Stratal slice: a tool for seismic sedimentologic imaging and reservoir prediction

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Abstract

Seismic sedimentology is the use of seismic data in the study of sedimentary rocks and the processes by which they were formed. Stratal slice is now a widely used tool for sedimentologic study with reservoir-level resolution. Stratal-slice imaging overcomes some limits of classic seismic stratigraphy caused by inadequate seismic resolution and difficulties in picking higher-order depositional time surfaces. Seismic sedimentology has become a useful tool for prospecting of stratigraphic traps. Major benefits include, but are not limited to, an improvement in facies imaging and high-frequency sequence stratigraphy and more efficient thin reservoir prediction.

Introduction

It is so convenient nowadays for us to view modern land surfaces from commercial airplanes or on satellite images, being amazed by the geomorphic form of depositional features such as river channels, deltas, barrier islands, and dune fields. These views represent complete images of the modern time surfaces. In fact, modern 3-D seismic technology has made it possible for us to image similar, but much older, geomorphic or depositional features preserved in the rock record. Historically, we have been very good at using seismic stratigraphy to scrutinize 3-D seismic volumes line by line, trace by trace to look for seismic anomalies of field-scale (50 m or thicker) geologic and depositional perspective. Unfortunately, although many reservoir-scale (3-10 m) features can be detected in vertical seismic lines, few such features can be resolved and interpreted in the vertical perspective because of limited bandwidth of the data. For example, the seismic facies around the dash line in Fig. 1a was referred to be fluvial deposits because of the discontinuous and patchy events with fast-changing amplitudes. And wells drilled through the interval proved that. However, correlation of individual channel-fill sand bodies and marginal facies (levee, crevasse splay, etc) in this data set of 50-Hz dominant frequency are difficult because these facies elements are too thin (3-10 m) and the seismic resolution (a quarter wavelength or 20 m) is not enough to resolve their tops and bases. Who could imagine what are the depositional elements represented by those subtle amplitudes pointed by these red arrows?

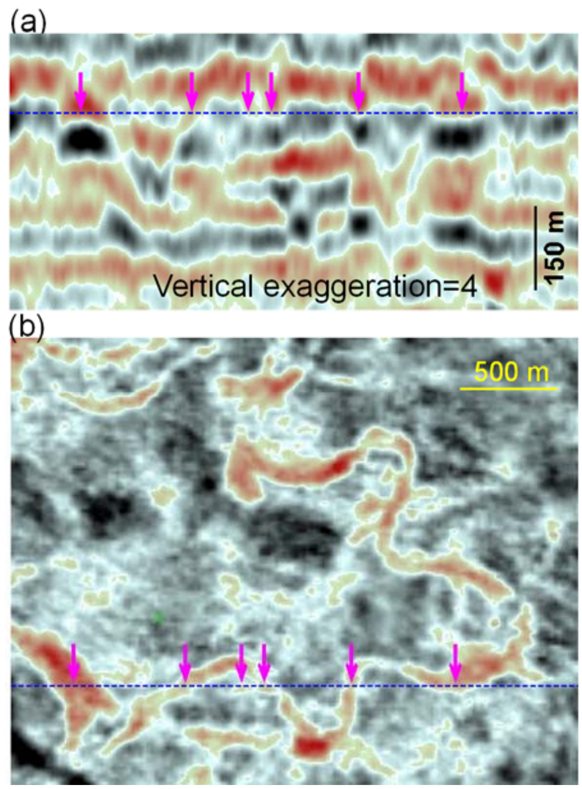

Fig 1. Stratal slice takes advantage of horizontal seismic resolution for high-resolution (10 m or reservoir level) seismic imaging of reservoir facies and hydrocarbon traps. (a) Vertical section. (b) Stratal slice. Red arrows point to the seismic features that are difficult to interpret in a vertical section.

To map depositional systems in high resolution, one strategy is to change the emphasis of seismic imaging from vertical sections to horizontal sections or stratal slices. It is a well-known fact that for a perfectly migrated 3-D seismic data set, horizontal seismic resolution is the same as vertical seismic resolution. Also, numerous outcrop and subsurface studies have revealed that depositional bodies are commonly characterized by a much greater horizontal dimension than vertical dimension. As a result, depositional bodies might be resolved in plan view, even if they can only be detected in vertical view. A stratal slice that follows the dash line in Fig. 1a and beyond in the 3-D seismic volume (Fig. 1b) images fluvial channels, crevasse splays, flood plain and mud plugs. Although the depositional elements are mostly less than 10-m thick and beyond vertical seismic resolution, they are resolved impressively well in horizontal dimension.

