

# Gas chromatographic analysis of whole oil samples: implications for biodegradation in the Niger Delta

A. W. Mode<sup>1</sup> · O. A. Anyiam<sup>1</sup> · J. O. Amobi<sup>1</sup> · S. U. Nweke<sup>1</sup>

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**Abstract** The levels of biodegradation of five whole oil samples from five oil fields in the Niger Delta were assessed using a high-resolution gas chromatography. The results show that all the samples are at different levels of degradation ranging from slight to heavy. The crude oils from Fs, Bs and Qe fields had undergone extensive to heavy degradation, while those from Ai and Ea fields had undergone slight to moderate degradation. The low paraffinic content values in the samples suggest that the *n*-paraffins have been degraded and reduced consistently. The aromatic fractions (C<sub>14</sub>–C<sub>18</sub>) have been reduced slightly, though the 3-Methylhexane component was observed to show strong resistance to the bacterial attack even at deeper fields. These levels of biodegradation show indications that they could be caused by the degrading anaerobic bacteria present in the deep reservoir and/or by the influx of meteoric water, especially for the Bs crude, which is from an onshore field. As this degradation continues to deplete the light hydrocarbon components, the residual heavy components such as sulfur and asphaltenes are gradually concentrated, while the API gravity is consequently lowered.

**Keywords** Whole oil · Gas chromatography · Biodegradation · Quality

## Introduction

The evaluation of the decline in crude oil quality associated with biodegradation has become critical in recent years as offshore drilling has progressed into deeper water horizons. Biodegradation is the most alteration process in hydrocarbon reservoirs in many areas, in addition to a number of other alteration processes, such as water washing, phase separation, gravity segregation and de-asphalting. It gradually destroys oil spills and oil seeps by the sequential metabolism of various classes of compounds present in the oil (Bence et al. 1996). When biodegradation occurs in an oil reservoir, the process dramatically affects the fluid properties (Miiller et al. 1987) and hence the value and producibility of an oil accumulation. Specifically, oil biodegradation typically raises oil viscosity that reduces oil producibility and reduces the API gravity, which reduces the value of the produced oil. It also increases the asphaltene content relative to the saturated and aromatic hydrocarbon contents, concentration of certain metals and increases the sulfur content of the oil.

The biodegradation and water washing of crude oil are common in reservoirs located in areas invaded by surfaced derived meteoric formation waters, such as in the Niger Delta of Nigeria. Wherever meteoric waters penetrate deeply into a basin, any petroleum accumulations that they contact are altered. Paraffins, naphthenes and aromatics, including gases, liquids and solids, are all susceptible to microbial decomposition. The order in which the hydrocarbon compounds are oxidized depends on a variety of factors, but in general small molecules up to C<sub>20</sub> are consumed before large ones, and within the same molecular weight range the order is usually *n*-paraffins first, followed by iso-paraffins, naphthenes and aromatics; single-ring naphthenes and aromatics are attacked before iso-prenoids, steranes and triterpenes. Preferential

✉ O. A. Anyiam  
okwudiri.anyiam@unn.edu.ng

<sup>1</sup> Department of Geology, University of Nigeria, Nsukka, Nigeria

consumption of the low molecular weight components causes the high density (low API gravity) of the unconsumed residue (Wenger et al. 2002). Empirically, it has been noted that biodegraded oil accumulations occur in reservoirs that are at temperatures less than 80 °C (Connan 1984; Barnard and Bastow 1991). At higher temperatures, it appears that many of the microorganisms involved in subsurface oil biodegradation cannot exist. However, not all oil accumulations at temperatures less than 80 °C are biodegraded.

