

Evaluating Some Aspects of Gas Geochemistry of some North Sea Oil Fields

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Abstract

Gas geochemistry, an integral part of petroleum geosciences, has been used for evaluating source rocks potential for shale gas and in conventional exploration as a guide for determining potential productive formations. However, in contemporary times, new concepts of gas geochemistry have been applied in delineating the effectiveness of caprocks. Caprock is a vital element of a petroleum system, the volumes of rocks overlaying reservoirs are responsible for the configuration on which the accumulation sits and fosters essential preservation. In this study headspace gas served the purpose of delineating leakage and determining migration pathways, mechanism and discriminating gas types in the formations overlaying the reservoirs.

Keywords: Gas geochemistry; Caprocks; Leakage; Thermogenic gas; Thermogenic signature

Introduction

Gas geochemistry – a new comer in the series of geochemistry has proved vital in delineating caprock leakage employing headspace gas. Prior to the present times, headspace gas data were employed to detect by pass-pays, interpretation of maturity, source and gas correlations [1], evaluate the maturity and productive capacity of corresponding formations and in most cases as indicators of petroleum accumulations [2]. In tandem, direct hydrocarbon indicators (DHIs) such as oil stains, oil shows and seeps, were also used to evaluate the presence of accumulations. Evolving studies on caprock has brought to bear the use of gas clouds in the crest of fields in seismic sections and essentially the application of headspace gas to discern the potential leakage mechanism and migration pathways of leaked petroleum in petroleum caprocks. The drivers for this study includes the fact that hitherto, headspace gas data were used for exploration purposes, recently the quest for a simple, reliable but versatile technique is in need for preliminary evaluation of caprock leakage before the use of robust methods such as mercury injection capillary pressure analysis. Secondly depleted hydrocarbon reservoirs are foreseen as carbon sinks in carbon sequestration studies; the ability for the caprock to hold back thermogenic wet gas could give an insight into the caprock integrity regarding CO₂ sequestration. The hypothesis on which this study rest is that, the occurrence of thermogenic hydrocarbon (as reflected in headspace gas data) in immature caprock formation overlying petroleum reservoirs, infers leakage of the caprock or migration of the hydrocarbon from the reservoir into the caprocks. Biogenic and thermogenic gases makes up the natural gas [3], biogenic gas consists mainly of methane from immature organic matter and lignite which is isotopically very light, while thermogenic gas is generated from kerogen or petroleum during burial, with heavier carbon isotope values [2]. Thermogenic wet gas refers to ethane, propane and butane components (C₂-C₄) of the thermogenic gas and is normally expressed as %wetness $((C_2-C_4)/C_1-C_4) \times 100$. In this study, the presence of thermogenic hydrocarbons in immature caprock sections overlying petroleum reservoir is established using thermogenic gas-depth profile (TGD) in corroboration with thermogenic signature-depth profile (TSD) and the vitrinite reflectance of the formations and some key conventional cross plots. The log view profiles were modelled with Techlog 2007.3 while the descriptive

lithology of the formations were modelled using Genesis 4.8.

Methodology

This study is part of a wider study on regional leakage evaluation of the North Sea. Data for this study were sourced from well completion reports, evaluation reports, composite logs and general information folios on 50 wells in 41 oil fields in the UK and Norwegian Sectors of the North Sea (Figure 1). Data types consist of headspace gas compositional and isotopic data pore pressure data expressed as EMW (Equivalent mud weight), organic matter maturation data and general geological information such as reservoir fluid types. Data were obtained from the Norwegian Petroleum Directorate, Public domain and a study report on hydrocarbon seepage by BP. The headspace data which consist of various gas compositions i.e. methane, ethane, propane and butane were presented as log plots of thermogenic wet gas-depth plots and thermogenic signature (*i*C₄/*n*C₄ ratio)-depth plot. The plots were corroborated with the descriptive lithology and vitrinite reflectance data to decipher depths for biogenic and thermogenic gases. Depths at which the thermogenic signature is greater than 1.0 were interpreted as consist of biogenic, immature and biodegraded gaseous hydrocarbons. The thermogenic-biogenic gas boundary is at values for which the *i*C₄/*n*C₄ ratio does not exceed 1.0. The consistence of the thermogenic signature from the reservoir sand body through the reservoir-caprock interface into the overlying formations indicates migration of hydrocarbons from the reservoir into the formations above inferring leakage.

