3D Subsurface mapping of the Dutch offshore – Results and progress

TNO is commissioned by the Dutch Ministry of Economic Affairs to provide free access to public domain information on the subsurface, in order to stimulate the exploration of oil and gas reserves in the Dutch sector of the North Sea. With this in mind, the institute is developing a comprehensive 3D subsurface model. The model encompasses a detailed 3D structural framework, including essential stratigraphic units and related faults, and improves on the initial regional subsurface model 'NCP-1' (Duin et al., 2006). Rock and fluid parameters and 3D burial history analysis are being used to perform a petroleum systems analysis (Verweij 2008, see elsewhere in this issue). Special attention is being paid as a whole to the reliability of the structural model. This model of the entire offshore will be finalised in 2010.

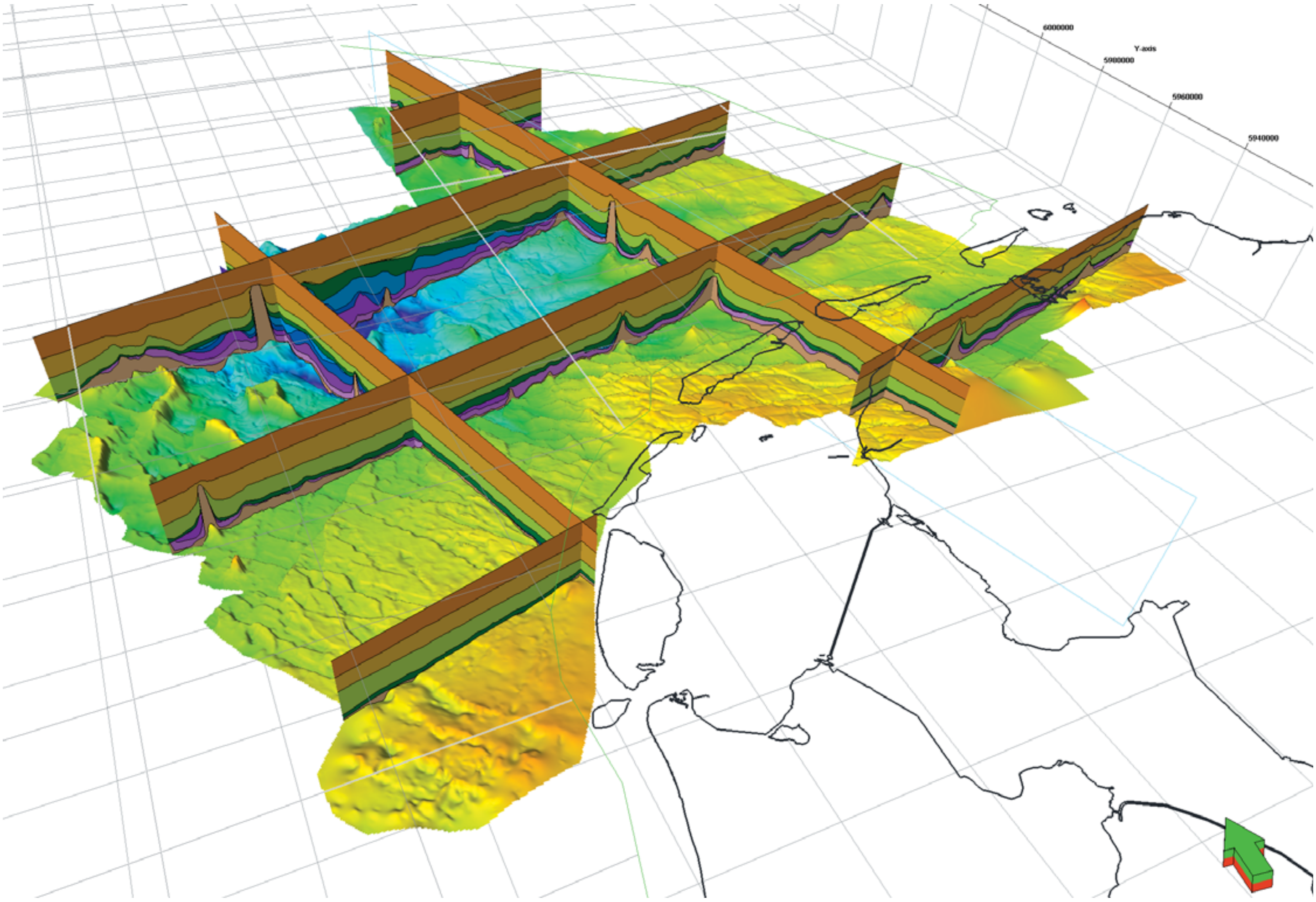

Figure 1. Perspective view of the NCP-2 model in NCP-2A, 2B and 2E. The surface represents the two way time depth of the base of the Zechstein Group.

