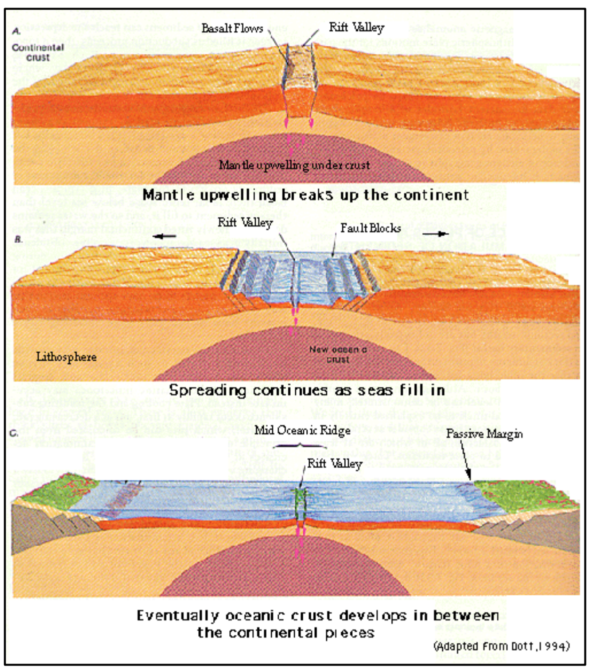
EBN & TNO Rifting Workshop

June 5th 2008



"Somehow the Netherlands has always managed to keep away from the orogenic turmoil that shaped most of Europe".
Salomon Kroonenberg in: Geology of the Netherlands, Foreword

Program Schedule

Coffee 9.30	**Registration**	
Session 1		
	10.00	Welcome (TNO/EBN)
	10.05	JAN DE JAGER (Shell - Rijswijk) – Rifting systems in the Netherlands and exploration – setting the scene
	10.20	FRED BEEKMAN (Vrije Universiteit Amsterdam) – Post-rift fault reactivation in the Netherlands
	10.40	Questions/discussion
	10.50	RICHARD RIJKERS (Gaz de France - Zoetermeer) – Structural development and sealing faults in the Central K&L blocks in the Netherlands
	11.10	Questions/discussion
Coffee 11.20		
Session 2		
	11.50	JAN DIEDERIK VANWEES (TNO) – Tectonic heat flow modelling for basin maturation: Methods and applications
	12.10	Questions/discussion
	12.20	KEES VAN OJIK (NAM - Assen) – The evolution of an hydrocarbon habitat system in Early Triassic sediments in the Vlieland Basin, offshore Netherlands, in response to Kimmerian rifting events
	12.40	Questions/discussion
Lunch 12.50		
Session 3		
	13.30	HERALD LIGTENBERG (NAM - Assen) – Characteristics or large-scale NW-SE trending faults along the Broad Fourteens Basin - and their influence on downthrown and pop-up development
	13.50	Questions/discussion
	14.00	FOKKO VAN HULTEN – HEERLEN / JO VAN BUGGENUM (EBN/WINTERSHALL - RIJSWIJK) – A 3D geological model of the Dutch Central Graben
	14.20	Questions/discussion
Tea	**14.30**	
Session 4		
	14.50	BERNARD GEISS (Total – Mariahoeve) – Late charge problems in the K5 area
	15.10	Questions/discussion
	15.20	HANNEKE VERWEIJ (TNO- Utrecht) – Impact of rifting on fluid migration in the Netherlands
	15.40	Questions/discussion
Panel Discussion		
	15.50	Are the effects of late movements, related to rifting, underestimated?
	16.45	Closing Remarks
Drinks 16.50		

ABSTRACTS

Post-Rift Fault Reactivation in the Netherlands

Fred Beekman - Vrije Universiteit, Amsterdam

Thermo-mechanical modeling shows that extended and weakened lithosphere slowly regains strength due to post-rift cooling. Rheological modeling indicates that the European rift systems are still weak, which explains the high level of seismic activity and neo-tectonic deformation in these areas. Also in the Netherlands, palaeo- and present-day natural earthquakes often occur on the pre-existing faults of rift systems in the Dutch subsurface.
Observations and numerical and experimental modeling studies show that the preferred mode of neo-tectonic deformation of the Roer Valley Rift System (RVRS) indeed is the reactivation of the pre-existing border faults. A fault slip tendency analysis of the RVRS border faults enables to assess the seismic hazard for society under the present-day intra-plate regional stress regime.
In the West Netherlands Basin, post-rift fault reactivation and basin inversion has caused considerable uplift and erosion. This shows that at geological time scales fault reactivation may result in removal of seals and reservoirs. Furthermore, reactivated faults may have disrupted reservoir seals, resulting in (partial) loss of hydrocarbons. Faults may also be reactivated at production time scales, as evidenced by the induced seismicity in the NE Netherlands. Geomechanical modeling and dilation and slip tendency analyses of faults may allow to quantify the reactivation potential of faults and to assess the possible (positive or negative) changes in seal capacity due to reservoir depletion.