Results and Discussions

The results are presented as log view plots of thermogenic wet

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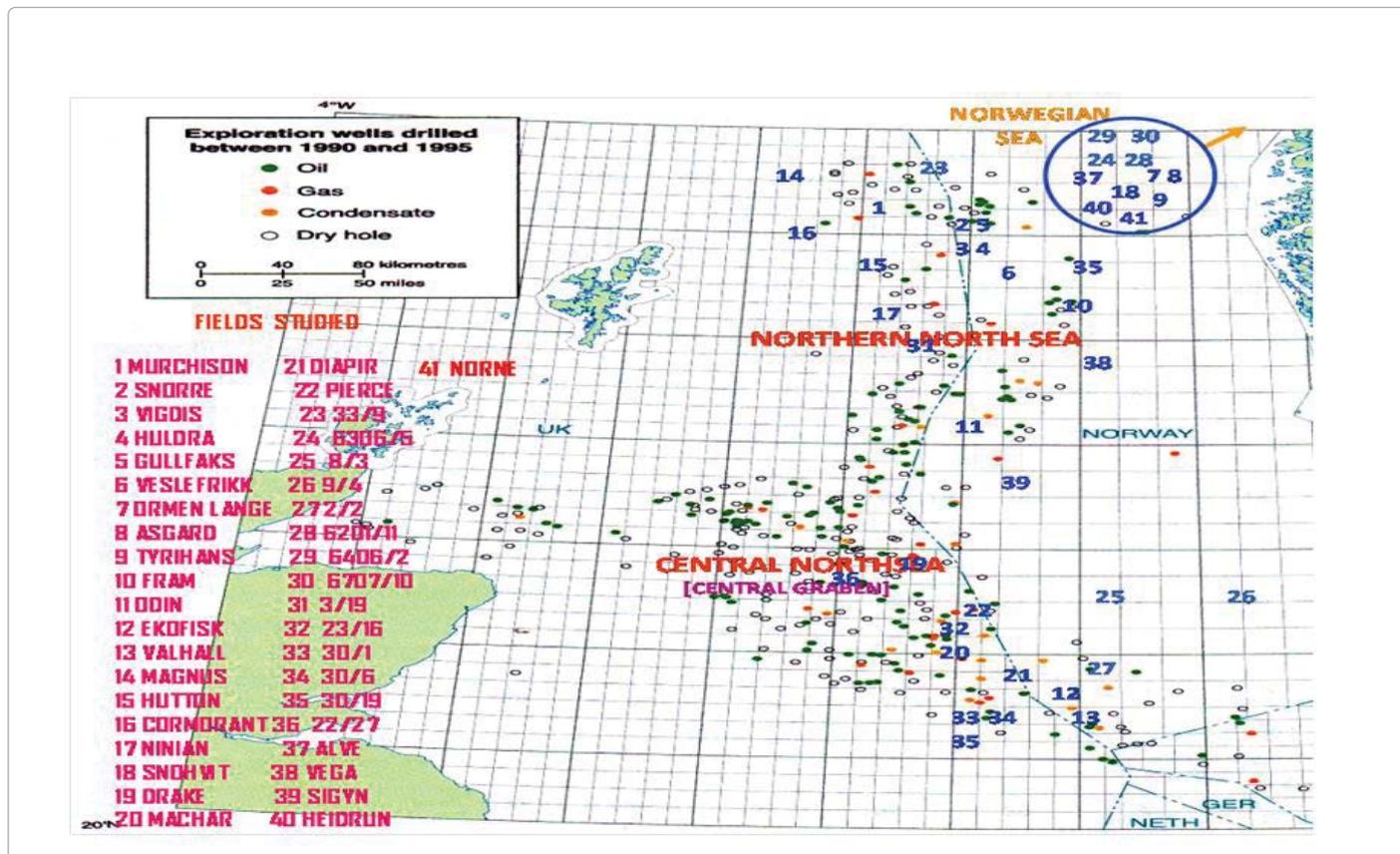


Figure 1: Locations of the studied oil fields. Modified [10].