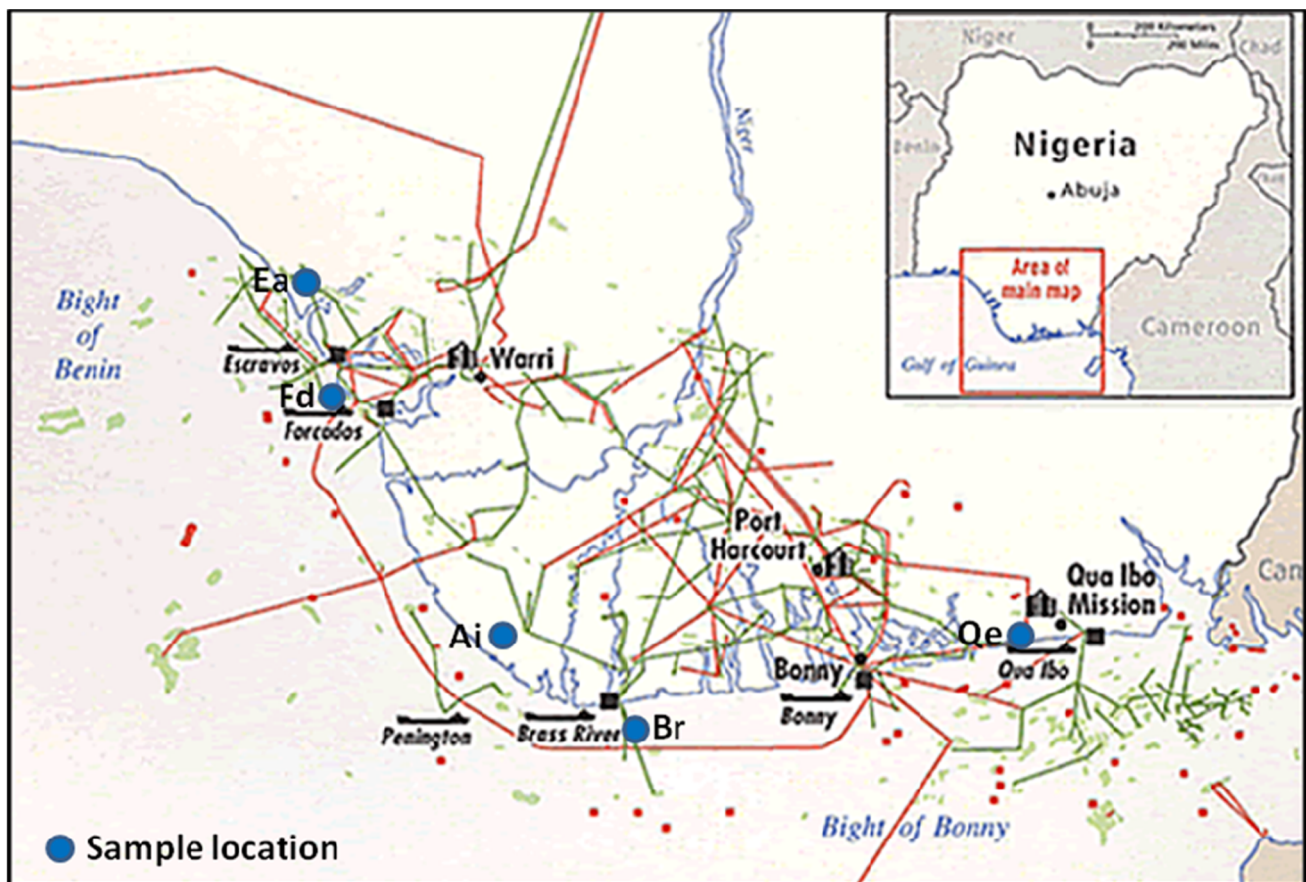
In the present study, the biodegradability of five crude oils of varied compositions from five different oil fields in the Niger Delta was examined. The results enabled the understanding of the different conditions in which crude oil composition and temperatures could affect hydrocarbon degradation.

### Geologic setting

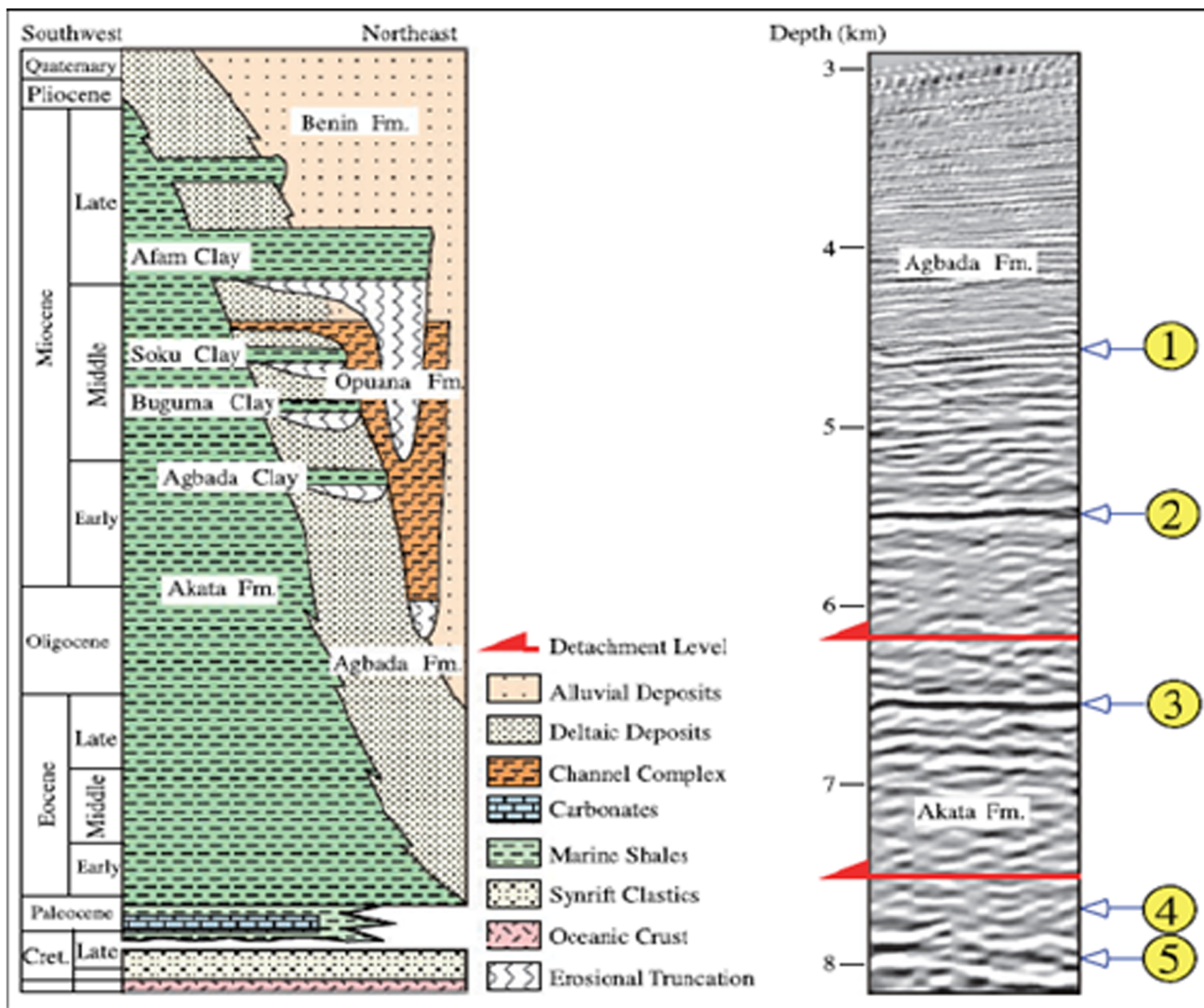
The Cenozoic Niger Delta is located at the intersection of the Benue Trough and South Atlantic Ocean where a triple junction developed during the separation of South America and Africa. The basin is situated between latitudes 3° and

