Quantitative Interpretation driven by a structurally consistent sequence stratigraphic framework: method and application to low SNR pre-salt thin beds

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Most of current workflows for post-stack seismic inversion are stratigraphically constrained by the interpretation of only a few horizons based on major reflections. The practicability of such methods is highly dependent on a sufficient number of available wells with P-wave sonic and density logs to overcome the underutilization of the details that are accessible in every seismic sample. The author here shows the results and perspectives of a unique global approach where seismic sample details are stratigraphically correlated through an automation-assisted, amplitude-driven and structurally consistent Relative Geological Time (RGT) model (Pauget et al, 2009). This continuous stratigraphic framework ultimately provides a versatile environment to drive geostatistics and inversion.

The described three-phase approach embeds geoscientists to keep the full control on the conversion of signal discontinuities with vertical displacement into faults, seismic reflections into horizons, and every seismic sample into relative geological time (Pauget et al, 2009). The first phase aims at imaging and extracting the faults from the seismic data, by using an advanced algorithm of 3D seismic gradient sum extrema. Output fault networks can be used to constrain the second phase for RGT modelling. Every step of the fault extraction and RGT modelling remains automated but under the supervision of the geoscientist. The fault networks can be filtered – dip, azimuth, size – and completed, and the RGT modelling can be refined by editing the auto-tracked and stratigraphically sorted seismic horizons in a discrete stratigraphic framework called ‘Model-Grid’. A 3D interpolation of the discrete Model-Grid converts each seismic sample into relative geological time and delivers a continuous RGT model.

Over a third phase, the RGT model is used as a continuous sequence stratigraphic framework to characterize geological settings at basin and reservoir scales. RGT gradient attributes (stratigraphic and structural) are combined with Wheeler-transformed seismic sections to enhance seismic stacking patterns, geological discontinuities, stratigraphic terminations, hiatuses, and fault-related deformations. They enable to delineate key stratigraphic surfaces then subdivide stratigraphic units in a vertically continuous way, ultimately driving the creation of a sequence stratigraphic model. Quantitative interpretation (QI) workflows such as kriging and cokriging geostatistics methods can be applied to guide the distribution of rock physics from mechanic well logs at a seismic sample precision. An initial acoustic impedance (AI) model from RGT-driven kriging reveals gradational pre-salt facies variations in the Dutch Cleaver Bank High province, North Europe Carboniferous Basin (image a.2). This first QI step enables to encompass aeolian and ephemeral fluvial thin beds at a log scale resolution and thus emphasizes the Early Permian Upper Rotliegend Group retrogradational sequence (fining-up blue shape). Over a second and last QI step (Deterministic Inversion), this initial AI model is low-pass filtered (High Pass 10Hz and High Cut 15Hz) and convolved with a statistic wavelet to compute a synthetic seismic image. The low frequency AI model is iteratively updated using a least-squares algorithm to minimize the misfit between the real and the synthetic seismic. This process is repeated to get a final AI inverted model and its corresponding seismic volume.

The stratal slicing of the Early Permian Upper Rotliegend Group reservoir level shows a retrogradational distribution of Deterministic Inversion AI facies (images d.1, c.1 and b.1). Three stages of transgression are described as early, mid and late from nearby the Base Permian Unconformity to nearby the base of Late Permian Zechstein salt, with a constant AI color scale. Corresponding depth maps (images d.2, c.2 and b.2) with relative color scale reveal the structural control of higher AI value distribution (light purple arrows). Green and orange arrows respectively highlight two NW-SE and N-S retrogradational components.

This RGT-driven QI approach unlocks perspectives of high order stratigraphic sequences (4th to 6th) emphasis in a context of orbital elements controlled depositional settings (Milanković cycles). The combination of stratigraphically consistent Deterministic Inversion and RGT-enabled sub-sample stratal slicing allows making the most of low signal-to-noise ratio seismic amplitudes and logs resolution to reveal subtle stratigraphic settings that expanded over short time spans. This workflow has been successfully applied on a broad range of geological settings, including the difficult challenges of carbonate systems with complex stratigraphy, differential fault-related subsidence, and influence of diagenetic and meteoric processes leading to fractures and karsts development.