Structural Style and Sealing Faults in the Central K&L Blocks

Richard Rijkers - Gaz de France PRONED BV

The offshore production licenses K9-K12-L10-L11a are operated by Gaz de France PRONED and gas is produced from the sandstones of the Slochteren Formation. Gas is sourced from the Carboniferous coal measures (Westphalian B) and the reservoir is sealed at the top by Zechstein salts. This area is nowadays a mature gas province were 154 wells have been drilled and already more than 40 bcm gas has been produced. This mature gas province is entering today in a new era of near platform gas exploration and appraisal. New seismic data is acquired in this area to find fault compartments and new gas fields near existing infra-structure.

Therefore a feasibility study on fault seals in the Rotliegend reservoir in the Central K&L blocks has been carried out to improve the comprehension of fault compartmentalization on reservoir pressure development during depletion. The K9-K12-L10-L11a blocks are located on the Central Offshore platform that connects structurally the Broad Fourteens Basin in the south with the Dutch Central Graben in the north. The Central K&L blocks are characterized by Jurassic rifting and tectonic inversion that is not straightforward from seismic data. Faults are mapped in mainly three different fault trends NE-SW, N-S and NNE-SSW that are recognized mainly as normal and locally with reversed and wrench components. N-S and NE-SW faults are clearly reactivated during the Late Cretaceous inversion phase (compression tectonics).

Of special interest, with respect to the structural development in the area, is the effect of fault seals that have formed flow barriers between the juxtapositioned sandstones in the hanging and footwall blocks. Because gas production and reservoir pressure development do locally not match reservoir models, it is believed that locally faults have sealing capacities. However, the fault seal mechanism is not identified easily since the Rotliegend clay stones show rather brittle rock behavior. Therefore, the clay smear mechanism (passive fault sealing) is not assumed to be the only mechanism. Rotliegend is situated at depths of 3500 to 4500m and shale layers show high strengths from logs and experimental laboratory data on rock samples. Cataclasis (or active fault sealing) is introduced to be an important fault sealing mechanism. A geological-geomechanical model and fault reactivation tool was developed for application on the fault patterns in the study area and to find a possible explanation for the fault sealing capacities encountered in the area. Tectonic compression in an oblique fault mode is an important geomechanical constraint for the development of cataclastic fault seals. An integrated approach in reservoir-geological studies with use of the ‘reactivation tool’ is tested to improve exploration and appraisal activities in this mature gas province.

Tectonic Heat Flow Modeling for Basin Maturation: Methods and Applications
J.D. van Wees – TNO Bouw en Ondergrond

Basement heat flow is one of the most influential parameters on basin maturity. Although rapid progress has been made in the development of tectonic models capable of modeling the thermal consequences of basin formation, these models are hardly used in basin modeling. Consequently heat flow is considered a user input, often marked by a constant value without temporal or spatial variation, resulting in erroneous maturation assessment. To better predict heat flows we have developed a multi-1D probabilistic tectonic heat-flow model, incorporating a variety of tectonic scenarios (including rifting, underplating and mantle upwelling). The model is capable of inversion of burial histories, calibrated to temperature and maturity data. Calibration and sensitivity analysis is done through Monte Carlo sampling analysis using an experimental design technique for computational efficiency. The model has been applied for a range of basin settings including the Netherlands. For (frontier) deep-water basins, we show that basin maturation is significantly higher and occurs much earlier when adopting tectonic heat flow instead of a constant heat flow extrapolated from shallow-water and onshore wells. For mature basins, we show that tectonic heat-flow scenarios considerably aid in identifying and understanding under-explored play systems, by putting temporal and spatial constraints on paleo-heat flow.

The Evolution of a Hydrocarbon Habitat System in Early Triassic Sediments in the Vlieland Basin, Offshore Netherlands - A Response to Kimmerian Rifting Events.

Kees van Ojik, Nederlandse Aardolie maatschappij bv

In late 1992, a new Triassic play was found by serendipity. NAM's well L09-7, on its way to a Volpriehausen prospect, drilled through a hitherto unknown thick sandstone interval of Early Triassic age, prior to reaching its planned objective. Whilst this new reservoir was water bearing, seismic amplitude anomalies suggested the possibility of an up-dip gas fill in the so-called "Fat Sand" play. Follow up wells discovered the L09-FD and L09-FF Fields along the same trend, with a maximum reservoir thickness of 165 meters. Many aspects of the hydrocarbon habitat such as the depositional environment, halite plugging and leaching, trap formation and hydrocarbon charge and retention are a function of variations in the burial history in response to Kimmerian tectonic events.

