Reconstruction of Depocenter Evolution through Time Using Relative Stratigraphic Thickness*

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Abstract

In this article, we describe a new approach to seismic stratigraphic interpretation. We build on the concept of the relative geologic time attribute introduced by Stark (2004) to define a relative stratigraphic thickness attribute, which can then be interpreted to reconstruct depocenter migration from seismic data.

The principles of seismic stratigraphy were established in the classic AAPG Memoir 26. At this time (1977), manual interpretation of 2D seismic was still typical in the E&P industry. Simple truncation geometries such as onlap, downlap, and toplap were used to characterize sequence boundaries and flooding surfaces. Recent work continues to emphasize these 2D concepts, for example, using them in introductory sequence stratigraphic exercises. The routine use of 3D seismic emerged in the 1980s and, with it, computer-assisted interpretation. The main focus of the industry was on large structural traps. Highly effective 3D structural interpretation workflows developed in the 1980s still form the core of current interpretation workflows. Given the time-consuming nature of seismic interpretation, most geoscientists are forced to limit their mapping to major unconformities and flooding surfaces. These correspond to first- and second order sequences boundaries and occupy only a small fraction of the typical seismic volume. It was common then, and now, to infer stratigraphy by averaging attributes such as seismic amplitude between structural picks.

Introduction

A general observation applicable to most good-quality seismic data is that nearly all of the reflection events are localized and cannot be followed far; these events represent higher-order stratigraphic boundaries. Although such events are exceedingly difficult to interpret using traditional methods, and may often be mistaken for noise, they are in fact remarkably well organized geologically, often characterized by high signal-to-noise ratios. In recent years, a new discipline of geophysics has emerged to exploit this localized seismic energy. This involves the use of computational methods to derive correlated stratigraphic surfaces in a 3D seismic volume, and the subsequent interpretation of the geologic information embedded in the interrelations between these surfaces. We might call this discipline computational seismic stratigraphy.

As noted by Hoyes et al. (2011), the global methods, which track a set of horizons simultaneously in a seismic volume, can be subdivided into several categories: dip-driven, horizon patches, and global optimization. These methods share a common goal and result in a dense set of horizons closely spaced in two-way time; their order can be thought of as representing geologic time. In this study, horizons are tracked or extracted from a continuous dip field. When compared to similar workflows, e.g., Lacaze et al. (2011), this method does not require construction or refinement of a global geologic model.

Discussion

If we extend all horizons across a seismic volume, honoring structural breaks and the relative geologic time concept, we will find that most of the associated isochrons are of zero thickness except locally. Consider the following two examples: (1) a series of prograding clinoforms and (2) a deepwater channel complex. In the former, a stack of horizons representing the clinoforms would be characterized by an isochron thickness of zero except where phases of clinoform growth occur (Figure 1 and Figure 2). The relative geologic time may be approximately hundreds to thousands of years to millions of years, and the relative stratigraphic thickness may measure several hundred meters thick.

The latter example of a deep-water channel complex would have a thickness of zero except where the complex exists. The relative geologic time spanned by the complex thus corresponds to a three-dimensional relative geologic time distribution, which can be thought of as a small-scale architectural element or geobody. In this case, the relative geologic time may be on the order of hundreds to thousands of years; the relative stratigraphic thickness, a few kilometers wide by less than a hundred meters thick.

These examples illustrate the scale-independent nature of computational seismic stratigraphy. The recognition of a relative geologic time attribute (Stark, 2004) and the relative stratigraphic thickness attribute presented here are novel approaches to mapping depocenter evolution. No longer limited to first and second-order sequence boundaries, we use the term “depocenter” to denote the area of thickest deposition in any given geometry. We emphasize that these concepts can be applied to any geologic feature or used to subdivide a feature; thus, they have applications across the entire E&P spectrum, from regional exploration to geologic modeling.

The HorizonCube

A HorizonCube is defined as a dense set of correlated 3D stratigraphic surfaces. The calculation of this HorizonCube is a crucial step in the seismic stratigraphic interpretation workflow described in this article. The single input required to create a HorizonCube is a continuous dip field. Mapped horizons can be used as boundary constraints and can be acquired by traditional horizon trackers or extraction from the continuous dip field. The dip field is available in the SteeringCube, a volume with local dip/azimuth information at seismic resolution. A special autotracker tracks the dip field to generate hundreds of horizons, each representing a relative geologic timeline (de Groot et al., 2006; de Groot et al., 2010). Using the dip field to track horizons has an advantage above using the amplitude field as it is much more continuous. In addition, the effect of noise can be significantly reduced by smoothing the dip field. Alternatively, the HorizonCube can be created using a model-driven approach (stratal slicing or parallel to the upper/lower boundary).