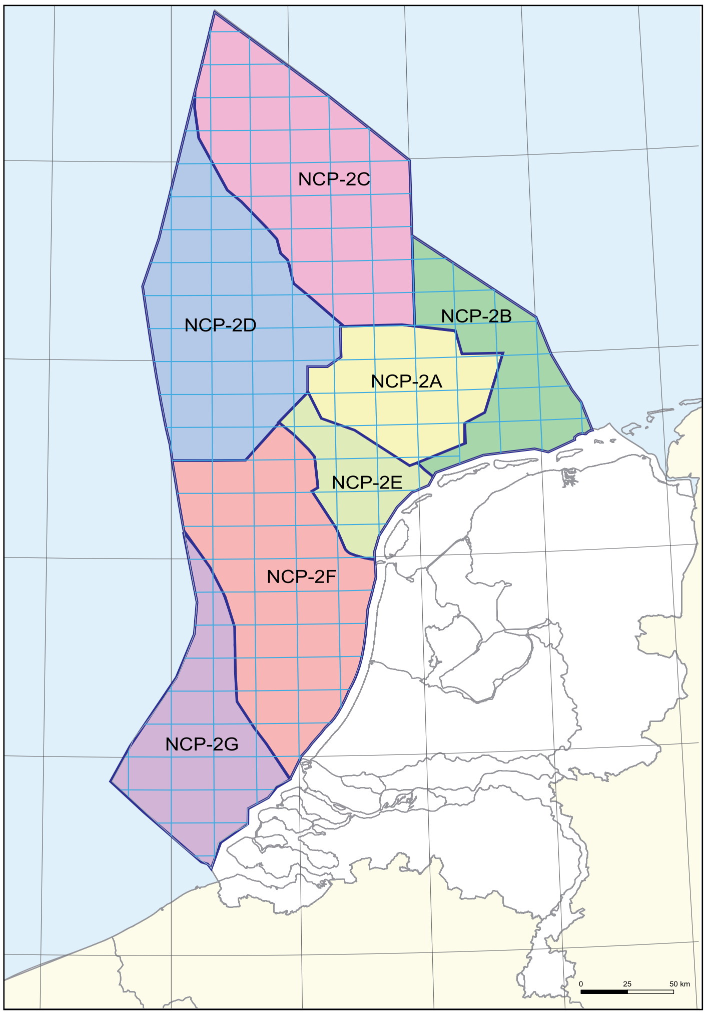

Figure 2. Location of the offshore mapping areas.

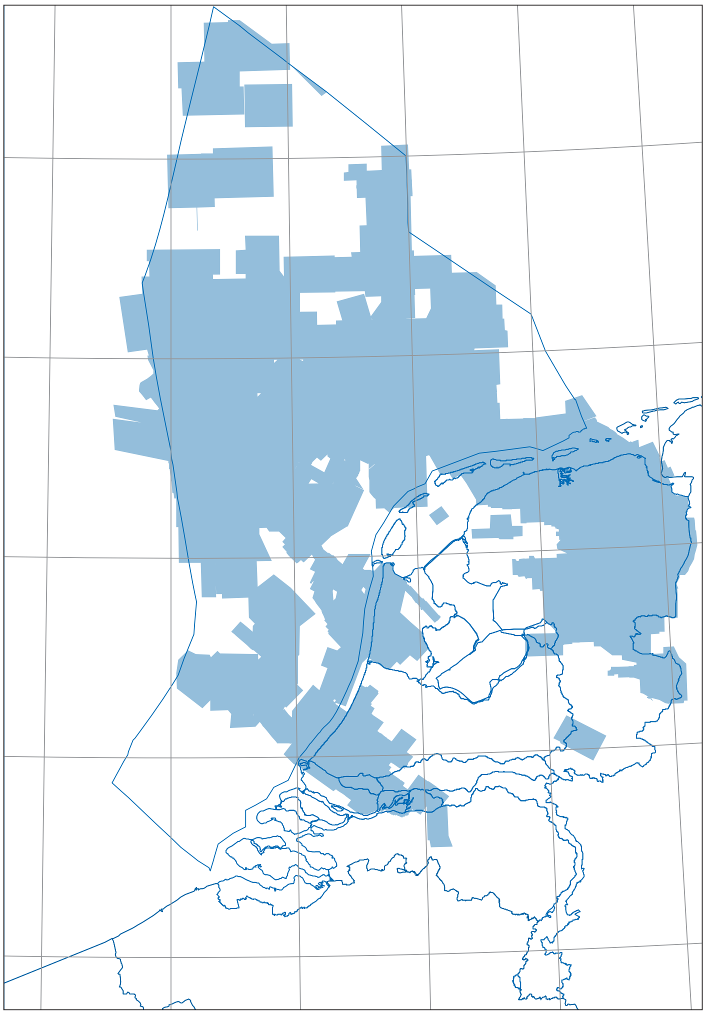

Figure 3. Location of 3D seismic surveys in the Netherlands on- and offshore.

