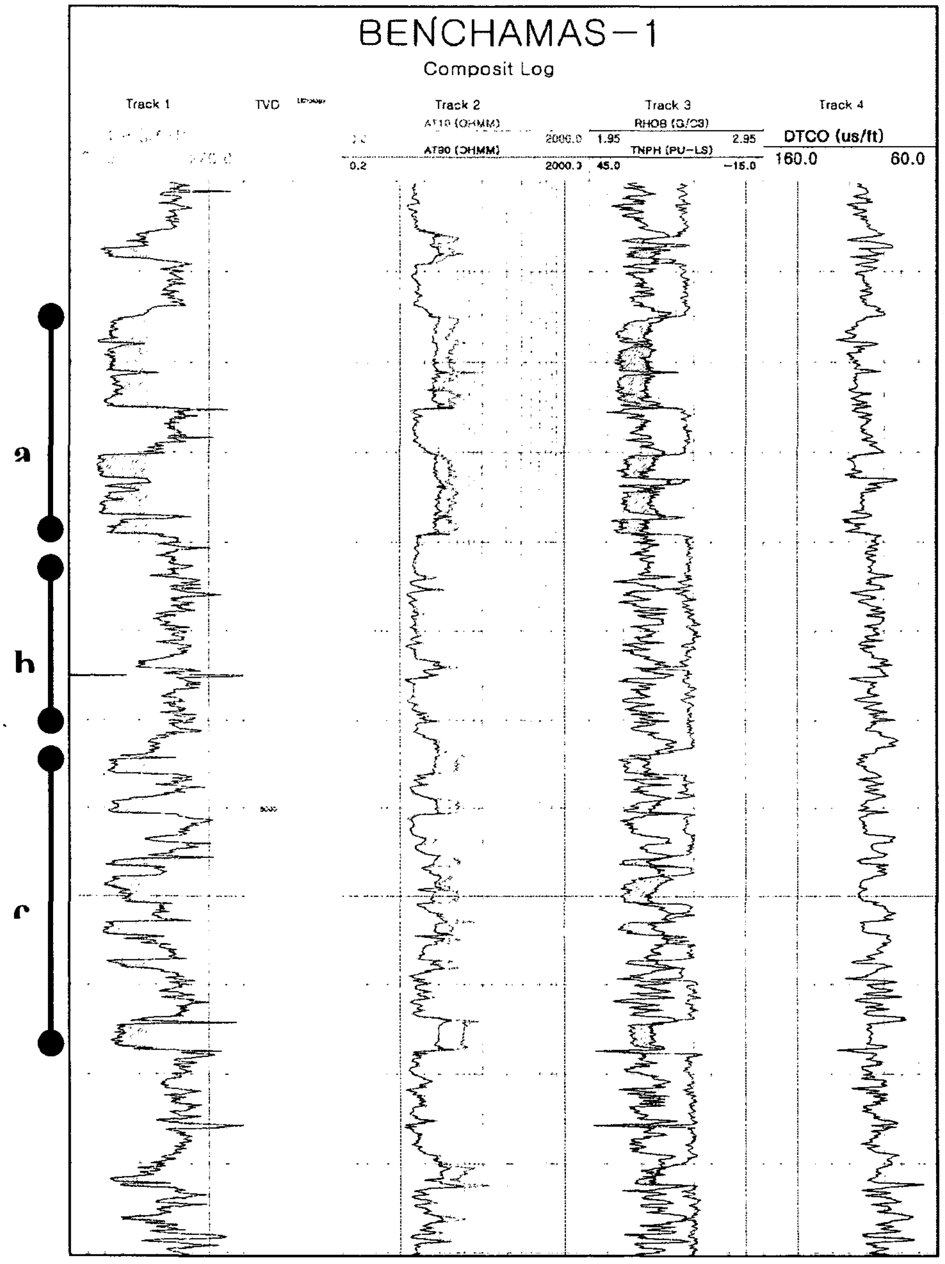

Fig. 3. Typical well logs of the Benchamas area (from Benchamas-1 well: 4300-5500 ft in TVD). (a) Sharp base and sharp-upward fining gamma-ray log patterns indicate stacked sandy meanderbelt. (b) Shaly floodplain facies flucturating high gamma-ray and constant density.

impedance of the surrounding shale.