6°N and longitudes 5° and 8°E (Fig. 1). The sedimentary fill shows an overall upward and updip transition from marine prodelta shales (Akata Formation) through an alternating sand/shale paralic interval (Agbada Formation) to continental sands (Benin Formation) (Fig. 2). The entire sedimentary succession of more than 8 km was deposited in a series of mega-structural units (depobelts) which become progressively younger from north to south, i.e., Eocene–Recent (Doust and Omatsola 1990).

The depobelts define a series of punctuations in the progradation of this delta system. Each of these mega-structures persisted for a given geologic time interval and was succeeded by a younger megastructure to the south. These depobelts strike northwest–southeast (NW–SE), sub-parallel to the present shoreline. They are tens of kilometers wide and are bounded by a growth fault to the north and a counter–regional fault seaward. Each sub-basin has its own separate integrity and contains a distinct shallow–upward depositional cycle with its own tripartite assembling of marine, paralic and continental deposits. Generally, these depobelts become narrower and tend to converge at the extremities of the delta (Evamy et al. 1978; Doust and Omatsola 1990).



**Fig. 1** Map of Niger Delta showing some oil fields and sample locations. Source Modified from GSO Corporation 2011, with permission from US Government



**Fig. 2** Schematic of the regional stratigraphy of the Niger Delta and variable seismic display of the main stratigraphic units in the outer fold and thrust belt and main reflectors, including (1) top of the

Agbada Formation, (2) top of the Akata Formation, (3) mid Akata reflection, (4) speculated top of the synrift clastic deposits and (5) top of the oceanic crust. Modified from Lawrence et al. (2002)

The top of the oil kitchen is variable across the delta; it ranges from below the top of Akata Shales to above the top of Akata Shales. The generated hydrocarbons rise along flanks from kitchens to structural culminations through appropriate migration pathways to be trapped as epigenetic hydrocarbons in the overlying reservoir rocks of mainly Agbada Formation (Nwachukwu and Chukwurah 1986; Stacher 1995).

**Materials and methods**

This study involves the analysis of five crude oil samples using a high-resolution Gas Chromatographic Varian 3400 GC machine fitted with 45 m × 0.25 mm fused

silica column coated with a nonpolar stationary phase (DB1). Both the injector and detector temperatures were set at 300 °C. The oven was heated at 30 °C for initial isothermal period of 2 min then followed by 300 °C at the rate of 6 °C/min for the final isothermal period of 13 min. The carrier gas is hydrogen, and it was set at a flow rate of 2 ml/min. The collection and processing of the gas chromatographic data were done using the Atlas software through a chromatographic server, which generated the respective gas chromatograms and the corresponding gas injection reports containing peak heights and areas. These injection results were used to make inference on the degree of biodegradation of the crude samples (Tables 1, 2, 3).

