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Methane on the Move: quantifying natural greenhouse gas emissions over geological time in the Orange Basin, South Africa

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ABSTRACT

In the assessment of past, present and future global climate the contribution of natural greenhouse gas emissions has been largely disregarded. Our studies in the Orange Basin, South Africa indicate a highly variable rate of methane emission from the basin to the hydro- and atmosphere through geologic time. In order to understand the interactions between sedimentary basin evolution in time and space and Earth´s climate a global assessment of thermogenic methane emissions is required.

Key words: Methane, Orange Basin, greenhouse gas, climate change

INTRODUCTION

In the assessment of past, present and future global climate the contribution of natural greenhouse gas emissions has been largely disregarded. A massive amount of organic carbon is known to be stored in sedimentary basins and its conversion into hydrocarbons and leakage into the hydro- and atmosphere is obvious from petroleum and marine geological studies. When taking into account the 23-fold stronger greenhouse gas properties of methane as compared to CO_2 it becomes evident that natural thermogenic and biogenic methane emissions have an enormous capacity for driving global climate: only a tiny degree of leakage, particularly when focussed through the clathrate cycle, can result in high emissions. Paleoclimatologists find evidence for a close relationship between global warming and atmospheric methane increase during the past 65 Million years of earth’s history. In fact, methane may be the main factor driving global climate past so called tipping points leading to dramatic climate changes within 50 years. Understanding the workings of sedimentary basins in time and space is, hence, fundamental to gaining insights into Earth’s climate.

METHOD AND RESULTS

The aim of our efforts is to predict methane migration and emission from the subsurface and to identify potential climate feedback processes by integrated subsurface, ocean and atmosphere modelling involving the main experts on the thematics world wide working now together within the MOM Research Group.

Timing of hydrocarbon generation from globally occurring prolific Jurassic and Cretaceous source rocks is regarded to be the key factor in quantifying gas release. In order to reach this goal the history of all petroliferous basins of the world needs to be reconstructed. In addition a better understanding of the fate of migrating methane in the subsurface as well as upon leakage to the hydrosphere and atmosphere needs to be reached. Here themes such as hydrate formation and decay, bacterial metabolisation rates of methane in different environments as well as the subsurface biogenic formation of methane need to be assessed in a quantitative manner. Our project Methane on the Move aims at integrating expertise on all the subjects listed in order to understand the interactions between sedimentary basin evolution in time and space and Earth´s climate. Initial studies performed in the Orange Basin of South Africa, the Mackenzie Basin of northern Canada, the Congo-Angola offshore basins as well the Western Canada basin indicate periods of strongly enhanced emission rates throughout the evolution of these basins.

THE ORANGE BASIN

Gas chimneys and gas leakage features such as mud volcanoes are observed frequently along the western margin of southern Africa. In the southern Orange Basin it is thought that the observed massive gas migration is fed by an active underlying hydrocarbon system.

Here we present a 3D petroleum systems model that covers the passive margin evolution from Early Cretaceous rift initiation to the establishment of a shelf margin. The modelling is based on interpreted 2D seismic, borehole data including sedimentological and geochemical analyses as well as structural, geophysical and heat-flow data (Figure 1). The model implements proven source rocks of Aptian/Albian age, and an inferred Cenomanian-Turonian source. After calibration against known temperature constraints hydrocarbon generation and migration has been modelled to explain the initiation, duration and spatial distribution of gas accumulation and leakage within and throughout the sedimentary column.

The Albian source rock started hydrocarbon transformation 90 to 80 Ma ago in the centre of the basin and between 75 to 65 Ma ago towards the distal part of the basin. A Tertiary episode (<15 Ma) of enhanced transformation is related to the prograding depositional wedge at that time. The modelling results indicate highest generation rates at 75 Ma, a strong decrease up to 15 Ma followed by a slight increase up to present day west of the Cretaceous shelf break accounting for the location of present day generation. The location of gas generation in the outer basin compared to the gas leakage sites, however, implies subsequent migration towards the inner part of the basin.

