An Integrated Seismic Reservoir Characterization Workflow for Sweet Spot Identification in Unconventional Resource Plays in Triassic Yanchang Formation, Ordos Basin, China*

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Abstract

A huge volume of organic-rich shale is developed in the deep or semi-deep lacustrine deposits in Triassic Yanchang Formation, Ordos Basin. Recent horizontal drilling and hydraulic fracturing show high hydrocarbon (shale gas) production potential in the shale formation. However, previous reservoir characterization efforts are mainly focused on the use of well logs and cores. Although the results are very informative, strong heterogeneity of lacustrine shale could lead to substantial uncertainty in interwell volumes. Consequently, this work presents an integrated seismic reservoir characterization workflow based on full-azimuth, high-density 3D seismic data to demarcate the most prolific reservoir volumes for further productive infill wells. The workflow begins with prestack simultaneous inversion for elastic properties, followed by a petrophysical evaluation to determine a spatial distribution of shale gas reservoir quality(RQ). The analysis shows that the inverted acoustic impedance is a good indicator of total organic content (TOC) richness and porosity, where low impedance corresponds to high TOC and high porosity, relating to favorable reservoir. In addition, the well completion quality(CQ) is evaluated through prestack azimuthal inversion for description of natural fractures and geomechanical modeling to investigate shale fracability. The results obtained demonstrate moderate minimum horizontal stress and high brittleness in the targeted shale formation with high possibility to form complex hydraulic fractures. The RQ and CQ are finally combined together by way of weighted average for sweet-spot identification with high-evaluation values representing high hydrocarbon production capacity volumes. The integrated shale reservoir characterization value is corroborated with the available wells drilled within the survey area and further helps to determine optimal well locations and to locate hydraulic fracture treatments. Also, the proposed characterization methodology can be a good reference for other lacustrine shale plays.

