Geological Analysis and Resource Assessment of selected Hydrocarbon systems

Authors and affiliation:

Margaret Stewart, BGS

Susanne Nelskamp, TNO

Rüdiger Lutz, BGR

Jashar Arfai, BGR

Stefan Ladage, BGR

Niels Schovsbo, GEUS

Peter Britze, GEUS

E-mail of lead author:
mstewart@bgs.ac.uk

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Verified (WP leader)	25/04/2019	Peter Britze, GEUS
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GENERAL INTRODUCTION

This report summarises the work carried out in acquiring and harmonising data as part of the Geo-ERA GARAH WP2: Assessment of North Sea Resources project.

The initial stages of this work have largely been concerned with the creation, dissemination and retrieval of questionnaires distributed to WP2 participants and focused on the current state of the art of conventional and unconventional resource assessments for the North Sea region.

Questionnaires were distributed in January of 2019 and have been returned by all participants. Collation and interpretation of the returned data is underway.

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1 RATIONALE AND AIMS

The aim of the GARAH WP2 project is to assess cross-border conventional and unconventional hydrocarbon resources, and our approach here is not only to compare existing reporting on resource assessments, but also to compare methodologies and units used, so that accurate comparisons and cross-border assessment can be made, and data gaps identified.

2 QUESTIONNAIRES AND TABLES

2.1 Conventional Resource Assessments (Task 2B)

The conventional resource assessment questionnaire (see Appendix 1) was intended to assess the data availability in participant countries (UK, Norway, Netherlands, Germany and Denmark) related to conventional oil and gas resources in the North Sea study area. Initially, we were interested in existing assessments of conventional resources and associated methodologies and existing assessments of potential resources, such as *yet to find*, and associated methodologies.

The next step is to take a play-based approach to collate information on conventional petroleum systems across the North Sea, and compare exploration data to see if further insight can be made regarding particular plays and regions of exploration interest.

A spreadsheet was created together with the questionnaire in order to harmonise reported data; including definitions of terms and units agreed upon by the participating countries and discussed with WP 4 and members of the IP project. Appendix 3 contains the example spreadsheet.

2.2 Unconventional Resource Assessments (Task 2C)

The unconventional questionnaire (see Appendix 2) was intended to assess the data availability in participant countries (UK, Norway, Netherlands, Germany and Denmark) related to unconventional oil and gas resources in the North Sea study area. Initially, we were interested in any existing knowledge and data and if any existing assessments of potential resources have been done, and its associated methodologies. The questionnaire for the unconventional assessment is a slightly updated version of the questionnaire developed in the EUOGA project.

We then plan to take a play-based approach to collate information on unconventional petroleum systems across the North Sea, and compare exploration data to see if further insight can be made regarding particular plays and regions of exploration interest.

A spreadsheet was created in order to harmonise reported data; including definitions of terms and units agreed upon by the participating countries. Appendix 4 contains the example spreadsheet.

3 APPRAISAL RESULTS: CONVENTIONAL AND UNCONVENTIONAL STUDIES

3.1 Conventional Resource Assessments

Questionnaires and spreadsheets were returned for the UK, Dutch, Danish, German and Norwegian sectors. All countries were able to return reserves and resource figures from recent studies. Full details of all play types were not able to be captured for the conventional resource assessment in the UK, Danish and Norwegian sectors; this will require further time as part of the overall project.

A brief update on current resource assessments for each country is included below.

3.1.1 Germany

The last exploration well in the German North Sea was drilled in 2010 (L-1-2). All other wells (~40) drilled since 2009 are production wells or near-field (<5 km) new pool test wells. So far ~100 wild cat wells have been drilled in the German North Sea and one oil field (Mittelplate) and one gas field (A6-A) are in production. Additionally, approximately 100 development wells have been drilled.

In Germany no public license rounds are conducted. Companies can apply for licenses at the respective mining authority, which is the State Authority for Mining, Energy and Geology of Lower Saxony (LBEG) for the North Sea.The search for economically meaningful natural resources are subjected to the regulations of the Federal Mining Law in Germany (BBergG).

