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Research Article

APPLICATION OF MOLECULAR MARKERS FOR THE DETERMINATION OF LEAKAGE THROUGH THE CAPROCK OF ASGARD FIELD

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ABSTRACT

The focus of this research is in the use of molecular markers to detect hydrocarbon leakage and to assess the mechanism by which this leakage occurred. Such a study is important in order to reduce exploration failure due to Caprock leakage. This was accomplished using rock-eval pyrolysis data and gas chromatography traces extracted from side wall cores and drill cuttings. The findings from this research provide evidence that organic matter within the caprock is immature, thus hydrocarbon within the Caprock is non-indigenous. Also the gas chromatography traces for rock extracts from the Caprock succession is similar in composition to the oil from the underlying reservoir. Furthermore, using the volume of hydrocarbon within the caprock, capillary leakage was inferred. The main conclusion drawn from this study is that capillary leakage is occurring from the reservoir rock into the caprock, and this will have minimal effect on preservation and subsequent production of hydrocarbon. This research work recommends that geochemical methods should be used as a complimentary tool to seismic reflection analysis to accurately detect hydrocarbon leakage, in order to reduce risk in field development.

INTRODUCTION

Leakage of trapped petroleum is a major concern in hydrocarbon exploration and has led to a large number of exploration failures. Changes in stress state, fluid pressure, and cap rock permeability may all result in a loss of trapped hydrocarbons. All petroleum traps leak to a greater or lesser extent and consequently petroleum is able to seep towards the earth's surface (Gluyas & Swarbrick, 2004). Leakage can be described as the movement of hydrocarbon from the reservoir, by diffusion or via fracturing the caprock, capillarity or extensive and stringers, interfacing with the reservoir at the reservoir caprock interface to the surface. Leakage through a caprock can also be referred to as dysmigration (Allen & Allen, 2005), through interchangeable, there is a slight distinction between hydrocarbon leakage and seepage; leakage refers to the movement of hydrocarbon out of the confines of a reservoir into migratory pathways (faults and fractures or pores), while seepage is the movement of hydrocarbon mostly via the secondary migratory pathway to the surface. Both processes can be regarded as tertiary migration of hydrocarbon (Gluyas & Swarbrick, 2004).

AIM AND OBJECTIVES OF THE PROJECT

The primary aim entails the use of molecular marker to define hydrocarbon leakage into the caprock of Asgard field. This is achieved by establishing genetic similarities between the extracts from the caprock and reservoir unit using gas chromatography technique, estimate the volume of petroleum leaked into the caprock and determine the mechanism of leakage through the caprock.

LITERATURE REVIEW

Reservoir cap rock is one of the essential elements in the petroleum system, its primary role is to prevent the escape of hydrocarbon. Trapping of hydrocarbon occurs when the cap rock possesses reservoir sealing properties; low permeability, high capillary entry pressure etc. thus, assessing the sealing capacity of a caprock should be top priority in an exploration program to prevent risk of hydrocarbon leakage form a reservoir.

The study of hydrocarbon leakage, has been an on-going task for many geoscientists for decades. Geoscientist have worked on different aspects of leakage i.e.; Clayton and Dando (1996) on the rate of leakage, while Clayton et al (1997) worked on alteration during leakage, Fischer et al., (2001). Ingram and Urai (1999), Leith et al (1993) on top seal, capillary and fracture leakage, Lietenberg and Connolly (2003) on gas cloud and sealing quality, Nordgard and Hemanrud (2002, 2003) on leakage and retention capacity. Zieglar (1992) and Sales (1997) worked on buoyancy pressure and seal efficiency.

