Experiences with Dual-Sensor Towed Streamer Acquisition and Imaging in the Eastern Mediterranean*

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Introduction

The launch of dual-sensor towed streamer technology in 2007 was probably the most important milestone in the seismic industry during the last 10 years. The launch kicked off huge interest and demand for broadband seismic methods and their benefits. It also triggered the development of new acquisition and processing technology on both the source and receiver side. Broadband benefits and the ability to accurately separate dual-sensor recordings into up- and down-going wavefields have been exploited throughout the entire seismic value chain (Widmaier et al., 2015). Since the first 2D dual-sensor applications in 2007, PGS has steadily converted its seismic fleet from conventional to dual-sensor streamers and will complete the fleet-wide roll-out during 2015.

The 2D and 3D dual-sensor seismic acquisition and imaging projects that were conducted to solve imaging challenges in the Eastern Mediterranean are regarded as important milestones both for the roll-out of the technology as well as for subsurface image quality in the region (Figure 1). This article revisits the key experiences made in the Eastern Mediterranean region during the last years.

Dual-Sensor Streamer Technology and Wavefield Separation

Ghost reflections from the sea surface have limited the bandwidth of towed streamer data in the past. The introduction of dual-/multi-component streamers has enabled the industry to overcome the receiver ghost problem (Carlson et al., 2007; Caprioli et al., 2012). Particle motion sensors with complementary ghost response functions compared to pressure sensors are utilised to remove ghost reflections in an accurate and robust way. The removal of the receiver ghost increases the seismic bandwidth and thus provides better resolution for interpretation (Figure 2). The ability to remove the ghost accurately allows the streamers to be towed deeper. The signal-to-noise ratio is improved by deeper tow, especially at the low frequency end of the seismic bandwidth. Improved low frequency content enhances the quality and accuracy of seismic inversion and reservoir characterisation (ten Kroode et al., 2013). Towing streamers deep also means that the seismic measurements are made further away from the sea surface; i.e., the recordings are less exposed to weather and rough sea-surface-related noise. Thus, if the streamer is located deeper than the wave base, data with good signal-to-noise can also be acquired under marginal weather conditions. Consequently, weather-related downtime has been reduced compared to conventional towed streamer acquisition (Osnes et al., 2010).

Solving Imaging Challenges in the Eastern Mediterranean

The Eastern Mediterranean is known for its extensive Messinian evaporites. These evaporites can regionally be very thick, complex, and can have large impedance variations. Consequently, accurate imaging and interpretation of pre-salt sections can be very difficult. Pre-salt imaging challenges are typically caused by strong acoustic distortion and wavefield attenuation in the Messinian anhydrite layer, and the presence of complex multiple diffraction noise (Keggin et al., 2007). Also, the evaporites lead to shadow zones and poor image quality when the salt velocity variations are not properly accounted for in velocity model building (Rønholt, 2014).

Keggin et al. (2007) successfully demonstrated how to overcome illumination challenges and multiple diffraction noise with multi-azimuth acquisition offshore Egypt. Imaging of deeper structures below complex layers with high wavefield attenuation can be further improved by increasing the penetration of low frequency seismic energy. Additional low frequency energy can be obtained by towing the seismic streamers deeper. Deeper tow with conventional streamer technology compromises the higher frequencies, and thus the bandwidth due to the receiver ghost effect. However, higher frequencies are desired in the Eastern Mediterranean, e.g., to image post-salt structural traps. Dual-sensor towed streamer technology which has been designed to deliver deep tow without compromising the higher frequencies was introduced to the Eastern Mediterranean in 2008. The dual-sensor surveys led to significant post- and pre-salt bandwidth and image quality improvements (Figure 3), e.g., offshore Cyprus (Montadert et al, 2010), Egypt (Semb et al., 2010), Lebanon (Rønholt et al., 2014), and Greece (Schjeldsøe Berg et al., 2014).

The breakthrough in seismic acquisition technology was closely followed by the application of state-of-the-art seismic signal processing and imaging technology. Pre-stack depth migration (PSDM) has been utilised to resolve the complex velocity variations especially in the Messinian salt sections, e.g., offshore Lebanon (Rønholt et al., 2014). Velocity model building, e.g., based on tomographic inversions, has been extended from utilising reflected waves only to diffracted wave and turning wave modes.