Tools

With current technology, seismic sedimentology is limited to the study of lithology, geomorphology, depositional architecture, and depositional history. Seismic lithology and seismic geomorphology are the two key components of seismic sedimentology.

In recent years, some key techniques have been developed that play an important role in the study of seismic sedimentology. Those techniques can be roughly divided into two categories: the techniques that convert seismic traces into pseudo wireline lithology logs and the techniques that can predict high-resolution depositional time surfaces from 3-D seismic data. Lithological conversion of seismic data is not a new topic; however, obtaining a high-resolution lithologic volume from 3-D seismic data is not automatic and requires considerable effort. Three tools are available:

1. Ninety-degree phasing (Sicking, 1982; Zeng and Backus, 2005a, b). This method is designed to tie the seismic waveform directly to the acoustic impedance (AI) profile for better correlation between seismic traces and stratigraphic architecture. If AI (in a relative sense) is linked to lithology, seismic waveforms can also be tied to lithology-indicative wire-line logs. This improvement should make a seismic section look more like a geologic section. A 90-phase data set typically produces better-quality images for thin-bed depositional units (Fig. 2).
2. Seismic inversion. A high-resolution seismic inversion serves a similar purpose to convert seismic traces into AI logs. However, all inversion algorithms are not unique; thus, multiple solutions may fit the same seismic trace, making interpretation risky and less reliable.
3. Seismic attribute analysis. Multiple attributes generated from seismic traces can be used to predict lithology if a statistical correlation between the two can be established through regression, neural network, or other means. This method is especially suitable for data sets that show ambiguous responses of seismic amplitude to lithological variation (e.g., Gao, 2007; Hart, 2008).

On the other hand, the techniques that can help interpreters pick geologic time surfaces from a 3-D seismic complex include time slicing, horizon slicing, and stratal slicing. Depending on depositional style and formation geometry, any of these methods may correctly

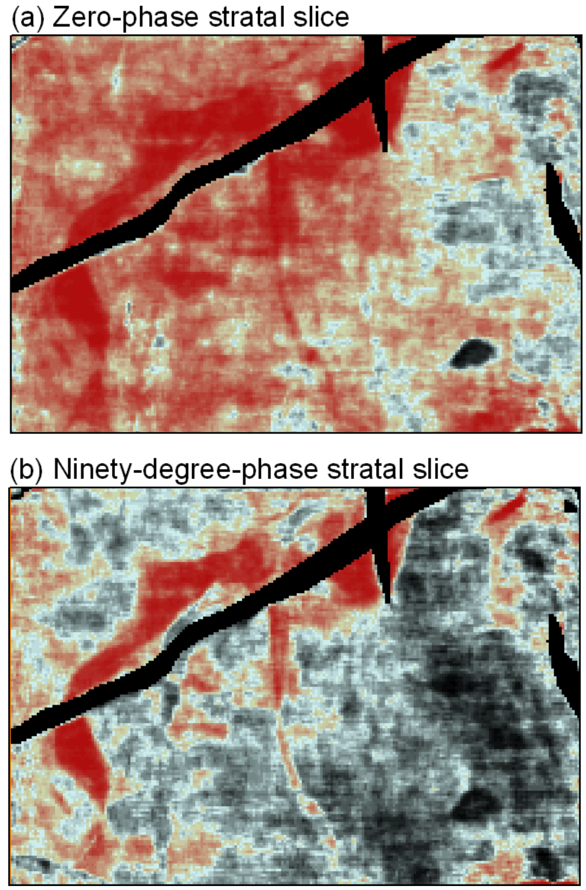

Fig. 2. Depositional facies imaging as a function of seismic wavelet phase. (a) Zero-phase wavelet generates an antisymmetrical waveform for a thin distributary channel system and poor-quality channel images. (b) 90°-phase wavelet leads to a symmetrical waveform for the thin bed that ties better to channel sandstones.

recover approximate geologic time surfaces, although the accuracy and applicability may vary:

1. If the formation is sheet-like and flat-lying, time slicing is probably sufficient.
2. If the formation is sheet-like but not flat-lying, horizon slicing is most appropriate.
3. If the formation is neither sheet-like nor flat-lying, stratal slicing is necessary.

