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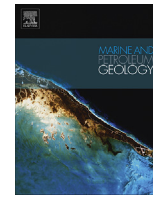


Research paper

# Generation, mixing and alteration of thermogenic and microbial gas in oil deposits: The case of the Alpine Foreland Basin (Austria)

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Molecular and stable isotope compositions were determined for forty eight gas samples taken from wells producing oil form Cretaceous and Eocene reservoirs. Gas was expelled from source rock at various maturity levels (0.6–1.2%Rr). Gas maturities based on stable carbon isotopes are in general agreement with those found in oils. Nevertheless, results revealed that most fields trap methane derived from a source which is not thermogenic. Shallow northeastern reservoirs trap methane interpreted as secondary microbial in origin. The same process is proposed here as source of methane in western deposits. Moreover, those gases are enriched in $^2$H isotope suggesting different methanogenesis pathways. Fields along the southern margin of the Alpine Foreland Basin where reservoir temperature exceeds 80 °C host methane generated during primary organic matter degradation. Thus, Eocene and Lower Oligocene layers should be considered as potential source rocks. This study gives new insight to filling history of traps and revealed a more complicated geological background and hydrocarbons generation than have been assumed until now.



## 1. Introduction

Significant progress has been achieved in the last decades in understanding the formation of natural gas accumulations as well as gas-oil and gas-source rock correlations. It has been shown that stable carbon isotopic ratios are mainly controlled by the formation mechanisms (thermogenic vs. microbial), the isotopic signature of the source rock and its thermal maturity (e.g. Berner and Faber, 1987; Chung et al., 1988; Clayton, 1991; Fuex, 1977; Galimov, 2006; James, 1983; Krooss et al., 1995; Littke et al., 1995; Rice and Claypool, 1981; Rooney et al., 1995; Schoell, 1980, 1983; Stahl, 1977; Whiticar, 1994). Hydrogen isotope compositions are controlled by hydrogen exchange between water and thermally maturing organic matter (Lewan, 1993, 1997; Schimmelmann et al., 2001, 2004; Yoneyama et al., 2002), whereas isotope exchange between already formed *n*-alkanes and water is limited (Hoering, 1984; Seewald et al., 1998; Sessions et al., 2004). An enrichment in $^2$H with increasing thermal stress is observed in natural samples (Dai, 1990; Radke et al., 2005; Schoell, 1980) as well as in theoretical and laboratory studies (e.g. Ni et al., 2011; Tang et al., 2005).

Microbial petroleum alteration has been identified as a significant factor influencing molecular and isotopic gas compositions and thus pressure-volume-temperature (PVT) properties (James and Burns, 1984; Larter and di Primo, 2005; Pallasser, 2000). Significant amounts of (secondary microbial) methane can be generated via hydrocarbons biodegradation (e.g. Head et al., 2003; Huang and Larter, 2014; Jones et al., 2008; Milkov, 2010; Zengler et al., 1999). Secondary microbial methane is characterized by varying carbon isotope ratio depending on methanogenic community and reaction pathways, isotopic signature of the substrate, progress of alteration, reservoir temperature etc. (Jones et al., 2008; Brown, 2011). Diagnostic features of secondary microbial gas include $CO_2$ enriched in $^{13}$C (Milkov, 2011 and references therein). The enrichment results from $CO_2$-$CH_4$ isotopic fractionation during methanogenesis (Botz et al., 1996; Feisthauer et al., 2010). When $CO_2$ reduction commences, isotopically light methane (−65‰ or lower) and $CO_2$ with moderately high $\delta^{13}$C values are produced (Jones et al., 2008). However, as $CO_2$ reduction progresses, carbon in methane becomes heavier.

Since the investigations of Schoell (1977, 1984), it has been recognized that both thermogenic and microbial gas exist in the Alpine Foreland Basin, which extends along the northern margin of the Alps from Vienna to Geneva (Fig. 1a and b). Based on these

