

# Implications of Slow Biodegradation Rates in Oilfields for Crustal Biospheres

Steve Larter (steve.larter@ncl.ac.uk)<sup>1</sup>, Ian Head (ian.head@ncl.ac.uk)<sup>1</sup> & Arnd Wilhelms (arnd.wilhelms@hydro.com)<sup>2</sup>

<sup>1</sup> NRG, Drummond Building, University of Newcastle, Newcastle, NE1 7RU, UK

<sup>2</sup> Norsk Hydro, Bergen, Norway

Biodegradation of crude oil in reservoirs at depths of 2 km or greater is an important alteration process with major economic consequences. Most of the world's petroleum is biodegraded, with a high biodegradation risk being associated with shallow reservoirs in the deep water continental margin areas of the world currently being actively explored (offshore Brazil, Angola, Nigeria, Gulf of Mexico and N.W Europe). While the effects of biodegradation on the molecular composition and physical properties of crude oils are empirically relatively well known (Connan, 1984), and anaerobic bacteria were first isolated from the deep biosphere associated with oilfield waters three quarters of a century ago (Bastin, 1926), the actual processes taking place during biodegradation of crude oil in deep reservoirs remain obscure. Thus the site, rates of degradation, the electron acceptors involved and the nature of the reduced products are not known in most cases. It is now generally agreed that multiple redox environments involving, among others, iron reduction and methanogenesis, do play an important role in anaerobic microbial oil degradation (Bennett et al, 1993) and that water may also be directly involved (Zengler et al, 1999) but the details of the processes and their rates remain unknown. Our recent experience in studies of biodegraded oilfields in China, California and the N.Sea (Horstad and Larter, 1997) indicate that to further complicate the picture the composition of oils in degraded oilfields are often controlled by the differential effects of mixing newly charged oil in a field with degraded oil and the rate at which the composite oil is degraded. We recently reported a study of a 2 km deep heavy oil reservoir in China (Larter et al., 2000) which locally shows an unusually well developed vertical biodegradation gradient in the reservoir with progressive and systematic loss of alkanes over a 130 m vertical interval towards the oil water contact and we use this gradient and a coupled diffusion reaction model to broadly estimate the degradation rate constant for oils in the field.

Many variables will affect the compositional gradient of a degraded oil column but we have found, using simple 1D diffusion models, where biodegradation is simulated by a first or zero order alkane degradation reaction in a narrow region at the

base of the oil column, that stable compositional gradients such as this are produced, after an initial diffusively controlled induction period, with diffusive alkane transport to the oil water contact being the potentially ultimate rate controlling step but the observed gradients suggesting that the degradation reaction at the base is limiting in the fields studied. The alkane compositional gradients can be used to assess the degradation rate constants, both Chinese and N.Sea cases, with different diffusion coefficients for alkane transport, giving first order alkane degradation rate constants of around  $10^{-6}$  to  $10^{-7}$  yr<sup>-1</sup>. Net degradation rates in the reservoir are comparable with many aquifer respiration rates and much lower than reported lab alkane degradation rates. Comparisons with the maintenance energy requirements of bacteria allows us to make a broad assessment of the maximum biomass size and suggests that the degradation flux of hydrocarbon could be consumed slowly by the maintenance energy requirements of, on the order of, as little as  $10^9$  bacteria per square meter of reservoir area. Diffusive transport rates of hydrocarbons to the degradation zone implies diffusion may potentially also be adequate in some instances to transport nutrient and electron acceptors in the water phase below the oil column. We discuss the implications of sourcing nutrient and electron acceptors internally from the reservoir and the effect of net low degradation rates on the status and nature of the deep slow (largo) biosphere in oil fields.

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