BGR does not have a recent published resource assessment for HC of the North Sea. For oil and gas reserves in the North Sea the LBEG is responsible. The E&P industry reports to LBEG the reserve estimates (P90 proven, P50 probable) which are published in yearly report series of LBEG are available here: http://www.lbeg.niedersachsen.de/erdoel-erdgas-reservenbericht/kurzbericht-erdoel--und-erdgasreserven-in-der-bundesrepublik-deutschland-786.html.

This information needs to be tabulated and translated into English to fulfill the GARAH resource assessment.

3.1.2 UK

Offshore oil and gas exploration in the UK sector of the North Sea has been ongoing since the 1960's. The oil and gas industry is regulated by the Oil and

Gas Authority (OGA), part of the UK Government Department for Business, Energy, and Industrial Strategy (BEIS). The OGA regulates, promotes and influences the oil and gas industry in order to maximise economic recovery of oil and gas from the UK. The OGA published an updated exploration strategy in 2016, which is publically available here: https://www.ogauthority.co.uk/media/2835/exploration_strategy_master.pdf
The OGA published an updated overview of their work in 2018: https://www.ogauthority.co.uk/media/5063/oga_overview_sept.pdf

Oil and gas production from the UK North Sea peaked in 1999, and the OGA reports 42.3 billion barrels of oil equivalent (boe) total hydrocarbons produced since 1975 (last updated October 2018). Of this, 39 bn boe of hydrocarbons have been produced from the North Sea area - 92% of total production. The last compilation of OGA reporting, from 2018, calculated 1.63 million boe/day was produced in 2017, similar to the figure in 2016. Up to date production information can be found and queried here:
http://data-ogauthority.opendata.arcgis.com/pages/production

From the 2018 OGA report, estimated production for UK total oil and gas in millions of barrels of oil (mboe) is: 89.35 for 2018; 87.56 for 2019; 85.33 for 2020; 81.06 for 2021; 77.01 for 2022; and 73.16 for 2023. The full report is available here: https://www.ogauthority.co.uk/media/5069/projections-of-uk-oil-and-gas-production-and-expenditure-march-2018.pdf
Production is expected to decrease to between 0.2 and 0.4 mboe per year by 2050

Data for UK resources have been harmonized within the GARAH spreadsheet (Appendix 3).

3.1.3 Netherlands

A yearly report on resource assessment is published on www.nlog.nl

Ministry of Economic Affairs and Climate Policy (2018) Natural resources and geothermoal energy in the Netherlands – Annual review 2017. https://www.nlog.nl/sites/default/files/yearbook%202017-%20englishversion.pdf

Details of Dutch reserves still need to be harmonized within the GARAH database.

3.1.4 Denmark

Denmark has, for many years, been net exporter of oil and gas. This is no longer the case due to tailing production rates. Denmark is in the middle of the 8th licensing round, where 4 companies have applied for 5 licenses in the North Sea west of the 6 deg. 15 min longitude. The 9th Licensing round will be announced

12 month after the grant of licenses from the 8th round. So approximately every 2nd year.

Revised legislation now limit the HC exploration possibilities to the North Sea, with open door applications east of 6 deg. 15 min longitude.
https://ens.dk/en/our-responsibilities/oil-gas

The DEA makes an annual assessment of Danish oil and gas resources on the basis of a pre-defined classification system. The aim of the classification system is to determine resources in a systematic way. https://ens.dk/en/our-responsibilities/oil-gas/resources-and-forecasts

Details of Danish reserves still need to be harmonized within the GARAH database.

3.1.5 Norway

Yearly licensing rounds in the North Sea with approximately 30 exploration and appraisal wells per year.

The Norwegian Petroleum Directorate (NPD) provide details of resources. The Resource evaluation for 2018 is found here:
http://www.npd.no/no/Publikasjoner/Ressursrapporter/2018/

Details of Norwegian reserves still need to be harmonized within the GARAH database.

3.2 Unconventional Resource Assessments

Questionnaires and spreadsheets were by 1st April 2019 returned for Denmark, UK and Germany countries. Initial returns show that many countries do not have current resource assessments for unconventional resources offshore.