Relative Stratigraphic Thickness: The 3D Chronostratigraphic Slider

A typical HorizonCube may comprise dozens or even thousands of layers; thus, a tool is necessary to investigate the relative geologic thickness attribute between any two horizons. The 3D chronostratigraphic slider is a method for computing the isochron for an arbitrary stack of horizons in real time, using a slider bar to specify the range of horizons to be investigated. In this way, the interpreter can immediately see the 3D thickness expression of a feature observed in a given cross section (Figure 1c).

Functionality of the 3D chronostratigraphic slider includes the ability to either: (1) move the top or bottom horizons up or down in the HorizonCube; or (2) "lock" the distance between the top and bottom horizons prior to moving them up and down within the HorizonCube. Changes in isochron thickness may be displayed automatically, and operations using this tool take seconds to complete (Figure 2).

The 3D chronostratigraphic slider can be used to investigate relative stratigraphic thicknesses at any scale. Two end-member applications are presented as case studies here. In the first, the 3D slider is used to map depocenter evolution in clinoforms of the North Sea. A much smaller scale application is also described, confined channel complexes on the Scotian Shelf. This tool has also been used in a number of other geologic settings, including: (1) regional submarine fan lobe switching; (2) localized fan lobe stacking patterns; (3) channel complexes migrating in a slope setting; and (4) subsalt successions including channel and lobe complexes and composite bodies.

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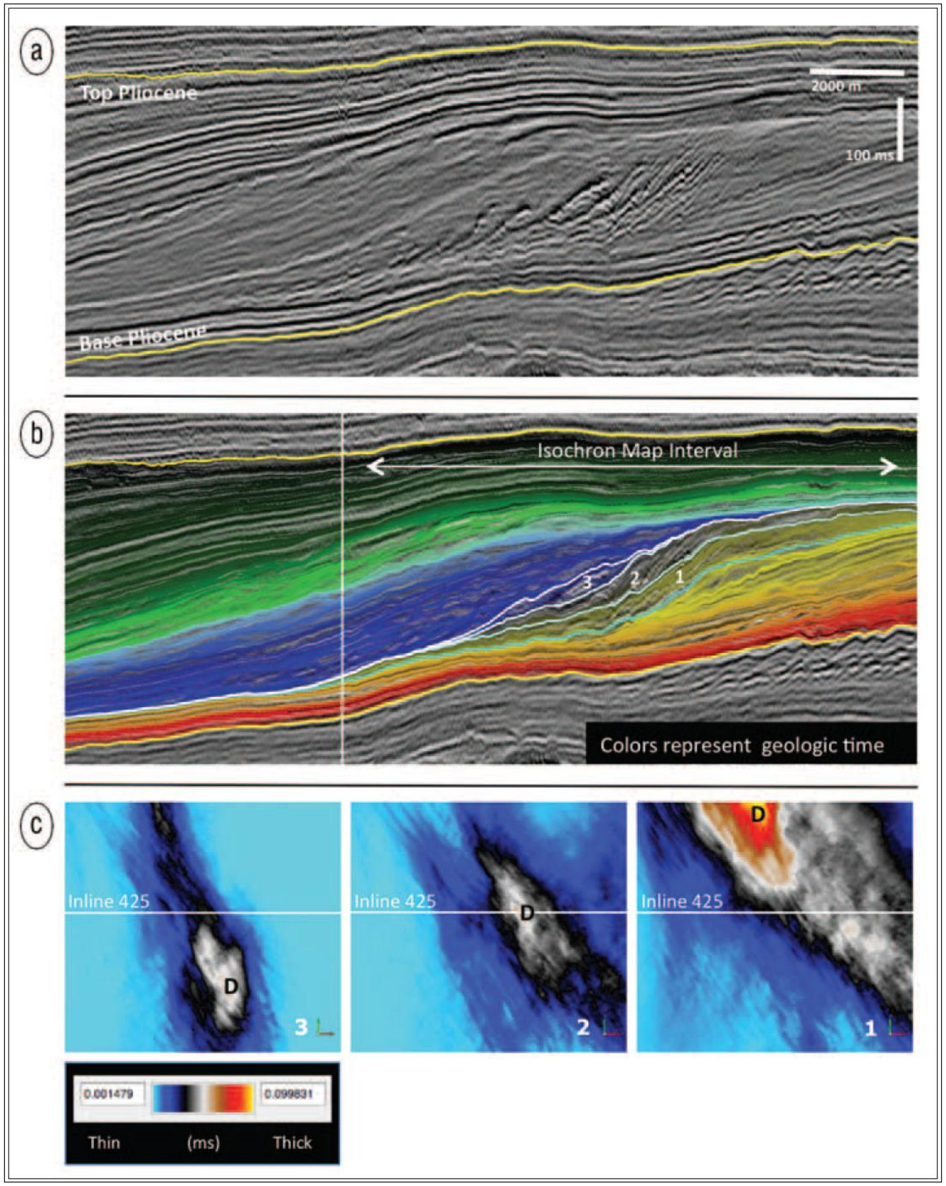

Figure 1. An example of depocenter evolution and clinoform progradation from the Dutch sector in the North Sea. Inline 425 is shown in (a), and the top and base Pliocene reflectors are labeled. (b) A dip-driven HorizonCube comprising more than 600 horizons that characterize clinoform packages, labeled 1, 2, and 3. Maps shown in (c) correspond to the isochron map interval on the right side of (b). Each map illustrates the 3D migration of deposition. Depocenters are labeled D.