gas-depth (TGD) and thermogenic signature-depth (TSD) profiles for the studied oil wells in the North Sea (Figures 2, 3 and 4). MF which indicates the migration front of the thermogenic wet gas signifies the boundary between the leaking thermogenic wet gas from the reservoir and the biogenic gas generated by immature organic matter and shallow lignite. The thermogenic wet gas profiles showed a general trend for which thermogenic wet gas content increases towards the reservoir depth wise, while the thermogenic signature decreases towards the reservoir. The profiles of some wells were not in consonance with the general observation i.e. Velsefrik and Gullfaks 7219/8-1S (Figure 4). Some degree of spikiness were observed which invariably indicates heterogeneity of the formations and the presence of zones with low permeability contact interface, requiring the migrating petroleum to build up hydrocarbon column to overcome the resistance posed by the pores in the matrix of the rocks. The height of thermogenic wet gas from the reservoir-caprock interface (TR) to the migration front (MR) varies from about 30m which could be termed short distance migration to above 1KM, with thermogenic wet gas content significantly above 20%–30% of the total gaseous hydrocarbon content and the corresponding thermogenic signature less than 1.0. This result implies pervasive (anomalous) occurrence of thermogenic wet gas in the reservoir caprocks and overlying formations in the North Sea.

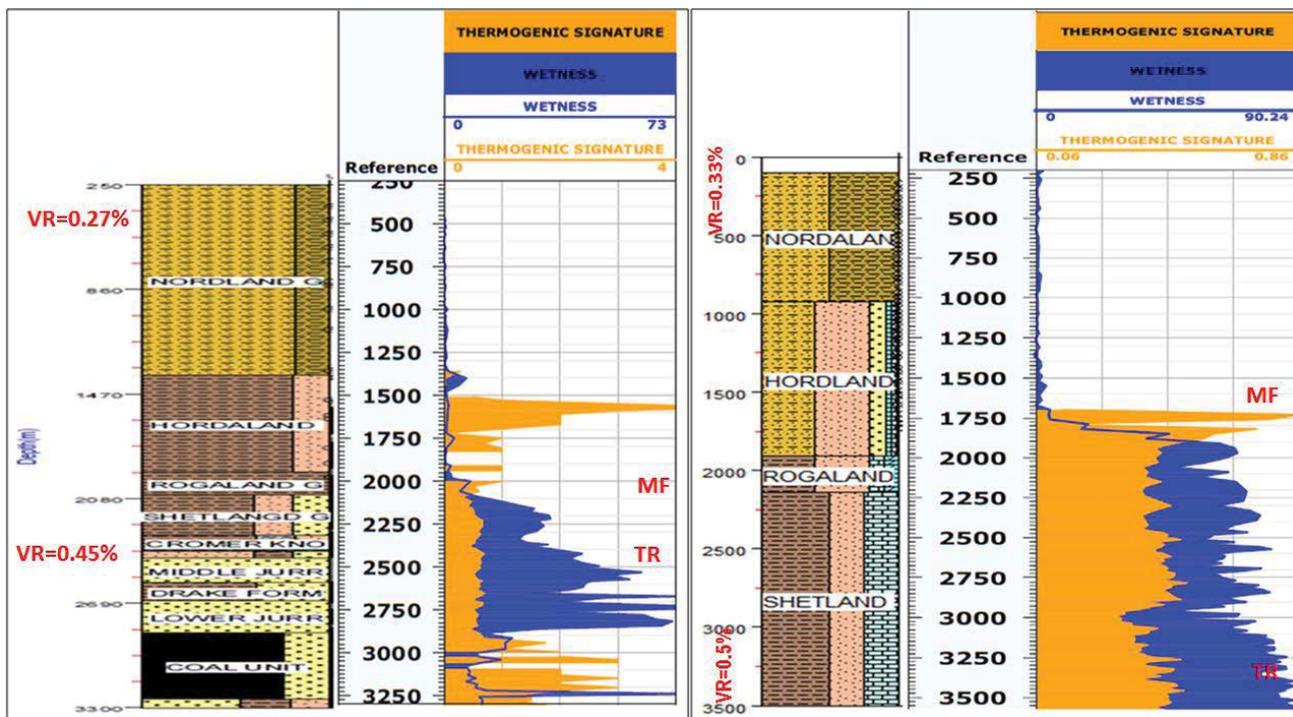
Hydrocarbon Leakage

The profiles shows the presence of thermogenic hydrocarbon from the reservoir to the formations overlying the caprock via reservoir-

