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Origin of gases from the geothermal reservoir Groß Schönebeck (North German Basin)

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ABSTRACT

The operation of a geothermal facility is largely affected by the content and composition of gases dissolved in the formation fluids. Typically, the geothermal gas mixtures consists of different types of gases of different origin. In this study, the origin of various gas components from the Rotliegend – Permocarboniferous geothermal reservoir Groß Schönebeck (North German Basin) was investigated. Three formation fluid samples were collected from the depth of the production well Gt GrSk 04/05 (between 4120 and 4240 m) at conditions of the Rotliegend/Permocarboniferus reservoir (about 140–150 °C and 430–450 bar). Identified and further investigated gases are N_2, CH_4, CO_2, H_2, higher gaseous alkanes, and noble gases. The stable isotope ratio of individual gas components range from 0.2 to 1.5‰ ($\delta^{15}N_{Air}$) for N_2, from −16.5 to −21.2‰ for CH_4, from −18 to −26‰ for C_2H_6, from −24 to −30‰ for C_3H_8, and from −13.1 to −20.2‰ for CO_2 ($\delta^{13}C_{V\text{-}PDB}$ for all hydrocarbons and carbon dioxide). Isotopic ratios measured for the noble gases He, Ne, and Ar indicated that $^{20}Ne/^{22}Ne$ and $^{38}Ar/^{36}Ar$ are indistinguishable from air, while all other isotope ratios show excess of radiogenic or nucleogenic isotopes.

Results of $\delta^{15}N_{Air}$ suggest that the source of N_2 are the highly matured Westphalian coals (Upper Carboniferous)l. Isotopic ratios of CH_4 and CO_2 confirmed thermogenic decomposition of terrestrial plants from a similar source as the most likely precursor for these gases. The inverse carbon isotope trend might be linked to heavy metal catalysed cracking of long-chain hydrocarbons and/or evolution of precipitates during fluid evaporation in the basin.

The observed $^{3}He/^{4}He$ ratios of $\leq 0.0642 \pm 0.0026$ Ra demonstrate a crustal origin of He. The $N_2/^{40}Ar$ ratio (1648 ± 480) indicates a crustal origin and practically without any influence of the air. $^{21}Ne/^{22}Ne$ is distinguished from the air and more enriched in nucleogenic ^{21}Ne, relative to ^{22}Ne, when compared to the average crustal Ne composition. The calculated residence time of fluids by means of in situ produced nuclides varies for ^{40}Ar from 72 to 80 Ma and for ^{4}He from 365 to 401 Ma. The apparent age discrepancy gives a hint for He migration from older stratigraphic layers or stratas enriched in parent nuclides (U, Th).

1. Introduction

Low enthalpy hydrothermal systems often contain a high proportion of dissolved gases with methane (CH_4), nitrogen (N_2), carbon dioxide (CO_2), and hydrogen sulfide (H_2S) as the most abundant ones. The gas content is often several times higher than the volume of formation water at standard conditions and can have a major impact on the operation of a geothermal facility. Depending on the fluid composition, a high gas content may lead to degassing already at reservoir conditions. This results in the formation of bubbles that might block the reservoir rock pores and thus reduce the permeability of the formation (Kummerow, 2014). Therefore, a high gas content can have a negative effect on the fluid production as well as on the operation of the production pump and the heat extraction in the heat exchanger (Kummerow, 2014; Francke, 2014; Thorade, 2014).

Continuous production of hot, gas-rich geothermal fluids, followed by injection of cold, degassed fluids lead to changes in the thermal and chemical state of the reservoir system. A geothermal reservoir is normally open to fluid migration from source rocks. Knowledge about the origin of formation gas does not only contribute to a better understanding on the evolution, diagenetic processes and migration of the geothermal fluid but also on potential risks by a possible fluid flux from

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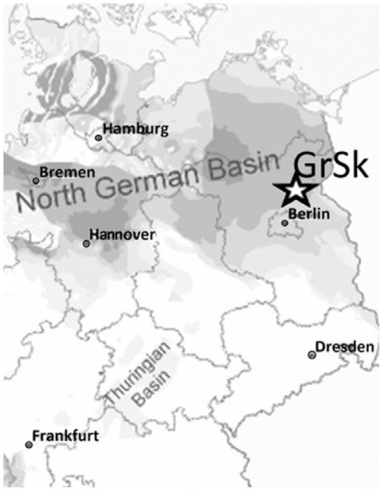

System	Group	Subgroup	Formation	Depth in TVD / MD (m) GrSk	Stimulated section (MD) GrSk	Lithology/ local description; porosity & permeability[1]
Permian	Zechstein (Upper Permian)	Zechstein Formation		2372-3863 / 2376-3891		interbedded strata of evaporates (limestone, anhydrite, halite), mudstone
		"Kupferschiefer" (lowest Zechstein Formation)		3863 / 3891		mudstone (0.4 m thickness)
	Upper Rotliegend (Lower Permian)	Elbe	Hannover	3863-4036 / 3891-4076		AS of silt, clay, and fine grained sandstone (Hannover Grauliegend)
			Dethlingen	4036-4164 / 4076-4249	4118-4122	AS of clay, silt and fine grained sandstone (Elbe AS); 3-18 % & 0.05-100 mD[2] 8-10 % & up to 16 mD[3]
		Havel	Mirow	4164-4210 / 4249-4318	4204-4209	[2] AS of poorly cemented silt, fine and medium grained sandstone, conglomerate; 3 - 8% & 0.001 - 0.1 mD
			Parchim			
Permian/ Carboniferous	Stephanian	volcanic rocks		4210-4264 / 4318-4400	4354-4389	volcanic rock; around 5% & < 0.01 mD

Fig. 1. Left: Map of Germany indicating the North German Basin (grey area in the North) as well as the location of GrSk (white star). Right: stratigraphic units and lithology description of reservoir rocks and hanging formations from the GtGrSk4/05 well in Groß Schönebeck (modified after Regenspurg et al., 2016; data from Moeck et al., 2005); TVD: True vertical depth; MD: measured depth. The grey areas mark the formations of the geothermal reservoir. AS: alternating sequences.