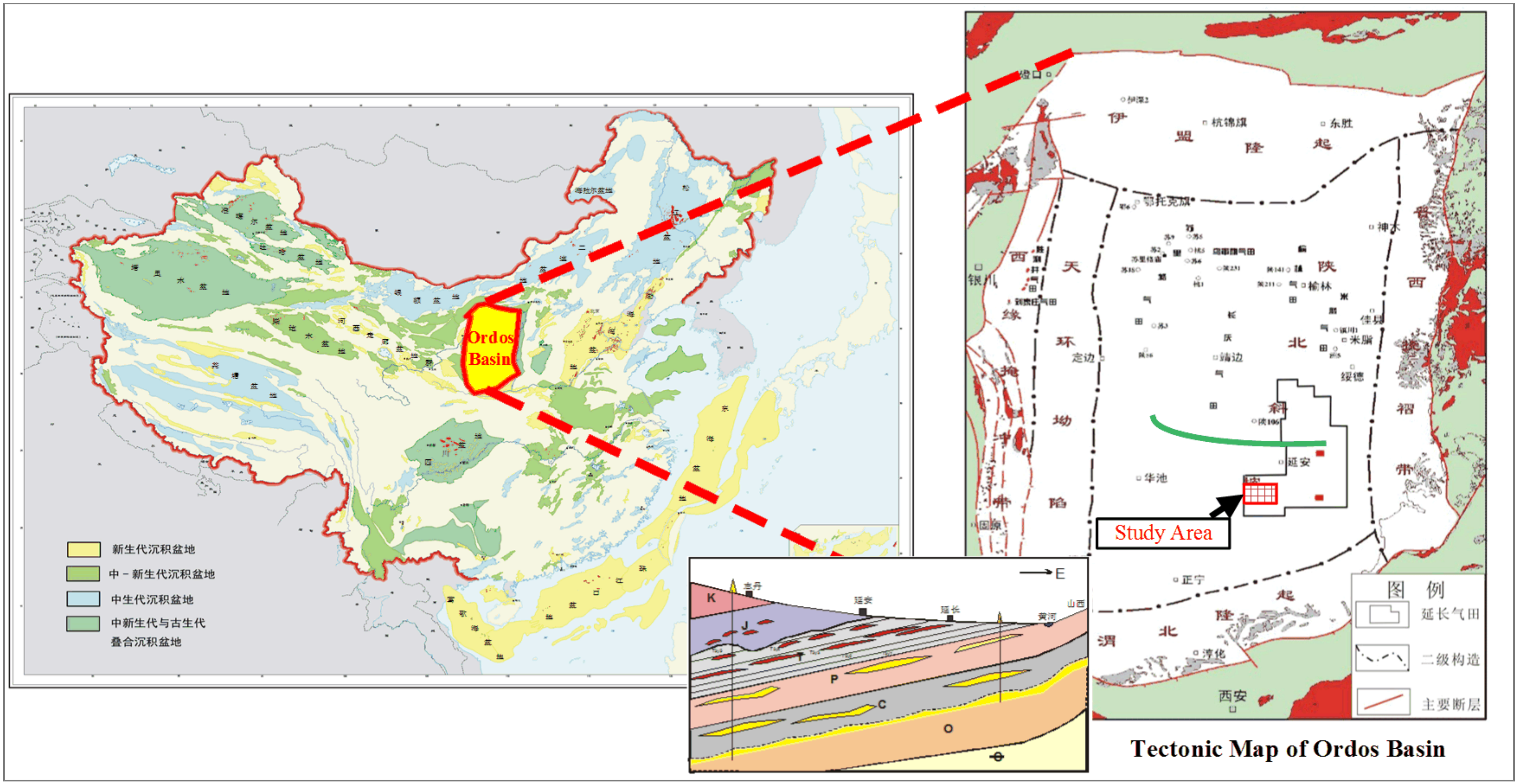

Figure 1. The study area is in the southeast of Ordos Basin, which is the second largest sedimentary basin; it is located in the middle of northern China. Simple tectonic structures are present in Ordos Basin with a single western-dip monocline with undeveloped faults.

