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Rare Gas Isotopic and Elemental Constraints on Oil Migration and Hydrogeological Processes: The Statfjord, Snorre and Gullfaks Fields, Norwegian North Sea Oil Province

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Noble gas isotopic and elemental data obtained from hydrocarbons can provide unique and hitherto often unavailable information on the hydrogeological conditions related to oil migration and subsequent reservoir processes. The solubilities of noble gases in hydrocarbons and water dictate that a source area/rock noble gas signature will be mixed and diluted with noble gases stripped from groundwater in contact with the hydrocarbons. Thus the hydrocarbon phase will retain a record of its evolution from source to reservoir which can be analyzed using mixing line analysis of $F(^{i}Ng)$ vs. $1/^{36}Ar$ and $F(^{i}Ng)$ vs. $F(^{j}Ng)$ [where $F(^{i}Ng) = (^{i}Ng/^{36}Ar)_{sample}/(^{i}Ng/^{36}Ar)_{air}$]. This should provide information on (a) the composition and total amount of the groundwater that the hydrocarbons interacted with; and (b) the composition and potential presence of multiple source rocks/areas.

The research area consists of three oil fields in the Tampen Spur region of the Norwegian North Sea Oil Province: the Statfjord, Snorre, and Gullfaks fields. The hydrocarbon deposits mainly occur in Jurassic sandstone sequences of the Statfjord Formation and Brent Group, which have been affected by rotational block sliding related to the main phase of rifting and uplift in the Viking Graben. For this study there are two main points of interest related to these fields. (a) There are several complex and conflicting reservoir filling hypotheses, that can not be unequivocally distinguished between using conventional methods like biogeochemical markers or gas/oil/water ratio changes between the fields. (b) For the Snorre field significant oil degradation is observed. Large water/hydrocarbon ratios (>5000 gH_2O/gC) suggest degradation driven by meteoric water derived oxygen, while low water/hydrocarbon ratios (<200 gH_2O/gC) indicate other mechanisms of degradation. A satisfying resolution of both these points will increase our knowledge of oil hydrogeology and can be of great importance to risk assessment for satellite field drilling.

A total of 13 gas samples for major and trace gas analysis were collected from the gas side of a gas/liquid separator at the production platforms (Statfjord field: 4; Snorre field: 5; Gullfaks field: 4). Noble gas data obtained to date suggests that the groundwater with which the hydrocarbons interacted had an initial composition not unlike water saturated with air at 5-15^{o}C, with additional contributions of crustally produced ^{4}He and ^{40}Ar. This resulted in a $^{40}Ar/^{36}Ar$ and $^{3}He/^{4}He$ groundwater composition of approximately 440 and $0.02R_A$ (R_A = $^{3}He/^{4}He$ in air), respectively. This groundwater interacted with hydrocarbons enriched in air-derived Xe and Kr, similar to, but with much smaller enrichment factors than observed in the Elk Hills oil field (Torgersen & Kennedy, 1999).

Mixing line analysis suggests the presence of at least two distinct source areas. One is defined by samples from the Statfjord field, which suggest that the source area is characterized by enrichments of crustally produced ^{4}He and ^{40}Ar similar to, but slightly higher than the groundwater. The second is defined by samples from the Snorre field, which define a distinctly different mixing line. Samples from this field are characterized by a correlation of increasing $^{40}Ar/^{36}Ar$ with increasing $^{3}He/^{4}He$ (ratios up to 0. $4R_A$) which suggests that a mantle derived component is present in the source area. This may be related to upwelling of hot mantle material beneath the Viking Graben and the ensuing uplift and extensional faulting.

Secondary mixing relationships observed in the data suggest that Statfjord type hydrocarbons contributed to the filling of the Snorre field, but that mixing was fairly limited. These reservoirs are described as single entities but the noble gas data suggests that internal mixing and homogenization was ineffective and incomplete. The data for the Gullfaks field suggest that the reservoir was filled with hydrocarbons from both the Statfjord and the Snorre field. However, once again mixing was incomplete, implying that lateral homogenization is ineffective or that the reservoir is highly compartmentalized.

If we assume that hydrocarbon source rocks are characterized by the extreme (>1000) $F(^{132}Xe)$ enrichments observed in laboratory measurements of carbonaceous rocks (e.g. Frick & Chang, 1977), then our data [$F(^{132}Xe)$ 8-12] suggest high water/hydrocarbon ratios, but not as high as required for meteoric water driven degradation. Furthermore the results of this study clearly identify a unique reservoir filling scenario, which serves to illustrate the great utility of noble gases in their application to oil hydrogeology.

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