**Table 1** Paraffinicity of the oil samples

Parameters	Oil samples				
	Fd	Bs	Ai	Qe	Ea
Isoheptane	1.67	1.38	0.96	1.42	1.37
Heptanes	0.05	0.07	0.07	0.05	0.06
nHeptane/mcHexane	1.1	1.01	4.55	1.26	1.37
Total	2.82	2.46	5.58	2.73	2.8
% Remained	17	15	34	17	17
% Lost	83	85	66	83	83

**Table 2** Aromaticity of the oil samples

Parameters	Oil samples				
	Fo	Bs	Ai	Qe	Ea
Benzene/ <i>n</i> -Hexane C <sub>12</sub> /C <sub>10</sub>	2.28	0.73	1.51	6.44	8.2
Toluene/ <i>n</i> -Heptane C <sub>25</sub> /C <sub>21</sub>	0.76	0.86	0.54	0.44	0.73
Xylene/ <i>n</i> -Octane C <sub>31</sub> /C <sub>29</sub>	0.74	0.68	0.76	0.31	0.25
Total = 25.23	3.78	2.27	2.81	7.19	9.18
% Remained	15	09	11	28.5	36.5
% Lost	85	91	89	71.5	63.5

## Results and discussion

The results of the high-resolution gas chromatographic analyses of the five crude oil samples show different degrees of oil degradation. In the Fs oil sample, there is a general depletion of the *n*-alkanes up to C<sub>13</sub> (Fig. 3). The fractions up to C<sub>9</sub> have been striped completely, and the fractions (C<sub>11</sub>–C<sub>13</sub>) have been severely degraded. The cycloalkanes from 2-methylhexane (nC<sub>13</sub>) through 1, 1-dimethylcyclopentane have been slightly reduced (Table 4). The pristine has been removed completely while the phytane has depleted slightly. The value of phytane to nC<sub>18</sub> is 1.05, which is an indication that the oil has been degraded moderately. The relatively low pristine/phytane ratio (low pr/ph ratio) indicates a reducing source (Hunt 1995). The aromatic content calculated with the value of toluene to *n*-heptane and that of xylene (m&p) to *n*-octane is 0.75 and 0.74, respectively (Table 2). These values are high showing that the light-end hydrocarbons have been depleted. It is suspected that anaerobic bacteria such as sulfate-reducing bacteria are responsible for this slight to moderate biodegradation of the Fs crude.

The light fractions of C<sub>5</sub>–C<sub>10</sub> and part of the C<sub>11</sub> fraction have been removed completely from the whole oil gas chromatograph of the Bs crude (Fig. 4). The remaining parts of the fractions (C<sub>12</sub>–C<sub>13</sub>) and the cycloalkanes from 2-methylhexane through 1-cis-3-dimethylcyclopentane have been depleted greatly. The ratio of the isoprenoids to

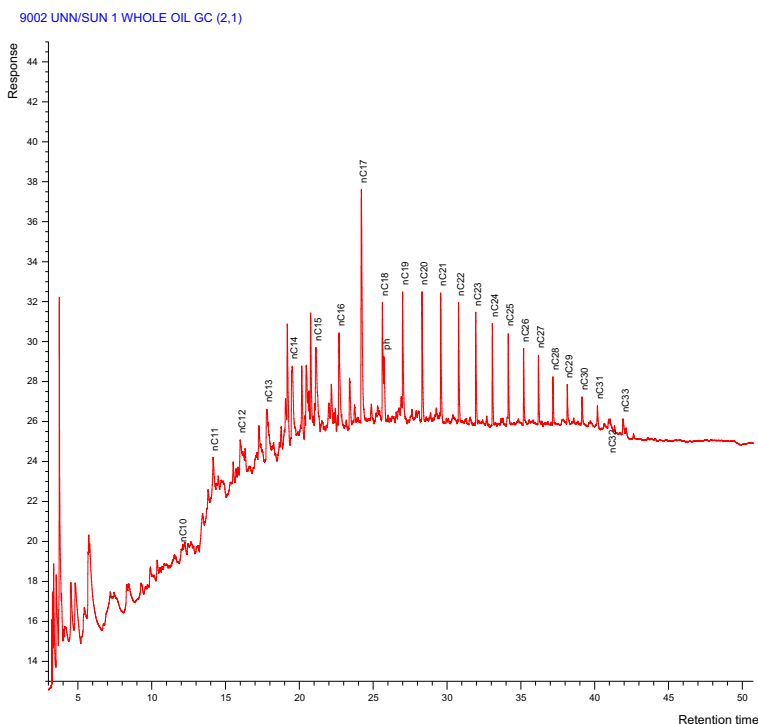
**Table 3** Integrated and percentage areas of Fd oil component