Note: Due to reasons of confidentiality this presentation is not included on the CD-Rom

Characteristics of large-scale NW-SE trending faults along the Broad Fourteens Basin

Herald Ligtenberg (NAM – Exploration)

From a structural geology perspective, the Southern Permian Basin is relatively complex due to the interaction between different fault systems and due to its complex structural history. The region underwent several phases of extension and compression with different main stress orientations, resulting in transtensional mechanisms and oblique inversion of structures. Fully understanding the structural development of the different fault systems is important to obtain a better insight in development of structural traps.

A regional approach highlights structural trends that otherwise would be missed when focusing on small study areas. In and around the rifting systems that are present in the Netherlands we observe very large-scale and deep-seated fault systems that are crossing the Netherlands and UK area for hundreds of kilometers. Their orientation has a northwest to southeast strike, parallel to the basin axis of the Broad Fourteens Basin. These are old fault systems that form the main regional structural grain.
The northwest to southeast trending faults have been reactivated at most or all subsequent tectonic events and have played a dominant role in the development of the Broad Fourteens Basin. They are presumed to be of Silurian age and better developed during the Pre-Carboniferous and Variscan tectonic stages, in which NW-trending wrench fault systems were developed in response to the prevailing stress pattern. In the Early Triassic, the North Sea became subject to regional tensional stresses that are related to the increasing rifting activity in the Norwegian Greenland Sea, having a transtensional effect on the NW-SE trending faults. Late Jurassic to Early Cretaceous extensional activity increased in relation to the break-up of Laurasia (opening of the Atlantic Ocean). The northwest to southeast trending faults were reactivated, inducing rapid subsidence of the Broad Fourteens basin and developing into a late-stage transtension. During the Alpine inversion at Late Cretaceous to Paleocene, northward compression induced inversion of the Broad Fourteens Basin. The consequence of this north-south compression is that the northwest to southeast trending fault zones underwent oblique strike-slip movements.
Since they have been reactivated at different extensional and compressional tectonic phases, they have developed interesting structural styles in the overburden, including en echelon faults, fault flower structures and related downthrown and pop-up structures.
The development and characteristics of these wedge-shaped zones and pop-up structures will be presented and explained in more detail by means of seismic cross-sections and top structure maps, together with observations in sandbox models, schematic sketches and analogues.

A 3D geological model of the Dutch Central Graben

F.F.N. van Hulten - Energie Beheer Nederland B.V. - P.O. Box 6500, 6401JH - Heerlen, The Netherlands
J.M. van Buggenum – Wintershall Noordzee B.V. – P.O. Box 1011, 2280 KA – Rijswijk, The Netherlands

The geology of the Dutch Central Graben is briefly summarized based on a 3 D geological model. This model visualizes the structuration of the larger Graben area, situated in the northern part of the Dutch shelf in the North Sea. The Dutch Central Graben is the southern extension of the UK Central Graben rift system.
The Dutch Central Graben is a promising Dutch geological province where, after the initial phase of exploration between 1970 and 1990's, only a limited amount of drilling has taken place since 1998. Quite a contrast compared to the UK Northern North Sea, a prolific oil province. Existing geological studies in the Dutch Graben area date back to the early phase of exploration. These studies did not take all the new 3D seismic into account. Therefore, in order to build a high quality geological model suited for 3D Basin Modeling a geological study was launched (see Van Buggenum et al., 2007). Data was used from different sources. Ten structural horizons with 3D-seismic interpretations from Total and Wintershall were merged by EBN. Geological well data from Fugro and EBN were used to refine the model resulting in a 1*1 km grid with 24 layers. Areas with no data were supplemented with information from the public domain.
The resulting model has many uses beyond conventional Basin Modeling studies. Spatial visualization provides new insights into the Graben structure. Using the model various rifting and inversion phases can be analyzed. The active tectonic elements in the Graben Area are clearly distinguishable on isopach maps. Movement of Zechstein salt is very important for the Dutch central Graben but is difficult to model. Salt doming is active as of the start of the late Triassic. From the structure and isopach maps it is clear that salt movements continue into the Tertiary. Salt movements sometimes obscure stratigraphic and tectonic trends. For example it is debatable to what extend the thickening of Upper Triassic layers is due to salt withdrawal or whether it can be related to Triassic rifting.