In contemporary times, the study of leakage started on the basic inference that oil and gas must have originated from a dispersed state, from which they have been impelled to their present position and entrapment. In general, sedimentary rocks are porous with pore spaces forming an intricately interconnecting three dimensional network. Furthermore, within the sub-surfaces, these pores and filled with water, thus the generation, migration and finally preservation occurs in a rather water-saturated environment. It can be envisaged that oil in its dispersed state is surrounded by water and the solid framework of the rock in which it occurs. In reference to the law of mechanics which states that; "if a system is at rest and it is not in a configuration in which its potential energy is at a minimum, it will move spontaneously unit it achieves that configuration. Applying this principle to petroleum in a dispersed state, it can be deduced that each element consist of a mechanical potential energy which is dependent on its environment. The elements will be acted upon by an impelling force which tends to move these elements from areas where it has high potential to areas of low potential. Thus, petroleum tends to migrate from areas where the energy is higher to those of lower energy, and will ultimately come to rest in areas surrounded by higher energy levels and impermeable barriers. Thus, a petroleum trap is a low energy region and exploration of oil and gas is restricted to these low energy regions.

The entrapment or expulsion of hydrocarbon within traps; structural, stratigraphic or hydrodynamic, are reduced to a relation of:

- Buoyancy force for the charging petroleum
- Capillary sealing pressure of the cap rock
- The height of the petroleum column in the reservoir

