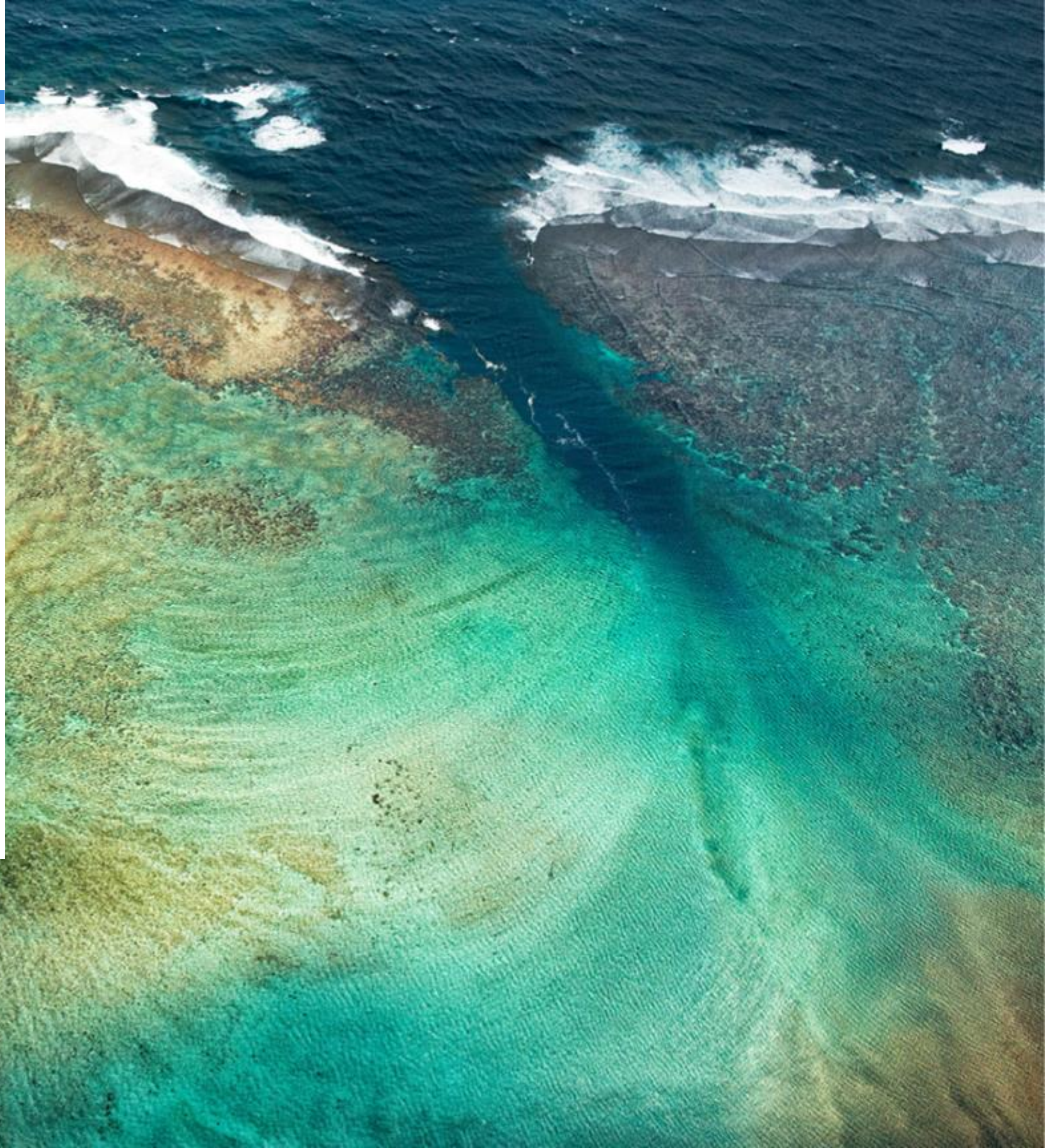
Maximising the use of publicly available data: porosity and permeability mapping of the Rotliegend Leman Sandstone, Southern North Sea

Claire Imrie & Henk Kombrink

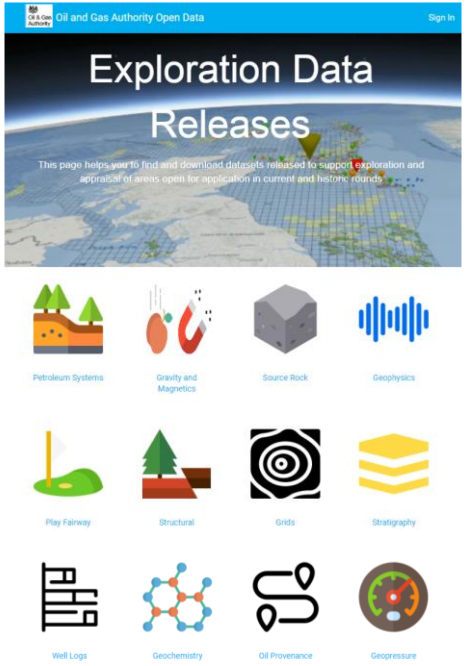
09 May 2018

Lloyd's Register



Overview

- The Oil and Gas Authority has recently made a number of UKCS data sets freely available for public use
- These data sets include:
  - the UKCS Regional Mapping project by LR
  - the routine core analysis database compiled by CGG
  - joined digital well logs for a large number of wells
- To assess the value of integrating data from this large database, a case study was undertaken using the data to map reservoir quality across the Rotliegend, Southern North Sea
  - although the basin is relatively mature for hydrocarbons, such maps may be useful for alternative uses such as CO_2 storage and geothermal energy