Name	Hydrocarbon	Fd oil	
		Integrated area (IA)	Percentage area (PA)
<i>n</i> -Hexane	nC <sub>10</sub>	10.57	1.48
2,4-DMP	nC <sub>11</sub>	23	3.18
Benzene	nC <sub>12</sub>	24.46	3.37
Cyclohexane	nC <sub>13</sub>	78.89	10.11
2-Mhexane	nC <sub>14</sub>	115.7	14.16
2,3-DMP	nC <sub>15</sub>	68.31	8.88
1,1-DMP	nC <sub>16</sub>	52.04	6.91
3-Mhexane	nC <sub>17</sub>	68.32	8.88
1-c-3-DMCP	nC <sub>18</sub>	22.268	3.08
Phytane	ph	23.37	3.22
1-t-2-DMCP	nC <sub>19</sub>	27.65	3.8
2,2,4-TMP	nC <sub>20</sub>	26.35	3.62
<i>n</i> -Heptane	nC <sub>21</sub>	23.2	3.2
MycycloHexa	nC <sub>22</sub>	21	2.91
2,5DMHexa	nC <sub>23</sub>	20.26	2.81
2,3,4-TMP	nC <sub>24</sub>	17.67	2.46
Toluene	nC <sub>25</sub>	17.5	2.43
3-Mheptane	nC <sub>26</sub>	13.55	1.9
2,2,5-TMP	nC <sub>27</sub>	12.68	1.78
Cycloheptane	nC <sub>28</sub>	7.96	1.12
<i>n</i> -Octane	nC <sub>29</sub>	8.87	1.25
Ethylbenzene	nC <sub>30</sub>	6.2	0.88
<i>m</i> -Xyle/pXyl	nC <sub>21</sub>	6.54	0.92
<i>o</i> -Xylene	nC <sub>32</sub>	0.014	0.2
<i>n</i> -Nonane	nC <sub>33</sub>	4.96	0.7

Percentage area = area of peak A/(area of peak A + total peak area) × 100

adjacent *n*-alkanes shows an increase with increasing biodegradation (Table 2). The pristine has been completely removed leaving small amount of phytane, while the phytane/nC<sub>18</sub> is also high (1.20), which indicates that the oil is moderately biodegraded (Table 3). The 3-Methylhexane (nC<sub>17</sub>) has strong resistance to the bacterial attack; hence, it remains the most abundant hydrocarbon component in the sample (Table 4). The isoheptane, heptanes and *n*-heptane to methylcyclohexane contents are 1.38, 0.07 and 1.01, respectively (Table 1). These values are very low indicating that the paraffinic content of the oil sample has been reduced greatly. The aromatic content calculated with the value of toluene to *n*-heptane is highest (0.86) compared to the aromatic content of other oil samples. Similarly, the content of xylene (m&p) to *n*-octane of the sample is also high (0.68). These values show that the aromatics have been degraded slightly. The Bs crude oils are produced from the onshore fields in the coastal swamp depobelt of the Niger Delta. Since shallow onshore