Seismic interpretation

The offshore area is subdivided into seven regions along the outlines of major Mesozoic structural elements (Figure 2). The regions are being modelled separately and will then be combined into one composite model for the entire offshore area. Interpretation of 3D and 2D seismic surveys (Figure 3) provides input for mapping the major stratigraphic units and 3D fault systems. Stratigraphic interpretations of available wells aid in the identification of horizons in the seismic data. In general, the base Zechstein horizon is the lowermost stratigraphic boundary to be interpreted. The base Rotliegend is created by adding an isopach grid, based on well data, to the base Zechstein surface. Intra- and sub-Carboniferous strata will be addressed in area NCP-2D (Cleaverbank High).

The detail to which faults and horizons are interpreted is aimed at a regional mapping scale of approximately 1 : 250,000 (grid cell size: 250 m × 250 m). Faults are only interpreted when they can be traced over a substantial distance and have resulted in a significant offset of the horizons they affect. In some cases, dense clusters of faults are reduced to a few larger faults, such that the regional structuration is still represented correctly. Areas that are not covered by 3D seismic surveys are filled in with interpretations from 2D surveys and therefore show less structural detail.

Fault model

The compilation of all faults and horizons into a single 3D model is an important and elaborate part of the modelling process. This model provides the structural basis for all subsequent modelling steps and is essential for gaining insight into the tectonic and stratigraphic evolution of the subsurface. Extensively faulted areas with many fault truncations, detached pre- and post-Zechstein fault systems, reversed faults, and halokinesis are just some of the structural challenges met during modelling. Figure 4, for example, illustrates the complexity of the pre-Zechstein fault model in the Texel-IJsselmeer High, North Holland Platform and Central Offshore Platform areas. The post-Zechstein faults in these areas are being modelled separately, since they are predominantly detached from the subsalt faults.

Time-to-depth conversion

So far, the modelling has been performed in two-way travel time. The structural model must therefore be converted to depth domain using a seismic velocity model. Except for the Zechstein layer, this velocity model is based on the equation $V_z = V_0 + K \cdot z$, where V_0 represents the velocity at zero depth and K describes the linear increase of