Our modelling constrains the migration pathways, timing and duration of the gas leakage and gives a basin-scale quantification of thermogenic gas contributions into the hydrosphere and atmosphere as a function of geologic time. Figure 2 shows the calculated methane emission rate from the study area as a function of geologic time.

As obvious from Figure 2 emissions from sedimentary basins depend strongly on the tectonic history. This result is further corroborated by ongoing studies in the Western Canada basin as well as the Mackenzie Delta. Figure 3 shows the calculated emission rates for the Western Canada basin based on the modelling results published by Higley et al. (2009).

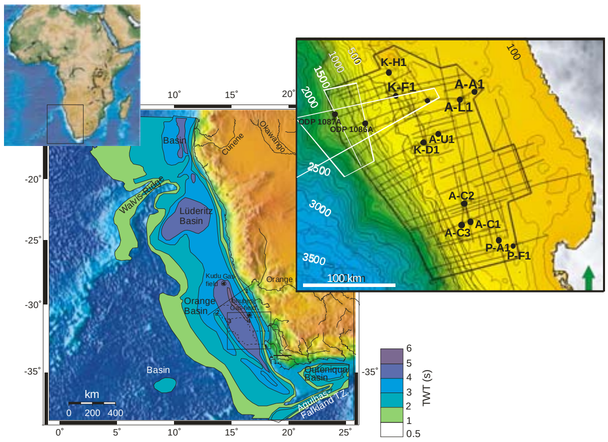

Figure 1. Basin location map with isopach distribution (after Séranne and Anka, 2005) and 2D seismic grid of the study area with superimposed bathymatery and borehole locations.

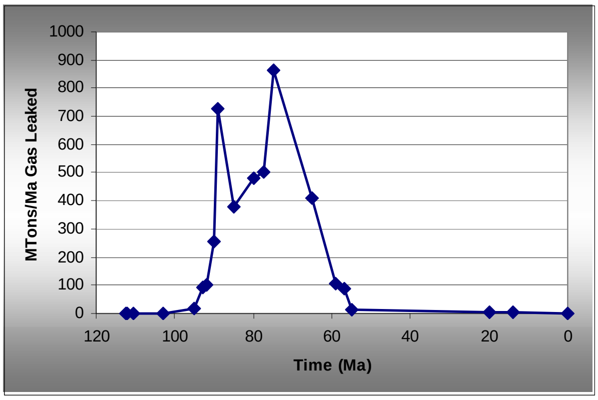

Figure 2. Calculated methane emissions to the seafloor from the Orange Basin study area as a function of geologic time.

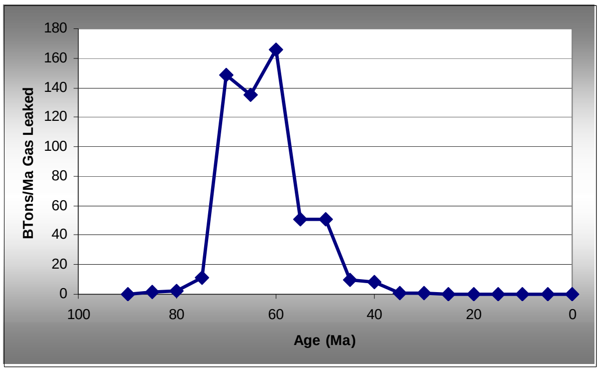

Figure 3. Calculated methane emissions to the surface from the Western Canada Basin (after Higley et al. 2009).

CONCLUSIONS

Methane exhalation is one of several explanations of spectacular negative $\delta^{13}C$ excursions found in the Tertiary sedimentary record such as the Paleocene Eocene thermal maximum (PETM), being at least a precursor of atmospheric CO_2 increase. In the IPCC global mass balance of methane sources and sinks the role of “geologic” methane production and supply to the atmosphere could not be included as only estimates were available. In essence this implies that a global assessment of subsurface methane generation and leakage over geologic time is of paramount importance. Our project Methane on the Move aims at quantifying thermogenic and biogenic methane emissions from sedimentary basins world wide and making the produced data available for global climate modelling. The first results from the Orange Basin and the Western Canada Basin have proven that understanding the workings of sedimentary basins in time and space is fundamental to gaining insights into Earth’s climate.

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