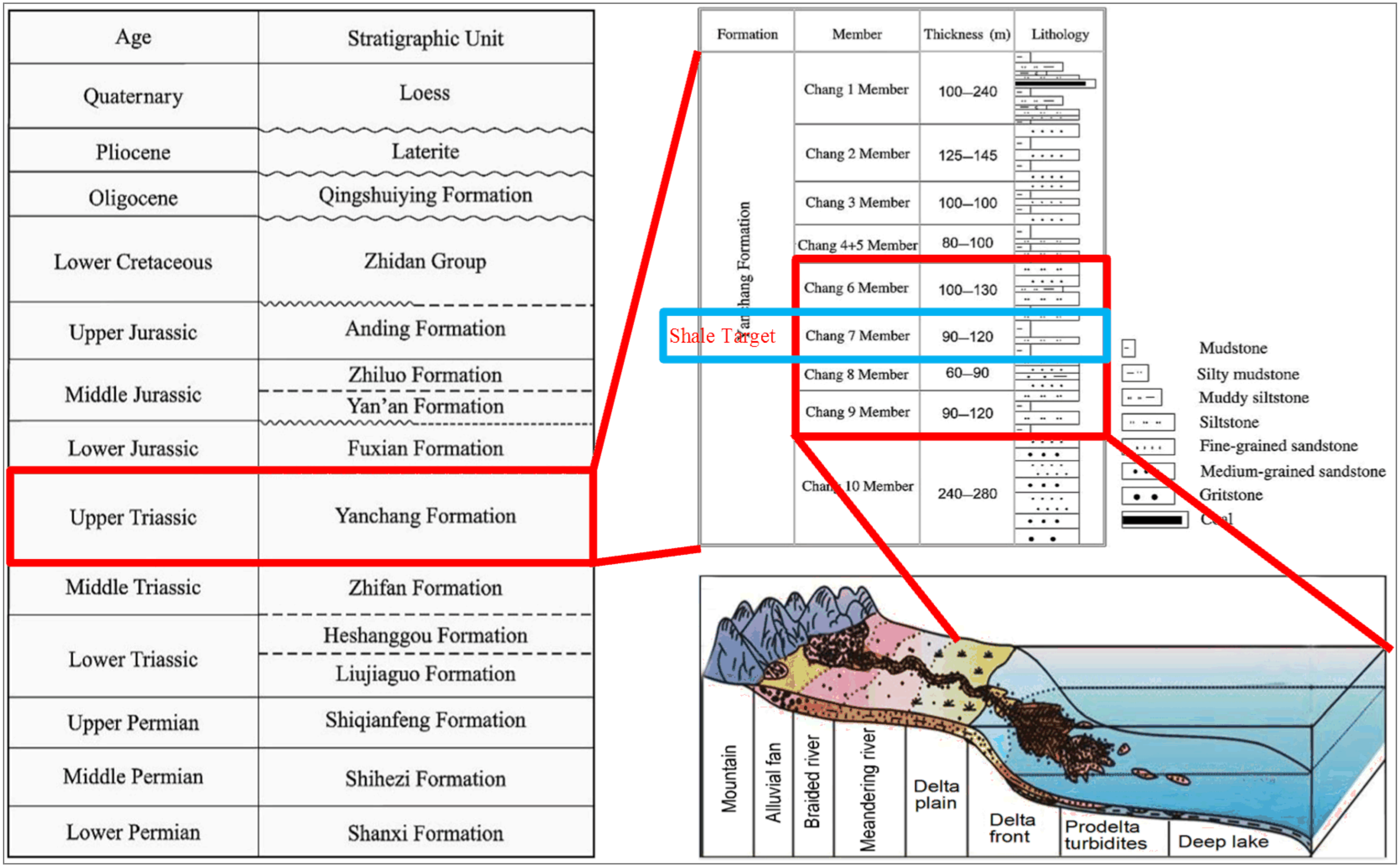

Figure 2. Ordos Basin is a multi-superimposed basin with several petroleum systems developed. Two huge shale strata are developed in the deep or semi-deep lacustrine deposits in the Upper Triassic Yanchang Formation, including Chang 7 Member and Chang 9 Member. Our study focuses on the shale target in Chang 7 Member.

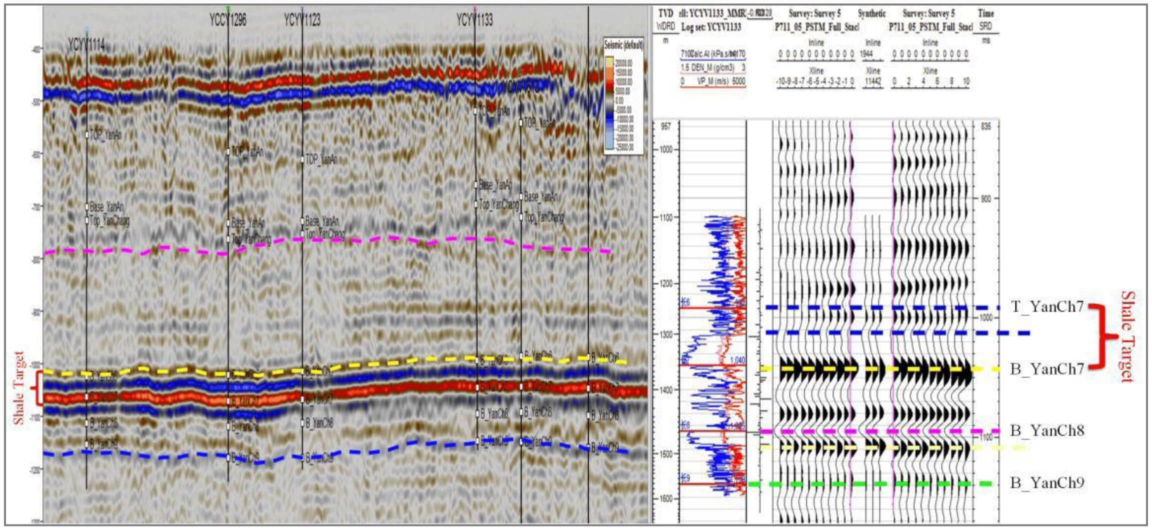

Figure 3. A vertical seismic slice across several wells is shown on the left. The synthetic seismogram of well YCYV1133 is shown on the right with log curves of density (light red), velocity (red), and calculated acoustic impedance (blue) calibrated. The bottom of the target shale; namely, B_YanCh7, corresponds to the strongest wave peak and its top; namely, T_YanCh7, corresponds to a wave trough.

