

**Evolution and structure of the Glueckstadt Graben by use of borehole
data, seismic lines and 3D structural modelling, NW Germany**

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Yuriy Maystrenko

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Gutachter:

Prof. Dr. U. Bayer

Prof. Dr. R. Littke

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*When a man has no longer any
conception of excellence
above his own,
his voyage is done, he is
dead*

Henry Ward Beecher

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Abstract

The Central European Basin System is one of the basins where the sedimentary cover is strongly affected by salt tectonics. The most significant stage of salt movement occurred during the Triassic. The largest Triassic subsidence occurred in the different sub-basins surrounding the Ringkoebing-Fyn High such as the Horn Graben, the Danish Basin and the Glueckstadt Graben. Furthermore, the thickest Triassic succession is observed in the Glueckstadt Graben where it reaches more than 9000 m. In the present study, the structure and the Permian to recent evolution of the Glueckstadt Graben are investigated by use of borehole data, seismic lines and 3D structural modelling.

The evaluation of the diverse deformation patterns of the sedimentary cover and their relations to salt structures show that the strongest salt movements occurred at the beginning of the Keuper when the Glueckstadt Graben was affected by extension. The onlap patterns of the Jurassic sediments onto the top of the Keuper succession indicate essential changes of the sedimentation style during the Jurassic. Thick Jurassic sediments are only observed around salt structures and are thinning away from salt walls or salt stocks. The Upper Cretaceous strata have an approximately constant thickness and the parallel reflections patterns indicate a quiet tectonic setting with very minor salt movements in the Late Cretaceous. Renewed salt flow during the Paleogene-Neogene caused rapid subsidence along the marginal parts of the Central Triassic Graben in the Westholstein, the Eastholstein and the Hamburger troughs. The thick Paleogene-Neogene strata within the marginal troughs may also be related to a regional component of tectonic subsidence in the area, contemporary with rapid subsidence in the North Sea.

The 3D modelling approach has been used to determine salt distribution at certain paleo-levels in response to unloading due to sequential removing of the stratigraphic layers. The modelling approach was also aimed to reconstruct the original Permian salt distribution immediately after deposition. The initial salt thickness varies from 1300 m at the flanks of the basin up to 3000 m within the central part and demonstrates a clear NNE-SSW trend of the basin. The regional trend of the restored salt distribution points to a westward continuation of the Permian salt basin.

The formation of the deep Central Triassic Graben and the subsequent Jurassic-Cenozoic marginal troughs was strongly controlled by the development of salt structures through time. It is shown that the depocentre of sedimentation was moving away from the central part of the of the original Graben structure towards its margins. The evaluation of the available data and results of the 3D reverse modelling demonstrate that a greater amount of subsidence occurred close to the active salt structures, and may have resulted in gradual depletion of Permian salt. Thus, this study indicates that the source of such long-term subsidence is derived from gradual depletion of the Permian salt, which started within the axial part of the basin and moved towards the basin flanks with time. In this sense, the Glueckstadt Graben was formed at least partially as a "basin-scale rim syncline" during post-Permian times. Therefore, the results show that salt withdrawal may have played an important role during the Meso-Cenozoic evolution and that the effects of salt-driven subsidence during the Meso-Cenozoic can be considered the main reason for the formation of the deep Central Triassic Graben and the subsequent Jurassic-Cenozoic marginal troughs.

Zusammenfassung

Das zentraleuropäische Beckensystem ist eines der Becken, in denen die Sedimentdecken stark durch Salztektunik beeinflusst sind. Die stärksten salztektonischen Aktivitäten traten während der Trias auf. Die größte triassische Subsidenz erfolgte in den verschiedenen Unterbecken rund um das Ringköbing-Fünen Hoch (Horn Graben, Dänisches Becken, Glückstadt Graben). Die mächtigste triassische Abfolge wurde im Glückstadtgraben beobachtet, wo sie mehr als 9000 m Mächtigkeit erreicht. In der vorliegenden Studie wurden die Struktur sowie die Entwicklung des Glückstadt Grabens vom Perm bis heute mit Hilfe von Bohrdaten, seismischen Linien und 3D-Strukturmodellierung untersucht.

Die Auswertung der verschiedenen Deformationsmuster der Sedimentdecke und ihr Bezug zu Salzstrukturen zeigen, dass die stärksten Salzbewegungen am Beginn des Keupers, während einer Dehnung des Glückstadt Graben auftraten. Die jurassischen Sedimente zeigen dann eine grundlegende Änderungen der Sedimentationsart während des Jura an. Mächtige jurassische Sedimente treten nur rund um Salzstrukturen auf und dünnen mit zunehmender Entfernung von Salzmauern oder Salzstöcken aus. Die Oberkreideschichten haben eine annähernd konstante Mächtigkeit, und die parallelen Reflektionsmuster weisen auf eine ruhige tektonische Subsidenz mit geringen Salzbewegungen in der Oberkreide hin. Erneute Salzbewegungen während des Paläogens-Neogens verursachten schnelle Subsidenz entlang der Randbereiche des zentraltriassischen Grabens, den Westholstein, Ostholstein und Hamburger Trögen. Die mächtigen paläogen-neogenen Schichten innerhalb der Randtröge sind eventuell auch mit einer regionalen Komponente tektonischer Subsidenz verbunden, zeitgleich mit schneller Subsidenz in der Nordsee.

Der 3D-Modellierungsansatz wurde genutzt, um die Salzverteilung für verschiedenen Paläolevels als Reaktion auf Entlastung durch sequentielles Entfernen der stratigraphischen Schichten zu bestimmen. Mit dem Modellierungsansatz wurde auch versucht, die ursprüngliche permische Salzverteilung unmittelbar nach der Ablagerung zu rekonstruieren. Die ursprüngliche Salzmächtigkeit variiert zwischen 1300 m an den Beckenflanken und bis zu 3000 m innerhalb des zentralen Teils und zeigt einen klaren NNO-SSW-Trend innerhalb des Beckens.

Die Bildung des tiefen zentraltriassischen Grabens und der nachfolgenden jurassisch-känozoischen Randtröge wurde stark durch die langandauernde Entwicklung von Salzstrukturen kontrolliert. Es wird gezeigt, dass das Sedimentationszentrum sich vom Zentralteil der ursprünglichen Grabenstruktur in Richtung ihrer Ränder verlagerte. Die Auswertung der verfügbaren Daten und die Ergebnisse der 3D-Rückwärtsmodellierung zeigen, dass der größte Teil der Subsidenz nahe aktiver Salzstrukturen auftrat, und eventuell zu einer graduellen Abwanderung permischer Salze führte. Daher zeigt die Studie, dass die Ursache der langzeitigen Subsidenz die graduelle Abwanderung permischen Salzes ist, welche im axialen Teil des Beckens begann und sich im Laufe der Zeit in Richtung der Beckenflanken bewegte. In diesem Sinne wurde der Glückstadtgraben zumindest teilweise in nachpermischer Zeit als "basin-scale rim syncline" geformt. Daher zeigen die Ergebnisse, dass dieser Salzrückzug während der meso-känozoischen Evolution eine bedeutende Rolle gespielt haben dürfte, und dass die Effekte salzgesteuerter Subsidenz während des Meso-Känozoikums als Hauptursache der Bildung des tiefen zentraltriassischen Grabens und die nachfolgenden jurasso-känozoischen Tröge angesehen werden kann.