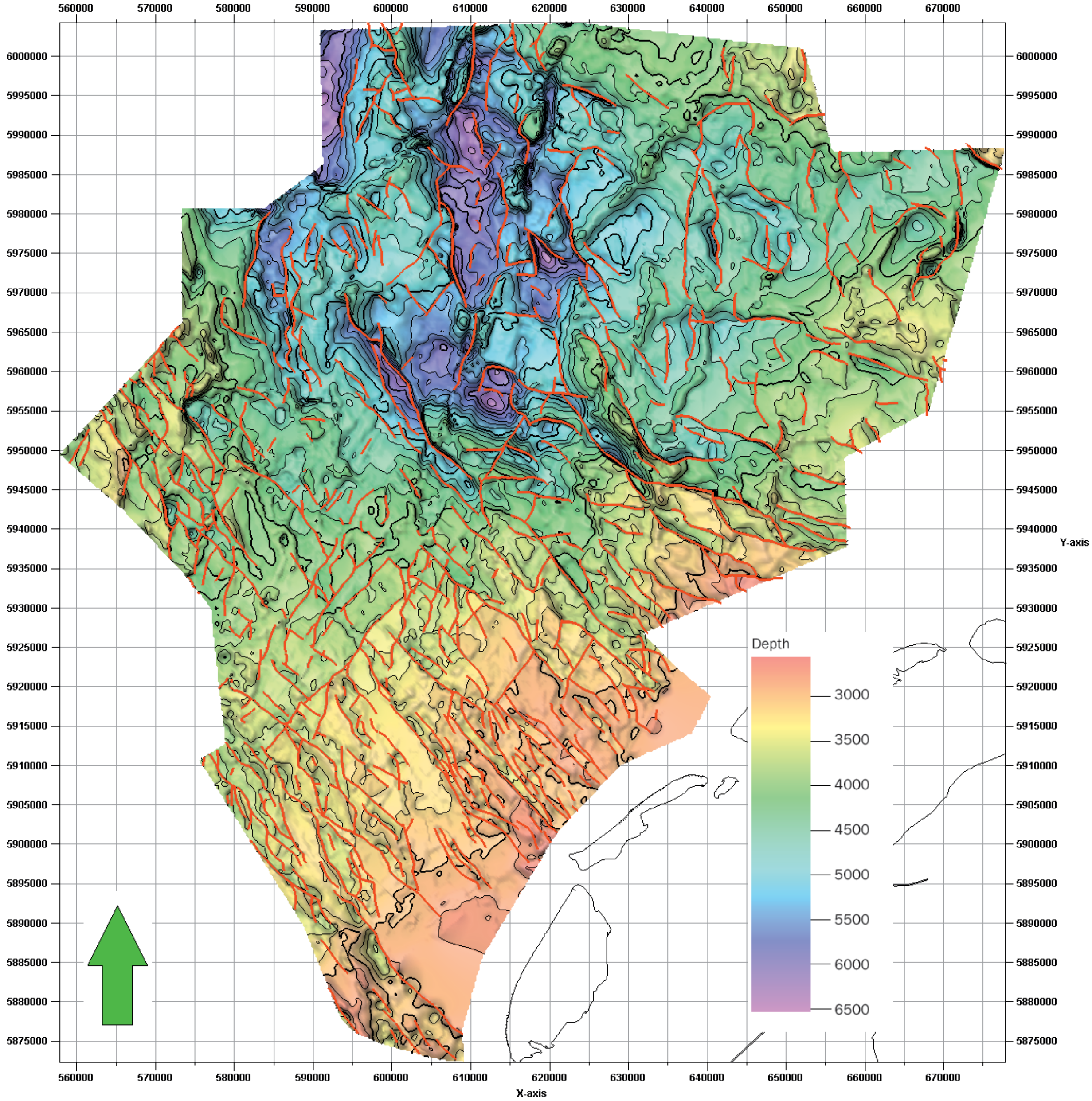

Figure 4a. Depth of the base of the Zechstein Group in area NCP-2A and 2E. Pre-Zechstein faults are shown in red.

velocity with depth. The Zechstein layer is converted to depth using a locally varying interval velocity model (V_{int}) that assumes a more-or-less constant velocity with depth in thick halite sequences in the Zechstein layer (e.g., salt domes). The local V_0, V_{int} and global K parameters are being determined per stratigraphic unit in the joint industry project VELMOD, using over 1,300 digital (calibrated) sonic logs (TNO, 2007). The depth model is tied to stratigraphic marker depths in wells. Final results are quality-checked and adjusted to ensure structural consistency.

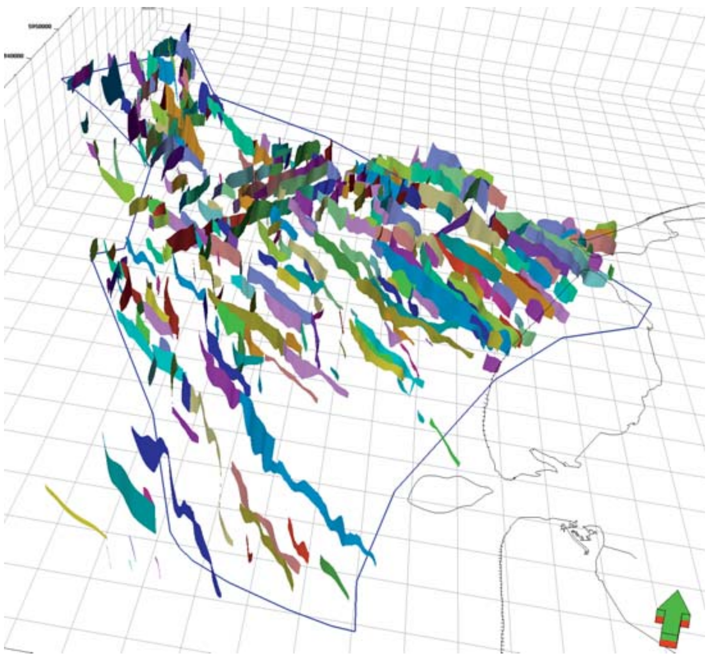

Figure 4b. 3D view of the pre-Zechstein fault model in NCP-2E.