Conclusions

New streamer acquisition and imaging technology has provided a step change in seismic data quality in the Eastern Mediterranean. The introduction of dual-sensor streamer provided a significant uplift in the pre- and post-salt data quality with benefits visible in three key areas:

- Firstly, enhanced resolution of the seismic image both shallow and deep, due to a broader frequency bandwidth;
- Secondly, better signal penetration revealing sub-salt and deeper targets, which has led to improved interpretation;
- Thirdly, increased signal-to-noise ratio due to the deep tow and receiver ghost cancellation.

In the presence of the Messinian evaporates, pre-stack depth-imaging supported by state-of-the-art velocity model building can provide significant uplifts.

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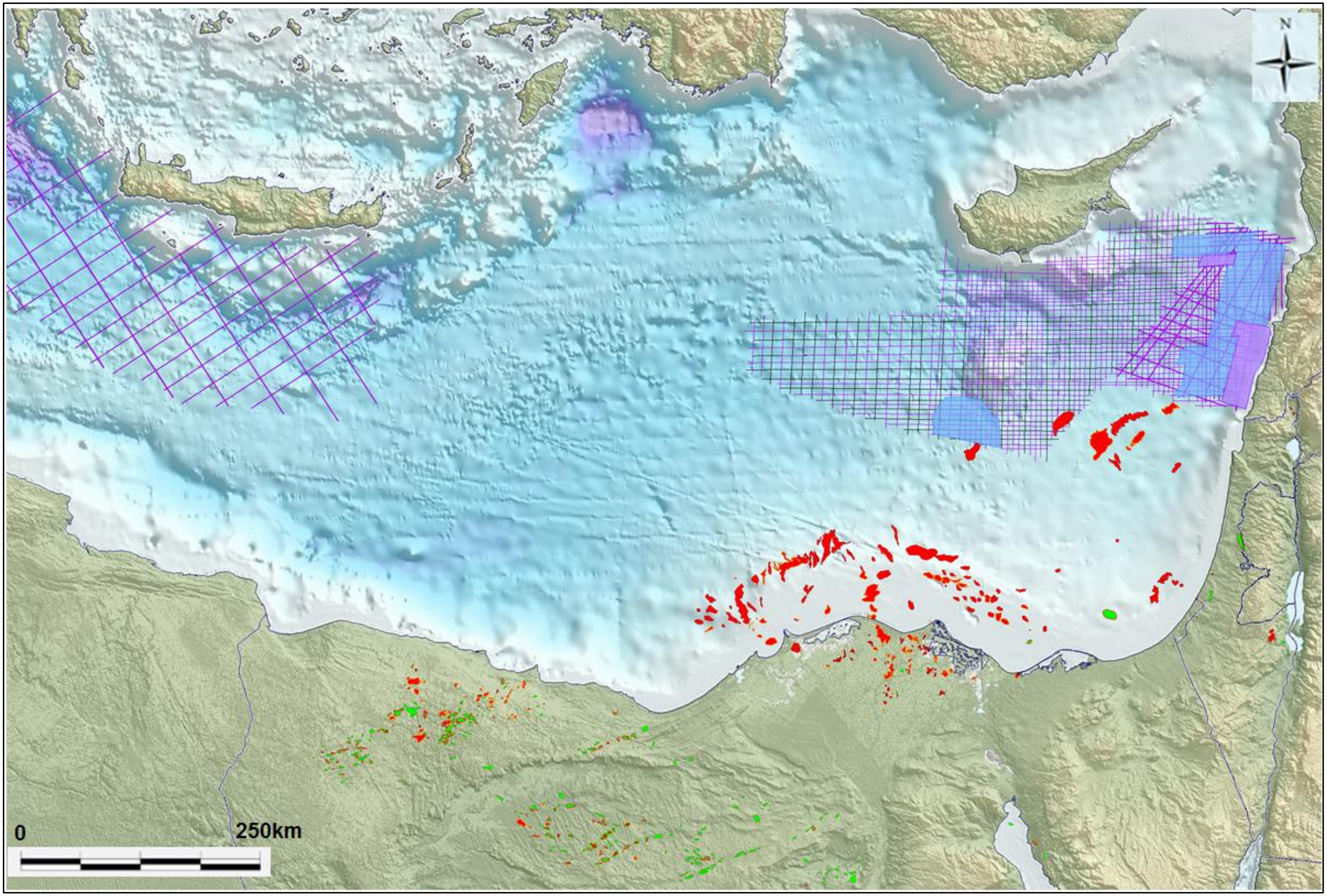

Figure 1. The 2D and 3D non-exclusive dual-sensor seismic data coverage in purple in the Eastern Mediterranean area.