Seismic attributes of real data were predicted from synthetic seismograms using an impedance model representing a channel fill encased in shales (Fig. 4). The characteristics of the synthetic seismic response of the channel sand model are; (1) a high negative amplitude at the top and (2) a high positive amplitude at the base of the channel. If the channel is thin or near pinch out, instantaneous frequency is very high positive or negative. Therefore, instantaneous frequency attribute is useful for imaging thin channel facies. Seismic interpretation results are improved by combining these seismic attributes (Fig. 5).

5. Conclusions

Successively sliced stratal surfaces were created by time-shifting from interpreted reference stratal surfaces. Depositional facies and their evolution for selected stratigraphic intervals were described in detail by interpreting seismic attributes of continuously sliced stratal surfaces.

The interpreted interval is illustrated in Figure 6. The shallowest interval, A, is the Quaternary transgressive succession corresponding to the upper part of seismic sequence VI. Channel images in the amplitude maps of the stratal surfaces are sufficiently distinct to interpret channel origin. Instantaneous frequency anomalies also follow channel traces as well as do amplitude characteristics. Each stratal surface shows variation of fluvial channels influenced by marine transgression. Two transgressive cycles were identified n interval A.

The fluvial depositional environments of seismic sequence V were mapped by interpreting stratal surfaces of interval B. There are two depositional cycles in interval B, and each cycle is divided into three phases (Fig. 7). The first phase of the first cycle is characterized by moderately to highly sinuous meandering channels with large intervening floodplains. In the second phase, wide, meandering channels were developed with a few large crevasse splays in the adjacent floodplains. The wide channels almost disappeared at the beginning of the third phase and developed again later with the same trend but different flow patterns. The first phase of the second cycle is characterized by a floodbasin dominated setting crossed by a few narrow channels. During the second phase of the second cycle, very wide and highly sinuous meandering channels associated with sandy crevasse splays developed. In the

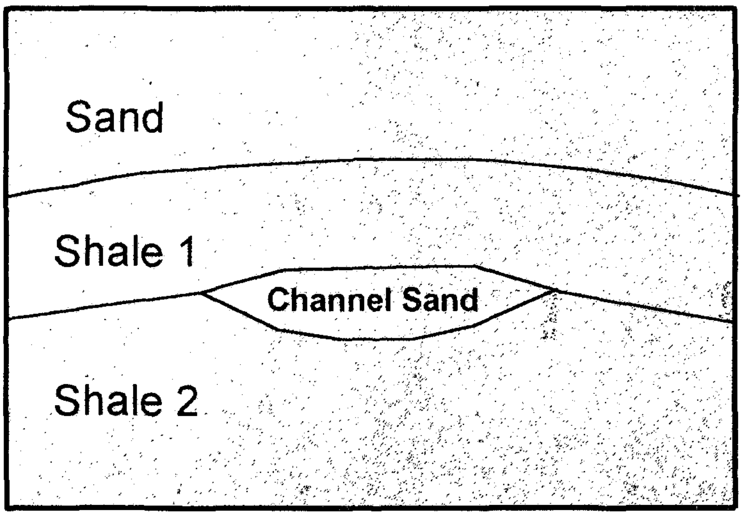

Fig. 4-A. Simplified channel sand model.