caprock interface, this potentially infers an association with down-dip oil leg and may also indicate sourcing from a mature source rock or secondarily by thermal cracking from the associated oil in the reservoir. Some profiles show more hydrocarbons in the caprock and overlying sections relative to the reservoir i.e. Velsefrik 30/3-4, Gullfaks 7219/8-1 and Well 6/3-1 while wells with more hydrocarbons in the reservoir are Asgard 6407/2-2 and Vigdis 34/7-29S. The presence of more hydrocarbons in the caprock sections suggests the presence of low capillary entry pressure caprock with a high permeability contact interface overlying the caprock sections, on the contrary, the wells with more hydrocarbons in the headspace gas from reservoir cuttings suggests low permeability or high capillary pressure contact interface [4-6]. The vitrinite reflectance data of the formation show that they are immature and cannot generate mature gaseous thermogenic hydrocarbons such as presence in the formations. The hydrocarbons in the caprock and overlying formations are non indigenous to the formation hence are migrant hydrocarbons. The consistency of the iC_4/nC_4 ratio from the reservoir into the caprock section indicates a continuous migration of hydrocarbon from the reservoir into the caprock and overlying sections, this infers leakage.

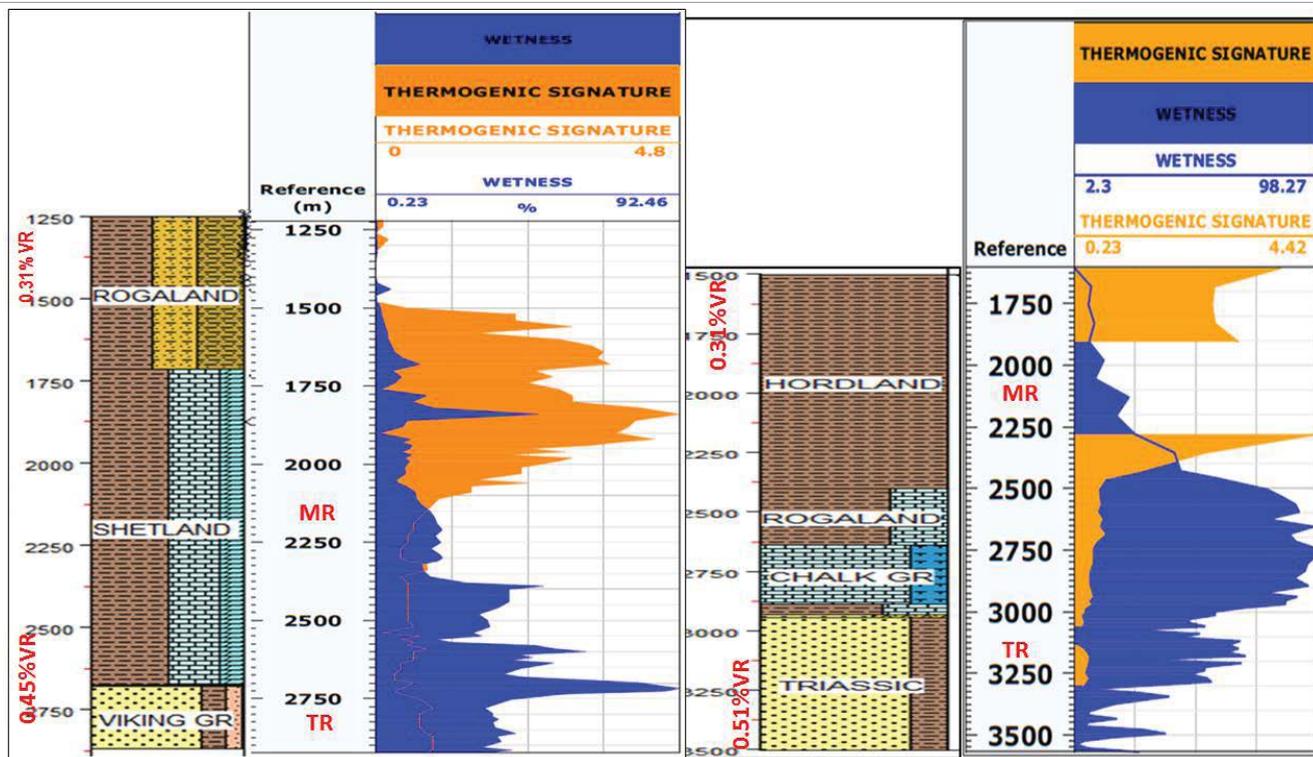
Leakage Pathway and Mechanism

The distribution of thermogenic hydrocarbon in the formations of the studied oil wells shows a high thermogenic hydrocarbon occurrence in the range of tens of meter to hundreds of meter in the caprock section and overlying formations. Some oil wells such as Huldra 30/3-1 has



Asgard 6407/2-2 Huldra 30/3-1

Figure 2: Log view of thermogenic gas profiles for Asgard and Huldra oil wells. Modified [10].