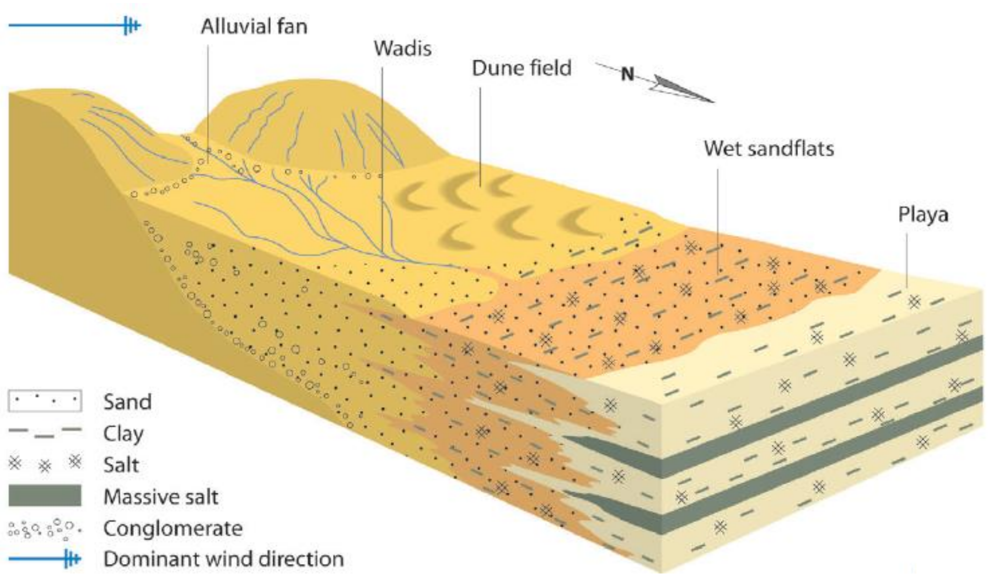
https://www.ogauthority.co.uk/data-centre/

Outline

- Geological overview of Rotliegend, Southern North Sea
- Brief description of available data
  - overview of database
  - summary of work required in data preparation and QC
- Methods used to map average porosity and permeability across the Rotliegend
- Comparison of estimated versus reported porosity and permeability at a number of locations
- Concluding remarks

Geological overview of the Rotliegend

- Towards the end of the Carboniferous the Southern Permian Basin was located just north of the equator and was entirely land-locked
  - Rotliegend sediments were deposited in a desert environment
    - terminal playa and saline lakes developed in the central, deepest parts of the basin
    - to the south of these, aeolian dune deposits were derived from fluvial sands sourced from the Variscan Mountains and transported by NE trade winds

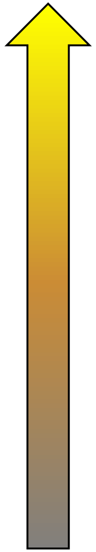


Depositional model of the Rotliegend (Doornenbal and Stevenson, 2010)

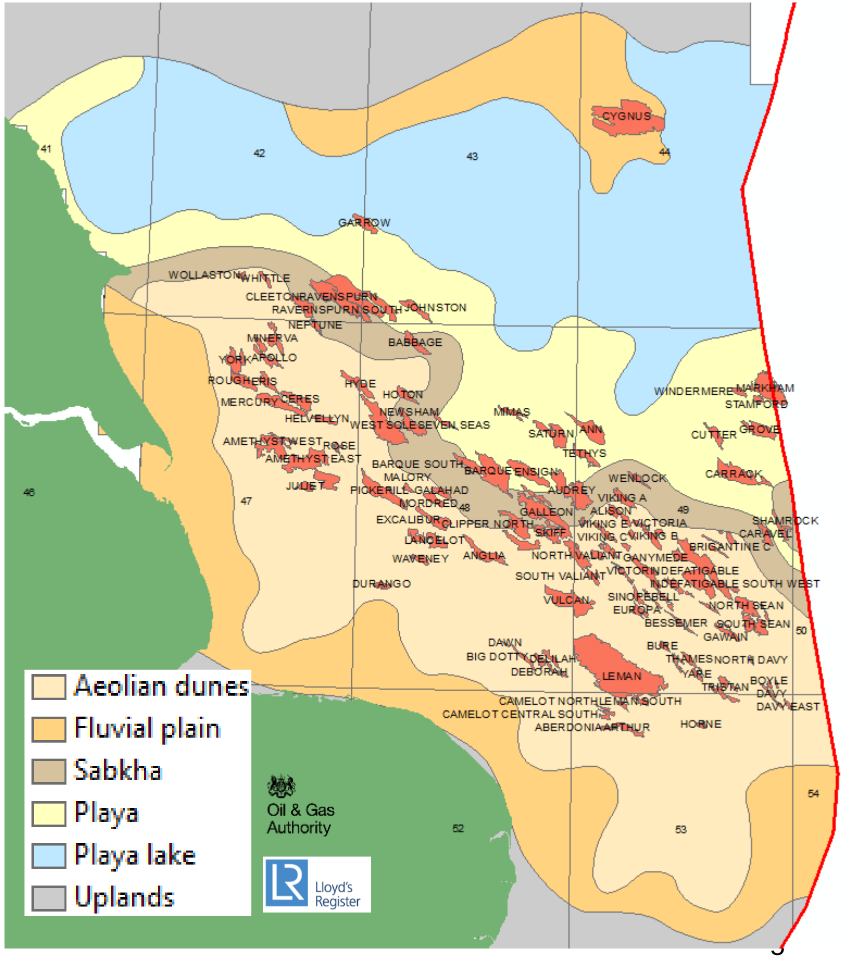
Controls on reservoir quality - facies

- Reservoir quality is influenced by depositional facies:
  - **aeolian dunes**: fine to coarse grained sandstones which are well to moderately sorted
  - **fluvial plain**: heterogenous fine-grained sandstones and siltstones
  - **sabkha**: poorly sorted, interbedded fine to medium grained sands, silts and clays
  - **playa**: sandstone and siltstone with clay layers
  - **playa lake**: silty mudstones with halite and anhydrite horizons