z

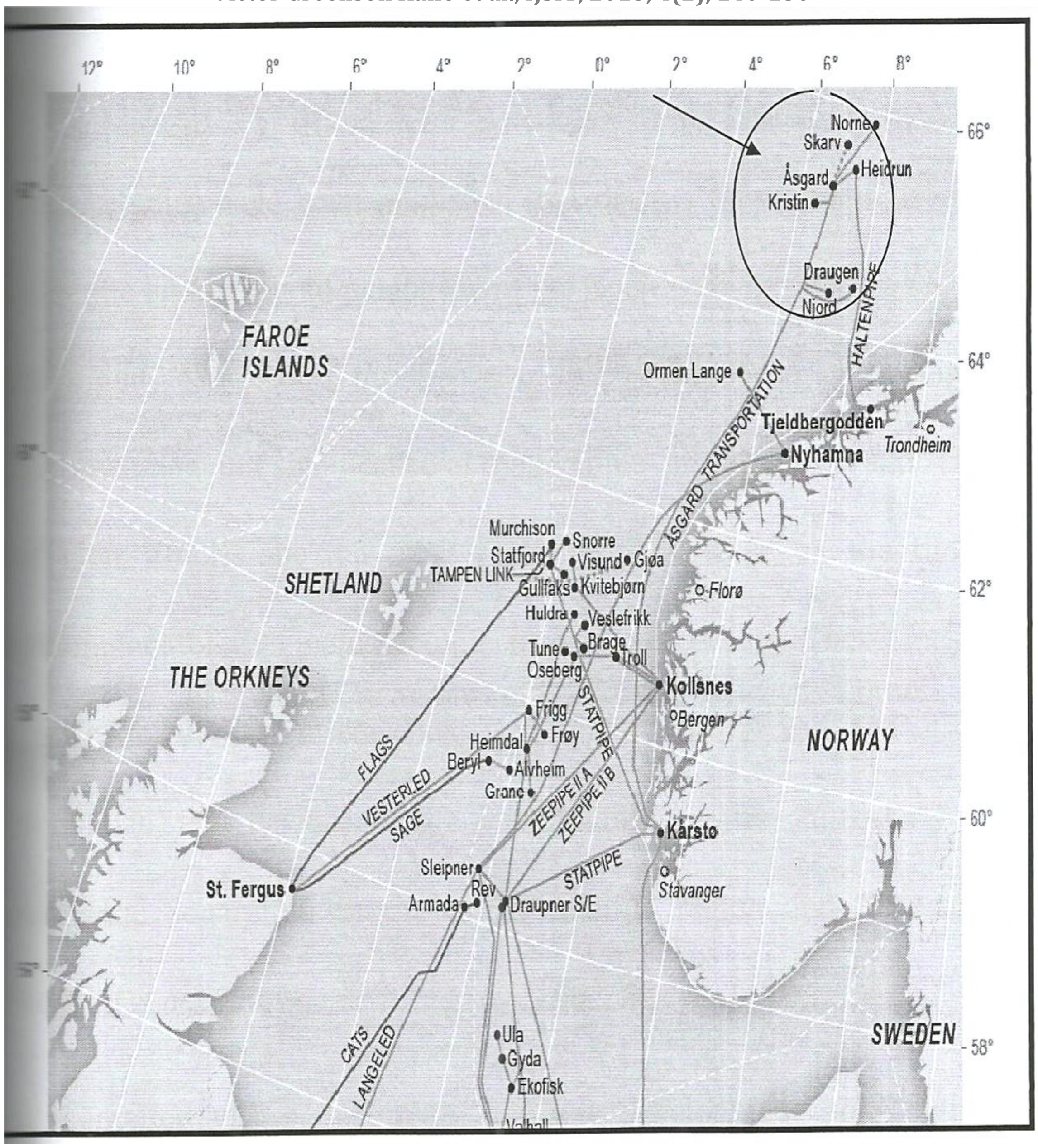

Figure 1: The location of Asgard oil field

GEOLOGIC AND LITERATURE REVIEW OF STUDY AREA

Tectonic Setting:

The present day Norwegian Sea is a NE-SW trending passive margin bounded to the west by a volcanic margin escarpment and to the east by the Norwegian mainland. Main structural elements are the More and Voring basins in the west, Halten and Donna Terraces and the Trondelag Platform in the east (Blystad et al.1 995).

Several studies have been published that discuss the tectonic development during the Cretaceous to Paleogene of the Norwegian sea (Blystad et a!. 1995: Lundin and Dora 1997; Gabrielsen et al 1999). These studies present partly variable timing and significance of the tectonic phases and events (Faerseth and Lien, 2002), but the most recent papers agree on the timing and development of the main tectonic phases and events. These include late Jurassic to earliest Cretaceous continental rifting and the Cretaceous (Campanian) to Paleocene rift culminating in the Paleocene/ Eocene continenta1 separation in the North Atlantic region and Norwegian Sea (Skogseid et al. 2000; Faerseth and Lien; 2002; Ren et al. 2003).

Sedimentation varies during the tectonic development both in terms of volume and rate. Dramatic variations in the spatial distribution of sediment occur during each phase of tectonic development. According to Faerseth and Lien (2002) the cretaceous evolution of the Norwegian sea following the late Jurassic/ Earliest Cretaceous rift episode, and lasting until the late cretaceous rifting, represents a post- rift thermal subsidence stage. This stage can be divided into an early post-rift stage and a late post-rift stage related to changes in the basin topography and reservoir development.

The study area is located in the Haltenbanken petroleum province on the mid Norwegian Continental Shelf **(Figure 1)**. The central part of the Haltenbanken region, the Halten Terrace is separated from Trondelag platform to the east by the Kistiansund-Bodo fault zone. Towards the west, the Haltenbanken region is a higly faulted, tectonically induced basin with major faults showing oblique (Gabrielsen et al., 1984; Boen et al.,1984). Structurally, the Haltenbanken wince -made up of N-S TO NNE-SSW striking faults with NNW-SSE trending faults making horst and garden structures (Hollander et aL,1 984). The Haltenbanken Petroleum province is situated on a passive rifted continental margin which is overprinted on the older structural elements formed during the Caledonian orogeny between Greenland and fenno scandian cratons, (Buckovics and Ziegler 1985; Karisen et al, 1995)

METHODOLOGY

DATA: The data extracted, for this study includes

1. The lithologic description of the formation penetrated by the well obtained from cuttings and side wall cores
2. Data on solvent extraction and Rock-Eval pyrolysis data
3. Gas chromatography (GC) traces data of the relevant formations penetrated by the well.

(a) Lithology: The description of the formations penetrated by the wild-cat well was extracted from the well information folios. This information included the various proportions of each component of the individual formations penetrated by the well, and these where used as inputs to model the lithology i.e formations. In this case Genesis version 4.8 software was used to model formation.