A comparison of the three methods is illustrated in Fig. 3. Stratal slicing (Zeng, 1994; Zeng et al., 1998a, b), or proportional slicing (Posamentier et al., 1996), linearly samples seismic amplitude (or other attributes) between seismic-reference events. The reference events should be geologic-time equivalent and should be able to be picked with less difficulty on seismic sections. The purpose of stratal slicing is to generate a seismic attribute display on an auto-picked depositional surface within a user-defined geologic-time framework. Most of the current 3-D seismic interpretation packages can make only time slices and horizon slices. The software used to make stratal slices, including necessary reconditioning of seismic data and various attribute applications, was developed by a joint effort of academia and industry, and is available at http://www.austingeo.com.

Another useful approach is volumetric (geobody) interpretation of pre-identified sequences or systems tracks. This method is suitable for targets that are easy to correlate in a seismic volume, however with dramatic and irregular thickness changes in space (e.g., Santos et al., 2000).

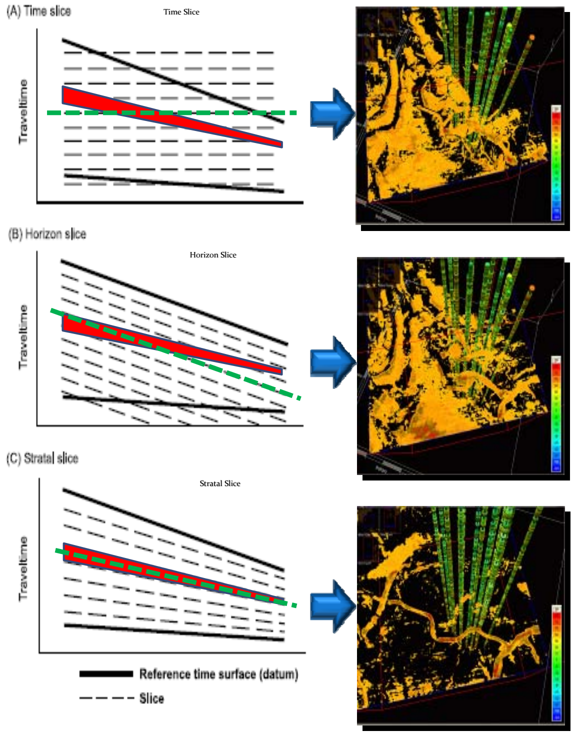

Fig. 3. Methods to auto-pick depositional time surfaces （a fluvial system in this case） from 3-D seismic data. (a) Time slicing. This method can be used only in sheet-like and flat-lying formations. (b) Horizon slicing. Formation does not have to be flat-lying but must be sheet-like. (c) Stratal slicing. Thanks to the use of both horizons, formation does not have to be either flat-lying or sheet-like.

Applications

The stratal slicing technique provides a new tool for facies imaging from 3-D seismic data. Interpreters no longer needs to first identify a seismic facies or anomaly on 2-D seismic profiles, then pick the event of interest based on their experience and intuition. Instead, they can quickly scan the whole sequence in 3-D and potentially find more interesting facies images and subtle stratigraphic relationships. Example stratal slices from various 3-D volumes in the Gulf of Mexico Tertiary section record some typical terrigenous clastic depositional facies. More examples will be discussed in conference presentation.

Fluvial-incised valley complex

Fig. 4 is a stratal slice made from a 3D seismic volume in onshore Louisiana. It illustrates amplitude channel-like patterns in a time-equivalent depositional unit formation. There are two types of channels. One is small and sinuous that is interpreted as fluvial channels deposited on costal flood plain environment during high sea-level period. The other is large and straight that is referred to be incised-valley fills formed when the sea-level dropped and the coastal plain area was eroded. Such a subtle relationship is very difficult, if not impossible, to detect in a vertical profile. Lateral resolution, measured by the width of the narrowest channel on the stratal slice, is about 30 m.

This project studied an animation of the stratal slices in this sequence, which lead to the discovery of many high-quality sandstone reservoirs developed exclusively in incised valley. Those sandstones are major hydrocarbon reservoirs in the area, providing potential targets for future drilling.

