Thermal Properties of Paleozoic Rocks from the Rhenish Massif

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Motivation

Large areas of Germany and neighbouring countries are formed by paleozoic rock formations. Beside large outcrops such as the mountain chains of the Rhenish Massif, paleozoic rocks also dominate the subsurface as forming the Northern Germany basement. Still, reliable data sets on thermal properties are rare. To improve this situation, paleozoic rocks samples from outcrops and drillings of North-Rhine Westfalia were investigated.

We studied about 230 core samples and obtained information on thermal conductivity, density, porosity and Vp-velocity of the rocks in dry and saturated conditions. In addition, about 50 core plugs were taken for measurements of heat capacity, and P-T-dependent thermal conductivity and thermal diffusivity. Chemical and mineralogical analyses were performed at almost 100 samples. Thus, a unique data set was created, which enables to connect thermal properties to rock porosity and to mineralogical and chemical rock composition.

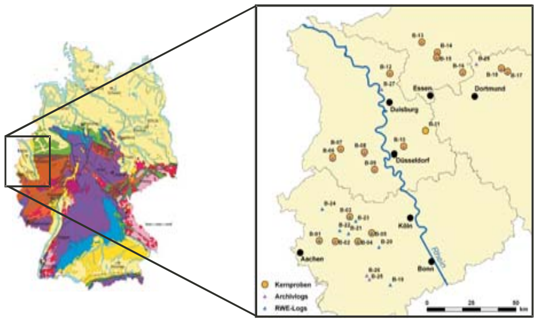

Fig. 1: Drilling locations

				Südl. Niederrhein					Nördl. Niederrhein						Ruhrgebiet							
Serie	**Stufe**	**Unter-stufe**	**Formation**	B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10	B-11	B-12	B-13	B-14	B-15	B-16	B-17	B-18	Gesamt
				<West				Ost>	<West					Ost>	<West						Ost>	
Ober-karbon	Stefan	Stefan C																				
		Stefan B																				0
		Stefan A																				
	Westfal	Westfal D																				
		Westfal C	Lambeck-Fm.													7						
			Obere Dorsten-Fm.		3											20						
			Untere Dorsten-Fm.														7					
		Westfal B	Horst-Fm.		1	3																85
			Essen-Fm.		1												1	3			8	
		Westfal A	Obere Bochum-Fm.		9															21	1	
			Untere Bochum-Fm.																			
			Obere Witten-Fm.																			
			Untere Witten-Fm.																			
	Namur	Namur C	Sprockhövel-Fm.																11			
		Namur B							28													39
		Namur A																				
Unter-karbon	Visé			3					11					2								16
	Tournai																					
Ober-devon	Famenne	Dasberg									9			3								
		Hemberg																				34
		Nehden								7												
	Frasne	Adorf								6		9										
Mittel-devon	Givet							3		20		1	15									44
	Eifel						5															

Tab. 1: 231 samples taken from 18 wells, covering different stratigraphic units of Devonian and Carboniferous age

Laboratory Measurements

Data analysis reveal the mineralogical composition as the most prominent factor for effective thermal conductivity. This is especially the case for the Carboniferous and Devonian sandstones with quarz contents varying from 35 % to 95 % (Fig. 2).

Rock porosity in paleozoic rocks is almost low and it's impact on thermal properties not as significant as the rock mineralogy (Fig. 3). Thus, the geometric mixing law is applicable only for rocks with similar mineralogical composition. (Fig. 4).

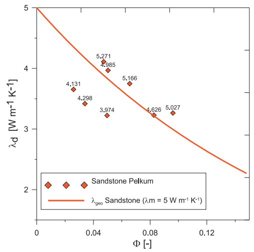

Fig. 4: Cross-plot of thermal conductivity (dry conditions) versus porosity. Thermal conductiviy of the matrix is given as label to each sample.

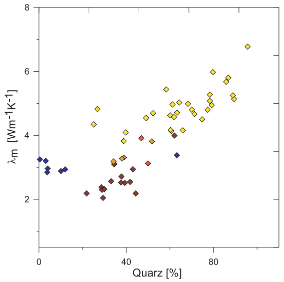

Fig. 2: Quarz content dominates the thermal conductivity in paleozoic claystones, siltstones and sandstones.

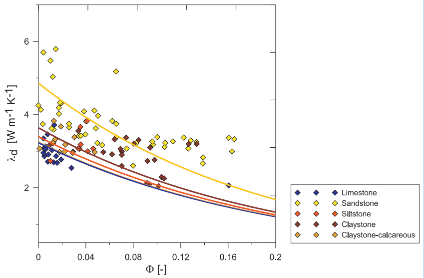

Fig. 3: Cross-plot of thermal conductivity (dry samples) versus rock porosity exibits large scattering, in particular for the paleozoic sandstones

PT - Dependency

Mineralogy strongly affects the temperature and pressure dependence of thermal properties. The strong mineralogical variation of the sandstones leads to non-uniform P-T trends of thermal properties (Fig. 6/7) Only, claystones and limestones show more consistent dependency trends. This allows the definition of rock type specific P-T-correction values.

