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Synthetic seismic modelling - an application to interpretation of structurally complex areas

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Abstract: This study presents the application of synthetic seismic modelling to structural interpretation of a complex zone of interaction between faults forming a conjugate system in the northern part of the Bonaparte basin, Australia. Three velocity models of this poorly imaged zone, assuming hard, semi-hard and soft linkage between faults were introduced. For each model the theoretical wavefield was then calculated and compared with the real seismic registration. This comparison allowed for the conclusion that the soft linkage is the most likely type of interaction within the conjugate fault system in this area.

Keywords: synthetic seismic modelling, conjugate fault system, fault linkage, Bonaparte basin, North West Shelf of Australia (NWSA).

Continental passive margins are structurally complex provinces which commonly undergo several phases of extension and fault reactivation. This results in complex three-dimensional fault geometries that are not always clearly imaged in seismic data. To deal with seismic interpretation uncertainty, synthetic seismic modelling can be applied in areas where no additional geophysical information is available to constrain a geological model (e.g. lack of well penetrations). In this study, synthetic seismic was used to characterize fault linkages in a conjugate system in the Bonaparte basin, North West Shelf of Australia.

Tectonic setting and location of the study area

The study area is located in the NW part of the Timor Sea, within the Bonaparte basin (Fig. 1). The Bonaparte Basin, together with three other NE-SW-trending broad sedimentary basins (Browse, Roebuck and Northern Carnarvon) forms the passive margin of the North West Shelf of Australia (NWSA), which is a significant frontier province for petroleum exploration (Kopsen, 2002). The formation of the basins of NWSA is attributed to the break-up of Pangea, which resulted in the opening of the Neo-Tethys Ocean in the Permo-Triassic (Golonka *et al.*, 2006).

The Bonaparte basin is a large, predominantly offshore sedimentary basin that covers approximately 270,000 km² of Australian northwestern continental margin. The basin contains up to 15 km of Phanerozoic, marine and fluvial, siliciclastic and carbonate strata (Cadman and Temple, 2004). The Bonaparte Basin is structurally complex and comprises a number of Palaeozoic and Mesozoic sub-basins and platform areas (Fig. 1). The basin has also undergone a complex structural history which includes two phases of Palaeozoic extension, a Late Triassic compressional event as well as further extension in the Mesozoic followed by the Neogene fault reactivation.