(b) Rock-Eval phrolysis: This is a process used to determine the type and maturity of organic matter and to detect petroleum potential in sediments. In this case, crushed sample (100mg) was weighed into a platinum crucible, the base and the cover of which are made of sintered steel, and analyzed on a Rock-eval pyrolyser

DEPTH	FORMATION	V.R	S1	S2	TOC	EOM	SAT	ARO	HC	NON-HC
2423	Kimmeridge clay	0.45	3.21	18.3	9.25	22.8	2.9	3.2	6.1	16.7
2459	Heather formation	0.48	0.16	0.99	0.98	17.7	4.1	5.3	9.4	8.2
2636	Drake formation	0.49	0.43	0.76	0.92	41.5	5.4	12.4	17.8	23.7
2672	Drake formation	0.4	0.29	1.1	1.32	51	7.8	8.5	16.3	34.6
2726	Lower Jurassic Sandstone	0.32	0.33	1.78	1.53	31.8	2.2	5.1	7.3	24.5
2744	Lower Jurassic sandstone	0.36	0.58	1.93	1.14	45.2	12.3	11.9	24.2	21
2933	Coal unit	0.47	6.34	115	44.3	17.4	3.7	45	8.2	9.2
3041	Coal unit	0.53	2.65	81.7	37.8	17.6	2.1	4.5	6.6	11
3149	Coal unit	0.48	2.89	88.1	31.6	22.1	1.6	4.6	6.2	15.9
3239	Coal unit	0.5	2.97	96.7	22	29.9	2.6	4.6	7.2	22.7