good quality



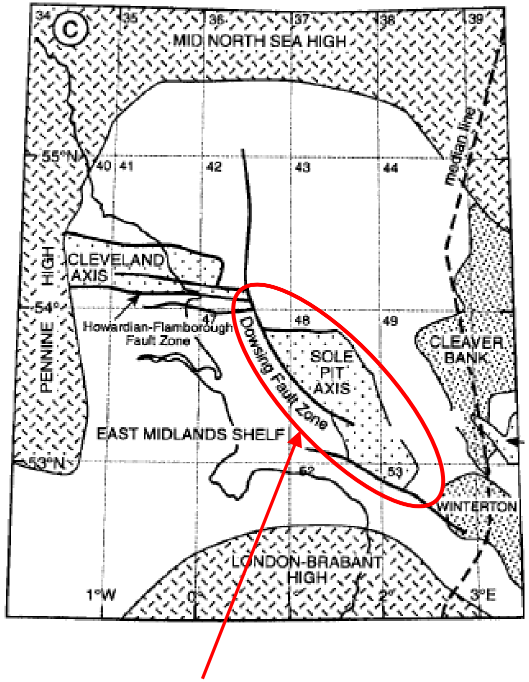
poor quality



Diagenesis and reservoir quality

- Early exploration of the Rotliegend revealed that some fields had much poorer reservoir quality than others
  - this variability in reservoir quality had little to do with depositional facies or compaction related to present burial depth
- The area has been subject to a number of tectonic events
  - early subsidence led to burial depths in excess of 13,000 ft
  - subsequent inversion has led to shallower present day burial depths
  - the maximum burial depth controlled compaction and influenced the formation of permeability-reducing fibrous illite
    - illite formation also related to mineralogical composition and hydrocarbon fill
- The amount of inversion has been estimated using sonic data from various overlying horizons (e.g. Hillis, 1995)
  - this has been exploited in the current study of Rotliegend quality

major tectonic events in the UK Southern North Sea (from Hillis, 1995)

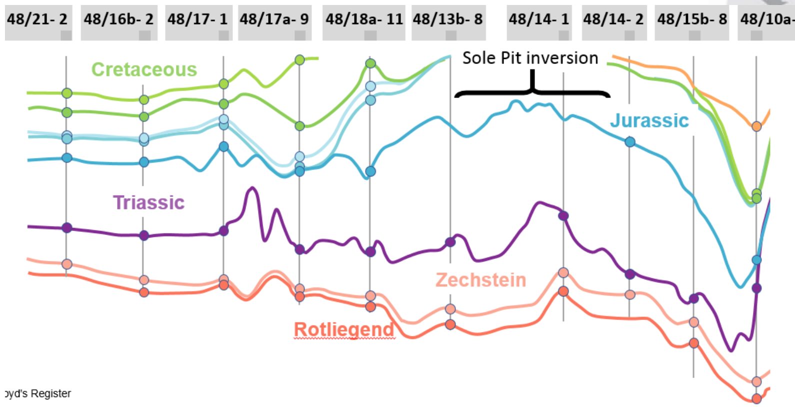


Sole pit area was once buried at great depths but is relatively shallow today

LR's regional mapping project for OGA

- 3 year project (2016-2019) funded by the Oil and Gas Authority
- Publication of maps on a rolling basis
  - Central North Sea and Moray Firth maps released (July 2017)
  - Southern North Sea maps released (Nov 2017)
  - Northern North Sea and East Shetland Platform (soon to be released)
  - Remaining areas to follow

- Depth and thickness grids
- Subcrop and supercrop maps
- Structural elements maps
- Depositional facies and reservoir maps
- Well penetration maps
- Hydrocarbon occurrences
- Stratigraphic diagrams
- Petroleum Systems Charts