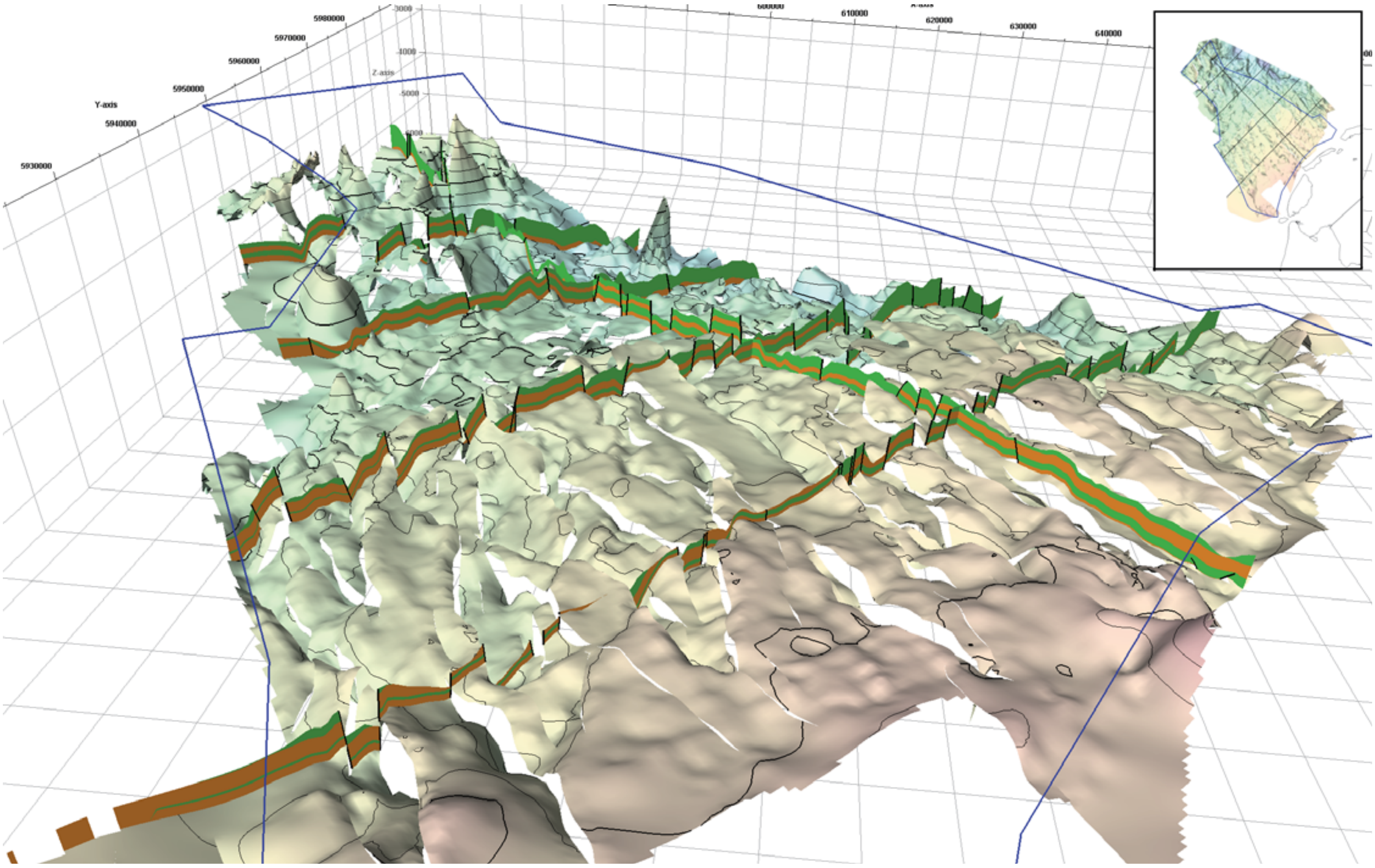

Figure 5. Perspective view of some cross sections in the Upper Rotliegend Group showing the location of Slochteren Sandstone layers (orange) and intercalated Silverpit claystones (green). The surface represents the base of the Upper Rotliegend Group.

Modelling of reservoir layers

Wireline logs (gamma-ray, sonic, neutron and density), sediment core descriptions, and company reports are being used to establish a stratigraphic interpretation at the member level for the available wells. These interpretations are then used to incorporate the reservoir layers important to petroleum systems (e.g., Rotliegend and Triassic sandstone layers) into the structural model. As an example, Figure 5 shows a N-S cross-section through the 3D model of the Rotliegend Group over the North Holland Platform and the Central Offshore Platform. The intra-group layers represent the Upper and Lower Slochteren Sandstone Members and the intercalated Silverpit claystones. The Slochteren sandstone layers pinch out to the North and are mostly absent in area NCP-2A (Dutch Central Graben and Terschelling Basin).