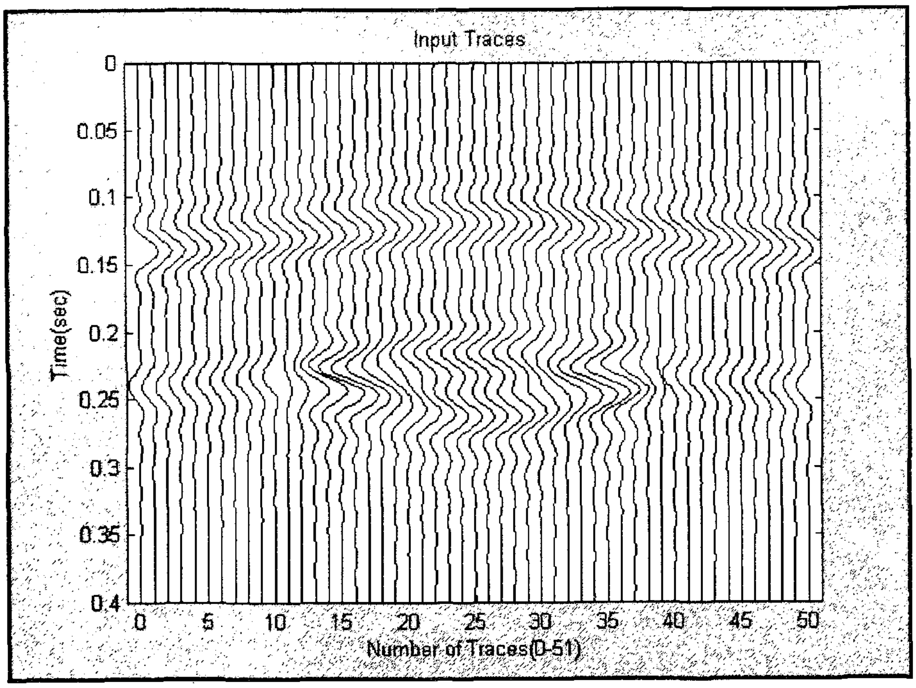

Fig. 4-B. Seismic response of the channel sand model. The illuminating wavelet is 35 Hz zero-phase Ricker wavelet.

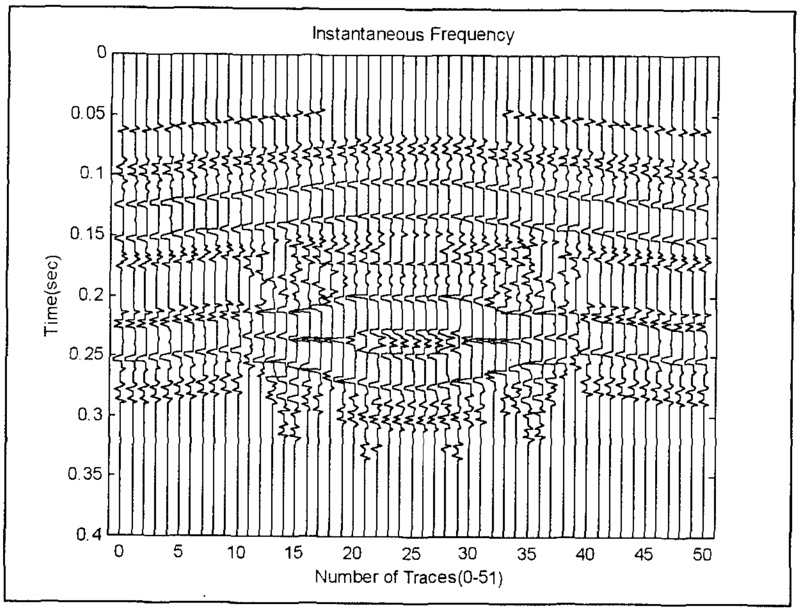

Fig. 5-A. Instantaneous frequency response of the channel sand model.

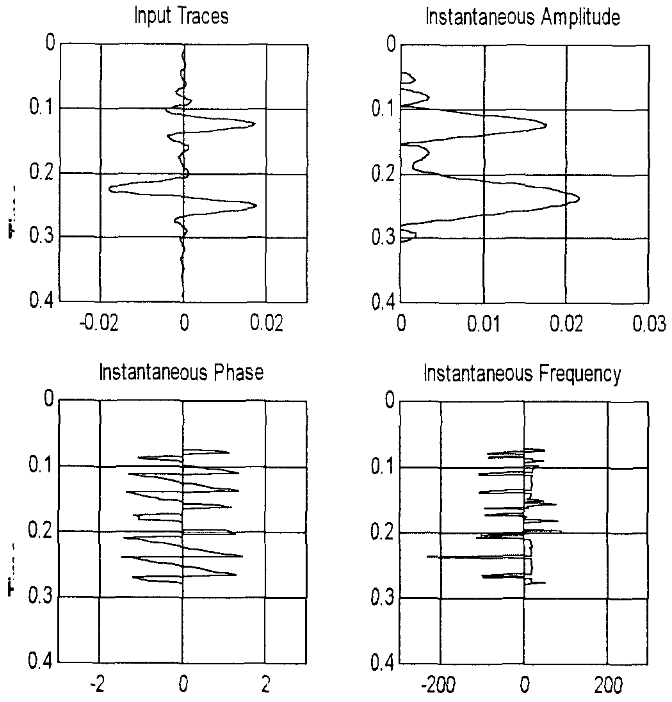

Fig. 5-B. Seismic attributes of a single trace (trace number 19 of the channel sand model). High peak-to-trough amplitute and instantaneous amplitute at 0.22-0.24 ms interval. Anomalous high negative instantaneous frequency is observed at 0.23 ms.