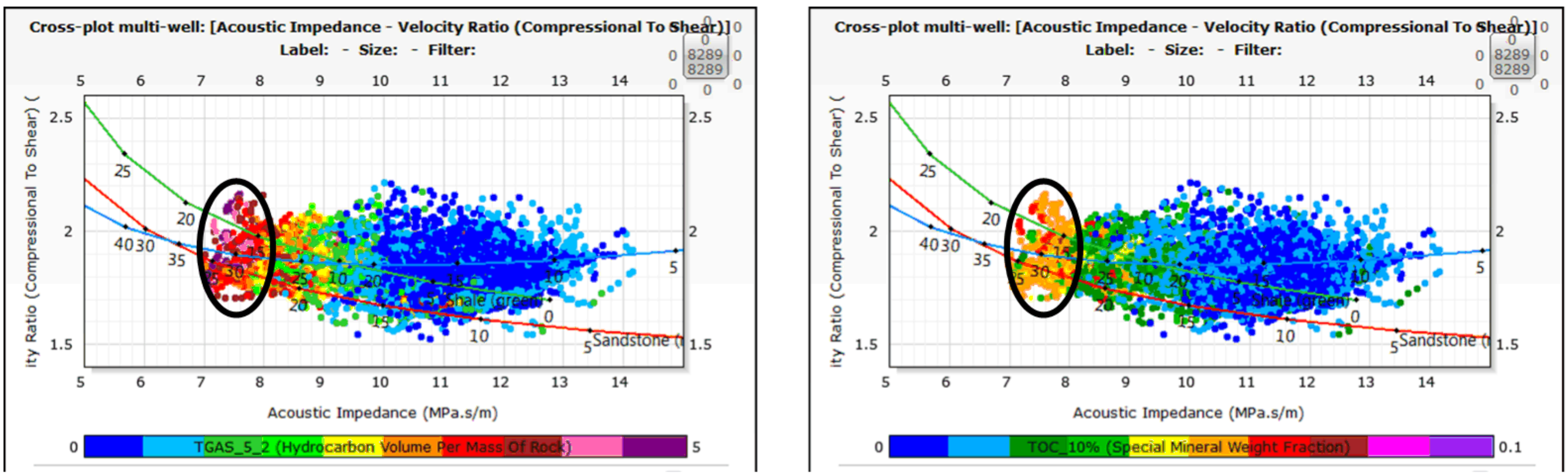

Figure 4. Cross plot of acoustic impedance (AI) and Vp/Vs using multiple wells. The color range in the left represents total hydrocarbon volume per mass of rock (TGAS).The color range in the right represents weight percentage of total organic carbon (TOC). The petrophysics analysis shows that low AI corresponds to high TOC and high TGAS shale.