**Fig. 3** Gas chromatogram for crude oil sample Fd

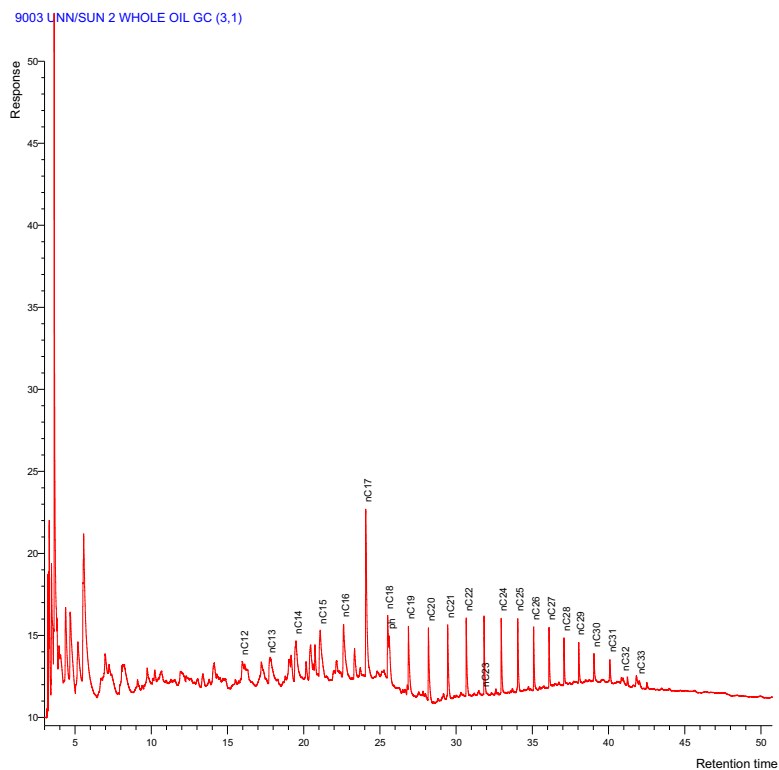


**Table 4** Integrated and percentage areas of Bs oil component

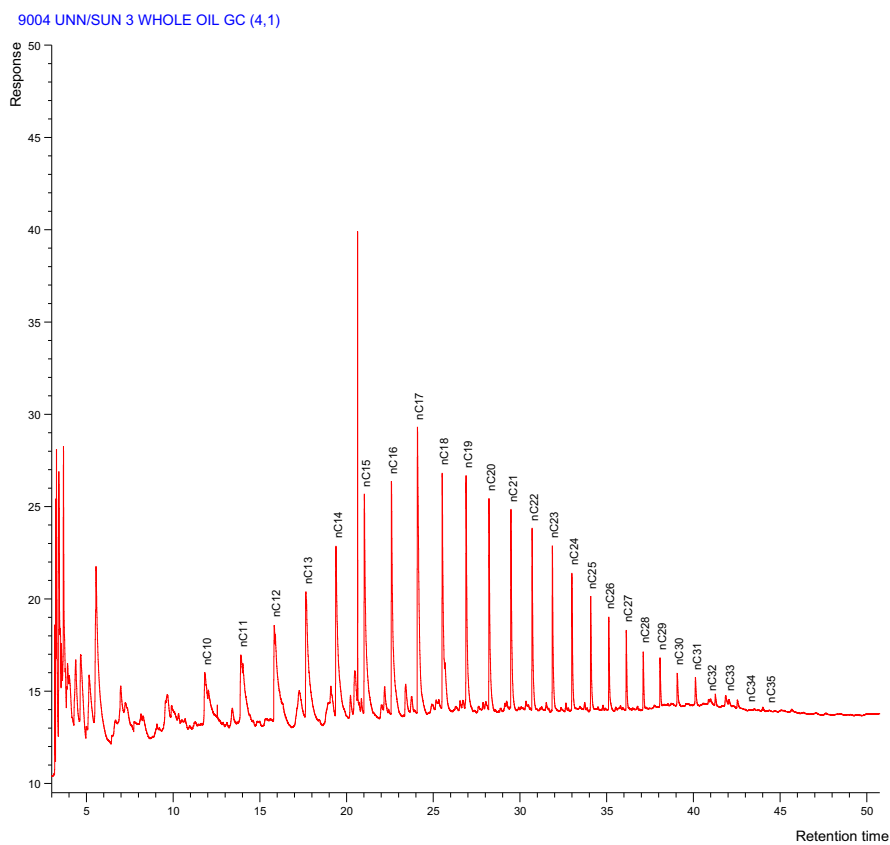
Name	Hydrocarbon	Bs oil	
		Integrated area (IA)	Percentage area (PA)
<i>n</i> -Hexane	nC <sub>10</sub>	—	—
2,4-DMP	nC <sub>11</sub>	—	—
Benzene	nC <sub>12</sub>	3.19	0.73
Cyclohexane	nC <sub>13</sub>	8	1.81
2-Mhexane	nC <sub>14</sub>	61.65	12.43
2,3-DMP	nC <sub>15</sub>	34.84	7.43
1,1-DMP	nC <sub>16</sub>	42.34	8.88
3-Mhexane	nC <sub>17</sub>	57.06	11.61
1-c-3-DMCP	nC <sub>18</sub>	15.806	3.51
Phytane	ph	19.02	4.2
1-t-2-DMCP	nC <sub>19</sub>	22.8	5
2,2,4-TMP	nC <sub>20</sub>	21.25	4.66
<i>n</i> -Heptane	nC <sub>21</sub>	18.48	4.08
McycloHexa	nC <sub>22</sub>	18.24	4.03
2,5DMHexa	nC <sub>23</sub>	16.94	3.75
2,3,4-TMP	nC <sub>24</sub>	16.43	3.64
Toluene	nC <sub>25</sub>	15.77	3.5
3-Mheptane	nC <sub>26</sub>	13.63	3.04
2,2,5-TMP	nC <sub>27</sub>	12.57	2.81
Cycloheptane	nC <sub>28</sub>	9.61	2.16
<i>n</i> -Octane	nC <sub>29</sub>	9.25	2.1
Ethylbenzene	nC <sub>30</sub>	7	1.59
<i>m</i> -Xyle/pXyl	nC <sub>21</sub>	6.24	1.42
<i>o</i> -Xylene	nC <sub>32</sub>	3.4	0.78
<i>n</i> -Nonane	nC <sub>33</sub>	0.83	0.19