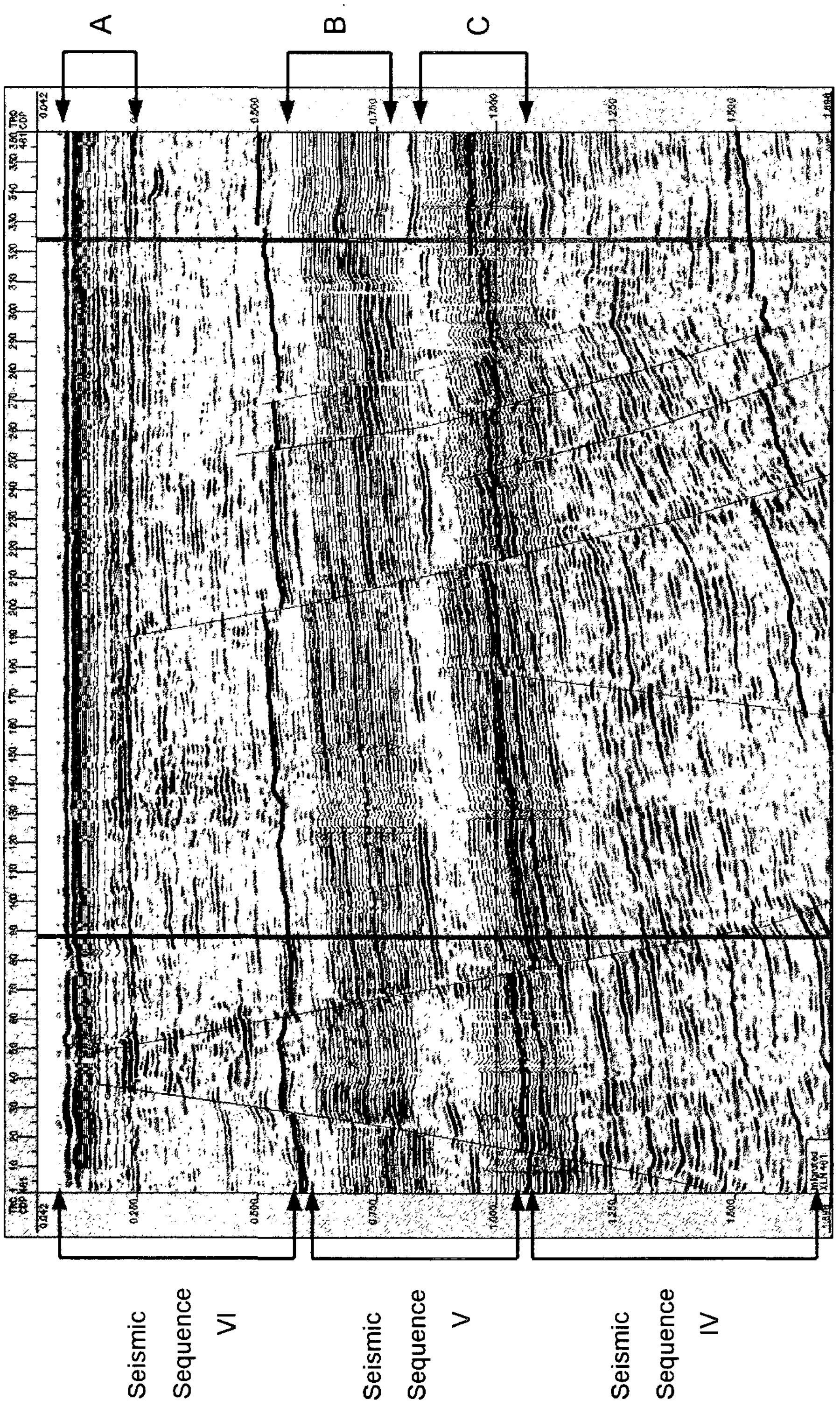

Fig. 6. The interpreted intervals - A, B and C.

