LogQM Methodology

The following text is part of Vis et al. (2010) and describes the methodology applied in LogQM, a tool developed by TNO.

2.2 Well data processing

2.2.1 Lithofacies

In the absence of core descriptions for the wells, sand-shale intervals were interpreted using gamma gay (GR) logs. For 3D facies modelling, 77 unique wells containing GR were used. When composite well logs were absent, GR logs were manually selected and joined into single GR logs. Cluster analysis was used to analyse the added value of neutron, density and sonic logs to create a better separation of sand-shale intervals compared with GR logs alone (Appendix 2). Cluster analysis is an exploratory data analysis tool which aims at sorting objects into groups in a way that the degree of association between two objects is maximal if they belong to the same group and minimal otherwise. The analysis of wells from the study area indicated that the use of logs other than GR logs does not lead to a better separation of sand-shale intervals. Accordingly, the sand-shale intervals have been distinguished using GR logs only.

The measured (absolute) GR value ranges differ between wells, mainly because the used tools are specifically calibrated to each well. Consequently, the GR values corresponding with sand and shale differ between the wells. Therefore, a ratio of the minimum and maximum GR values has been used, to identify the extremes of GR for each lithology. The ratio was defined based on a comparison of GR and lithology as recorded in composite well logs. After clipping of the logs to the studied stratigraphic interval and removal of peaks (GR > 150), relatively low GR values were labelled as sand and high GR values as shale. The sand-shale division based on the GR logs (Fig. 3), resulted in three lithofacies: sand, clay and a waste class (sandy clay/clayey sand).

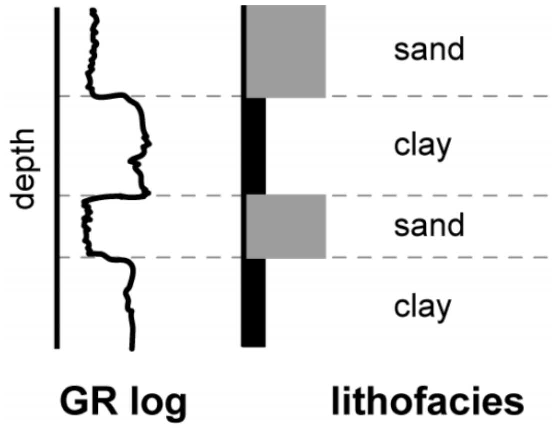

Figure 3. The creation of lithofacies using gamma ray logs and stratigraphic markers. In case a gamma ray log was absent, lithofacies were defined based on stratigraphy.

2.2.2 *Porosity logs*

Porosity logs for deposits within the Rijnland Group were calculated for 94 wells using bulk density (RHOB) and neutron (NPHI) logs, and core plug measurements (Fig. 4):

A. When only bulk density logs were available, porosity logs were calculated using grain density data from core plugs and fluid density (Fig. 4A). Fluid density was set at the average value between fresh and salt water (1.1 g/cm^3), without correction for hydrocarbons in the fluid;
B. Otherwise, neutron logs were used, with a correction (0.045) for the fact that neutron logs represent porosity based on carbonate rock (Fig. 4B)
C. If bulk density and neutron logs were available, both aforementioned methods were used and averaged (Fig. 4C).

When available, core plug measurements were used to correct the calculated porosity log towards the measured core plug porosity values.