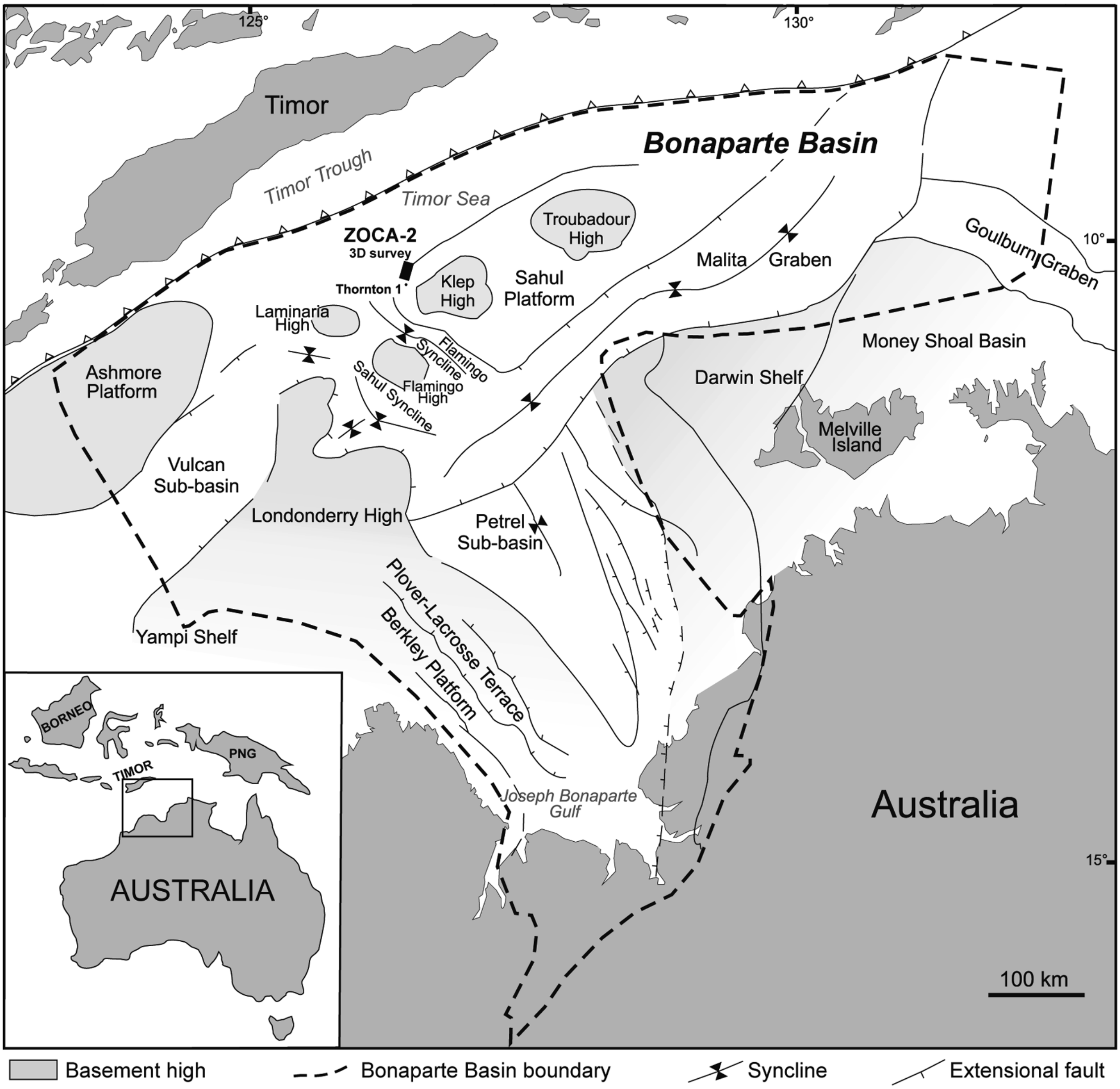

Figure 1. Main structural elements of the Bonaparte Basin. The map shows the location of the 3D dataset ZOCA-2 and the Thornton-1 well.

The widespread Neogene reactivation of pre-existing faults was caused by the convergence of the Indo-Australian and Eurasian plates in the Miocene to Pliocene (Keep *et al.*, 2002).

The analyzed 3D seismic survey (ZOCA-2) is located in the northern Bonaparte basin, within the NW part of the Sahul Platform, where reactivated in Neogene, Mesozoic extensional faults, form major petroleum traps. As a result of the Neogene reactivation extensional faults cluster above the Mesozoic faults forming a conjugate fault system (Fig. 2). The Neogene reactivation has a big impact on the integrity of structural traps (Keep *et al.*, 2002), strongly controlled by the type of linkage developed between the "upper" (Neogene) and the "lower" (Mesozoic) segments of the conjugate system. The exact identification of the character of interaction between these two segments (soft/hard linkage) is therefore essential to assess a possible leakage of traps. However, the zone of interaction between faults forming the conjugate system within ZOCA-2 seismic survey is poorly imaged (low amplitude, discontinuous reflectors (Fig. 2), which allows for assumption of several interpretational solutions. To constraint the interpretation uncertainty and finally determine the type of linkage within the conjugate fault system synthetic seismic modelling was performed.

Database and methodology

The 3D seismic cube (ZOCA-2; marine pre-stack time-migration data) and the logs from Thornton-1 well were used to perform the structural interpretation and the subsequent synthetic seismic modelling. Although this study focuses on 2D synthetic seismic modelling, it is essential to emphasise that the detailed 3D structural analysis of ZOCA-2 dataset, including fault interpretation as well as interpretation of four main unconformities (u1, u2, u4 and u5) dividing the dataset into packages of different seismic characteristic was carried out (Fig. 2).

