# Aspects of natural gas generation and migration in sedimentary systems

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The present state of natural gas research could be described as comprising a substantial amount of empirical wisdom with certain – more or less isolated – conceptual chemical and physical models on gas generation, migration and concurrent fractionation processes. The apparent lack of a comprehensive framework for quantitative description and prediction of natural gas generation and accumulation processes must be attributed to the complexity of this issue and the limited control on starting and boundary conditions of the pertaining processes in geological systems.

Some basic issues of gas generation and migration that have been addressed in our recent research from an experimental and theoretical point of view will be presented and discussed in the following sections.

## Origin of natural gases

Primary control on natural gas composition (both chemical and isotopic) is exerted by the sources and the generation processes. One of the main problems in gas research is that multiple sources of natural gas can occur in sedimentary systems which either, cannot be identified unambiguously, are unknown and/or extend to depths beyond control of sedimentary records and geochemical analysis (deep gases; mantle gases).

Numerical basin modelling capable of simulating physical processes under well-defined and constrained conditions can contribute to the validation of hypotheses and theories on gas sources.

This approach is exemplified by a modelling study on the evolution of nitrogen-rich natural gas reservoirs in the NW German Basin. Using experimental data on the kinetics of methane and nitrogen generation from coals the gas composition in a sequence of reservoirs was modelled taking into account the structural and thermal history of the sedimentary basin in a 2D model (Frielingsdorf 1998). The results of one of the scenarios shown in Fig. 1 document a distinct mismatch of the predicted and actually encountered $N_2$ volume percentages in the natural gases encountered. As a consequence of this finding the research work was directed towards dispersed organic matter in marine Carboniferous shale sequences as a potential additional $N_2$ source.

## Gas transport in sedimentary rocks

The movement of gases in sedimentary systems can occur either by separate phase flow or molecular

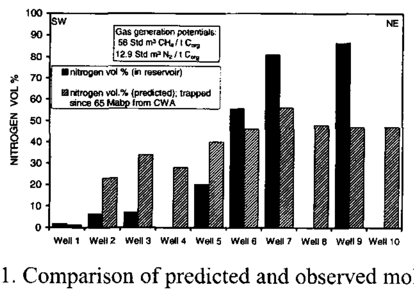


FIG. 1. Comparison of predicted and observed molecular nitrogen contents in natural gas reservoirs of NW Germany.

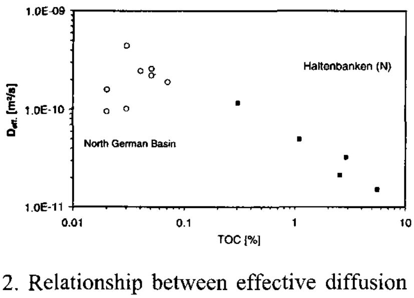


FIG. 2. Relationship between effective diffusion coefficients of methane in water-saturated shales (at 150°C) and TOC content.

diffusion. Separate phase flow is by far the more efficient of these two processes. It is impeded, however, by capillary forces which need to be overcome before the gas phase can move through the pore system of sedimentary rocks. Capillary breakthrough experiments with gases on pelitic rocks indicate a strong non-linearity in the gas breakthrough behaviour depending on the lithological and mechanical properties of the rock. The strong dependency of the permeability of pelitic rocks on effective stress introduces a feedback effect which renders the volume flow of gases essentially unpredictable on the geologic time scale.

Contrary to separate phase flow, the diffusive transport of gases in water-saturated sedimentary rocks is ubiquitous and continuous throughout time. Experimental measurements conducted on a variety of sedimentary rocks ranging from shales to sandstones have resulted in a database of diffusion coefficients of hydrocarbon gases and molecular nitrogen at different temperature and pressure conditions (Schlömer and Krooss, 1997).

The effective diffusion coefficients of methane in shales (Fig. 2) exhibit a negative correlation with the TOC content. This effect was found to affect the molecular transport more strongly and systematically than any other single petrophysical parameter.

A numerical 2D-basin modelling code has been developed to take into account molecular diffusion of gas in water-saturated sedimentary rocks during basin evolution. Computations show that the explicit inclusion of aqueous solubility of methane has severe effects on the hydrocarbon balance of the basin and the predictions of reservoir filling. Diffusive losses from reservoirs can be modelled by this application as well as specific situations, like the formation of a free gas phase by diffusion from an underlying reservoir through a cap rock. While separate phase flow is the main gas transport mechanism during phases of subsidence and intense gas generation, diffusive transport processes may predominate during periods of quiescence and uplift of sedimentary basins (Muscio *et al.*, 1997).

## Compositional and isotopic fractionation

Transport-related fractionation processes affecting both the molecular and the isotopic composition of natural gases have been invoked recurrently in the study of natural gas migration and accumulation.

Chromatographic-type fractionations can be envisaged to occur during separate phase flow of gases interacting with stationary phases (mineral matrix, organic matter, adsorbed or stagnant water). Although the general direction of compositional fractionation trends may be estimated based on adsorption parameters or partition coefficients, quantitative predictions must remain speculative because the exact (palaeo-) flow pathways and the transport regimes (pervasive or focussed) in geological settings are usually unknown. Sporadic fluid flow events along fracture systems will transport large amounts of gas without any fractionation.

Diffusion of gases in water-saturated sedimentary rocks results in compositional and isotopic fractionation effects.

Under equal conditions the diffusive mass flux of nitrogen is higher than for methane. Expressed in terms of standard volumes the diffusive transport rates for the two gases are very similar for rocks with low organic carbon contents. Higher TOC contents reduce the molecular transport rate for methane with respect to $N_2$.

Experimental measurements have also been performed to assess the isotopic fractionation effects resulting from diffusion of hydrocarbon gases in water-saturated sedimentary rocks. Diffusion coefficients for the individual isotopic species derived from these measurements can be used in basin modelling to study the extent of isotopic fractionation during gas diffusion in natural systems.

## Gas sorption and desorption

Sorption and desorption processes of methane on coals are considered as an important mechanism affecting the hydrocarbon balance of coal-bearing basins. Experimental measurements up to 18 MPa (have provided new a database for more reliable quantification of these processes under geologic conditions. As an additional aspect the influence of humidity on the gas sorption capacity of coals has been investigated.

## References

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