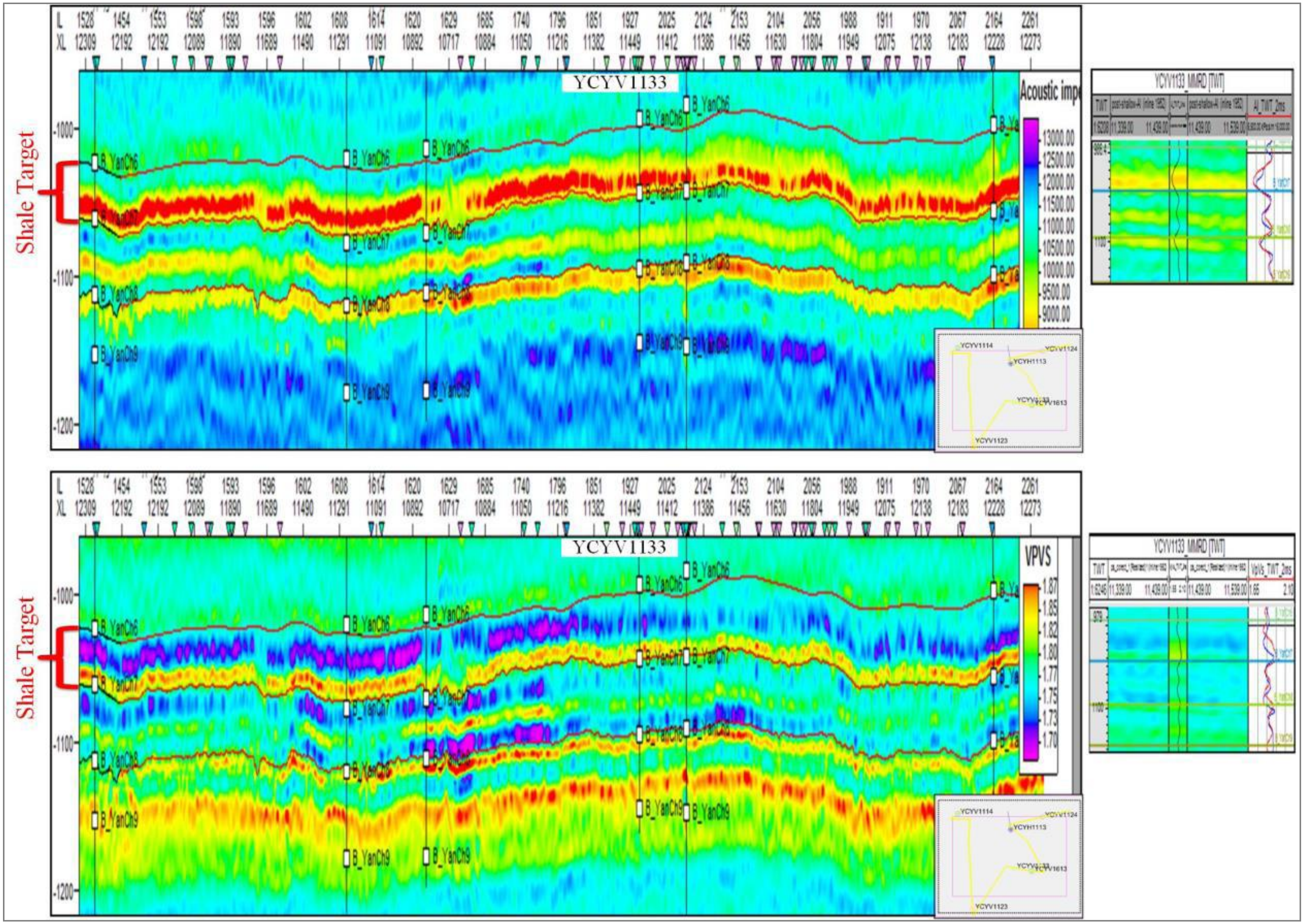

Figure 5. The results (Top: AI, Bottom: Vp/Vs) generated by prestack simultaneous inversion process. Well logs of a typical well YCYV1133 are used to compute AI and Vp/Vs at the well bore position. Good correlation could be observed both for AI and Vp/Vs while comparing the inverted curves with the computed curves at the well bore position.