The aim of the GARAH project is to assess cross-border resources, and the specific aim here is to compare existing data relevant to the EUOGA methodology assessment of any shale bound oil and gas resource. This questionnaire is intended to assess the data availability in your country related to un-conventional oil and gas resources in the North Sea study area. Initially, we are interested in any existing knowledge and data and if any existing assessments of potential resources has been done, and its associated methodologies. We will then take a play-based approach to collate information on unconventional petroleum systems across the North Sea, and compare exploration data to see if further insight can be made regarding particular plays and regions of exploration interest. Adopted EUOGA screening criteria are presented in Table 1 and 2. For more information on the EUOGA methodology please refer to the reports that can be found on https://openecho.jrc.ec.europa.eu/project-deliverables

3.3 Screening for potential unconventional hydrocarbon resources

Guidelines for screening of relevant unconventional are presented in Table 3.1. Screening of their relevant part of the North Sea basins and gather data for shale attributes based on the selection criteria. Initial selection criteria for both thermogenic and biogenic shale gas and oil plays are to be mapped. Finalized selection criteria and the procedure of screening a basin will be finalized during the project.

Geological Properties:	**Value/comment**
TOC content and type	> 2%, Type I-II marine
Thermal maturity	>0.7% Ro, oil mature
Thickness	>20 m
Present day depth	< 7 km
Mineralogy	Brittle preferentially
Pressure regime	Normal to overpressure
Structural complexity	Low to moderate
Geographical Properties:	
Areal distribution	Offshore

Table 3.1. Screening criteria.

3.3.1 Denmark

Unconventional hydrocarbon exploration is in Denmark only allowed offshore – in the North Sea Area. At current two main plays are recognized: The Palaeozoic Alum Shale and the Jurassic Farsund play.

The Alum Shale paly have been drilled onshore with poor results and no drilling offshore has been made. With the abolishing of onshore oil and gas exploration in Denmark no new data from onshore will incur to help evaluation of the offshore extension of the play.

The Farsund Fm is the main source rock in Danish part of the North Sea and does not extent onshore Denmark. The Farsund unconventional potential is current unknown and currently only assessed in academic thesis and research projects and dedicated exploration well data is lacking.

The Farsund Fm may have an exploration resource, but it is at this stage not possible to quantify the potential. There has been a few test production (DST) from the formation. The well Jens-1(drilled 1982) thus intersected a > 60 f thick fractured zone of shales and dolomite stringers. The well tested around 1200 BOPD. In connection with a production well in the Lower Cretaceous Valdemar Field a planned horizontal well track was planned. The operator estimated a possibility of 1.5 109 m3 for oil in-place within the upper 700 m of the formation within an area of 50 km2. The test track did not, however, produce, and the test was abandoned with the conclusion that the production potential was very limited.

Still continued interest exist and the operator continues with geotechnical test of the formation.

3.3.2 Germany

In Germany there are no activities currently or planned that BGR is aware of.
The geological development during the Late Triassic and the Early Jurassic, the southern North Sea area was dominated by a shallow epicontinental sea, which is manifested by the deposition of fine-grained mudstones. After the Mid-Jurassic uplift of the central North Sea area during the late Aalenian to Bajocian, which is attributed to the development of the Central North Sea thermal dome, main rifting of the Central Graben started at the. The uplift event marked the end of a laminar depositional system, which dominated during the Early and Middle Jurassic and resulted in a regional unconformity. Within the German Central Graben, the uplift stopped the deposition of the Altena Group and resulted in erosion at structural highs. The end of the thermal uplift and a resuming subsidence is manifested at first by the deposition of continental and deltaic sediments and then of marine claystones. A more complex system of platforms and basins evolved due to increased rifting and intensified halokinesis during the Upper Jurassic. While platform areas were subject to erosion or sediment starvation, major rifting resulted in differential subsidence and rapid deposition of Upper Jurassic sediments in the Central Graben.

Potential Source rocks include:
Rhaetian shale (Upper Triassic) is onshore considered as potential shale gas and oil source rock and the potential has been assessed. Its offshore equivalent, the Sleen Formation, is present in the southern Central Graben area. The formation contains mostly < 5 wt% OM of type II-III kerogen with good petroleum potential. It is assumed to be a fair source rock for oil and to have contributed to HC accumulations in the southern Dutch Central Graben. Its potential in the German Central Graben is still hypothetical and was assessed recently in a PSM.