Thornton-1 well, located 5 km to the south from the southern margin of the ZOCA-2 dataset (Fig. 1), was the only well available in this area. The well was first projected on inline 280, and then tied to it using a synthetic seismogram (Fig. 3). Inline 280 was chosen for synthetic modelling as well-imaging faults and horizons architecture. In the following stage, to determine velocity distribution on inline 280, seismic inversion was calculated (Fig. 2b). Obtained velocities were then used in the construction of three geometrically different models for the interpretation of poorly imaged linkage of faults within the conjugate system (Figs. 4a, 4b and 4c). The models assumed three possible interpretations, each of which involved a different type of linkage between faults forming the conjugate system (hard, semi-hard, and soft). The horizons and faults geometries used in these models were obtained from detailed structural interpretation of inline 280. Synthetic seismic was calculated using these models representing a fragment of the inline 280 (Figs. 4a', 4b' and 4c'). The computation of the synthetic seismic was based on Ray Tracing method, using Vertical Incidence option, which simulated fully migrated seismic. Obtained synthetic sections were then compared with the real seismic registration and the most probable linkage type was chosen (Fig. 5).

Velocity models

The velocity distribution used in the computation of the theoretical wavefield was obtained from seismic inversion of inline 280 (Fig. 2), calculated on the basis of *Model Based Algorithm* using Sonic log from Thornton-1 well as input data.

To tie Thornton-1 well to inline 280, a synthetic seismogram (using 43 Hz Ricker wavelet and Sonic log) was constructed (Fig. 3). Despite significant distance (approximately 12 km) between the projection point

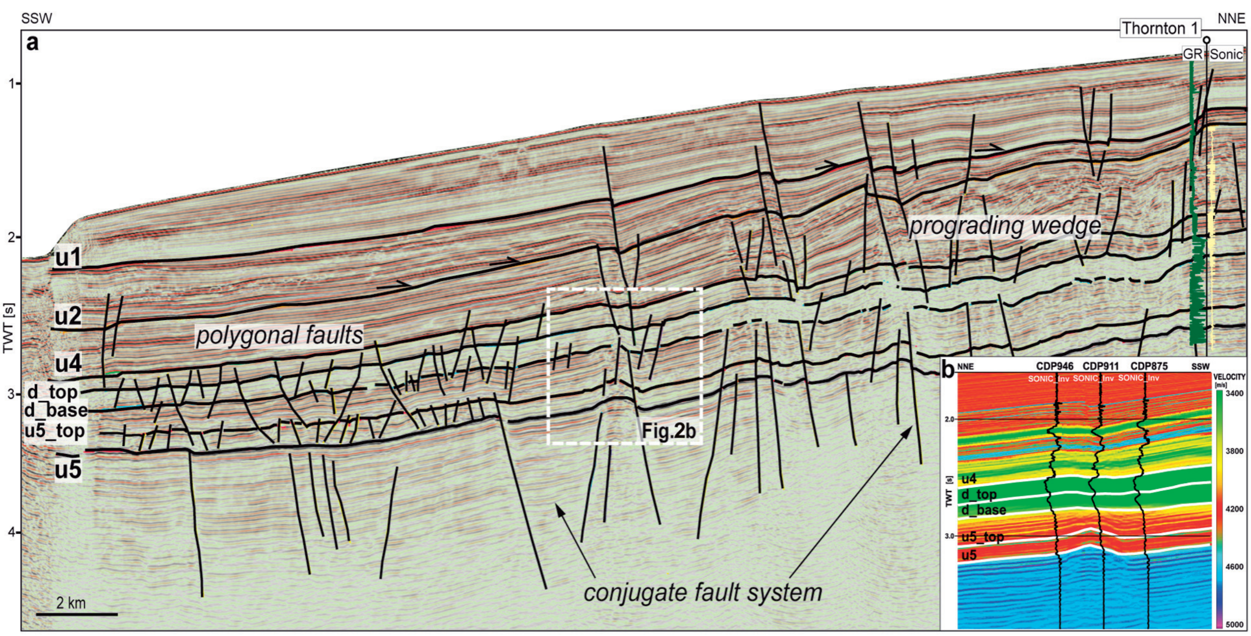

Figure 2. (a) Structural interpretation of inline 280 showing the main unconformities and structural style of the study area, (b) seismic inversion calculated for inline 280 (figure shows velocity distribution only for a part of the data (linkage zone) marked by a rectangle in figure 2a).