Based on thickness and structure maps it is proposed to subdivide the Dutch Central Graben area in a Northern, Mid and Southern part. These major blocks may well be related to larger tectonic lineaments that can be seen in the region. The relation of the southern part of the Graben with the Terschelling basin is of importance to understand the larger tectonic framework. For example the inversion at the end of Cretaceous is sometimes shown as curved. From the isopach maps a NNE-SSE compressional direction can be deduced. The curved pattern may very well be an erosional feature. Erosion is important for the Basin Modeling, however because of present day overprint not easy to quantify from information such as vitrinite profiles. The 3D model is helpful to study erosion trends. Estimation of missing sections outside the Graben areas remains difficult, however with the model regional trends can readily be observed.

Van Buggenum, J.M., Van Hulten, F.F.N. & Gibson, P.W. (2007) *Aspects of 3D basin modeling of the Dutch Central Graben area.* AAPG Hedberg Research Conference, Basin Modeling Perspectives: Innovative Developments and Novel Applications, May 6-9, 2007, The Hague, The Netherlands, abstract volume p. 50.

Late Charge Problems in the K5 area

Bernard Geiss - Total E&P Netherlands B.V.

Drilling K5-13 has ended a series of 23 successful exploration and development wells in the K5/K6 area. The post-mortem of the well recognizes a geological success confirming the reservoir distribution model based on the Westphalian subcrop. Fluid inclusions indicate that a possible reason for the failure is a lack of gas migration in an area where charging has never before been considered as a problem. As the Carboniferous SR may be too immature to expel sufficient amounts of HC's below the horst block, migration from the kitchen areas located to the North and South of the block is needed to fill the structures, Up to now this has proved to be a working petroleum system. So what did go wrong for K5-13?

Only the structural position in relation to N45 (NE-SW) oriented transfer faults may explain the difference of K5-13 to the other fields. These faults are due to Late Cretaceous to Tertiary oblique inversion along pre-Westphalian directions. They are known to be dynamic barriers even though they have hardly any vertical throw. These transfer faults may have created a barrier to fluid migration when the maximum horizontal stress turned to its present day position (N135) i.e. perpendicular to them. Also they may have controlled hydrothermal circulation and hence fault cementation or diagenesis and porosity/permeability evolution in the vicinity of the faults.

The Impact of rifting on fluid migration in the Netherlands

Hanneke Verweij - TNO Built Environment and Geosciences, PO Box 80015, 3508 TA Utrecht, The Netherlands; hanneke.verweij@tno.nl

Tectonic processes and sedimentary loading and unloading are the major stress related mechanisms that impart a first order control on the development of excess pore pressures and migration of fluids (water, oil, gas) during basin evolution. An important part of this influence is due to the combined control of tectonics and sedimentation on the geometry and lateral continuity of reservoirs and seals and the location, permeability and storativity of tectonic elements.

This presentation will focus on the influence of rifting on the permeability framework and associated fluid migration characteristics in the Netherlands during the main Mesozoic rifting phases and at present-day.

For this purpose information from recently completed stratigraphic and structural maps and burial history simulations will be shown in combination with interpretations of observed pressures, temperatures, salinities from 500 wells, as well as gas compositions and diagenetic features.

Tectonic forces exert both static and dynamic influences on the permeability and storativity of the basin fill. Permeability and storativity tend to be higher in basins in an extensional stress regime compared with a compressional stress regime. Major normal fault displacements in the Netherland are related to the Jurassic rifting of the Mesozoic basins and the late Oligocene to recent rifting of the Roer Valley Graben system. During active deformation fault zones and associated fracture zones may have acted as permeable pathways for fluids. Flows along deeply penetrating active faults in the Netherlands during Mesozoic rifting have been recognized before. This paper will indicate the significance of such increase in vertical permeability for the charging of gas during rifting.

Results of several integrated studies of the offshore Netherlands at present-day reveal the differences and similarities between the permeability framework in the fault dominated southern rift basins and the salt dominated northern basins and their relation with the observed differences in fluid migration conditions (such as lateral migration through pre-rift and Mesozoic reservoirs, vertical migration, compartmentalized highly overpressured Mesozoic reservoirs, normally pressured reservoirs). The characterization of the permeability framework includes the identification of the major regional seals as well as the role of major basin boundary fault systems as barrier or conduits to lateral and vertical flow. For example, present-day patterns of hydraulic head revealed that basin boundary fault systems may act as barriers for lateral flow and separate the pressure and fluid flow systems in the basin from adjacent platforms; in some areas flow is towards the fault zone suggesting it is also acting as a conduit for vertical flow. Temperature anomalies, and geochemical composition of natural gas accumulations, and their isotopic signatures, near recently active fault zones (e.g. in the

Roer Valley Graben) suggest that these faults have acted as flow zones in recent times. Understanding the present-day permeability framework in relation to the pore pressure distributions and fluid flow conditions are of critical importance for the appropriate evaluation of late oil and gas charging and preservation of oil and gas accumulations.