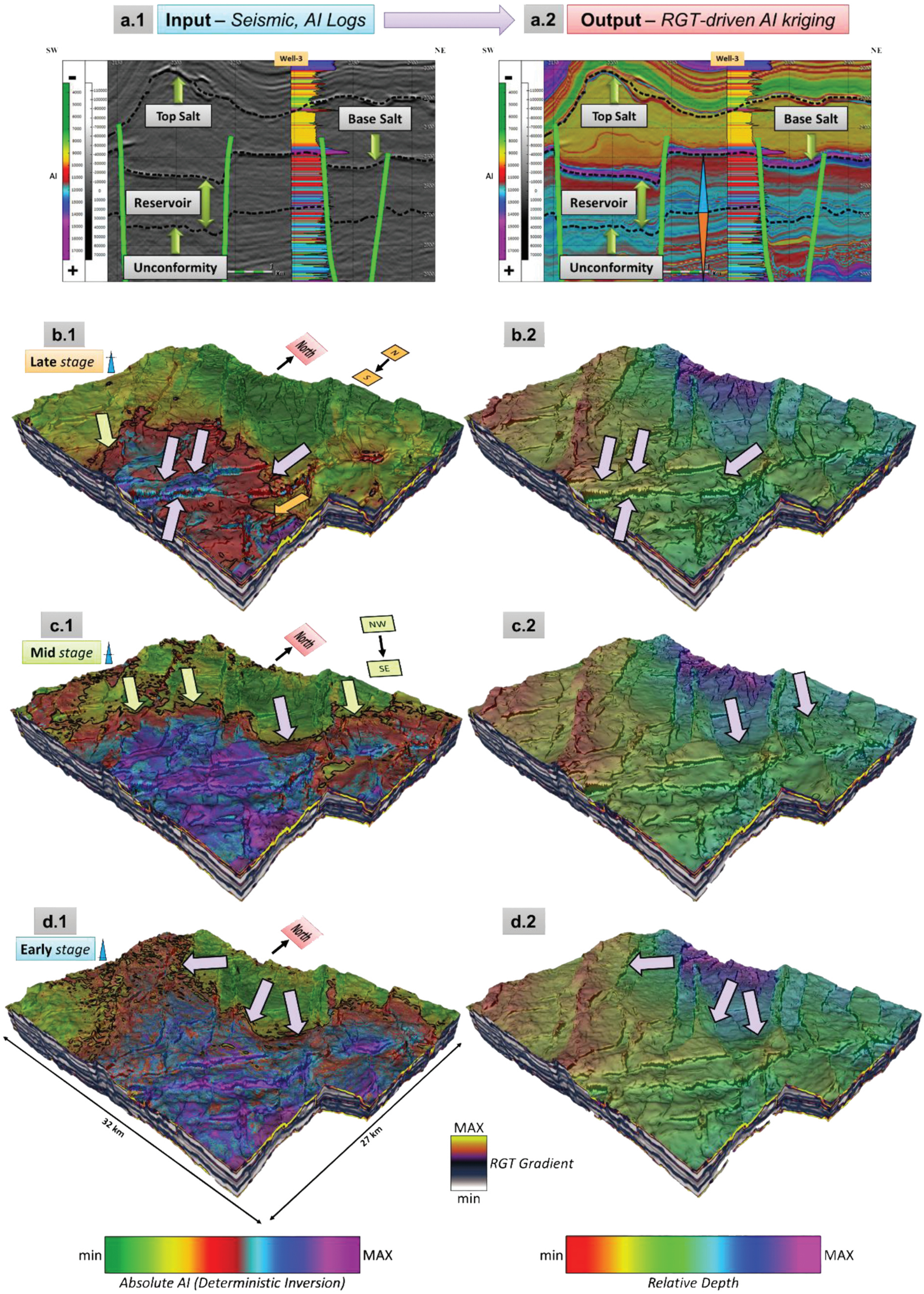

Figure: **a.1**: Seismic data and acoustic impedance (AI) logs used to build **a.2**: initial AI model from 3D RGT-driven kriging. Coarsening-up orange shape highlights Late Carboniferous (source rock prone) progradational sequence, whereas fining-up blue shape highlights Early Permian (reservoir and seal rock prone) retrogradational sequence between Base Permian Unconformity 'BPU' and base Zechstein salt 'Top Silverpit'. **d.1**, **c.1**, **b.1**: RGT gradient (both structural and stratigraphic) volume sculpted with RGT isochrones mapped with final AI from deterministic inversion, for 3 stages of transgression within the Early Permian retrogradational sequence. d.2, c.2, **b.2**: same isochrones with Z-value. Light purple arrows show fault-controlled distribution of facies with higher AI property, whereas green and orange arrows show respectively NW-SE and N-S retrogradational components. *K05 3D seismic data, Dutch Cleaver Bank High province, offshore Netherlands, courtesy of TNO.*