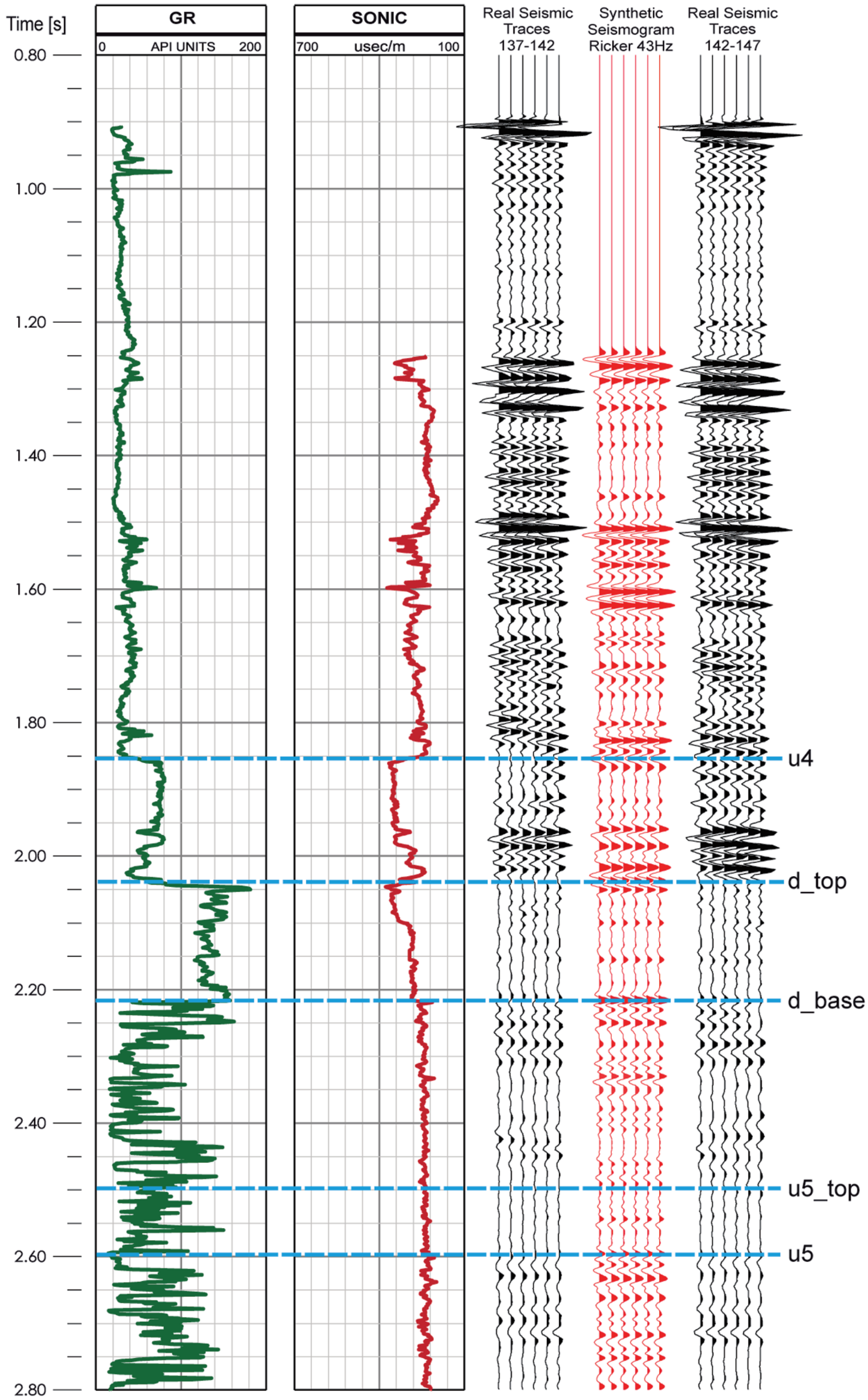

Figure 3. Gamma Ray and Sonic log from Thornton-1 well were converted into the time domain and tied to the seismic data using a synthetic seismogram. The figure shows synthetic seismogram juxtaposed with seismic traces registered closest to the point of projection of Thornton-1 well on inline 280.