TABLE 1: Solvent Extraction Data and Rock-Eval Pyrolysis Data

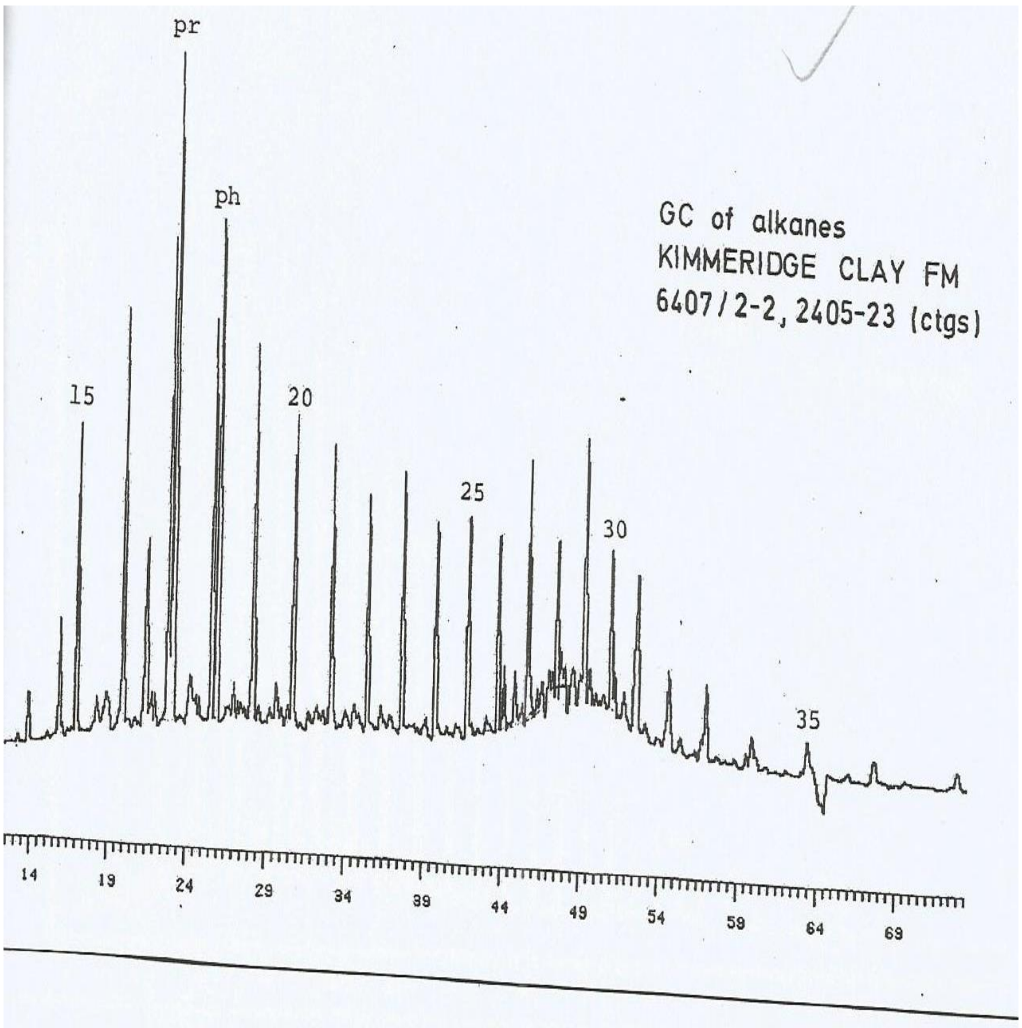

Figure 2: A G.C Fingerprint of the Kimmeridge Clay Formation

RESULT AND DISCUSSION

(i) Thermal maturation: The transformation of kerogen to oil is interpreted to be initiated at a vitrinite reflectance (Ro) value of 0.55%. The process of oil generation reaches completion at a vitrinite reflectance value of 1%. The last liquid hydrocarbons are cracked to wet gas at a Ro value of 13%. The shift from wet gas to dry gas occurs at Ro value of 2.0%. The production of dry gas ceases at an Ro value of 4.0% (Sweeney & Burnham, 1990).

The kerogen types associated with source rocks (Kimmeridge clay and Coal unit formations) of the Midgard segment in the Asgard field penetrated by the wi1d-cat well 6407/2-2, are mainly type 2 (kimmeridge clay) and type 3 are formation-coal units) kerogens. This is evident in the maceral composition of these formations. Where within the Kirnmerigde clay, the proportion of exinite (70.8-94.0) far exceeds that of inertinite (4.8-6.3) and exinite (1.2 — 22.9). Also, within the coal unit, the proportion of the vitrinite 43.3-68.8) exceeds the proportion of inertinite (2 1.6-39.9) and exinite (7.1 -21.6).

The vitrinite reflectance value of these source rocks (kimmeridge lay and coal unit) range from 0.45-0.53%, with an average value of 0.486%. This value indicates that the source rocks are immature and hydrocarbon generation from these source rocks cannot occur. This is further corroborated by the production index (P.1), which is the ratio of already generated hydrocarbon to potential hydrocarbons. Low ratios indicate either immaturity extreme or post mature organic matter. High ratios indicate the mature stage of contamination by migrated hydrocarbon or drilling additives (Chilingarian et al, 1995). From the result, the P.1 values for both the kimmerigde and coal unit formation are 0.54 and 0.04 respectively. This indicates that the source rocks are immature and incapable of generating hydrocarbon at this time. Hence it is imperative that any hydrocarbon in these rocks above are migrants.

(ii) Analysis indicating the presence of hydrocarbons: Using the extractable organic matter (C_{15+}) as a reference; it consist of both hydrocarbon and non-hydrocarbon components. The values of EOM ranges from 6.1-24.2. This value should be at a minimum (<0) within all the analyzed formations, ranging from kimmeridge clay to the coal units. An EOM value >1, is an indication of the presence of hydrocarbon within the formations. From the vitrinite reflectance values, it can be inferred that the source rocks are immature, and thus cannot generate hydrocarbon. So, the presence of the high EOM values, in particular the hydrocarbon component, is an indication that hydrocarbon must have migrated from lower sections (the Beta or Alpha compartment of the Midgard section) into the reservoir unit, which is the Middle Jurassic sandstones.

Comparing the hydrocarbon (HC) contents of the Heather formation (caprock) - 9.4, and that of the Kimmeridge clay(source rock)-6.1. It can be observed that the HC value of the Heather formation is higher than that of Kimmeridge clay, which is contrary to the fact that, Kimmeridge Clay has a higher petroleum production index, compared to heather formation. This is an anomaly, because the migrated hydrocarbon from the lower series is suppose to be situated within the reservoir unit (Middle Jurassic sandstone to lower Jurassic sandstone). Thus, the caprock unit (Heather formation), is suppose to have a lower HC value, due to its tiny pore spaces. Thus, a higher HC value of the Heather Formation compared to that of the kimmeridge clay, is an indication that hydrocarbon from the reservoir unit has leaked into the caprock. This is further confirmed using the Gas chromatography fingerprint technique, where an oil-oil correlation is established.