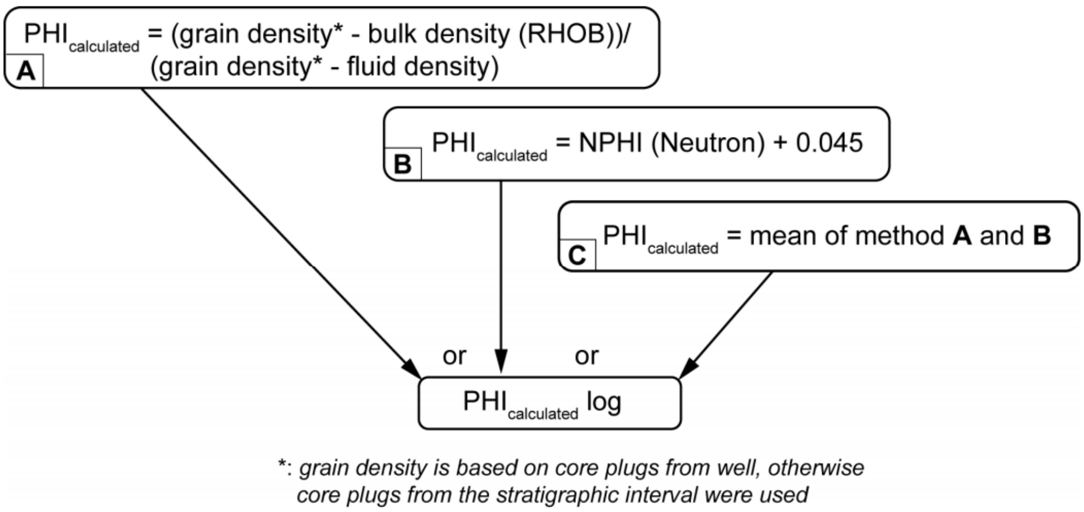

Figure 4. Calculation of porosity logs following method A, B or C, depending on data availability. The calculated porosity log was corrected to core plug porosity measurements when available.

Data type	Available	Source	Application
Well locations (oil and gas, including sidetracks)	538	DINO BRH	General overview, not all wells were used
Well deviations	496	DINO BRH	Building 3D model, not all wells were used
Well logs (GR, RHOB, NPHI)	GR=77, RHOB=50, NPHI=39	DINO BRH	Calculating properties for 3D model
Composite well logs	43		
Stratigraphic markers	510	DINO BRH	General overview, not all wells were used
Core plugs (PHI, K)	Poro-perm relationship=76	DINO BRH,	Calculating properties for 3D model
Base CK+N, KN and S surfaces	n/a	(Duin et al. 2006)	Creating stratigraphic horizons
3D faults	n/a	(Duin et al. 2006)	Constructing fault model and 3D pillar grid
3D seismic surveys:	n/a	DINO NLOG	Reconstructing palaeo topography and sedimentary basin fill configuration
Biesbosch_L3NAM1986A			
DenHaag_L3NAM1991A			
Dordrecht_Noord_L3NAM1988H			
Dordrecht_Zuid_L3NAM1988J			
Gouda_Noordoost_L3NAM1989B			
Gouda_Zuidwest_L3NAM1989A			
Haastrecht_L3NAM1988G			
Leiden_Pijnacker_Gouda_L3NAM1989K			
Leiden_Pijnacker_L3NAM1989J			
Monster_L3NAM1990C			
Mookhoek_L3NAM1991B			
Pijnacker_dl1_L3NAM1985P			
Pijnacker_L3NAM1985R			
Waalhaven_L3NAM1985A			

Table 1. Data used for modelling. See Appendix 1 for well names. DINO BRH = TNO DINO borehole table.