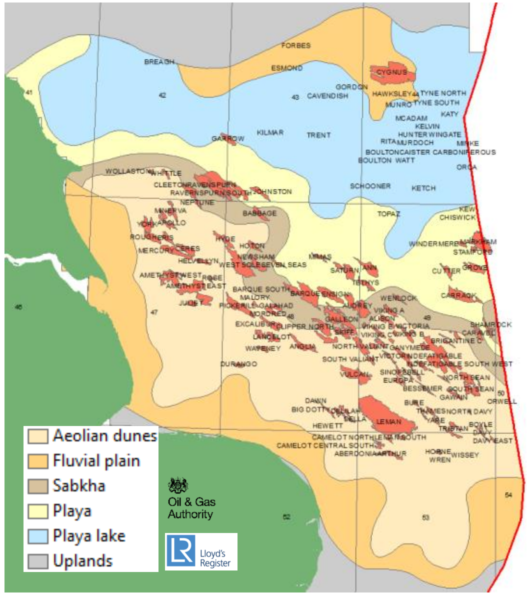


improvement on previously existing depth maps by tying surfaces to well tops

LR/OGA data used for Rotliegend quality mapping

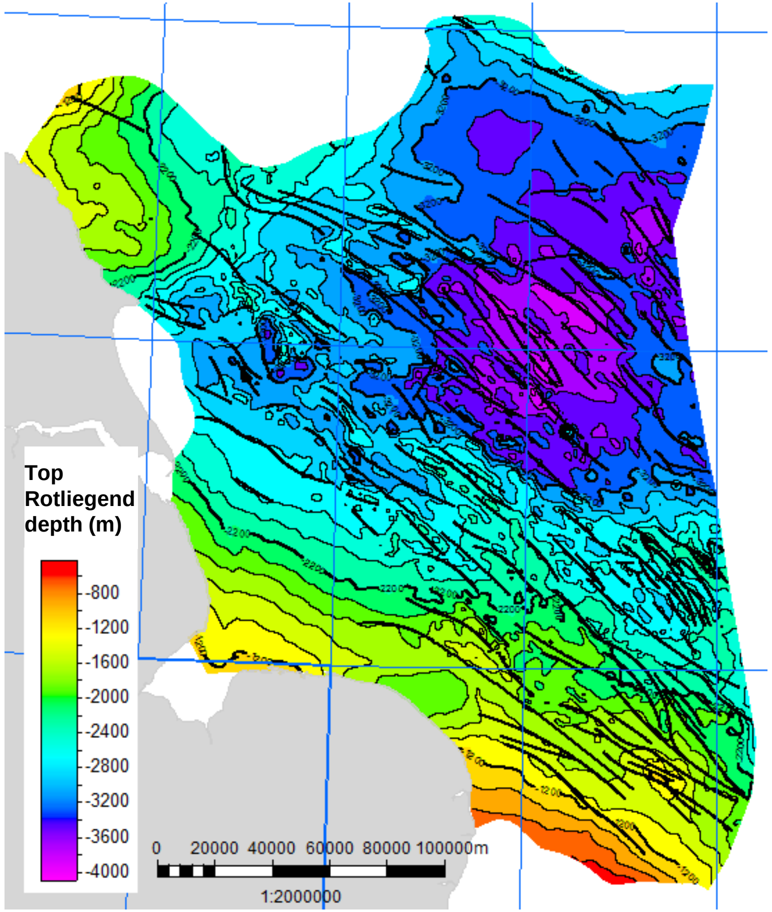
DEVEX2018

- Top Rotliegend and Top Carboniferous depth surfaces for the Southern North Sea
  - based on Southern Permian Basin Atlas (SPBA) depth maps and tied to well tops
- Rotliegend faults (SPBA)
- Rotliegend depositional facies maps
  - primarily based on SPBA data but with some interpretation
    - this simplified map shows the average facies expected at each location



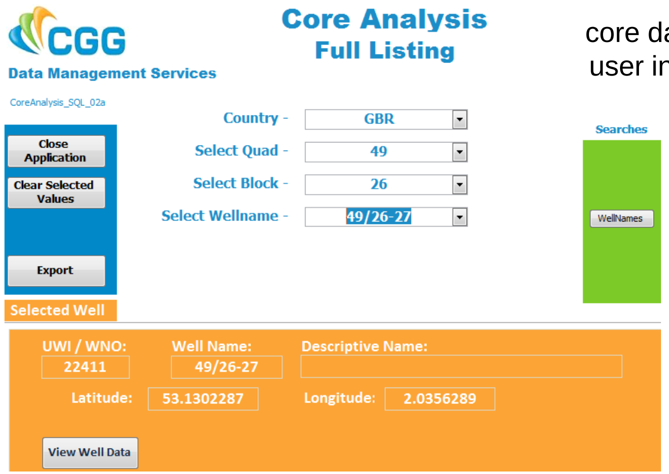
Rotliegend depositional facies map

Top Rotliegend depth map

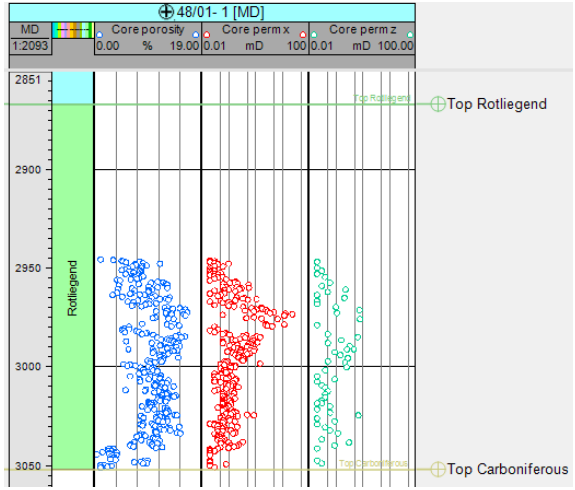


CGG core analysis database

- The CGG core database contains conventional core analysis data for around 2,600 UKCS wells within a MS Access database
  - including: porosity, permeability (horizontal and vertical), grain density and water saturation
  - source documents are also provided
- The data require formatting and QC
  - to ensure data consistency, e.g.:
    - using helium porosity measurements only
    - using only air permeability measurements made at ambient pressure (or not greater than 400 psi)
  - applying core shifts



core database user interface

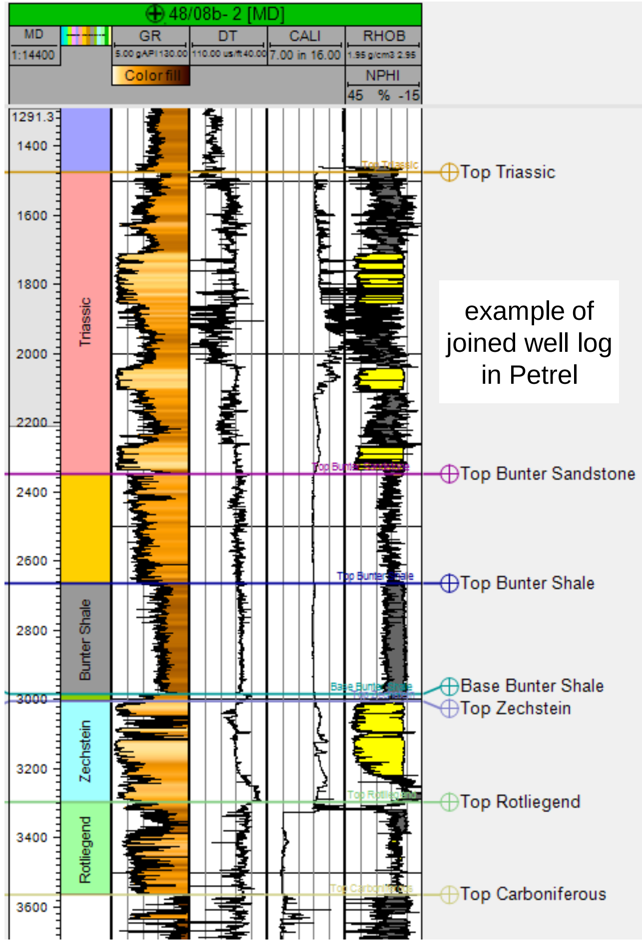


example of core data in Petrel

Joined digital well logs

DEVEX2018

- The joined well logs database contains well logs for around 900 UKCS wells
  - data for 292 SNS wells compiled by CGG
  - available well logs (e.g. gamma ray, DT, caliper, density, etc) vary for each well
  - deviation surveys are also provided
- The SNS well log data were imported into Petrel
  - 265 wells with sonic data (DT_p) were given formation tops for the Bunter Sandstone and Bunter Shale so that average DTs could be calculated
    - average DT was calculated for the Chalk (101 wells), Bunter Sandstone (193) and Bunter Shale (196)
    - **Bunter Shale DT** was found to correlate best with Rotliegend core porosity and permeability