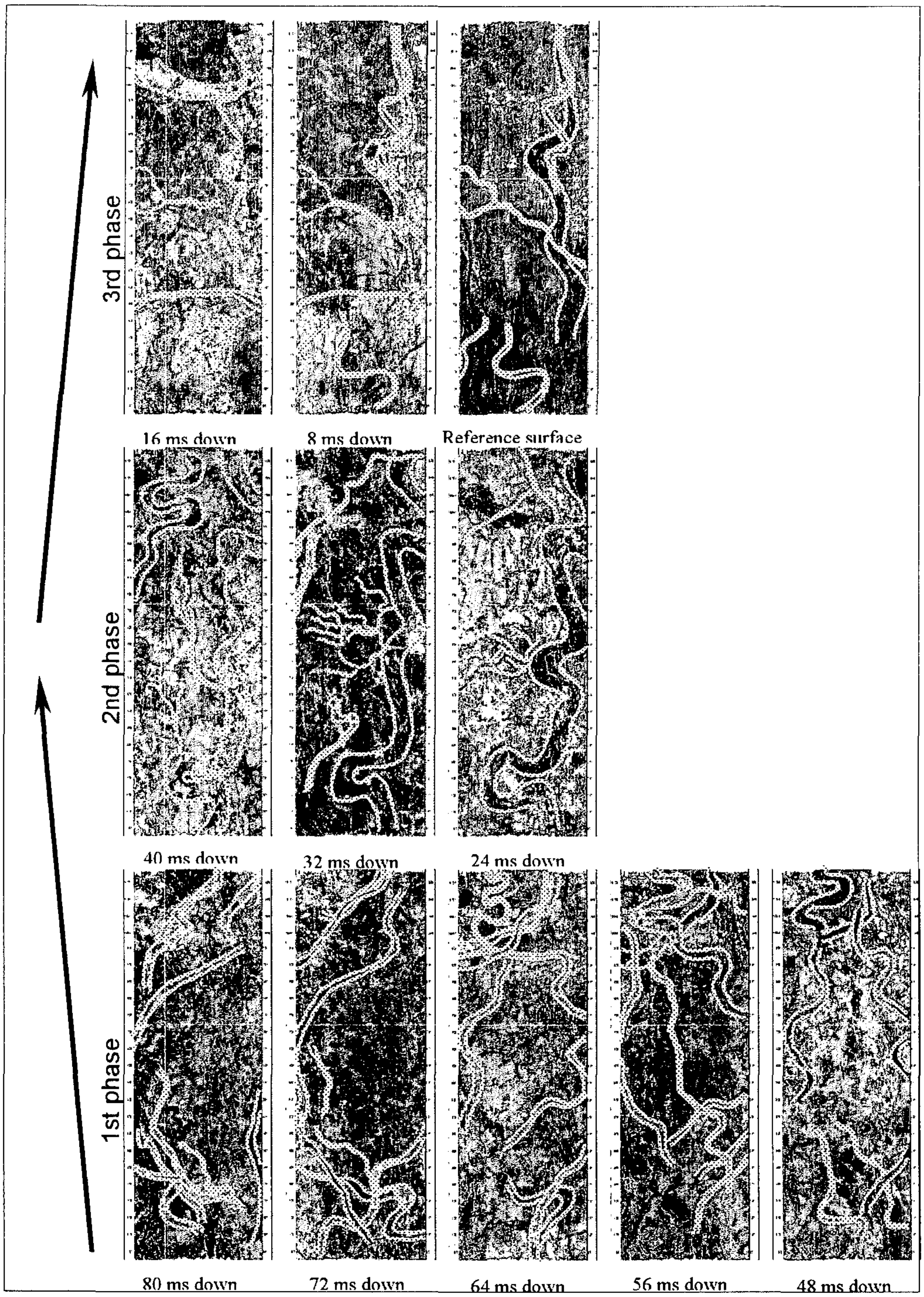

Fig. 7-A. The first cycle of interval B. There are three phases in this cycle. Arrows represent the trend of increase in sand-rich sediment deposition in the second phase.