of the well on inline 280 and its real location, a good correlation between real seismic and synthetic seismogram was observed (Fig. 3). It was however concluded that reliable velocity distribution can be estimated along the whole line only between u4 and u5 horizons which bound the uniform package of homogenous seismic characteristics (Fig. 2). This package is also characterized by relatively high Gamma Ray registrations (Fig. 3), which along with its seismic signature (low amplitude, discontinuous reflectors) might indicate increased content of shale between u4 and u5 horizon. Assuming that the velocity within this pack-

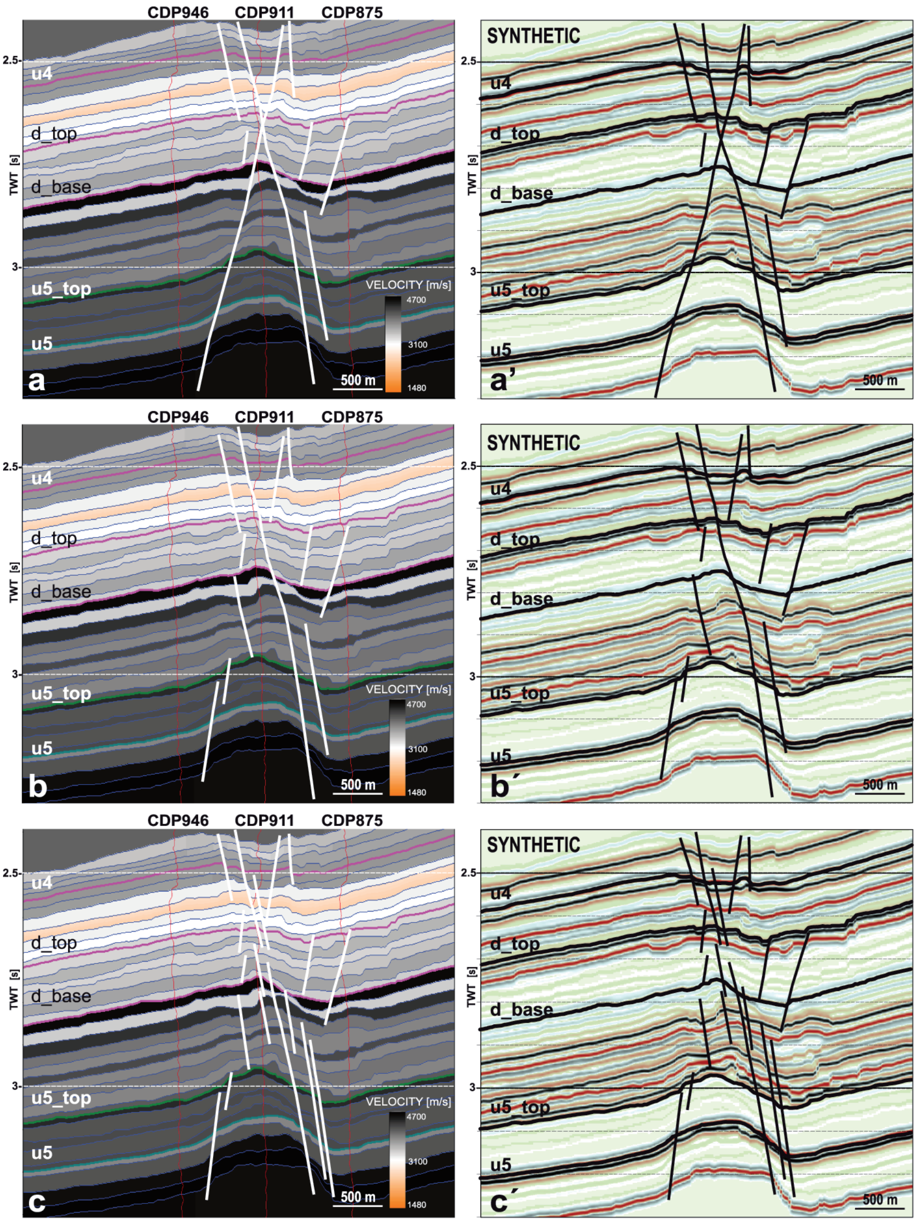

Figure 4. Synthetic response (a', b', c') calculated for general velocity models (a, b, c) assuming different types of linkage within the conjugate system: a, a' – hard linkage; b, b' – semi-hard linkage; c, c' – soft linkage.

age does not change laterally, which means that the extrapolation of velocity based on available Sonic log and seismic response is correct, pseudo-Sonic logs (Sonic_Inv, Fig. 2b) for three different CDP locations were extracted from seismic inversion and then served as a velocity field in the synthetic modelling.