Special interest is being paid to the stratigraphic subdivision of the Upper Jurassic sediments in the Dutch Central Graben and Terschelling Basin. Biostratigraphic and sedimentological analysis has led to new insights, and an improved lithostratigraphic subdivision for the entire Dutch subsurface is in preparation. A proposal for revising the stratigraphic nomenclature is planned upon completion of the structural model in 2010.

Structural elements

As the interpretation and modelling proceeds, a more refined insight into the structuration of the offshore is emerging. These new insights are captured in revised structural element maps, such as that presented in Figure 6. Besides the improved outline of major structural elements, the modelling is yielding a higher resolution of intra-element structures. Figure 7, for example, illustrates the appearance of smaller SE-NW and SW-NE trending faults that didn't show up in the earlier regional maps of NCP-1. The timing of tectonic events, which is essential for burial history analysis, is captured in tectonostratigraphic charts per structural element.

Reliability

Two important sources of uncertainty in constructing the 3D structural model are the seismic interpretation and the velocity modelling. The reliability of the seismic interpretation depends on the quality of the seismic data, the availability of wells for correctly identifying seismic horizons for interpretation and, of course, the skill of the interpreter. Since the seismic interpretations are being interpolated to surfaces, regions with a low density and irregular distribution of seismic data (e.g., regions only covered by 2D surveys) will be less reliable in areas removed from the data, especially when these