The Lower Jurassic Posidonia Shale Formation (type I–II kerogen) is the most important source rock for oil onshore Germany. In the German North Sea, the Posidonia Shale Formation is the source rock of Mittelplate, the only German offshore oil field. In the southern North Sea area, the formation is only preserved in main Mesozoic rift basins and deeper subsided basin parts such as the Central Graben. Remnants of the Posidonia Shale Formation are also assumed in the German Central Graben, but are not confirmed by wells.
The Late Jurassic ‘hot shales’ are bituminous claystones and mudstones deposited near the Jurassic – Cretaceous boundary (Tithonian/Volgian – Berriassian/Ryazanian), overlying the Kimmeridge Clay Formation. They are called Clay Deep Member in the Dutch Central Graben, Bo Member in the Danish Central Graben and Mandal Formation in the Norwegian Central Graben and are time-equivalent to the Draupne Formation in the Northern North Sea. The Bo Member is the most important oil and gas source rock in the Danish Central

Graben. The ‘hot shales’ were deposited under euxinic marine conditions resulting from stagnation of basin circulation in parts of the southern North Sea. Their present-day maturity in the German Central Graben is in an early stage of the oil window.

3.3.3 United Kingdom

No current offshore shale gas exploration. One offshore licence was let for shale gas (2014) but no activity took place- see https://www.bbc.co.uk/news/business-26157228

Onshore: 11 wells drilled. ~10 additional wells planned or permitted. One vertical well hydraulically fractured (6 stages). One horizontal well hydraulically fractured. Acquisition of 3D seismic data underway. Tax incentives and simpler planning process implemented by Government. Community benefit fund set up. Up to $750M pledged for exploration. Moratorium in place in Scotland (Jan 2015) pending assessment of environmental impacts. Moratorium in place in Wales (February 2015). No active licenses in Northern Ireland. Multiple licenses in place in England, limited amount of drilling and/or seismic acquisition presently.

Detailed regional assessments made for three principal regions/geological units: Mid-Carboniferous Bowland-Hodder unit, northern England; Mid-Carboniferous shales, Midland Valley, Scotland; Jurassic shales, Weald (South-east England). Also, countrywide assessments of shales completed (separate studies for Scotland, Wales, and United Kingdom as a whole). Criteria used- high gamma, organic rich shales, Rock-Eval, maturity, shale cut off, mineralogy and depth cut-off, targeted in three principal basin accumulations.
Offshore, we expect there to be shale resource in the offshore extensions of the Pennine Basin (mid- Carboniferous shales), Midland Valley, Scotland (again mid-Carboniferous shales) and Weald/Wessex basins (Jurassic shales). For these, an assessment of the following shale units has been completed: Bowland-Hodder unit (Pennine Basin), Limestone Coal, Lower Limestone, West Lothian Oil Shale, Gullane formations (Midland Valley, Scotland) and Kimmeridge Clay, Coralian Clay, Oxford Clay (Peterborough Member), Upper Lias Clay, Mid Lias Clay, Lower Lias Clay (Weald and Wessex basins).

3.3.4 The Netherlands

In the Netherlands there is currently no offshore shale gas/oil exploration and also no assessment have been done or are planned for the unconventional resources in the offshore. Several assessments have been published for the onshore area of the Netherlands, the latest in the context of the EUOGA project (reference). Onshore exploration has been on hold since 2010 in order to perform research into possible effects and risks of shale gas. The moratorium status has been extended a number of times, latest by a decision in 10 July 2015, extending the moratorium for 5 years without drilling activities for shale gas. There are currently no licenses for shale gas/oil exploration and no wells have been drilled for that purpose have been drilled.

Potential shale gas/oil source rocks in the Dutch offshore region are expected to be the same as onshore and include the Toarcian Posidonia shale formation and the Lower Carboniferous Geverik shale member. The Posidonia shale formation in the Dutch offshore is present in the West Netherlands Basin, the Broad Fourteens Basin and the Dutch Central Graben at a present-day burial depth between 500 and 7000m. It is approximately 40m thick and contains between 2 and 18 wt% of marine type II organic matter. The offshore distribution of the Geverik shale member is uncertain but is postulated to be present in most of the Dutch offshore region. Its present-day burial depth is estimated between 500 and 10000m and the formation on average has a thickness of 50m. Onshore wells have determined that the Geverik shale member contains beween 1 and 9% of marine Type II organic matter.