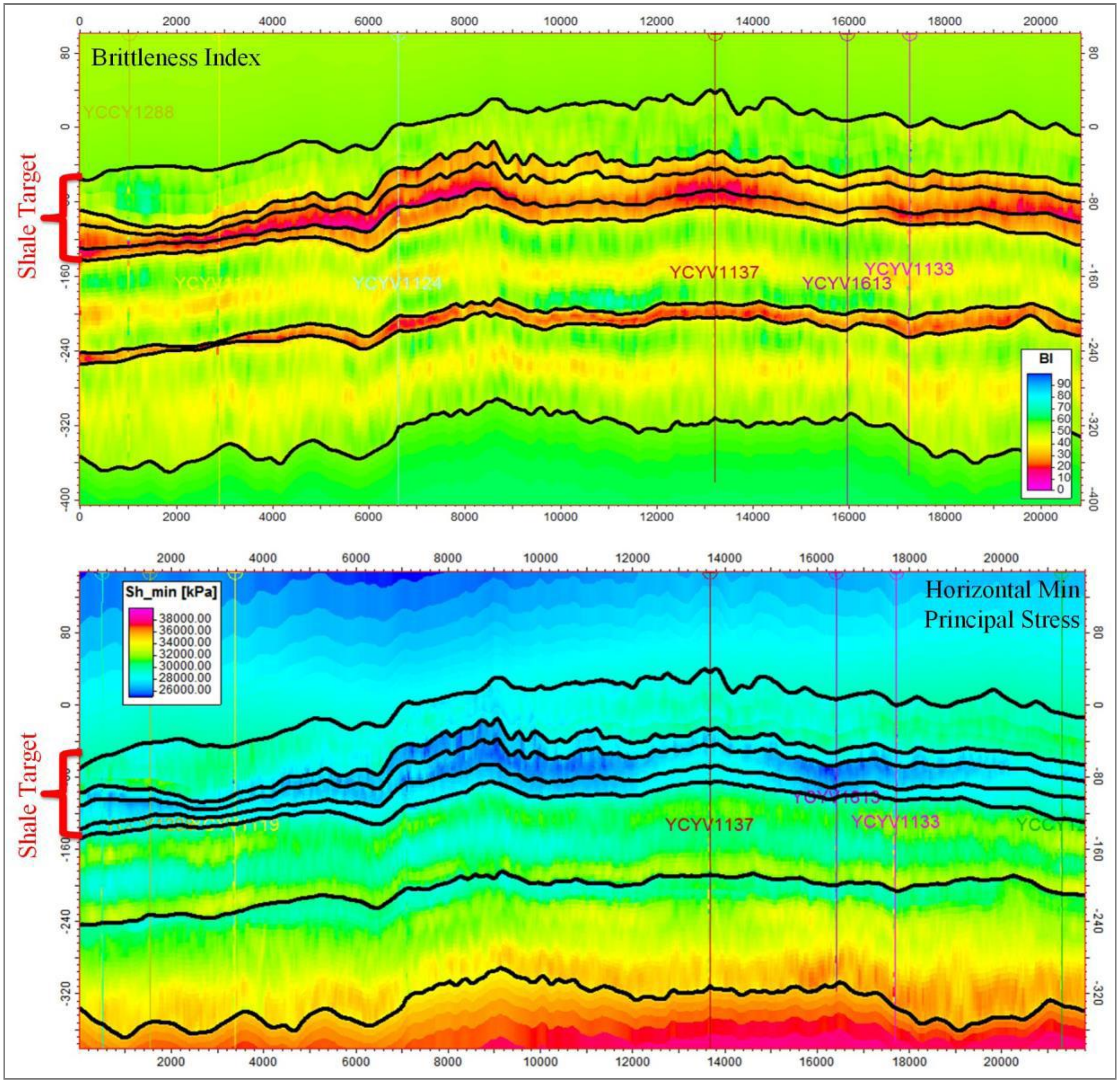

Figure 6. The results (Top: Brittleness Index(BI), Bottom: Minimum Horizontal Principal Stress(Shmin)) generated by 3D geomechanics modeling. The pure shale rock, which is mainly distributed in the lower part of the shale targetYanCh7, shows the characteristics of low BI and low Shmin. The regions of relatively higher BI and lower Shmin could contribute to good completion quality.