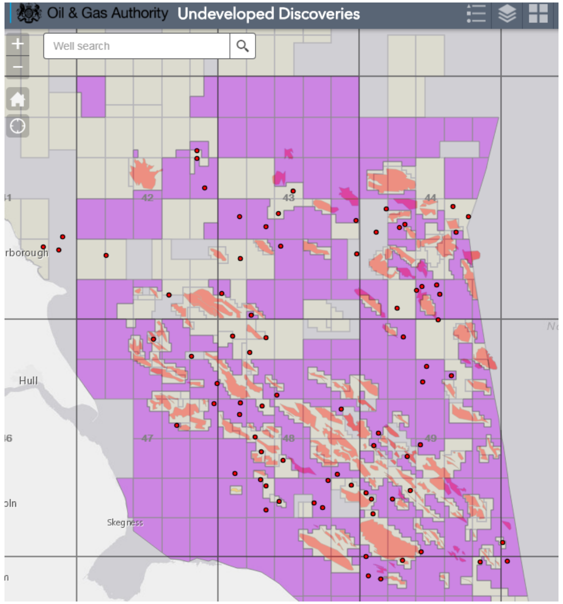


example of joined well log in Petrel

Additional public domain data used

- OGA well top database
  - mainly provided by the BGS for the Southern North Sea
  - used for adding Bunter Sand and Bunter Shale tops
- Data from literature
  - additional sonic log data for 145 wells were obtained from Hillis (1995)
    - average DT for Cretaceous Chalk, and/or Bunter Sandstone and/or Bunter Shale
- OGA undeveloped discoveries and relinquishment reports
  - data packs were used to identify wells with reported average porosity and permeability data for the Rotliegend
    - this data was used to compare with the porosity and permeability maps to test their ability to predict reservoir quality

OGA undeveloped discoveries in the SNS

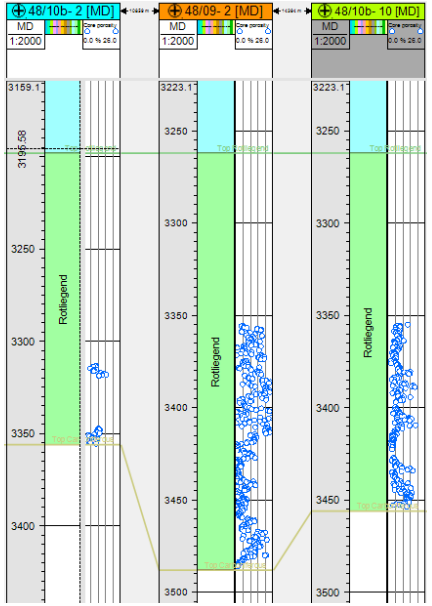


Possible sources of error associated with the data

DEVEX2018

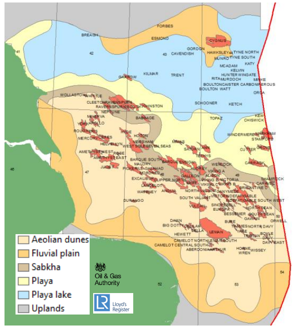
- Core porosity and permeability data sources of error include:
    - whether the samples are representative of the whole Rotliegend interval at each location
    - different measurement methods and quality control procedures have been used to obtain porosity and permeability data
    - different detection limits (e.g. permeability <1 mD in older wells)
    - transcription errors
- Rotliegend facies map sources of error include:
    - maps are based on the interpreted predominant facies at each location
    - facies boundaries are interpolated from well data that may be sparse in some areas
    - in reality the predominant facies will grade into other predominant facies
    - therefore the sharp boundaries are not realistic and may be wrongly located
- Sonic log sources of error include:
    - measurement uncertainty and accuracy of well top picks

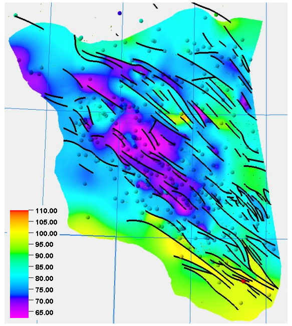
example of three core porosity logs indicating differences in the number of samples

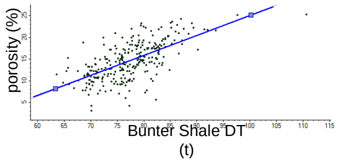


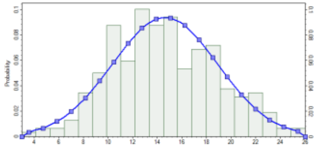
Porosity and permeability mapping procedure

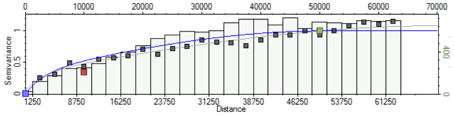
1. Data compilation in Petrel
2. Preparation of 3D grid for Rotliegend (1 layer)
3. Mapping of Bunter Shale DT across SNS
4. Data analysis of average core porosity and permeability per regional depositional facies
   - core data upscaled arithmetically to grid
   - data ranges and distributions assessed
   - variograms modelled
5. Mapping of porosity and permeability
   - porosity co-kriged with Bunter Shale DT
   - permeability co-kriged with porosity

