Geophysical Research Abstracts, Vol. 7, 00128, 2005
SRef-ID: 1607-7962/gra/EGU05-A-00128

Seismic and sub-seismic deformation in the North German Basin – first results from seismic and tectonic interpretation of a 3-D reflection seismic data set

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Introduction

The evolution of sedimentary basins entails a variety of spatial and temporal processes, which exhibit a complex pattern of structural and deformational features and styles. The sedimentary North German Basin (NGB) was affected by different deformational events since Permian time (e.g. Gast 1988, Ziegler 1990, Kossow et al. 2000, Kockel 2002). Large-scale subsurface deformation causes structures which can be identified in seismic data. However, small-scale subsurface deformation also accommodates a significant amount of the total strain (up to 50%), the so-called sub-seismic deformation (e.g. Marret & Allmendinger 1991, Walsh et al. 1998, Tanner et al. subm.).

We currently lack a deeper understanding of how structures and the responsible deformation processes relate to each other across the range of scales between lithospheric faults and grain-scale fractures. The understanding of the structural inventory of the NGB as observed today requires an integrated approach over such a large range of scales to understand the above complexity and to provide appropriate predictions.

In this project, we study the seismic and sub-seismic deformation in the NGB to quantify the distribution, magnitude and accumulation of strain during basin formation.

Study area

The study area is located east of Bremen, north Germany, at the northernmost margin of the Lower Saxony Basin at the transition to the Pompeckj Block. The Lower

Saxony Basin was affected by multiphase deformation processes: different fault systems and inversion structures are known. The available published data base shows that the Lower Saxony Basin suffered deformation during transtensional and transpressional stress regimes, thermal subsidence and inversion. The geographical position and the available extensive data base make the working area important for solving the question: to which extent are different crustal properties a function of Permian and Cretaceous deformational events?

Both appropriate well and prestack depth-migrated 3-D reflection seismic data from oil industry (RWE-DEA) were used. The reflection seismics cover an area of about 17.5 x 22.5 km, and reach depths up to the Carboniferous (ca. 7 km depth). In this volume, 13 wells contain information about lithology, petrophysical data, core sections, log curves, or FMI/FMS data.

The 3-D structural inventory is examined by the interpretation of seismic and borehole data, and the resulting structural model will be later validated by retro-deformation. To classify fractures, faults and deformation, coherency and neural network analyses will be fed outcrop and core data. The accumulation and scaling of deformation will also be addressed by analogue experiments.

Tectonic interpretation

After data base installation and validation and correlation of the available data sets, the 3-D reflection seismic volume was interpreted, calibrated by well data, and horizons and fault surfaces were picked.

The investigation area is characterized by four Zechstein salt diapirs, rooted above the Rotliegend at depths between 4500 to 4800 m. The basement underneath the salt is disturbed by large N-S to NW-SE striking graben systems, which were active in the upper Permian. The steep normal faults on the flanks of the grabens show the largest vertical displacement of 300 m at the Top A2 horizon (Lower Zechstein). These faults can be traced down to about 7000 m depth. However, also younger sediments of Triassic age were affected by a deformation along these faults, indicated by a small down-drag of these layers. This indicates that post-Zechstein deformation was not uncoupled by the Zechstein salt. The cover rocks on top of the salt generally show a pervasive deformation of predominately normal faulting, but at a much smaller scale than the basement rocks. Listric normal faults developed within Mesozoic layers of more competent rocks and detach horizontally along bedding. Salt uplift causes normal faults on top of the diapirs.

The whole area is disturbed by a large-scale NW-SE striking strike-slip system, influencing Carboniferous to Cretaceous rocks, but also partly Tertiary rocks. Steep dipslip normal and thrust faults, as well as positive and negative flower structures indicate inversion tectonics during multistage-deformation, causing this fault system to operate in transtensional and transpressional modes. The complex kinematics along this strike-slip zone involves rocks at least down to the Carboniferous, and is, therefore, a dominant and important structural feature in the area.

To improve the identification of subtle lineaments and small-scale structures, coherency processing is a helpful tool for interpretation of deformational processes in the working area. An ensemble of workflows was developed for a better coherency processing based on the used 3-D seismic data set. The new coherency algorithms "Structural Entropy" (measure of local discontinuity on a scale from zero to one) and "Shaded Relief" (consideration of different intensities of reflected light with color) allow better identification of small-scale lineaments, which are barely visible on the conventional seismic amplitude display. With the help of these methods we have recognized persistent lineaments of N- to NNE-orientation, as well as lineaments of NW-orientation, which in part parallel the large-scale structures. However, the importance of these small-scale features has to be investigated yet in terms of large-scale faulting and fault timing. A good correlation between coherency and core description analyses already exists, allowing the calibration of the seismic data with well data.

Future investigations

The next steps of our project will involve a more detailed interpretation of the seismic volume with respect to the large-scale and small-scale fault systems, with classification of kinematics, transmissivity and stress regime. The determination of the strain tensor will be combined with core and FMI/FMS studies. Core, thin section, logs and outcrop analyses will yield data on fracture and fractal characteristics (e.g. orientation, length, density, etc.).

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