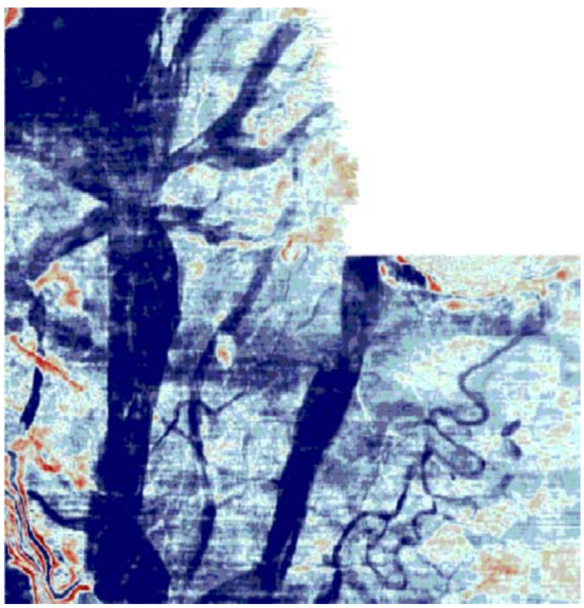

Fig. 4. A seismic stratal slice showing a fluvial-incised valley fill complex in Tertiary onshore Louisiana.

Deepwater slope-fan system

Our work using the stratal slicing technique in the deep water Gulf of Mexico has produced many high-quality seismic images of turbidite deposits. A stratal slice made in a 3D data set in a continental-slope area (Fig. 5) illustrates a slope-fan complex. The complex is composed of many elongate and narrow lobes that were derived from point sources in the shelf-edge area to the northwest direction (up-left corner). The turbidite system migrated from time to time, with the last one located in the center of the complex with clear image of channel in the middle and bank sediments on both sides. A series of linear features that cut cross the complex at roughly 90º are gravity faults formed during and immediately after the slop-fan deposition.

The turbidite sandstones developed in the channels and banks could be effective hydrocarbon reservoirs in the formation; potential pools can be formed where the sandstones are sealed by gravity faults.

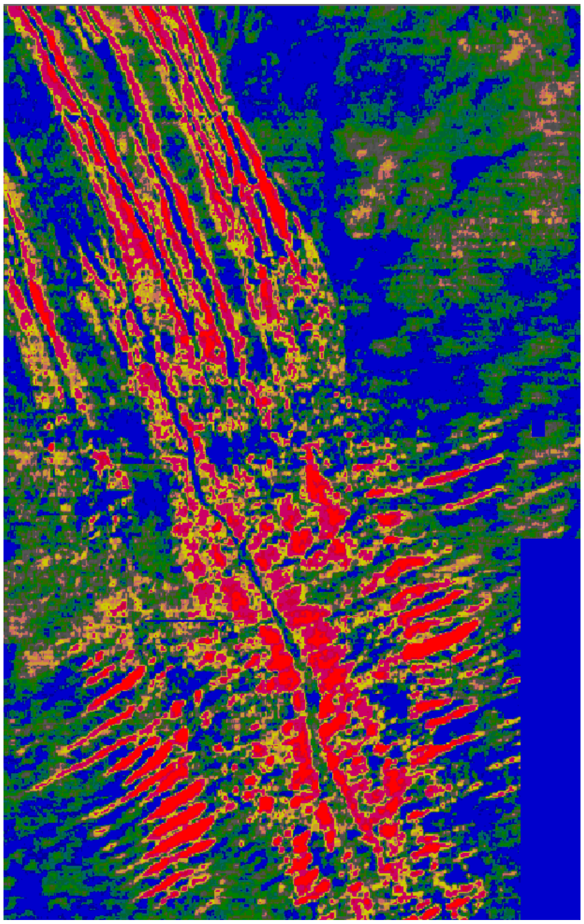

Fig. 5. A seismic stratal slice showing a deepwater slope-fan system in continental slope area, Tertiary Gulf of Mexico Basin.

Conclusions

1. Stratal slice is a powerful tool for high-resolution facies imaging and reservoir prediction, and should get more attention by geoscientists and industry.
2. Key techniques for stratal slicing and seismic sedimentology include seismic lithology by 90º phasing of seismic traces and seismic geomorphology by stratal slicing.
3. One of the major advantages of stratal slicing over other methods is that it can handle complex thickness changes in the formation and predict high-frequency geologic time surfaces.
4. Major applications include, but not limited to, predict high-resolution depositional facies images and use these images for hydrocarbon exploration and production.

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