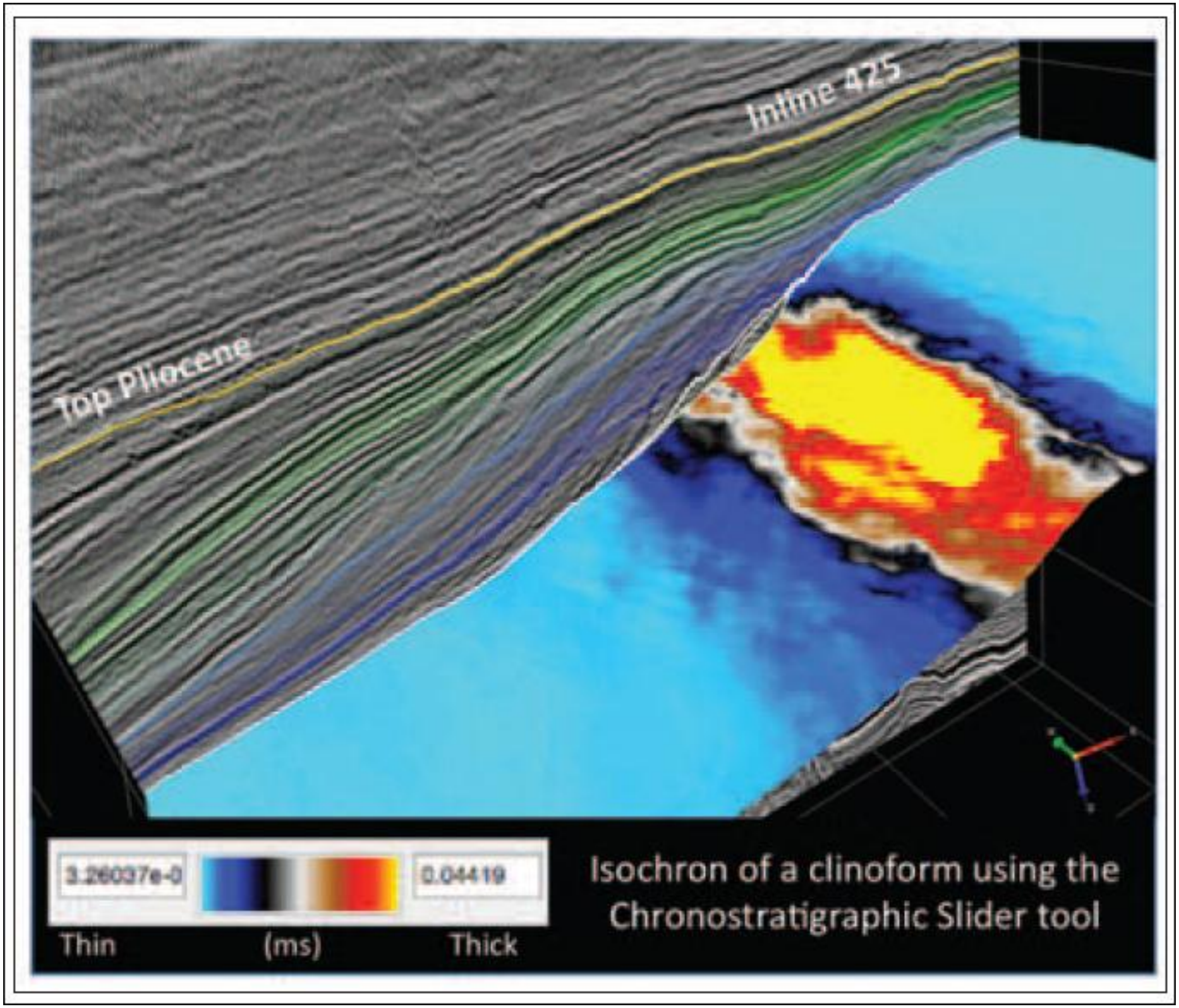

Figure 2. Illustration of an isochron generated using the 3D chronostratigraphic slider tool. In this case, the thickness of a single clinoform is calculated and displayed on the basal horizon of the clinoform.