Percentage area = area of peak A/(area of peak A + total peak area) × 100

**Fig. 4** Gas chromatogram for sample Bs



**Fig. 5** Gas chromatogram for sample Ai



**Table 5** Integrated and percentage areas of Ai oil component

Name	Hydrocarbon	Ai oil	
		Integrated area (IA)	Percentage area (PA)
<i>n</i> -Hexane	nC <sub>10</sub>	39.25	3.79
2,4-DMP	nC <sub>11</sub>	52	4.8
Benzene	nC <sub>12</sub>	62.67	5.73
Cyclohexane	nC <sub>13</sub>	82.2	7.38
2-Mhexane	nC <sub>14</sub>	125.57	10.85
2,3-DMP	nC <sub>15</sub>	87.4	7.81
1,1-DMP	nC <sub>16</sub>	95.78	8.49
3-Mhexane	nC <sub>17</sub>	95.8	8.5
1-c-3-DMCP	nC <sub>18</sub>	71.32	6.46
Phytane	ph	–	–
1-t-2-DMCP	nC <sub>19</sub>	56.98	5.23
2,2,4-TMP	nC <sub>20</sub>	47.84	4.43
<i>n</i> -Heptane	nC <sub>21</sub>	43.35	4.03
McycloHexa	nC <sub>22</sub>	5.36	0.52
2,5DMHexa	nC <sub>23</sub>	31.41	2.95
2,3,4-TMP	nC <sub>24</sub>	27.06	2.56
Toluene	nC <sub>25</sub>	22.92	2.17
3-Mheptane	nC <sub>26</sub>	18.02	1.72
2,2,5-TMP	nC <sub>27</sub>	15.2	1.45
Cycloheptane	nC <sub>28</sub>	10.41	1
<i>n</i> -Octane	nC <sub>29</sub>	9	0.86
Ethylbenzene	nC <sub>30</sub>	7.75	0.75
<i>m</i> -Xyle/pXyl	nC <sub>21</sub>	6.76	0.65
<i>o</i> -Xylene	nC <sub>32</sub>	3.89	0.38
<i>n</i> -Nonane	nC <sub>33</sub>	0.96	0.09
Cyclooctane		0.02	0.02

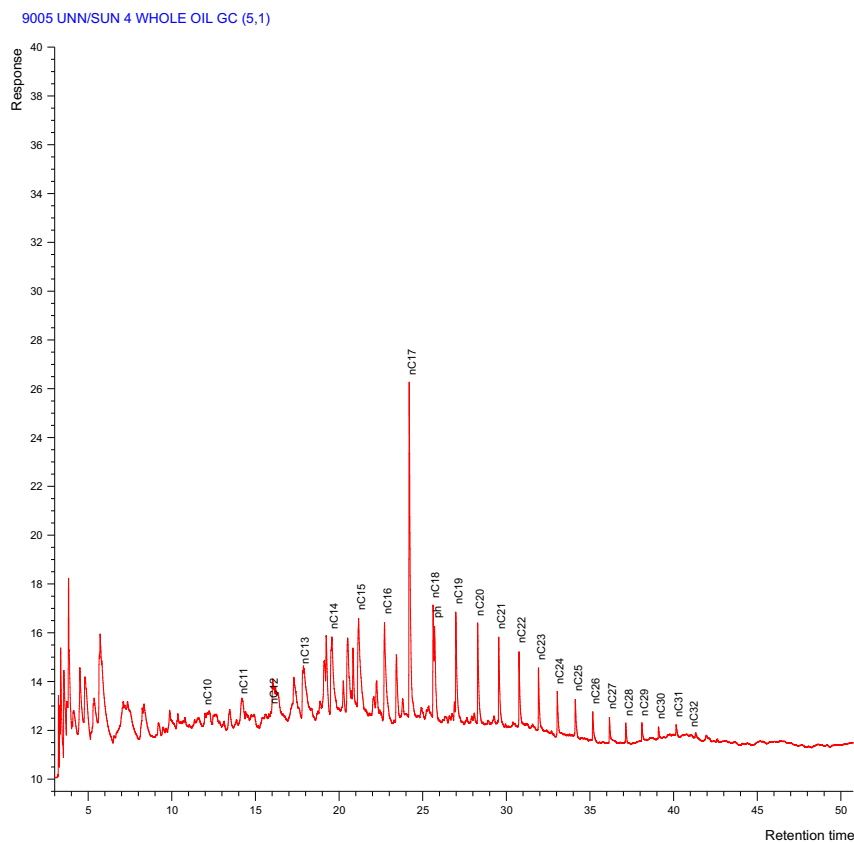
Percentage area = area of peak A/(area of peak A + total peak area) × 100

reservoirs with hydrodynamic drive from meteoric water influx are the precursor for heavy biodegradation (Wenger et al. 2002), it is suspected that influx of meteoric water could be the cause of this moderate to heavy biodegradation for the Bs crude.

The GC fingerprint of the Ai crude shows that the light fractions have been removed up to nC<sub>9</sub> while the fraction of C<sub>11</sub>–C<sub>13</sub> has been reduced slightly (Fig. 5; Table 5). It could be observed that the complete suite of the cycloalkanes (the naphthenes) from 2-Methylhexane through 2, 2, 4-Trimethylpentane is still intact, whereas the isoprenoids (pristine and phytane) are totally absent. This is an indication that some pristine and phytane may be preferentially removed from sediments by the reaction of isoprenoids with hydrogen sulfide (H<sub>2</sub>S) to form thioisoprenoids or degradation of C<sub>40</sub> to form isoprenoid ethers (Albaiges et al. 1985). The preferential removal of these isoprenoids occurs where methanogenic bacteria were the dominant degrading organisms. The oil had undergone slight to moderate biodegradation because of the removal

of the light-end *n*-alkanes, including isoalkanes and isoprenoids by anaerobic bacteria such as sulfate-reducing bacteria, iron oxide-reducing bacteria and bicarbonate-reducing bacteria.