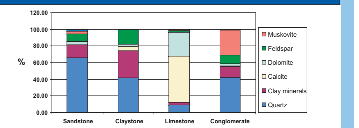

Fig. 5: Average mineralogical composition of rocks measured under increased PT-conditions.

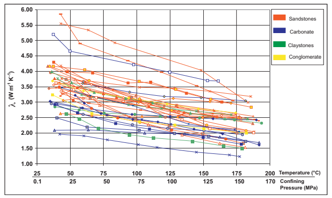

Fig. 7: P-T dependency of thermal conductivity, shown for the different rock types.

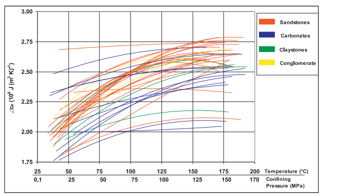

Fig. 7: P-T dependency of volumetric heat capacity, shown for the different rock types.

TC- prediction from log data

In a following step, the results from the discrete taken core samples were combined with continuous borehole geophysical data. Log interpretation revealed a well defined correlation between core/cuttings descriptions and the log derived lithology (Fig. 8).

Based on the laboratory data, petrophysical models were built up. This allows to derive continuous profiles of volumes of shale, sandstone, coal (Fig. 10) and carbonates for the different wells. Rock porosity was derived by standard procedures from sonic or from density logs. Fig. 8 shows the porosity prediction for a carboniferous section. The comparison with the core data exhibits up to 12% porosity for the paleozoic rock suites.

By this information, the geometric mixing law could be applied to calculate continuous profiles of thermal conductivity (Fig. 10). These profiles give information on the vertical and lateral heterogeneity of thermal properties and were used to derive statistically proven value ranges for entire stratigraphic units. These values can serve as input parameter for geothermal models and can help to reduce the uncertainty of numerical simulations.

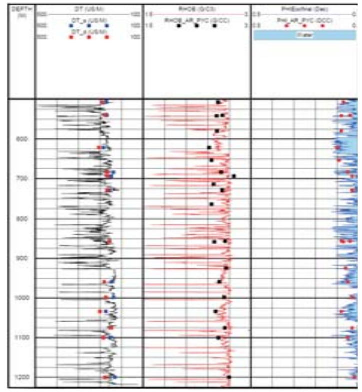

Fig. 9 : Porosity calculated from density log compared with core data (red dots). Sections with coal layers (density < 2 g/cm³) are excluded from calculation.

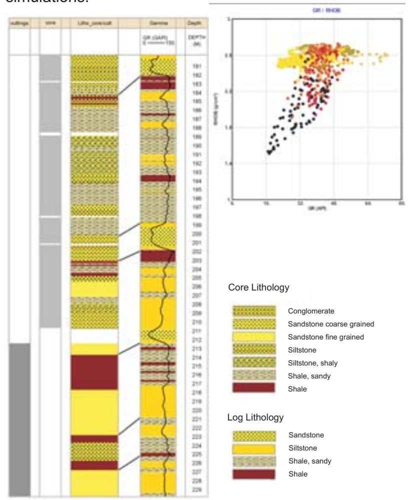

Fig. 8: Log lithology compared to the core/cuttings profile.

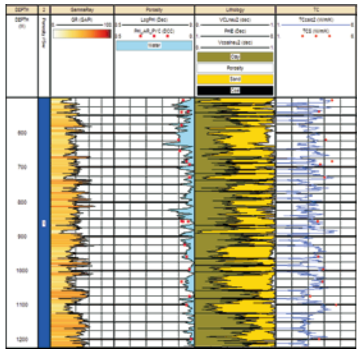

Fig. 10: TC-profiles calculated by the geometric mixing law with: λ_m Sandstone 4.86 W/m/K, λ_m Shale 2.4 W/m/K, λ_m Coal 0.7 W/m/K.

Summary

- Database of statistically proved petrothermal values for paleozoic rocks
- Pressure and temperature dependency of thermal properties
- Relation of thermal properties to rock type, facies and mineralogical composition
- Petrothermal characterization of stratigraphic units - information on vertical and lateral heterogeneity
- Properties of stratigraphic units improve input parameter of numerical geothermal models

Acknowledgement

The research project was funded by the German Federal Ministry of Environment (BMU). Core and log data were provided by RWE Power AG, RAG Deutsche Steinkohle AG and the Geological Survey of NRW