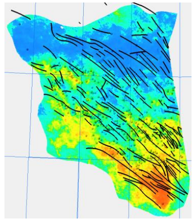


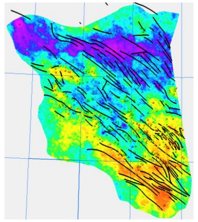








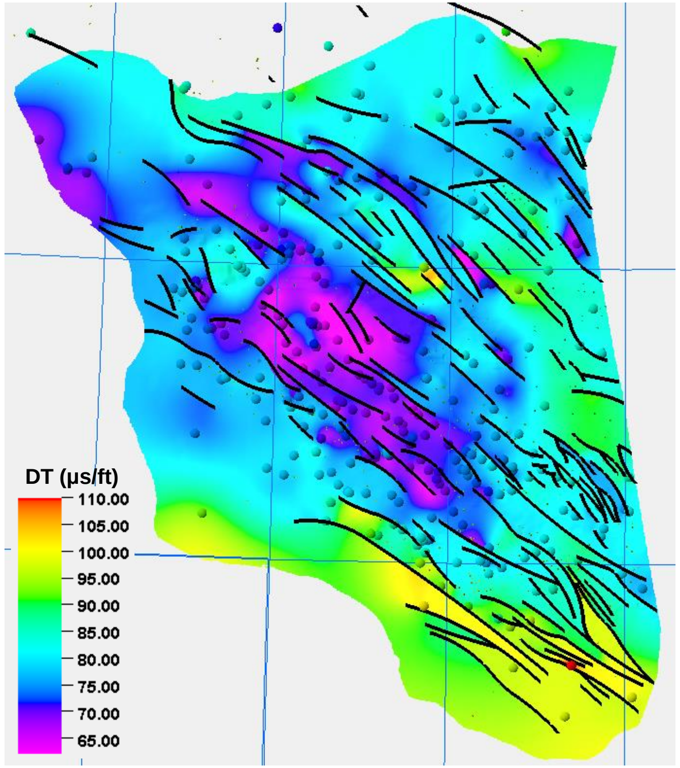




Bunter Shale sonic log data map

DEVEX2018

- Bunter Shale DT is related to maximum burial depth and hence the irreversible compaction of the Rotliegend sediments
  - DT_p reflects the slowness of p-waves through the rock
  - lower DT suggests higher compaction and therefore poorer reservoir quality
- The Bunter Shale DT was mapped across the Southern North Sea using data from both joined well logs and the Hillis (1995) publication
  - 295 data points in total
  - mapped to have alignment with faults
    - first pass effort to represent structural control
    - could be improved!



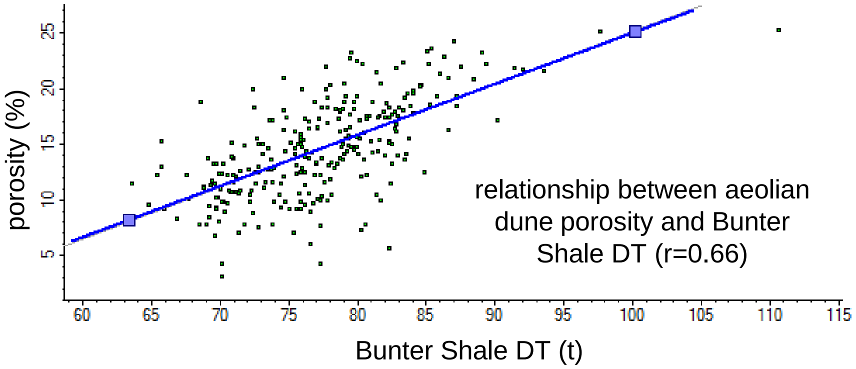
map of Bunter Shale DT across SNS using data from 295 wells

Analysis of core porosity and permeability data

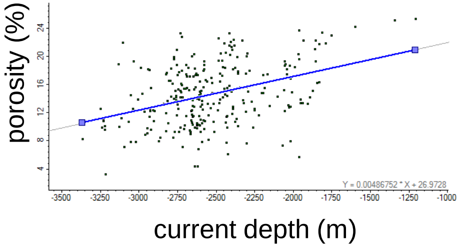
DEVEX 2018

- In total there are:
  - 421 average porosity (ø) points
  - 391 average horizontal permeability (k_h) points
- Data ranges per facies reflect the variation in reservoir quality from poor quality playa lake sediments to the aeolian dune facies
- The relationships with Bunter Shale DT are stronger than with depth

Depositional facies	No. samples (ø / k_h)	Mean ø (%)	ø range (%)	Mean k_h (mD)	k_h range (mD)
Aeolian dunes	278 / 262	14.6	3 – 25	146	0.06 – 1383
Playa	69 / 64	8.8	3 – 14	17	0.01 – 364
Fluvial	4 / 3	9.7	9 – 11	8	4 – 10
Sabkha	62 / 56	12.4	4 – 22	54	0.1 – 812
Playa lake	8 / 6	2.0	1 – 4	0.3	0.03 – 1



relationship between aeolian dune porosity and Bunter Shale DT (r=0.66)

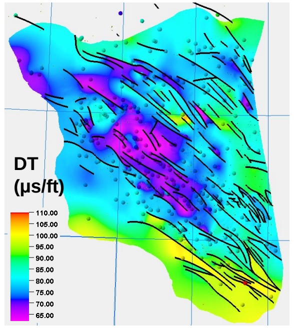


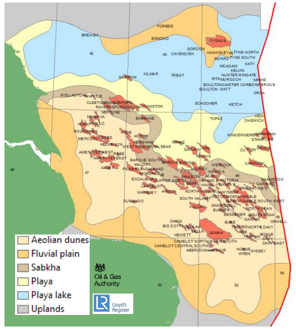
relationship between aeolian dune porosity and present day depth (r=0.39)

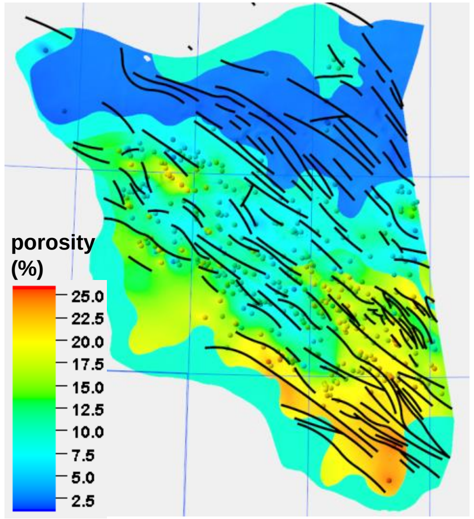
Rotliegend porosity maps

DEVEX2018

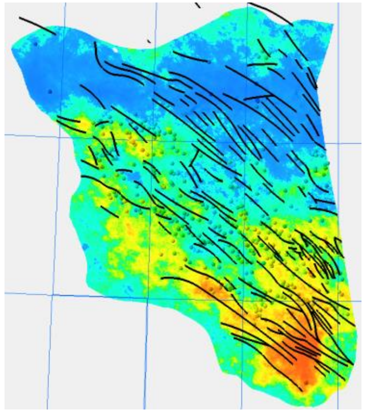
- Porosity was mapped by kriging by facies, correlated to the Bunter Shale DT map
- Kriging is a geostatistical algorithm that allows estimation uncertainty to be calculated
  - uncertainty can also be characterised using a stochastic modelling algorithm, co-kriged with the interpolated maps
  - this gives a more natural-looking distribution and blurs the facies boundaries

