Structural investigation and strain analysis of a polyphase flower structure in the Lower Saxony Basin, Germany

Poster

Lars Wagner[1] Tina Lohr[2] David C. Tanner[3] Charlotte M. Krawczyk[2] Onno Oncken[2]

Introduction

The Lower Saxony Basin (LSB) is a part of the post-Variscan Central European Basin System. We used a 3-D reflection seismic dataset in the northern LSB, provided by RWE-DEA AG, Hamburg (*c.f.* Lohr et al. submitted) for our investigation, which is concerned with the detailed structural and kinematic analysis of a flower structure within Mesozoic strata. This data is used in turn to determine input parameters for further 3-D geometrical retro-deformation. The retro-deformation verifies our assumptions about the structure and tectonic processes, and gives further information about sub-seismic strain distribution with respect to the branch faults of the flower structure.

Structural and kinematic analysis

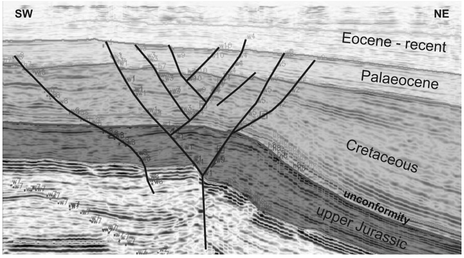

Figure 1: Interpreted 2-D seismic cross-section of the flower structure (width of figure ca. 4 km, depth from 0–3.5 s TWT). An earlier Upper Cretaceous compressive stage leads to reduced sedimentation towards the central part of the structure. The following Paleocene extension led to increased sedimentation and reduction of displacement in the deeper parts of the branch faults.

In a preliminary step, *structural analysis* was carried out to ensure our interpretation of the investigated flower structure was correct. We analysed it by using the criteria of Harding (1990). The investigated structure shows a planar, steeply-dipping main fault zone which indicates wrench tectonics, and also divergent branch faults at higher levels; both features are characteristics of a flower structure (Fig. 1). In addition, competing structural interpretations could be ruled out. For example, the collapsed crest of an anticline would not show a deeper main fault zone. Furthermore, cross-sections at varying distances from a nearby Zechstein salt diapir to the SE of this structure show no change in structural style, suggesting salt tectonics was not the main driving force for the tectonic evolution of the flower structure. The structure shows a polyphase synsedimentary evolution, with a compressive stage from Late Cretaceous up to earliest Tertiary, followed by extension during the later Tertiary (Fig. 1).

The main goal of the *kinematic analysis* was to determine the transport vector as one of the input parameters for later retro-deformation. In this example, direct determination of the transport vector was not possible because

---

[1] Department of Geology, University of Gießen, Senkenbergstraße 3, D-35390 Gießen [2] GeoForschungsZentrum Potsdam, Telegrafenberg, D-14473 Potsdam [3] Department of Structural Geology and Geodynamics, Geoscience Centre, University of Göttingen, Goldschmidtstraße 3, D-37077 Göttingen

of the lack of suitable markers, and also of the polyphase tectonic history of this structure. Instead, minimum transport distances are defined on fault planes by the cutoff relationships of sedimentary horizons. Additional kinematic indication is given by the topography of the branch fault planes, which shows strongly-corrugated morphologies (Fig. 2, 3). These asymmetrically-shaped corrugations have an amplitude of some ten meters and a spacing of approximately 1000 meters. Their axes, which indicate the direction of tectonic transport (Needham et al. 1996), show less than 20° deviation from the dip azimuth of the fault plane (Fig. 3). As a consequence of this, the post-Paleocene evolution of the flower structure seems to have been mainly dominated by extensional tectonics, since lateral transport is negligible. Indications for splitting of the strike-slip and dip-slip components to different branch faults was not found, since all of the fault planes show steeply-dipping curvature lineations.

Restoration and strain analysis

We perform 3-D geometrical retro-deformation of the fault displacement using the Midland Valley 3DMove software. For this, input parameters such as heave distance, transport direction, and inclined shear vector were obtained from the previous structural and kinematic analysis. Iterative tests of some of the parameters and the use of different restoration algorithms provide an indication of the reliability of our modelling and give some insights on their effect on the distribution of sub-seismic strain distribution (Fig. 4).