[1]Permeability data obtained from the injection well E GrSk 3/90.

[2]Havel subgroup, Trautwein, 2002; Blöcher et al., 2016.

[3]within the reservoir section (Trautwein & Huenges, 2005).

[4]section can be attributed either to Elbe-Basis sandstone or Havel subgroup.

other stratigraphic layers and change of gas composition during the continuous operation of a geothermal facility.

The Middle European Permian Basin is known and exploited for its high (> 75%) methane (CH_4) content since about a century (Boigk, 1981; Slotta, 1982). Deep wells have been drilled into Rotliegend sandstone reservoirs in many areas in the Netherlands, North Germany, the North Sea, etc. (Müller et al., 1973; Gerling et al., 1988; Gerling et al., 1997; Gerling et al., 1999; Lüders et al., 2005). The GrSk well EGrSk3/90 is one of those gas exploration wells within the North German Basin (NGB; Fig. 1) as part of the Permian Basin that was abandoned after drilling because of a too low CH_4 content (around 15 vol.-%). Due to its water-bearing, however, the well was re-opened ten years later and deepened to 4100 m to allow research on geothermal energy exploitation. The GrSk site, located about 50 km north of Berlin (Fig. 1) became the geothermal research platform of the Helmholtz Centre Potsdam that enabled detailed research on technology development and process understanding for all aspects of a complete cycle from drilling to power plant operation (Hoth et al., 1997; Rockel and Hurter, 2000; Huenges et al., 2004). A second well (GtGrSk4/05) was drilled down to 4100 m true vertical depth (TVD), which equals, since drilling of tis well was deviated, 4400 m measured depth (MD). In both wells, hydraulic stimulations were performed in different sections: Two in the Rotliegend sedimentary rocks and one in the underlying Permocarboniferous volcanic rocks (Huenges and Hurter, 2002; Zimmermann et al., 2009). Thus, the reservoir yields three water-bearing stratigraphic units (Fig. 1): The volcanic rocks represent the lowermost stimulated reservoir section between 4354 and 4389 m (MD). They have been determined to be of dacitic composition and after comparison with the nearby wells considered to be the oldest of the volcanic rock sequence of the Stephanian at this location (Regenspurg et al., 2016). The overall thickness and distance to the underlying Carboniferous sedimentary rocks, however, is not known. Above the volcanic rocks, siliciclastic sediments of the upper Rotliegend represent the main reservoir sections. Their mineralogy is similar to the dacitic rocks indicating that they both consist predominantly of the older, weathered volcanic rocks (Regenspurg et al., 2016). The Rotliegend conglomerates and sandstones, stimulated between 4204 and 4208 m can be attributed to the Havel subgroup or to the Elbe-Base sandstone and the fine sand- and siltstone between 3891 and 4249 m to the Dethlingen formation (Fig. 1). The Rotliegend is isolated towards the overlaying Zechstein evaporites, by a low permeable mudstone layer ("Kupferschiefer"; Fig. 1; Müller, 1969; Tesmer et al., 2007). A set of NW and NE trending fault zones has also been described that cut through the reservoir rocks sections down from the volcanic rock layer up into the Zechstein (Blöcher et al., 2016).

The NGB is located in the central part of the Permian Basin. Paleozoic (Permo-Carboniferous) rifting of the basin began with volcanic activity and deposition of various volcanic rock sequences on top of the Carboniferous sedimentary deposits (Benek et al., 1996; Geißler et al., 2008). During the following Rotliegend era climate was arid and the center of the Basin was covered by an intercontinental sabkha (Lotz, 2004; Walter, 2003; Grim, 2012). The formation water of the GrSk geothermal Rotliegend reservoir was previously identified as predominantly autochthonous meteoric water of this continental sabkha that was strongly affected by evaporation, about 260 million years ago (Regenspurg et al., 2016).

The studies from Friberg et al. (2000) and Friberg (2001) regarding the thermal evolution of the Northeast German Basin show that due to the crustal thinning basal heat flow was most probably increased during the first phase of basin evolution (Permian to Lower Jurassic time) and decreased thereafter. Possible hydrothermal events within the Jurassic show no influence on the present-day coalification pattern, which was reached in Upper Cretaceous or Tertiary times. According to Friberg (2001), methane generation took place during Upper Rotliegend and Triassic times. Details on the present-day temperature and heat flow distribution of the northeast German basin are presented in Norden et al. (2008), showing surface heat flow values of about 77 mW/m^{2}and Moho temperatures of about 800 °C for a 75-km thick thermal lithosphere.

The object of the present study is to determine the origin of various gases of the GrSk fluid. The chemical composition and isotopic ratio of individual gas components was analysed and evaluated by comparison with data of other Rotliegend reservoirs of the North German Basin (NGB). Apart from methane (CH_4), Rotliegend reservoirs of the NGB typically are characterized by high proportions of N_2 and helium (He) (Müller et al., 1973; Gerling et al., 1997; Lüders et al., 2005, 2010).

Hydrocarbons and N_2 are primarily of organic origin derived from fossil organic matter of different maturity (Müller, 1990; Gerling et al.,