(iii) Geological age: Grantham & Wakefield (1988) demonstrated a general trend in the carbon number distribution of steranes through time, with the potential to act as age indicator for oils from marine sources, and indicated an overall increase in the amount of C steranes, and a decrease in C steranes through geological time.

Grantham & Wakefield (1988) calculated the C28/C29 ratio using both 20S and 20R isomers of the aaa steranes (m/z 217) e.t.c. They stated that this ratio is less than oils of lower Palaeozoic age and older, 0.4 - 0.7 for oils of upper Palaeozoic to lower Jurassic age, and greater than 0.7 for upper Jurassic to Miocene oils.

From the C28/C29 values, it can be inferred that the oil extract from the caprock and that within the reservoir rock are from source rocks of upper Paleozoic to lower Jurassic age range.

(iv) Degree of maturity: The CPI ratio is maturity dependent and decreases with the increasing thermal maturity of organic matter at the beginning of catagenesis. Values of about 1.0 indicate the advanced maturity of the investigated organic matter (Tissot & Welte, 1984).

The carbon preference index (CPI)-the numerical expression of odd-to-even- carbon-numbered C25-C35 n-alkanes- reaches an average value of 1.45 for the reservoir unit (drake-lower Jurassic unit), and 1.5 for the caprock unit (Heather fmt). This is an indication that both oils were generated from organic matter with similar degree of maturity. In addition, the other parameters are Pr/n-C17 and Ph/n-Cia are maturity and source dependent, and the lower these ratios, the higher the maturity. Thus, the values of these ratios in the reservoir and caprock are similar. This indicates that the oil extracts have similar thermal history.

(v) Depositional environment: Pristine/Phytane (Pr/Ph) is an indication of depositional environment with low specificity due to interference by thermal maturity and source input (Peters et al.,2005).The Pr/Ph ratio is a potential indicator of redox conditions during sedimentation and diagenesis(Kenneth, 1993). Ten Haven et al. (1987) stressed that high Pr/Ph (>3.0) indicates terrigenous input under oxic conditions and low Pr/Ph (<0.8) indicates anoxic/ hypersaline or carbonate environments, while a range of 0.8-3, indicates a mixed environment (having both marine and terrigenous inputs).

(vi) Source location: The distribution of C27:C28:C29 steranes has been found to be suitable for typing the organic matter and therefore it is a powerful tool for correlations (Jerry L. Clayton, 1994). The C27 dominance indicates marine algae or phytoplankton input, whereas abundant C29 steranes can generally indicate the terrestrial origin of sediment. The high concentration of the C28 steranes considered as a contribution of lacustrine algae.

The correlation of the oil extract in the caprock and reservoir rock based on genetic similarities confirms that the hydrocarbon within the reservoir unit is similar to that within the caprock. This establishes the fact that vertical migration of hydrocarbon occurred, from the reservoir rock into the caprock.

CONCLUSION

In this research, gas chromatography and rock-eval pyrolysis techniques were used to establish the presence of hydrocarbon within the caprock (Heather formation) in the Asgard field. The rock-eval data (vitrinite reflectance) indicates that the organic matter within the Caprock is immature, thus the hydrocarbon present within this section is non-indigenous.

Also, using the gas chromatography traces, it was established that the hydrocarbon within the caprock, originated from the reservoir rock, that is, vertical migration of hydrocarbon from the reservoir rock unit into the caprock occurred. This was confirmed by the genetic similarities of the rock extracts from the reservoir and caprock unit, in terms of; geological age, degree of maturity, depositional environment, and source location.

Furthermore, the volume of hydrocarbon within the caprock was estimated using an equation, where the saturation, porosity and thickness of both the reservoir unit and caprock material were considered. The results show that the volume of hydrocarbon within the caprock is less than 1% of the original oil in place within the reservoir. This indicates that the hydrocarbon migrated via capillary leakage mechanism, through the pores of the caprock material. Also, the rate of capillary leakage of hydrocarbon was estimated, and this was used to assess whether it will have detrimental effect on the preservation of the hydrocarbon within the reservoir. The results of this assessment showed that, the leakage rate will have minimal effect on the preservation and subsequent production of the hydrocarbon.

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