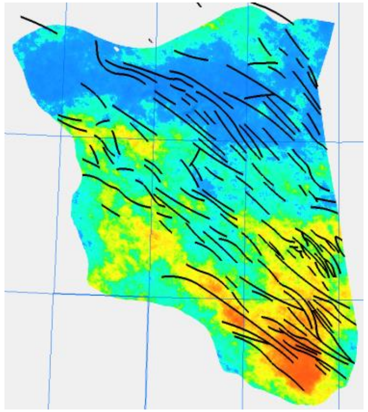


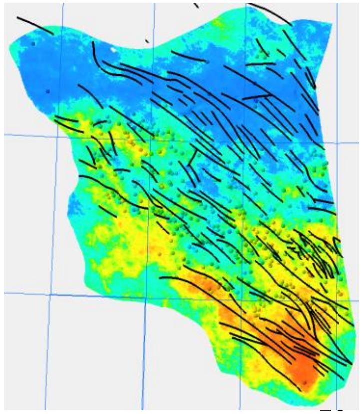




kriged map (right) and 3 examples of stochastic simulations (below)

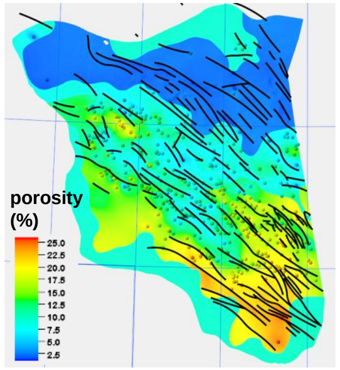


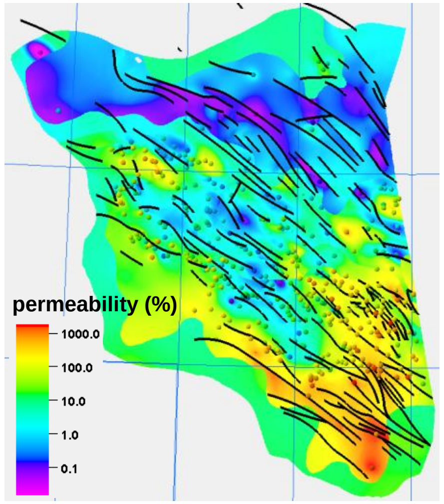




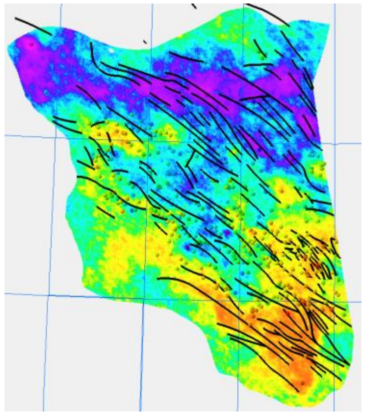
Rotliegend permeability maps

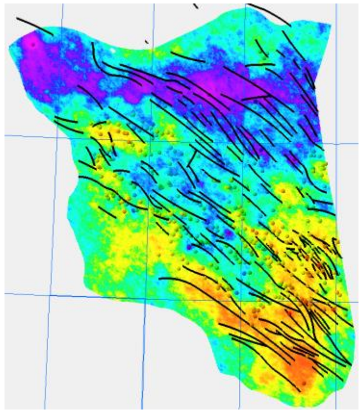
- Permeability was mapped by kriging by facies, correlated to the kriged porosity map
- As for porosity, stochastic simulation based on the kriged map gives more natural-looking permeability distributions

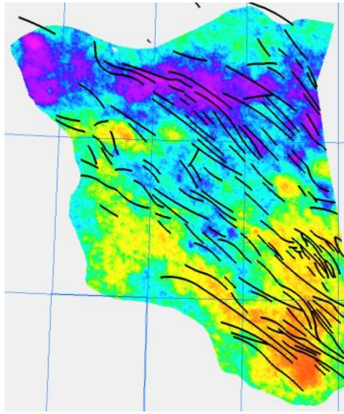




kriged map of porosity (above left) and permeability (above right) and 3 examples of stochastic permeability simulations below