Calculation of synthetic response

Constructing velocity models three possible versions of structural interpretation of the linkage zone within the conjugate fault system were proposed: 1) hard linkage, 2) semi-hard linkage, and 3) soft linkage (Figs. 4a, 4b and 4c). The synthetic response was calculated for each model and then compared with real seismic. Theoretical wavefield obtained from the model assuming soft linkage (Fig. 4c') was assessed as the best approximation of the registered wavefield, therefore this model was chosen to further analysis. The other indirect premise to use soft linkage was the occurrence of polygonal faulting between u4 and u5 horizon, indicating the presence of a ductile shaley package, within which the faults are likely to die out rather than propagate through. Polygonal faults are discussed below.

The assumption of the soft linkage between faults forming conjugate system resulted in detailed seis-

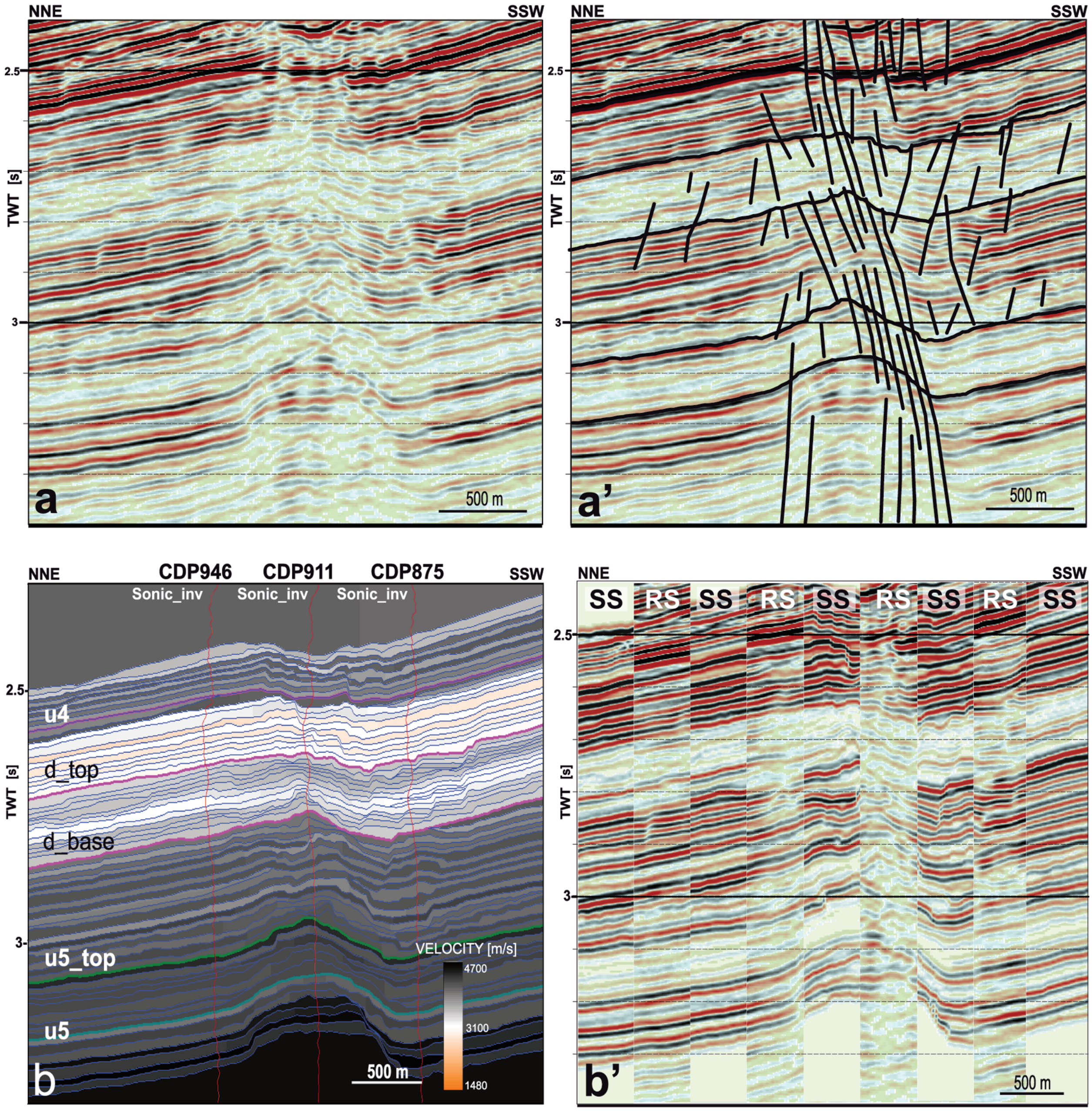

Figure 5. Uninterpreted seismic (a) and its detailed reinterpretation (a') based on the theoretical response from the model with soft linkage (Figs. 4c and 4c') chosen as the best approximation of the registered seismic. Detailed velocity model of a part of seismic inline 280 (b) assuming soft linkage in the conjugate fault system was constructed based on the reinterpreted seismic. Theoretical wavefield was compared with real seismic record (b'). The good correlation between synthetic and registered data confirms accuracy and validity of the model. SS: synthetic seismic; RS: real seismic.

mic reinterpretation of the zone of interaction (Figs. 5a and 5a'). The reinterpretation of registered seismic took into account the complexity of the linkage zone and was used to improve the soft linkage model. Displacement in the detailed model is accommodated by series of high-angle, small-displacement, telescopic extensional faults rather than few major faults with an array of minor synthetic faults. SW-dipping conjugate flank accommodates more displacement than the NE-dipping flank (Fig. 5a'). The faults die out in the low amplitude package, between d_base and d_top horizon. Furthermore, the uniform sedimentary package between u4 and u5 horizon is affected by small-scale extensional faults (Fig. 2a), which in plain view form regular polygons.