Vigdis 34/7-29S

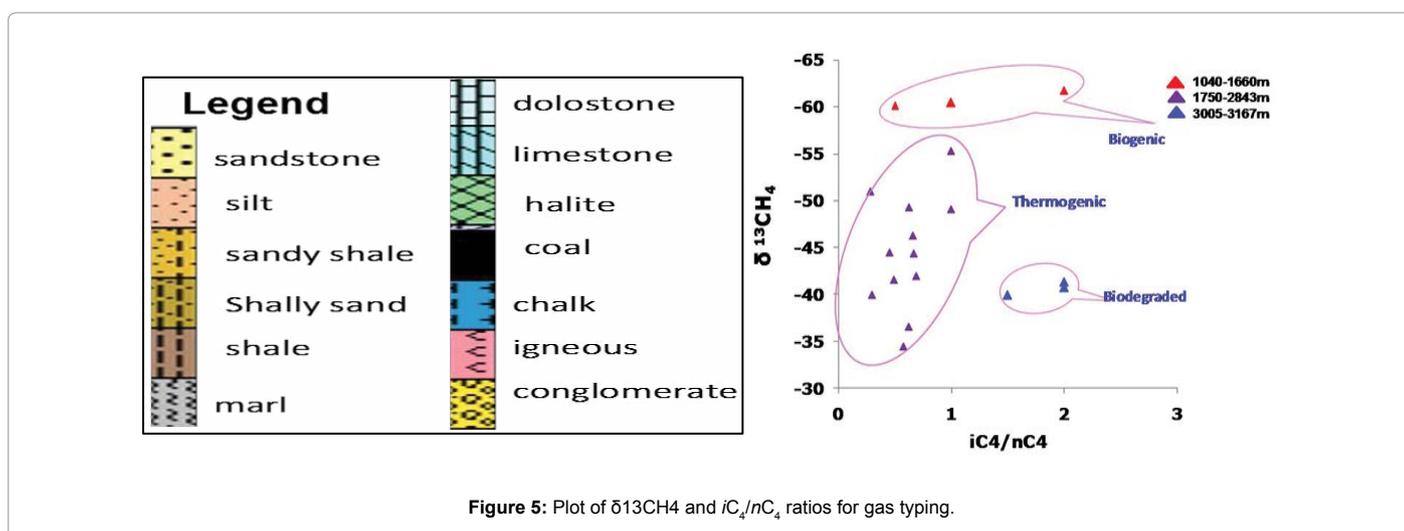
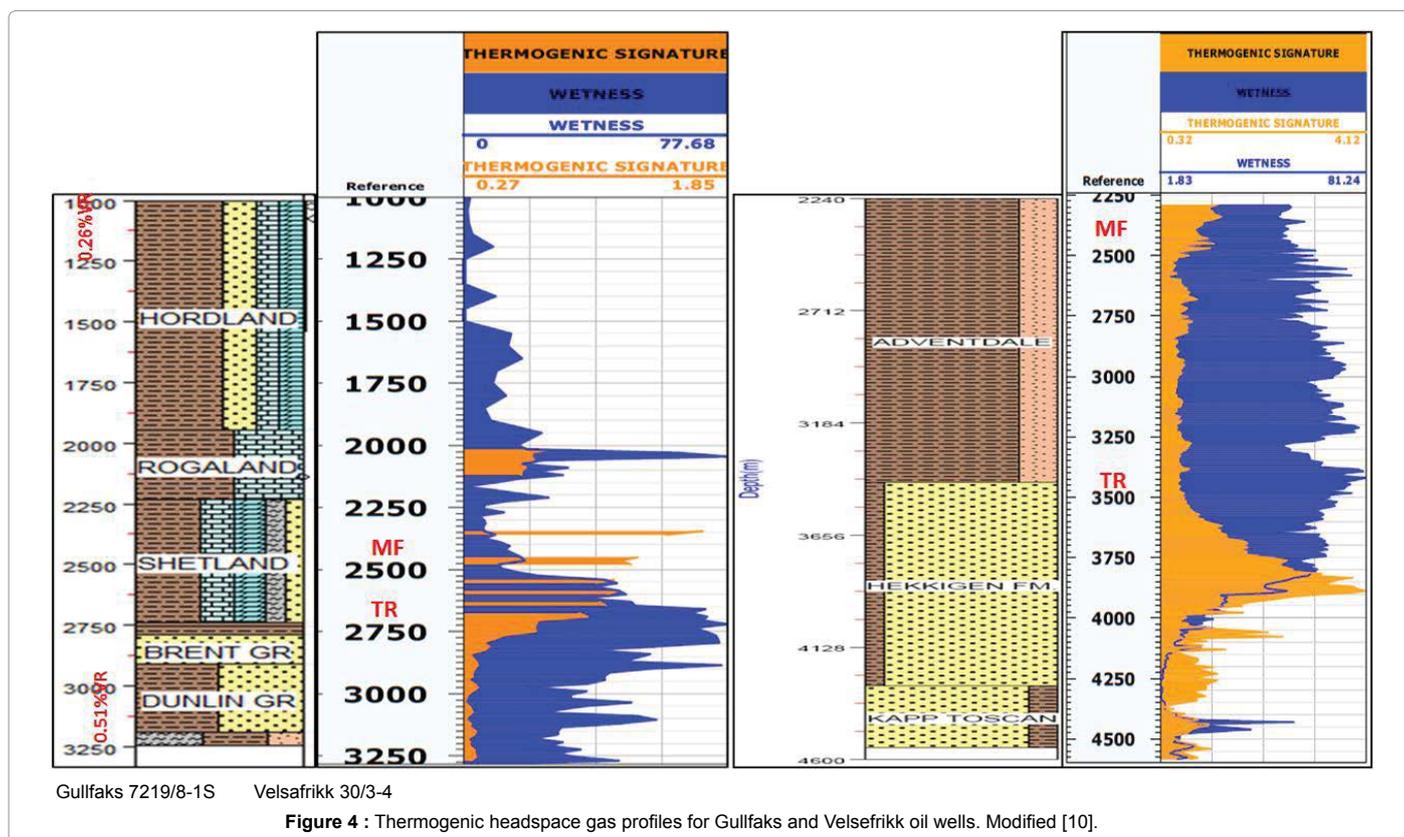
Figure 3: Log view of thermogenic gas profiles for Vigdis 34/7-29S and 6/3-1 oil wells. Modified [10].