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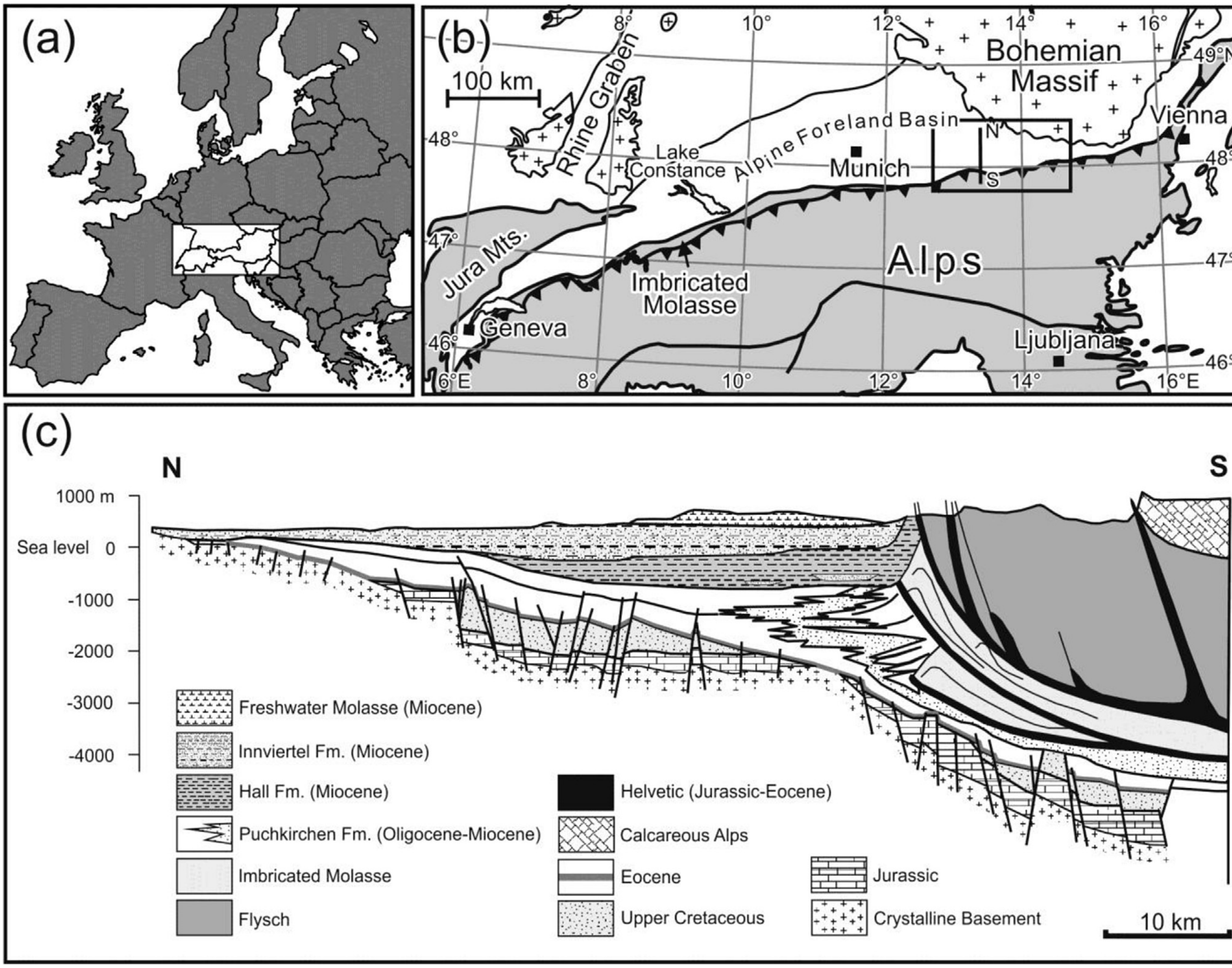


**Fig. 1.** (a) Overview map of Europe with location of area shown in Fig. 1b (b) Geological situation of the study area, Austrian part of Alpine Foreland Basin is highlighted by rectangle, N-S cross section is presented in Fig. 1c (c) Cross section through the Northern Alpine Foreland Basin (modified after Wagner, 1996).

investigations, a thermogenic petroleum system with oil and associated gas in Mesozoic and Eocene reservoir rocks and a microbial petroleum system with Oligo/Miocene reservoirs have been distinguished in the Austrian sector of the Alpine Foreland Basin (Malzer, 1993). However, gas samples representing Mesozoic and Eocene reservoirs in the Austrian sector were limited to only four fields. Moreover, methane from one of these fields (Trat) is isotopically strongly depleted in $^{13}C$ ($\delta^{13}C$: ~ −70‰) contradicting a thermogenic origin. Recently, Reischenbacher and Sachsenhofer (2011) compiled a wealth of molecular gas data from all reservoir horizons obtained by industry and limited isotope data. They found relative dry gas in some Eocene reservoirs and a wet gas component in some Oligo/Miocene reservoirs and concluded that there is no strict separation of thermogenic and microbial hydrocarbons. Within this context it is important to note that according to Schoell (1977, 1984) gas in Eocene reservoirs between 1000 and 4500 m depth in the eastern Bavarian sector of the basin (E Munich) also contains a mixture of microbial and thermogenic methane. This author argues for downward migration of microbial gas. Alternatively in-situ trapped microbial gas may have mixed subsequently with northward migrating deep thermogenic gas.

The present paper focusses on gas in Mesozoic and Eocene reservoirs in the Upper Austrian sector of the Alpine Foreland Basin (Figs. 1c and 2), which should contain thermogenic gas. Gas in Oligo/Miocene reservoirs is will be studied in a companion paper. Most Mesozoic and Eocene reservoirs host light oil with a low gas-oil ratio (GOR) (Industrial data). A gas cap is developed only in fields located in the eastern part of the study area (E of Rodl Fault; e.g. V Field; Fig. 3), whereas the easternmost fields (e.g. Wir, Har, Teu) contain a gas accumulation overlying a thin layer of heavily biodegraded oil (Gratzer et al., 2011).

The main aim of the present contribution is to determine the origin of gas in Mesozoic and Eocene reservoirs including possible mixing and alteration processes. For the interpretation, we take advantage of a fairly good understanding of source rocks in the study area (Sachsenhofer and Schulz, 2006; Sachsenhofer et al., 2010), oil families (Bechtel et al., 2013; Gratzer et al., 2011), and thermal hydrocarbon generation and uplift histories (Gusterhuber et al., 2012, 2013; 2014). Thus the Alpine Foreland Basin offers a great opportunity to study different mechanisms of gas generation and gas mixing, which may be relevant also in other foreland basins.

## 2. Geological background

The asymmetric Alpine Foreland Basin stretches along the northern margin of the Alps and dips below the Alpine nappes (Fig. 1c). In the Upper Austrian sector of the Alpine Foreland Basin