Polygonal faulting is believed to predate the Neogene fault reactivation and probably interfere with faults forming linkage zone of the conjugate system. Because of the complexity and poor seismic image it is difficult to distinguish between faults belonging to the polygonal system and the ones which are part of the reactivated system. Presence of polygonal faulting is however a significant lithological information, as this type of faulting develops only in fine-grained sediments (Cartwright *et al.*, 2003), such as shale. This information along with mentioned above high GR registration between u5 and u4 horizons leads to the conclusion that this uniform sedimentary package must have a high shale content, and as such should be more ductile than the surrounding rocks.

The synthetic response obtained from the final detailed soft-linkage model revealed high conformity with the real seismic in terms of amplitude, frequency and time at which particular seismic reflectors occur (Fig. 5b').

Conclusions

Successful application of synthetic seismic modelling to interpretation of the 3D seismic dataset ZOCA-2 confirmed its importance in detailed structural analysis of complex areas. Synthetic modelling has proven to be especially helpful in verification of seismic interpretation of poorly imaged structures, where little data to constrain a geological model is available.

Synthetic response from three velocity models assuming different type of linkage compared with the registered seismic, allowed for the conclusion that the soft linkage is the most likely type of interaction within the conjugate fault system in the study area.

The synthetic seismic calculated for the detailed velocity model assuming soft linkage correlates very well with registered seismic, which confirms accuracy and validity of the model (velocity field) as well as the structural interpretation (geometry of horizons and faults).

The subtle differences in amplitude between synthetic and real seismic in the linkage zone (reduced amplitudes on the real seismic; figure 5b') might be due to the presence of number of sub-seismic resolution faults. Higher attenuation of seismic waves (and resultant low amplitude zone) is typical of strongly faulted areas. The software used for the computation of synthetic response did not take into account the attenuation.

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