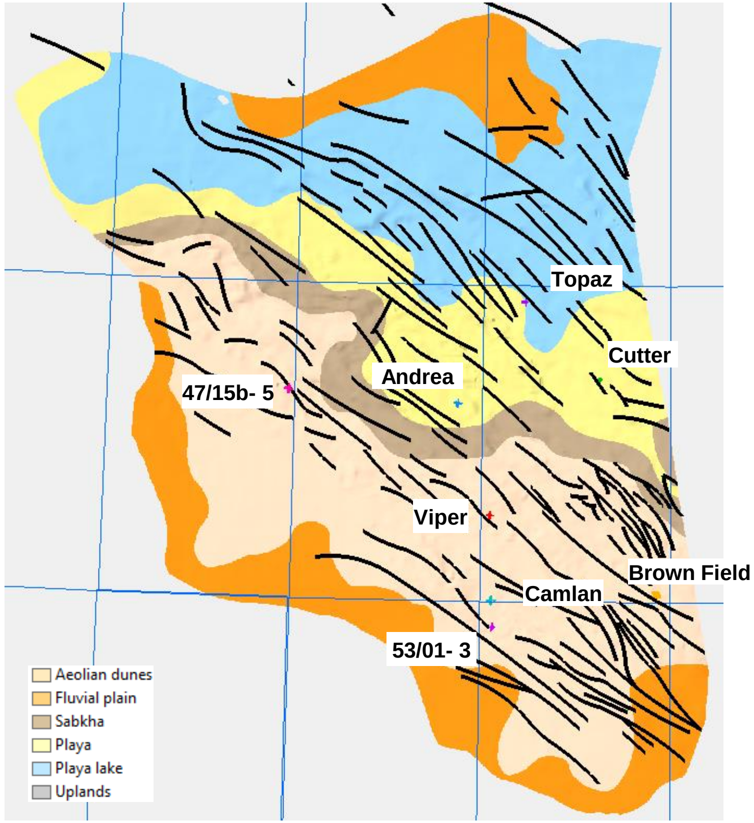


Comparison of maps with reported data

DEVEX2018

- A validation exercise was performed to test the prediction power of the maps
  - test location data were not used in the mapping process

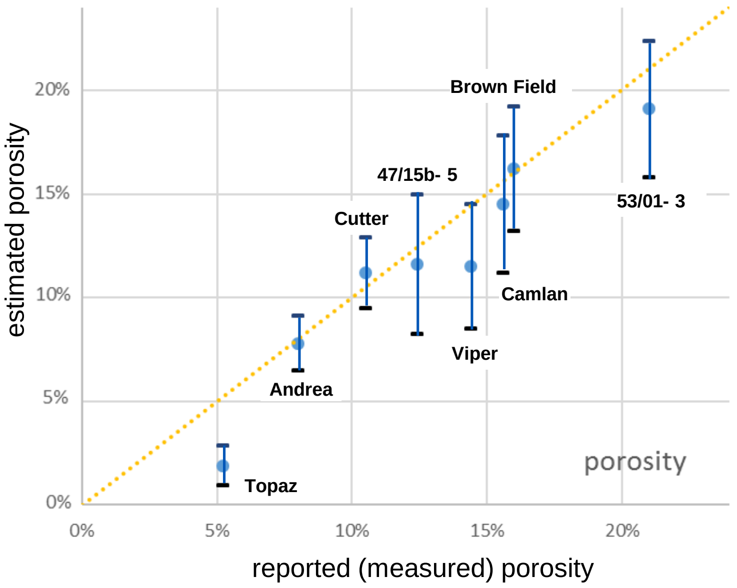
Well/location	Mean ø (%)	Mean k_h (mD)	Depositional facies region	Data source*
47/15b- 5 discovery	12.4	18.8	Aeolian dunes	1
Brown Field	16.0	30.0	Aeolian dunes	2
49/21- 9Z (Viper)	14.4	4.8	Aeolian dunes	1
49/02a- 6 (Topaz)	5.2	0.05	Playa lake	1
48/15b- 10 (Andrea)	8.0	~1.0	Playa	1
49/09a- 7 (Cutter)	10.5	30.0	Playa	1
49/26- 29 (Camlan)	15.6	~23.0	Aeolian dunes	1
53/01- 3 discovery	21.0	n/a	Aeolian dunes	1

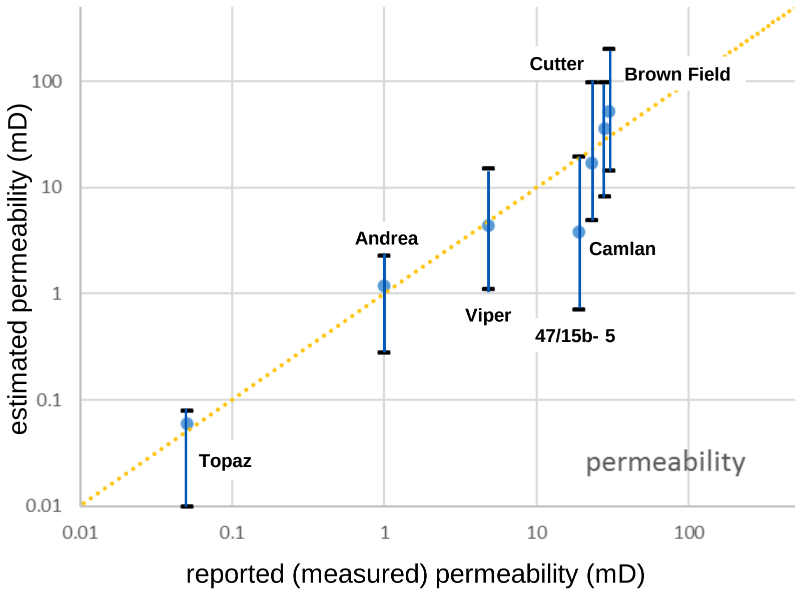


*1: OGA Undeveloped discoveries data packs
2: UK Oil and Gas Fields Geol Soc Memoir 20 (2003)

Good match between reported and mapped data

- The plots show mapped versus reported porosity and permeability
  - the error bars represent the 80% confidence interval (P90 and P10)





  - in general, there is a good match between reported and mapped porosity and permeability
  - the porosity is underestimated at the Topaz well, although the permeability prediction is very good
  - with the exception of Topaz porosity, all reported values are within the confidence bounds

Concluding remarks

- A great deal of subsurface data is now available in the public domain for the UKCS
  - this study, which focused on the Rotliegend in the Southern North Sea, demonstrated how the data can be integrated to provide regional maps of reservoir quality
    - although the Rotliegend is relatively mature for hydrocarbons, such maps may be useful for alternative uses such as CO_2 storage and geothermal energy
    - some undeveloped areas of the Rotliegend may still be of interest
    - similar maps of other North Sea plays may also be useful for exploration
  - the data require significant QC and formatting prior to use

Thank you

Thanks to LR colleagues in Reservoir Services and Rock Properties:

Matt Jacobs

Maria Romero

Moira Belka

Iza Zubizarreta

Maria Velazco-Roa

Michelle Ferris

Please contact:

Claire Imrie

claire.imrie@lr.org

Henk Kombrink

henk.kombrink@lr.org