GeoChronicle Panorama, Vol.1, Special Issue No.1, December 2021 pp.69-71

Integrating Sequence and Seismic Stratigraphy: Concepts, Methodology, and Applications in Sedimentary Basin Analysis.

B. Mishra
Associate Professor of Geology (Retired)
D.D. Autonomous College, Keonjhar
Email: bmishrageol@gmail.com

Abstract

Sequence and seismic stratigraphy are fundamental tools in sedimentary basin analysis, offering insights into depositional processes, sea-level fluctuations, and tectonic controls on sedimentation. Originating from the pioneering work of Peter Vail in the 1960s, these methodologies have evolved to combine geophysical, sedimentological, and ichnological data to interpret stratigraphic sequences and system tracts. This paper revisits the fundamental principles of sequence and seismic stratigraphy, explores their methodological framework, and highlights their applications in hydrocarbon exploration and basin analysis. Emphasis is placed on the integration of seismic reflection characteristics, depositional environments, and eustatic controls that form the basis for modern stratigraphic interpretation.

Introduction

Sequence stratigraphy is a cornerstone of modern sedimentary geology, providing a temporal and spatial framework for understanding depositional systems (Vail et al., 1977; Posamentier et al., 1988). The concept, first articulated by Peter Vail during his tenure at Exxon in the 1960s, revolutionized subsurface interpretation by linking seismic reflection patterns to stratigraphic surfaces and depositional sequences. Vail's three key postulates that seismic reflections are generated by physical bedding surfaces, that these reflections define depositional sequences, and that unconformities are synchronous across basins—remain foundational to the field (Vail et al., 1977).

This paper summarizes the development, concepts, and applications of sequence and seismic stratigraphy, focusing on methodological integration and its relevance to basin analysis and hydrocarbon exploration.

Conceptual Framework of Sequence Stratigraphy

Sequence stratigraphy focuses on the study of rock relationships within a time-stratigraphic framework of repetitive, genetically related strata bounded by unconformities or correlative conformities (Van Wagoner et al., 1988). These unconformities represent periods of erosion or non-deposition, providing insights into relative sea-level changes and tectonic subsidence (Obaje, 2013). Vail's model (Vail et al., 1977) assumes that eustasy—the global change in sea level—is the principal control on unconformities and depositional system tracts. Later refinements incorporated the interplay of sediment supply, tectonic activity, and climate (Catuneanu et al., 2011; Embry, 2009).

Methodology of Seismic Stratigraphic Interpretation

Seismic stratigraphy interprets the geometry and configuration of seismic reflections to deduce depositional environments, lithofacies, and geologic history (Mitchum et al., 1977). Key interpretative features include reflection continuity, amplitude, configuration, frequency, and velocity. Reflection terminations such as onlap, downlap, toplap, and truncation are diagnostic of depositional and erosional boundaries (Mitchum et al., 1977). These features allow geologists to delineate depositional sequences and interpret system tracts such as the Lowstand System Tract (LST), Transgressive System Tract (TST), and Highstand System Tract (HST). The standard workflow in seismic stratigraphy typically includes:

1. Seismic sequence analysis
2. Well log correlation
3. Synthetic seismogram generation
4. Seismic facies analysis
5. Depositional environment interpretation
6. Lithofacies mapping
7. Seismic modeling (Catuneanu et al., 2011; Posamentier & Kolla, 2003).

Sequence Stratigraphic Units and System Tracts

A depositional sequence is bounded by unconformities formed in response to relative sea-level changes, subsidence, and sediment supply. Within these sequences, parasequences and parasequence sets are defined by marine flooding surfaces, typically forming aggradational or progradational stacking patterns (Van Wagoner et al., 1988).

- Lowstand System Tract (LST): Forms when sea level is low but begins to rise, characterized by progradational parasequences.
- Transgressive System Tract (TST): Associated with sea-level rise; deposition is retrogradational, culminating in the Maximum Flooding Surface (MFS).
- Highstand System Tract (HST): Occurs when sea level stabilizes or falls; marked by aggradational to progradational parasequences (Catuneanu, 2006).

Each system tract reflects changes in sedimentation rates and accommodation space—key parameters in reconstructing basin evolution (Embry, 2009).

Applications in Hydrocarbon Exploration

Sequence stratigraphy is indispensable in hydrocarbon exploration. It aids in identifying potential reservoir facies, source rocks, and seals within third-order depositional sequences (Obaje, 2013). The method enhances predictability of facies distribution and improves reservoir characterization by correlating seismic facies with lithological and petrophysical data (Martinsen & Helland-Hansen, 1995). Seismic stratigraphic interpretation also provides insights into sediment routing systems, stratigraphic traps, and paleogeographic reconstructions, thereby optimizing exploration strategies in rift and passive margin basins (Posamentier & Kolla, 2003).

Integration with Modern Analytical Techniques

By the early 21st century, sequence stratigraphy had evolved into an integrative discipline combining ichnology, isotope stratigraphy, and 3D seismic visualization. Trace fossil analysis provides valuable information on depositional energy, sedimentation rates, and paleo-oxygenation (Pemberton & MacEachern, 2005). Likewise, isotope proxies assist in correlating stratigraphic surfaces across basins, refining chronostratigraphic models (Catuneanu et al., 2011).Advances in 3D seismic interpretation software and digital visualization have improved the precision of sequence stratigraphic interpretation and basin modeling, allowing for more accurate predictions of facies architecture and reservoir heterogeneity (Posamentier & Kolla, 2003; Catuneanu, 2006).

Conclusion

Sequence and seismic stratigraphy provide a unified framework for understanding the dynamic interplay between sedimentation, sea-level changes, and tectonism. Since its inception by Vail in the

1960s, the methodology has evolved into a multidisciplinary approach integrating geophysics, sedimentology, and basin modeling. For geoscientists and exploration professionals, sequence stratigraphy remains a vital interpretative tool for predicting stratigraphic architecture and hydrocarbon potential in sedimentary basins.

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