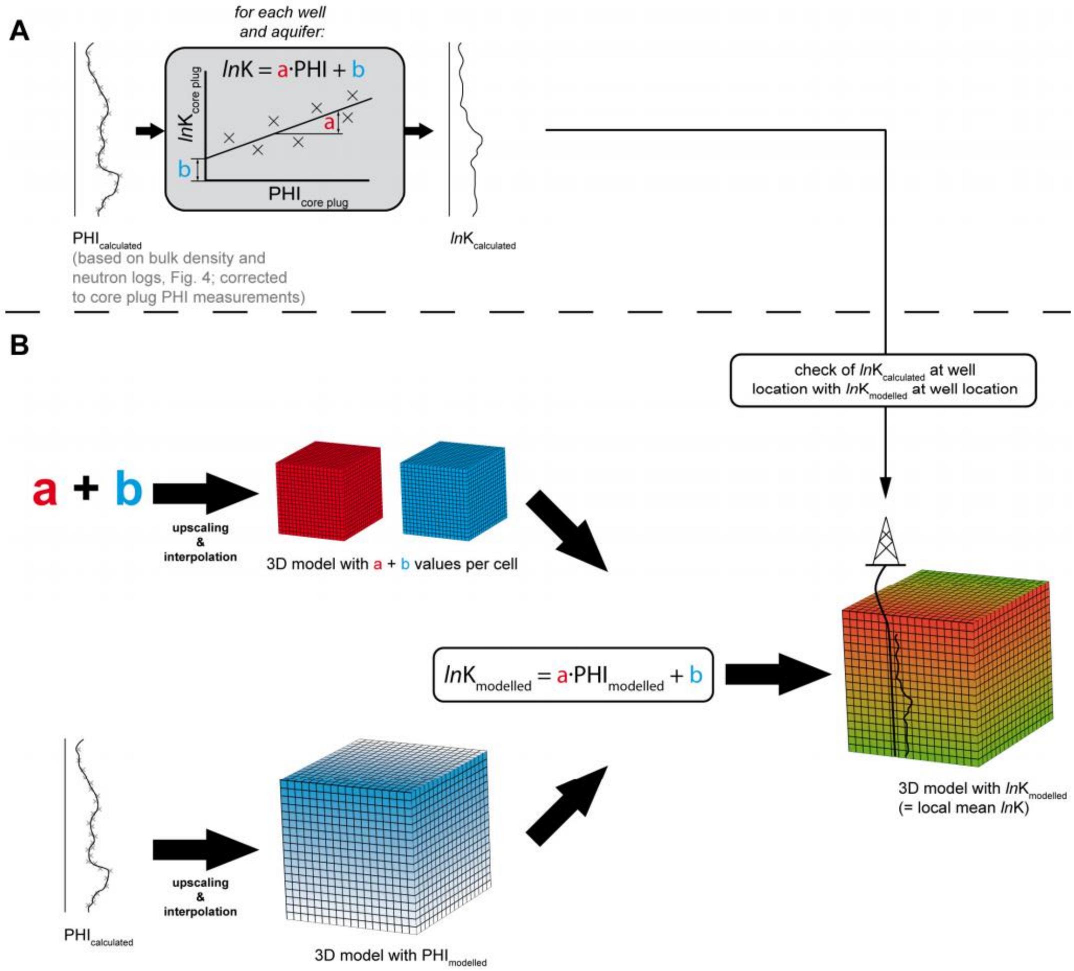

Figure 5. Permeability calculations: (A) calculated porosity ($PHI_{calculated}$) logs which are corrected to core plug measurements, are used to calculate permeability logs ($lnK_{modelled}$). The linear core plug *ln*K-PHI relationship was used to convert porosity to permeability for each well with core plug measurements; (B) the parameters of the linear core plug *ln*K-PHI relationship is used to calculate the 3D *ln*K model. Inputs for this formula are values from 3D models of a, b and $PHI_{calculated}$ values.

2.2.3 *Permeability logs*

Permeability logs were calculated using the linear relationship between porosity (PHI) and the natural logarithm of permeability (*ln*K). This relationship was calculated for each well containing core plug measurements (Fig. 5A). The slope (**a**) and intercept (**b**) of this relationship were used to calculate permeability logs from porosity logs, but only when core plug measurements were available for the well, otherwise no linear relationship could be constructed. The calculated permeability log ($lnK_{calculated}$) was used later in the modelling workflow to adjust permeability values in the 3D model at well locations (Fig. 5B & 15).

Reference

Vis, G.J., Van Gessel, S.F., Mijnlieff, H.M., Pluymaekers, M.P.D., Hettelaar, J.M.M., Segers, D.P.M., 2010. Lower Cretaceous Rijnland Group aquifers in the West Netherlands Basin: suitability for geothermal energy. TNO report: TNO-034-UT-2009-02410.