4 3D PETROLEUM SYSTEM MODELLING (WP2 – TASK 4)

4.1 Introduction

As part of the overall objective of the GARAH project, a 3D basin and petroleum system model covering the Danish, German, and Dutch Central Graben area will be constructed. The 3D model will be used as a pilot study to reconstruct the thermal history, maturity and petroleum generation of potential source rocks. In a first step this will focus on the source rocks (shales; unconventionals) and later on in a second step will consider conventional plays.
The 3D pilot study is heavily dependent on mapping campaigns carried out by GeoERA 3DGEO-EU project. Therefore, an early meeting was held in Hannover (11.-13. September 2018). During this meeting the projects participants agreed on the area of interest, the stratigraphic framework and mapping as well as responsibilities. Additionally, necessary parameters for petroleum system modelling and to characterize relevant source rock formations in the pilot study area, are to be provided by the project participants.

4.2 Area of Interest

The area of interest for the 3D basin and petroleum system modelling study has been defined as shown in (Fig. 4.1). This area comprises the cross-border area of the Danish, German, and Dutch Central Graben in the central North Sea.

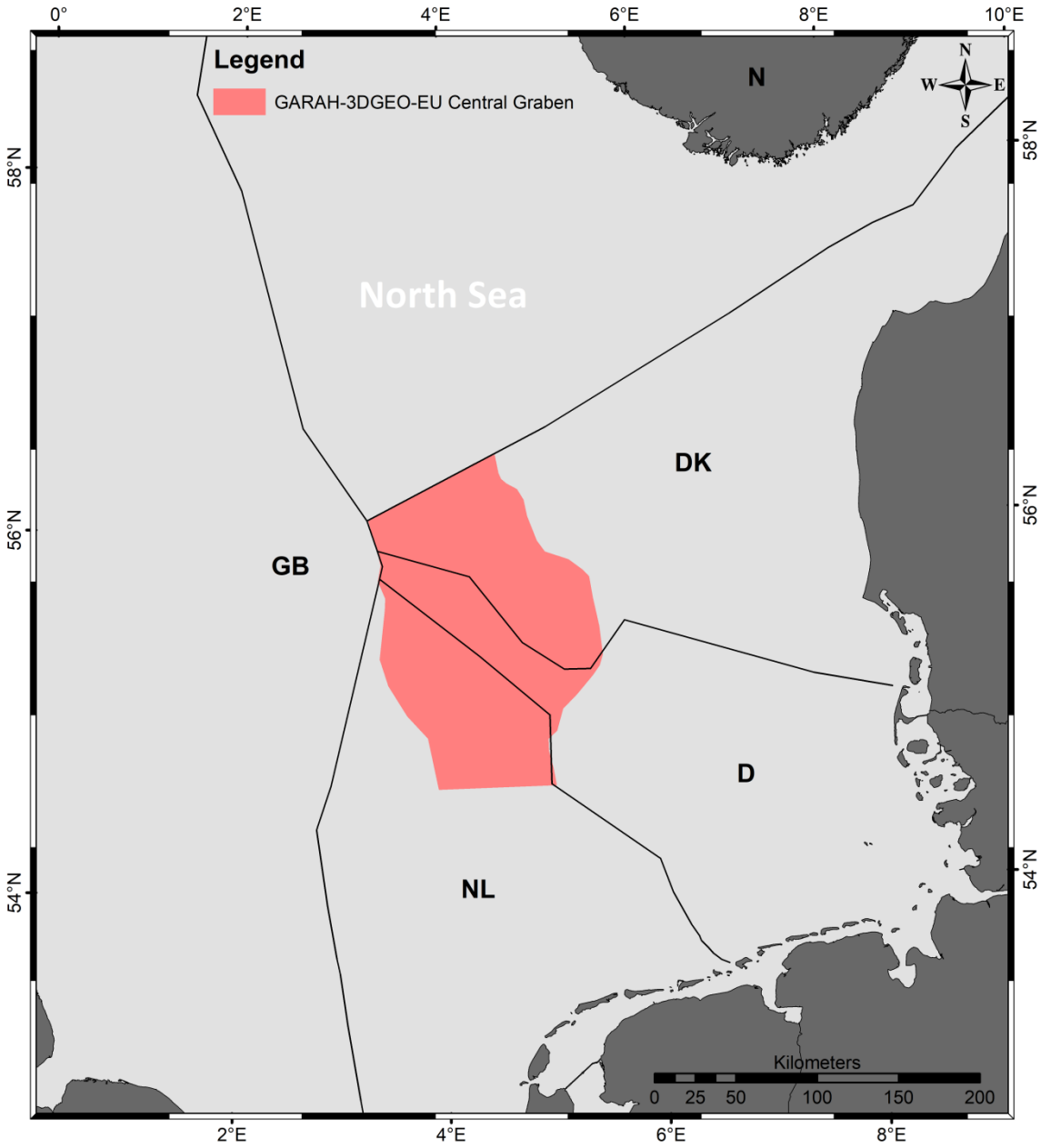

Figure 4.1: Location map of the central North Sea with outlines of the maritime borders. The 3D pilot study area is shown in red. It comprises the “Entenschnabel” in the German sector and adjacent Dutch and Danish offshore areas.

4.3 Stratigraphic Framework

Nine key horizons have been selected for building the stratigraphic framework of the 3D basin model in the central North Sea (Fig. 4.2). These are:

0. Sea floor
1. MMU – Mid Miocene Unconformity
2. Near base Tertiary
3. Base Upper Cretaceous
4. Near base Lower Cretaceous
5. Posidonia Shale / Toarcian
6. Near Base Lower Jurassic
7. Near base Middle Triassic
8. Top Zechstein
9. Base Zechstein

For building the key horizon grids a workflow has been agreed upon by the project partners. Each horizon and its corresponding grid or point data in time domain, whichever is available, is merged to a time grid covering the pilot study area. These are cross-checked and corrected for obvious geological inconsistencies (e.g. such as cross-cutting layers). These time grids are then depth converted using the TNO procedure and algorithms for depth conversion. Resolution of the grids is 250 mx250 m and coordinates are given in UTM 31 N (WGS 84). The project partners have been contacted to provide information, for which horizons data are available for the GARAH project. The corresponding listing is given in appendix 5.

One of the 3DGEO-EU project objectives is to reduce discrepancies and enhance the quality of cross-border geological features and interpretations in the central North Sea. Highest quality horizon grids are thus expected to be delivered at the end of the project. The 3D pilot study will therefore start by incorporating merged horizon grids, where significant cross-border issues might still exist. This is the first task to identify the cross-border issues and develop workflows to eliminate them. In principle, the 3D model can later be updated as higher quality horizon grids are prepared by the 3DGEO-EU project. A comprehensive report on the status quo on cross-border issues is given in the QC report of the 3DGEO-EU project.