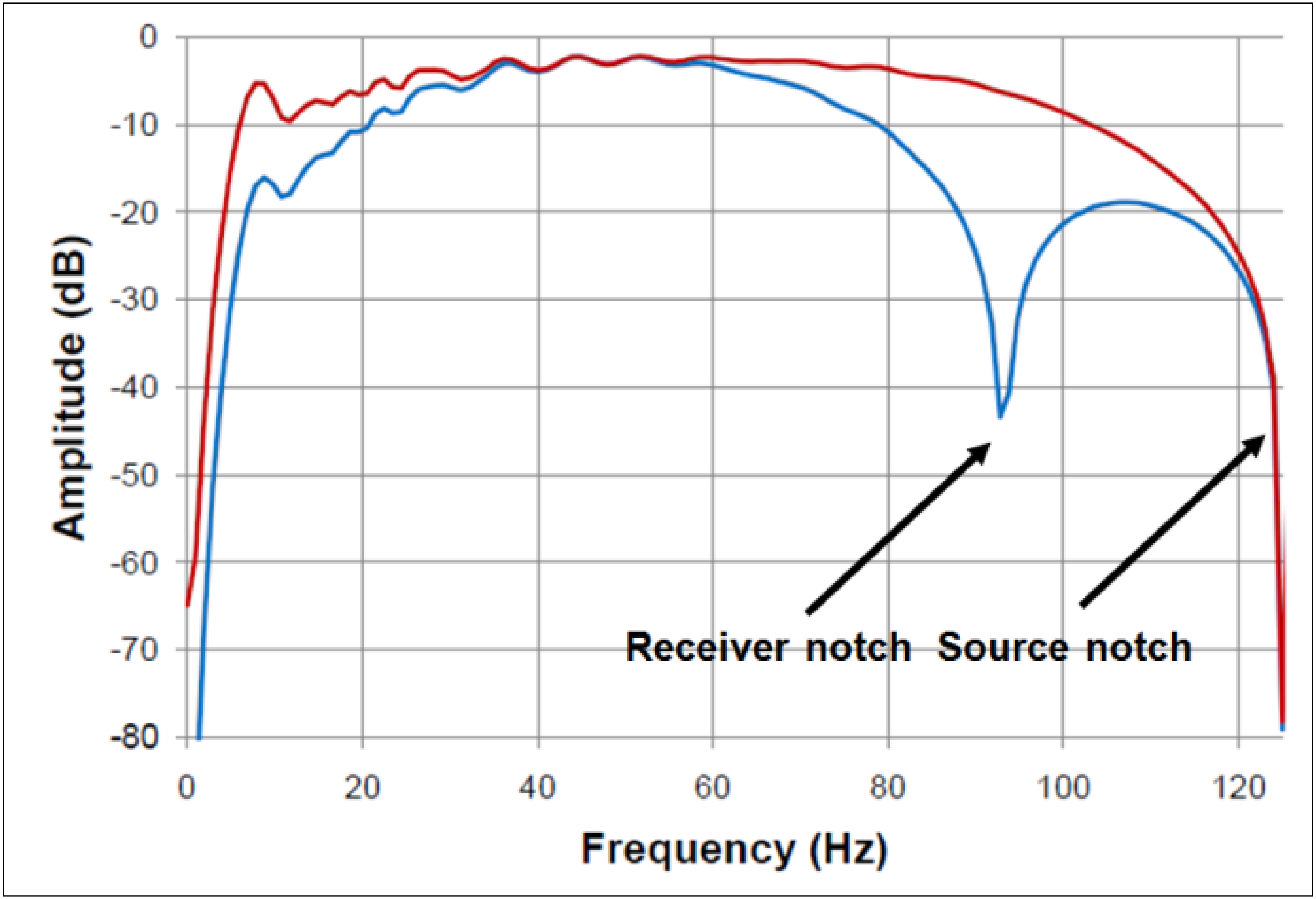

Figure 2. An illustration of the amplitude spectra of conventional data (blue) and dual-sensor data (red). The receiver notch is removed from the dual-sensor data due to dual-sensor summation (Carlson et al., 2007).