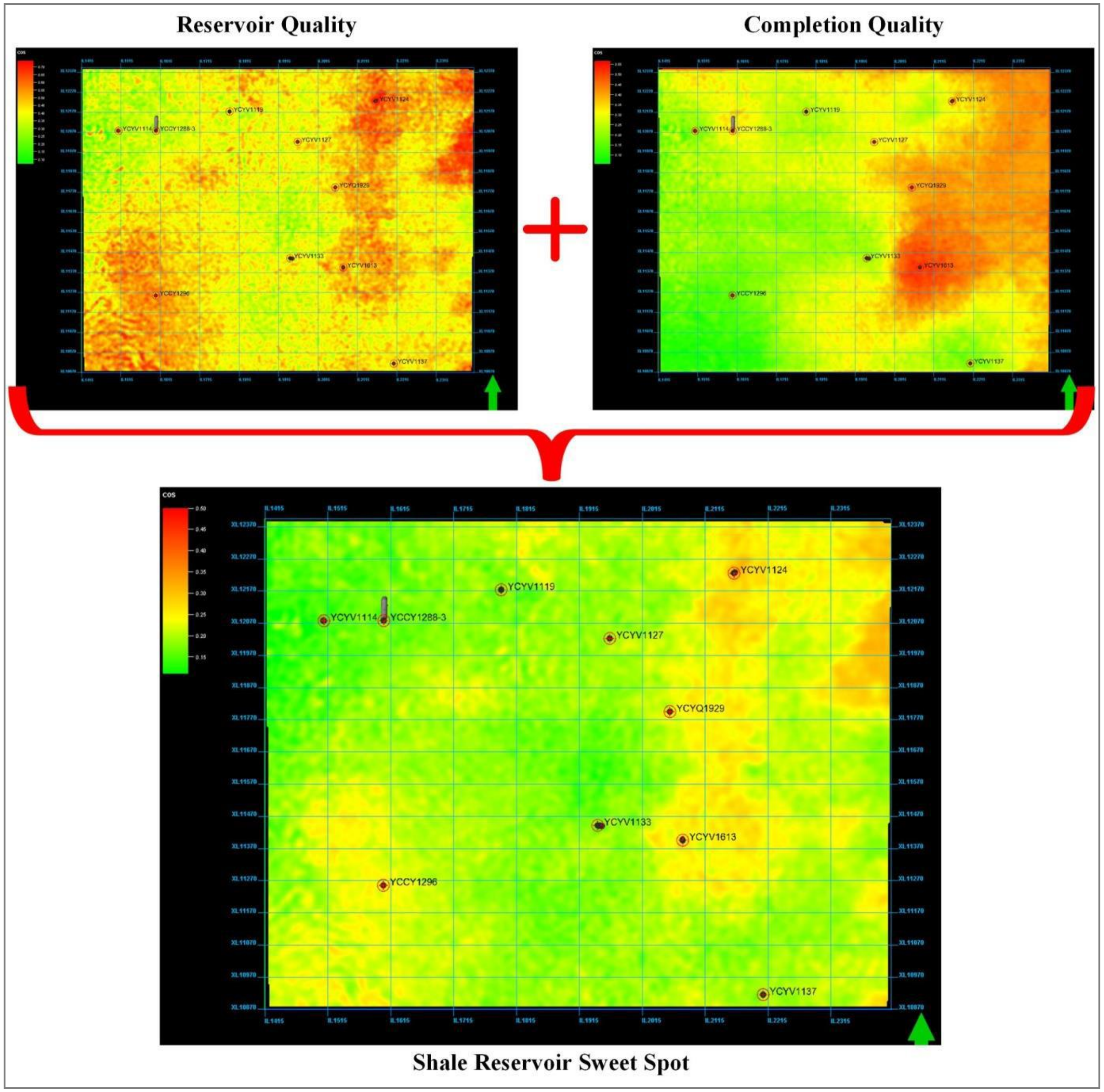

Figure 7. Combining reservoir quality (RQ) and completion quality (CQ) to identify the "sweet spot" in the lower part of YanCh7. The RQ is obtained from an integrated attribute analysis of lithology, thickness, TOC, porosity, and permeability of the shale rock. The CQ is obtained from an integrated attribute analysis of BI, Shmin, and fracture distribution of the shale rock. The final "sweet spot" attribute of warm color indicates the shale of high hydrocarbon production capacity.