high thermogenic gaseous hydrocarbon in the caprock and overlaying sections, with high pore pressure which is about 80% of the lithostatic pressure. Majority of North Sea wells with unusually high thermogenic gas in the caprock section had attained their fracture pressure and experienced healing of the fractures. It has been observed that high pore pressure wells usually have high thermogenic gas readings, especially for wells in gas chimneys [7]. This observation invariably indicates that reservoirs with high pore pressure are normally fracture prone. Hydrocarbons in fracture prone caprocks are emplaced by fracture failure via fractures and faults. Some oil wells with low reservoir pressures having immature caprock sections i.e. Asgard 6407/2-2 could

be characterized by continuous high thermogenic wet gas sections, this means that leakage may be largely due to the presence of a high permeability contact interface between the reservoirs and the caprocks suggesting that hydrocarbons were delivered into the caprock sections by capillary leakage via network of pores in the caprock matrix.

Gas Types

In-reservoir processes could result in changes in gas compositions. Biodegraded gas could be identified by $iC_4/nC_4 > 1$ due preferential loss of normal alkanes. This observation could portray the incursion of sea



water into the reservoir, or a Gas-water contact interface (GWC). Cross plot of carbon isotope values of methane (Figure 5) against iC_4/nC_4 . The plot shows the biogenic-thermogenic mixture phase, the thermogenic and the biodegraded gases [8,9]. The formations bearing the gases could also be inferred, i.e. the biodegraded gases in the Asgard oil well, are present below the Lower Jurassic sand body into the coal unit, while the reservoir sands bears thermogenic hydrocarbons.

Conclusion

Thermogenic wet gas are observed to be present in immature caprocks and overlying sections, the hydrocarbons are not indigenous to the formations but bears a consistent character (i.e. iC_4/nC_4) from the reservoir into the caprock and overlying formation indicating leakage. The pathways are suggested to be via fractures, faults for fracture prone or hydraulic leakage or migration via pores in the matrix of the rocks for capillary leakage. The significant of this study is that it unravels most of the North Sea caprocks as leaky. It also presences a fast and reliable method of evaluating the integrity of a caprock rock using headspace gas data in corroboration with formation maturity data. It could also serve the purpose of studying the compositional distribution of headspace gas (thermogenic hydrocarbon) in the formations.

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