The 3D retro-deformation points to a strong correlation between fault surface morphology and strain distribution in the hanging wall, especially above ramp structures and with respect to fault surface corrugations. Furthermore, the strain distribution also depends strongly on the angular differences between the orientation of corrugation axes and transport direction. The modelling shows that deviations of more than 20–30°between transport direction and corrugation axis may lead to

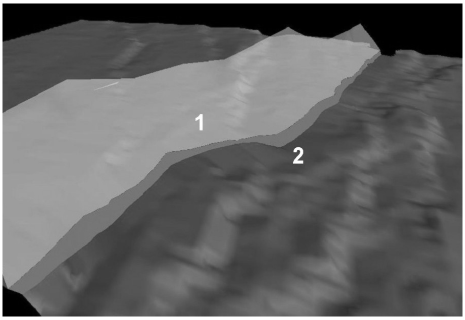

Figure 2: Branch fault planes, showing a strongly-corrugated morphology.

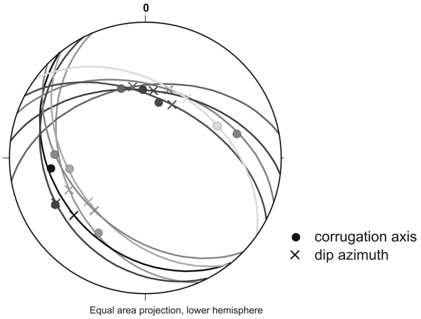

Figure 3: Stereonet-diagram with dip azimuth (crosses) and corrugation axis direction (circles) of branch fault planes (great circles). Calculation of the displacements and dipping angles of the branch fault planes, typically between 40–50°, allows to calculate the minimum extension amount of 240 m, or 10%, with respect to Base Tertiary level's width of 2400 m.

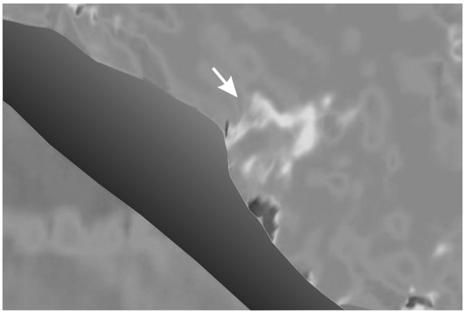

Figure 4: Greyscale map showing the relationship between strain accumulation (light grey — highest strain (15%) in the hanging wall of the Base Tertiary horizon and the fault surface morphology. View from top, fault plane dips toward upper right.

significant higher strain amounts. This is in agreement with the modelling results of Needham et al. (1996), in their analysis of North Sea faults. The use of different restoration algorithms shows only few differences (and therefore the results shown here are representative) in amount and distribution of sub-seismic strain in our models. That is, we predict strains of 10–15% (e_1 magnitude) within 200 m of the faults, extending to 400 m above ramp structures.

Conclusions

Using the criteria of Harding (1990), we established the flower structure nature of the investigated structure. Our investigation demonstrates that this flower-structure has undergone a polyphase evolution, with compression in the Upper Cretaceous and predominately extension during Paleocene to Eocene times. The minimum amount of this extension is 240 m, with respect to the Base Tertiary level. There is no evidence for wrench tectonics in the latter tectonic stages. The 3D retro-deformation points to a strong correlation between fault surface topography and strain distribution, but the strain value also depends strongly on the angular difference between the corrugation axes of fault planes and transport directions. In our models, the use of different restoration algorithms shows only few differences in amount and distribution of sub-seismic strain. The modelling show that deviations of more than 20–30° between transport direction and fault plane corrugation axis may lead to significant higher strain amounts in the hanging-wall.

Acknowledgements We thank RWE-DEA AG, Hamburg for allowing us to use their 3D seismic database and borehole data for this project. The project is part of the DFG SPP 1135; we acknowledge DFG grants TA 427/1 and KR 2073/1.

References

Harding TP (1990) Identification of wrench faults using subsurface structural data: criteria and pitfalls. AAPG Bull 74, 10

Lohr T, Krawczyk CM, Tanner DC, Samiee R, Endres H, Trappe H, Oncken O & Kukla PA (under review) Structural evolution of the NW German Basin over time from 3-D reflection seismic data — a case study at the border between Lower Saxony Basin and Pompeckj Block. Submitted to Journal of Structural Geology

Needham DT, Yielding, G & Freeman B (1996) Analysis of fault geometry and displacement patterns In: Buchnan, PG & Nieuwland, DA (eds) Interpretation, Validation and Modelling. Geol Soc Sec Publ 99