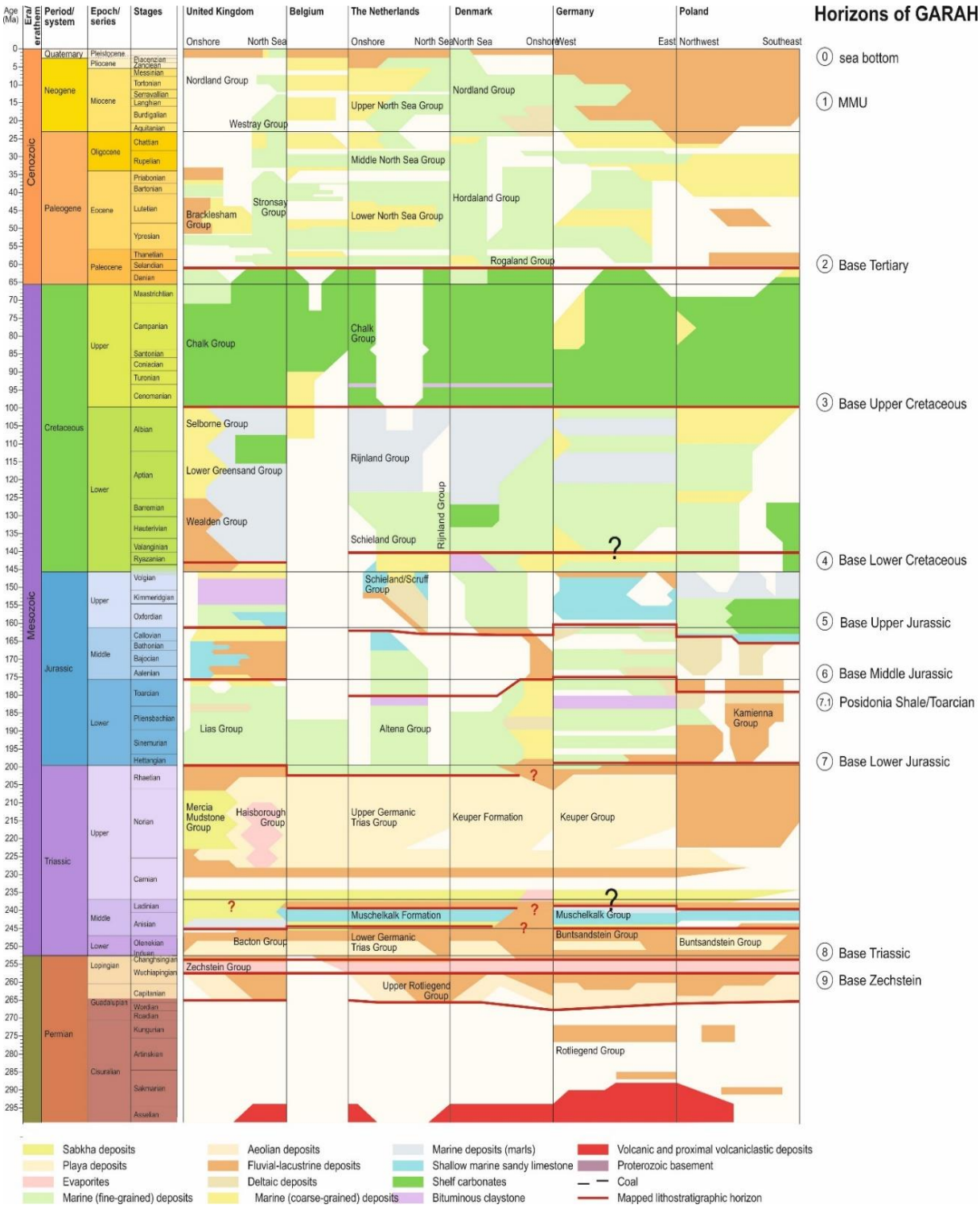

Figure 4.2: Stratigraphic framework after Doornenbal and Stevenson (2010) and key horizons annotated to the right, which are used for construction of the 3D basin model.

4.4 Building the 3D basin model

For petroleum systems modelling the software PetroMod 2018 (Schlumberger) is used. A set of attributes and parameters have been defined, which are necessary for building the model:

1. Present-day input
    - Absolute ages of horizons
    - Lithology
    - Facies maps
    - Fault surfaces (only selected main faults in the study area)
2. Paleo Geometry
    - Erosion events
    - Erosion maps - Paleo thicknesses of eroded formations
    - Salt maps, initial salt thicknesses, and salt activity during the geological periods
3. Boundary conditions
    - Sediment Water Interface Temperature (SWIT)
    - Heat flow data
    - Palaeo water depths
4. Calibration data
    - Vitrinite reflectance data
    - Tmax
    - Temperature
5. Source rocks and their properties
    - Upper Jurassic (Clay deep, Kimmeridge, Lola FM)
    - Lower Jurassic (Posidonia Shale)
6. Reservoir rocks

The project partners have been contacted to provide information, for which parameters data are available for the GARAH project. The corresponding spreadsheet is given in appendix 6 (GARAH_PSM_24.09.2018).

5 OUTLOOK - NEXT STEPS

A number of actions were identified after the initial return of questionnaires and spreadsheets including:

- Further detailed work required on collating information on play types in conventional resources and harmonizing resource assessments.
- Further work required for harmonization of units, although this is not an onerous task.
- Integration of resource assessments and data into a GIS project

- Identification of data gaps, both geographical and methodological

6 LITERATURE

Doornenbal, J.C. & Stevenson, A.G. (Eds) (2010): Petroleum Geological Atlas of the Southern Permian Basin Area. EAGE Publications b.v., Houten, 342 pp.

7 APPENDICES

Appendix 1: Conventional Questionnaire

Appendix 2: Unconventional Questionnaire

Appendix 3: Conventional Spreadsheet

Appendix 4: Unconventional Spreadsheet

Appendix 5: Petroleum System Model - Horizons Spreadsheet

Appendix 6: Petroleum System Model - Parameters Spreadsheet