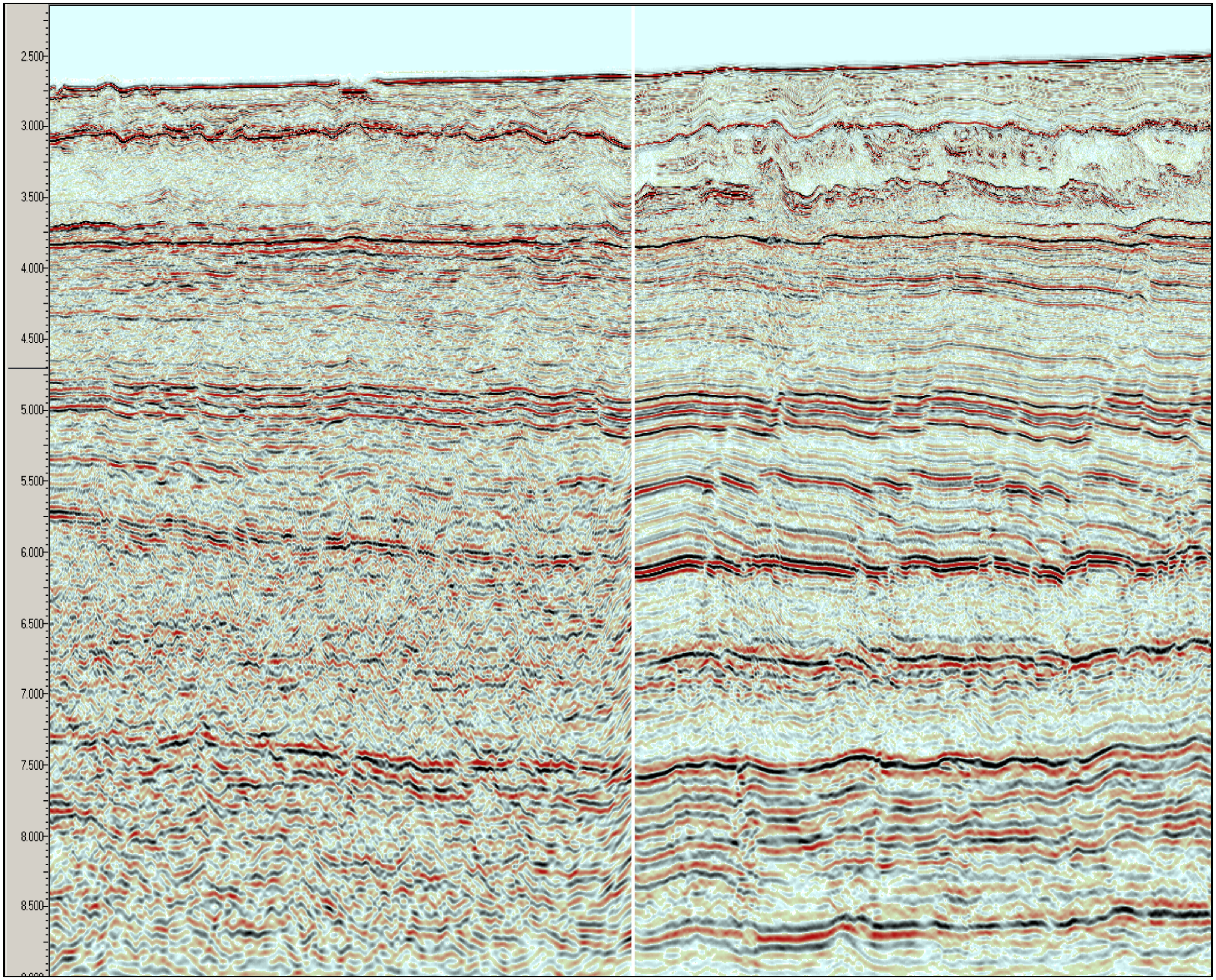

Figure 3. 2D conventional PreSTM stack (Left) and 2D dual-sensor PreSTM stack (Right) where the seismic image improvement is significant at all levels from shallow to deep. The Messinian evaporites are situated between 3.1s and 3.7s.