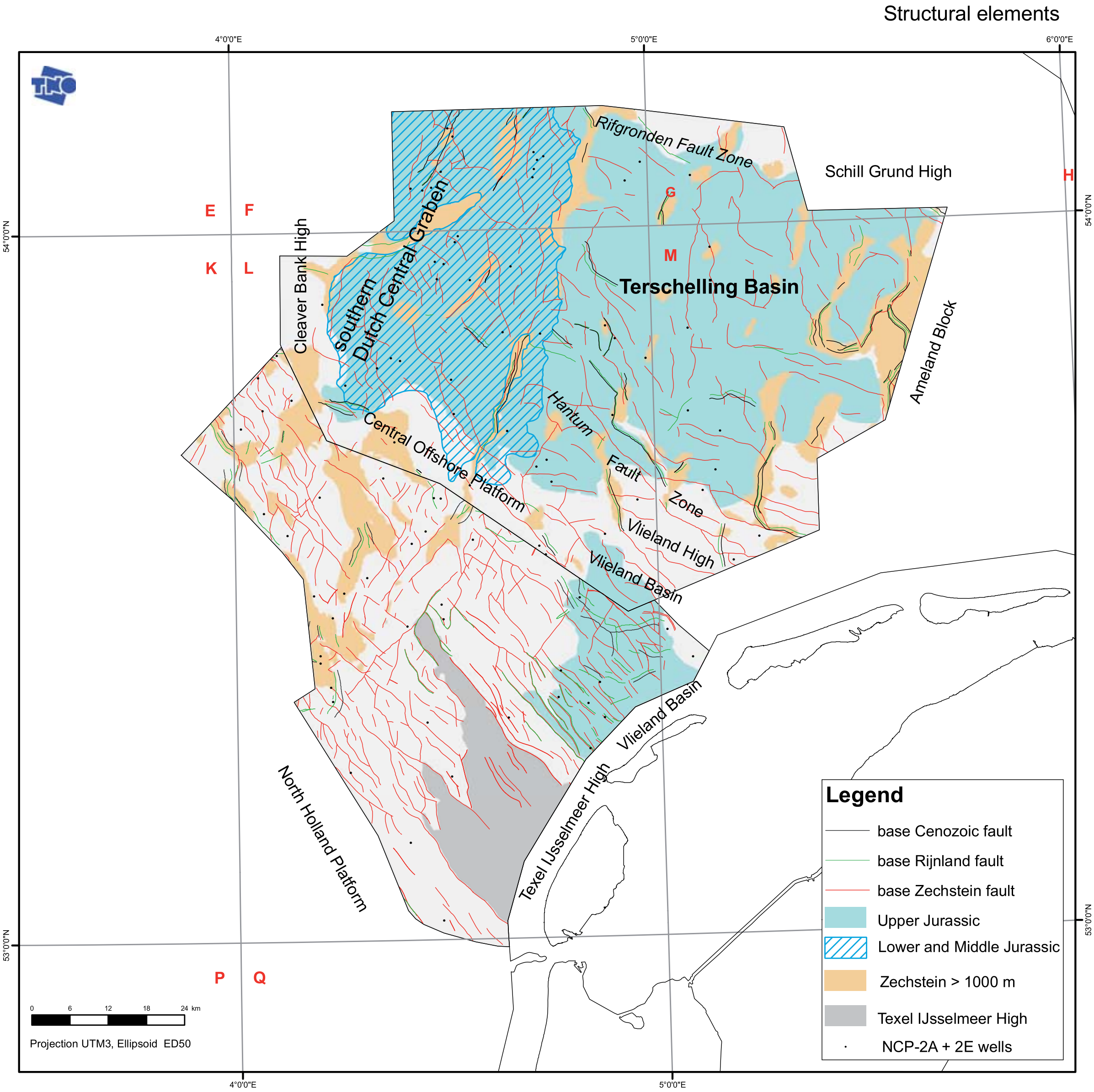

Figure 6. Structural elements map of NCP-2A and 2E.

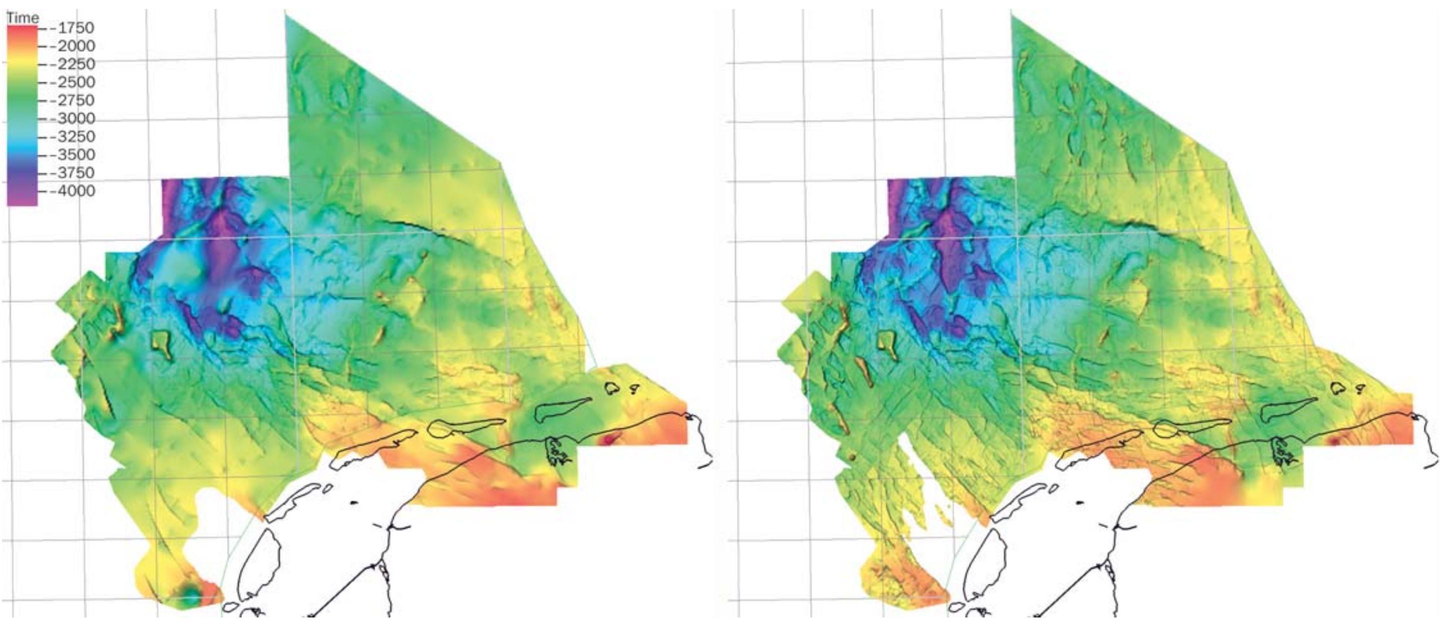

Figure 7. Two way time depth of the base of the Zechstein Group in NCP-1 (left) and its successor NCP-2 (right). Notice the improvement of detail of the fault structures.