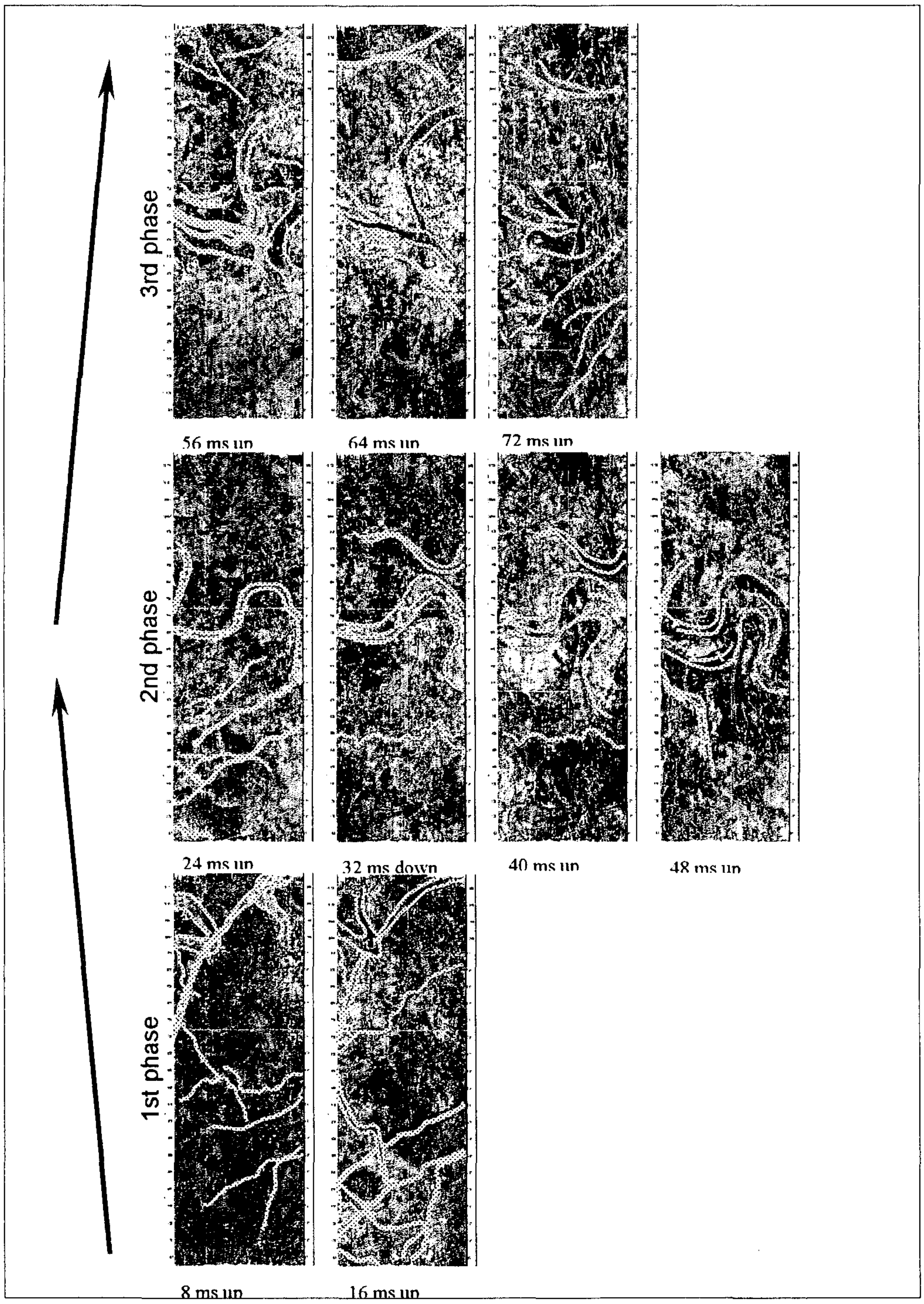

Fig. 7-B. The second cycle of interval B. Arrows represent of increase in sand-rich sediment deposition. regional flow direction changed from N-S in the firstcycle to W-E in this cycle.

last phase, stream power decreased.

Depositional facies analysis using seismic attributes on successive stratal surfaces enabled detailed description of individual facies, assisted understanding of their three-dimensional architecture, and described a high-frequency depositional sequence. When 3-D seismic interpretation is integrated with well data controlled by reliable velocity data, complex depositional systems should be correctly described even in deep sections.

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