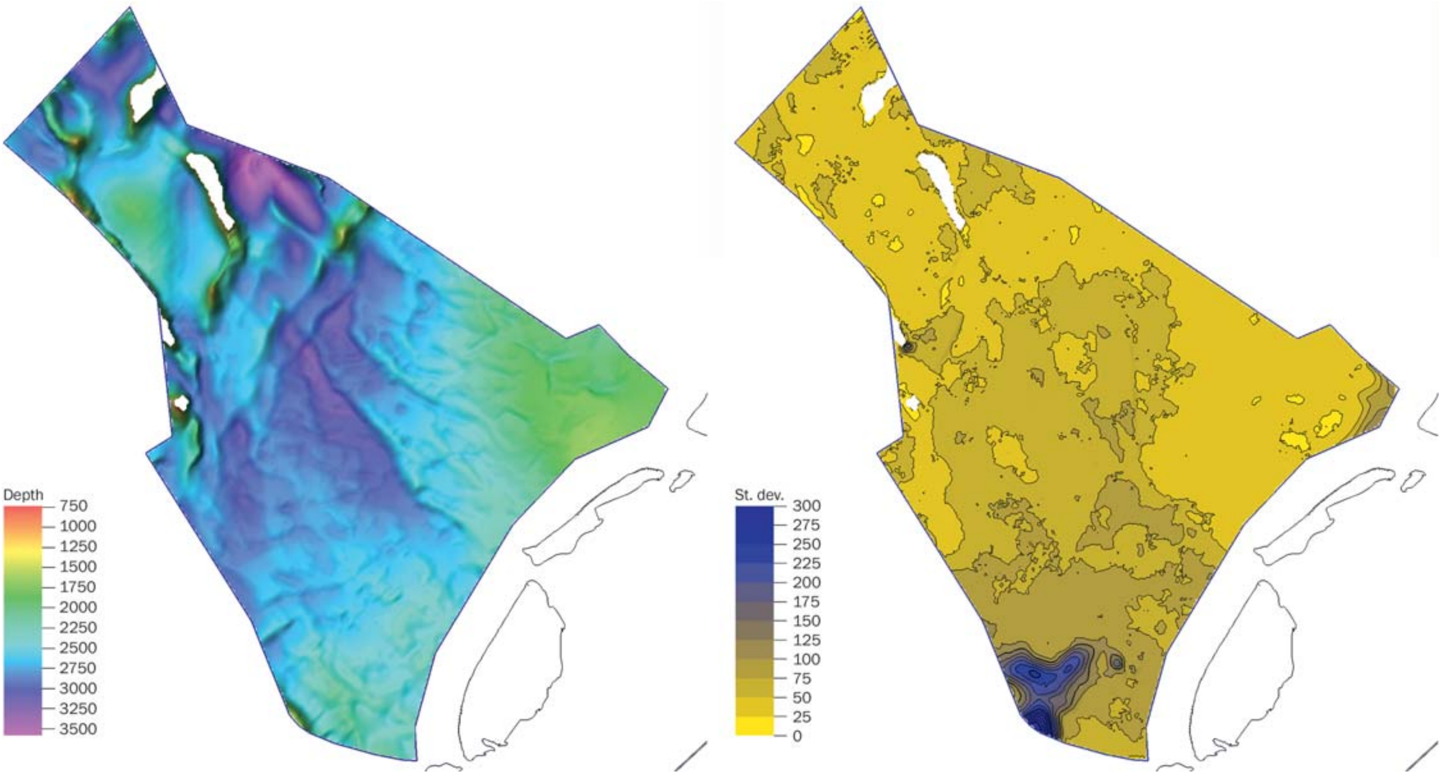

Figure 8. Depth of the base of the Chalk Group (left) and the associated standard deviation map (right).

regions are characterised by a structurally complex subsurface. Seismic velocities introduce uncertainty because they are based on sparse well data only and have to be interpolated to regional surfaces. Some uncertainty also exists in terms of the velocity measurements themselves.

A stochastic approach was chosen for correctly combining these different sources of uncertainty. With Monte Carlo simulations, it is possible to produce multiple, equiprobable realisations of the seismic horizons in two-way travel time, as well as of the seismic velocities. All realisations of the seismic horizons are subsequently passed through each realisation of the seismic velocity model, producing a multitude of possible outcomes for the depth of the horizons. In the case of area NCP-2E, 2,500 realisations of each depth surface were obtained from 50 seismic horizon realisations and 50 seismic velocity model realisations. The final reliability is displayed as the standard deviation of all outcomes (Figure 8).

Dissemination and progress

Standard deliverables from the structural model are published per mapping region in NLOG (*www.nlog.nl*) and comprise maps of depth and thickness for each major stratigraphic unit and several reservoir layers, cross-sections, structural element maps and corresponding tectonostratigraphic charts, and fault maps. File formats comply to industry standards (e.g., Zmap, Esri Arc-Gis, PDF and Excel). For some areas, reports of special studies are published. Areas NCP-2A and NCP-2E are now available on NLOG. NCP-2B and NCP-2C will be published later this year, and NCP-2D, NCP-2F and NCP-2G are planned for 2009 and 2010.

References

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