Additionally, the GC result of Qe crude sample shows that the *n*-paraffins have been degraded up to C<sub>13</sub>, with the C<sub>5</sub>–C<sub>10</sub> fractions having been completely removed. The fractions (C<sub>14</sub>–C<sub>18</sub>) have been reduced slightly from 2-Methylhexane through 1-cis-3-Dimethylcyclopentane (Fig. 6; Table 6). The 3-Methylhexane has strong resistance to the bacterial attack; hence, it remains the most abundant hydrocarbon compound in the sample. The phytane/nC<sub>18</sub> value is higher (1.45) compared to the values of the other oil samples. The values of isoheptane, heptanes and *n*-heptane to Methylcyclohexane are 3.7, 0.05 and 1.26, respectively (Table 1). These values are very low indicating that the paraffinic content of the oil sample has been reduced greatly. The value of the aromaticity calculated with that of toluene to *n*-heptane is the lowest (0.44) compared to the aromatic content of other oil samples.

**Fig. 6** Gas chromatogram for sample Qe**Table 6** Integrated and percentage areas of Qe oil component

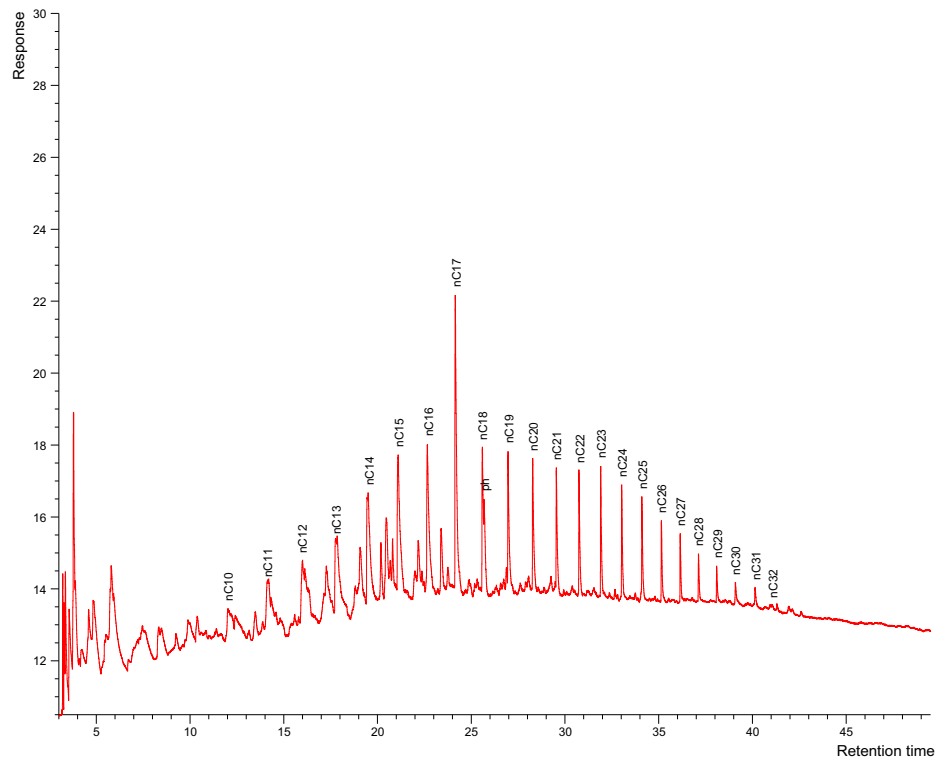
Name	Hydrocarbon	Qe oil	
		Integrated area (IA)	Percentage area (PA)
<i>n</i> -Hexane	nC <sub>10</sub>	1.1	0.25
2,4-DMP	nC <sub>11</sub>	1.4	0.31
Benzene	nC <sub>12</sub>	7.5	1.66
Cyclohexane	nC <sub>13</sub>	37.5	7.79
2-Mhexane	nC <sub>14</sub>	69.1	13.47
2,3-DMP	nC <sub>15</sub>	45.4	9.28
1,1-DMP	nC <sub>16</sub>	52.8	10.63
3-Mhexane	nC <sub>17</sub>	71	13.79
1- <i>c</i> -3-DMCP	nC <sub>18</sub>	16.574	3.6
Phytane	ph	24.5	5.23
1- <i>t</i> -2-DMCP	nC <sub>19</sub>	23.3	5
2,2,4-TMP	nC <sub>20</sub>	19.4	4.19
<i>n</i> -Heptane	nC <sub>21</sub>	16.7	3.62
McycloHexa	nC <sub>22</sub>	13.1	2.87
2,5DMHexa	nC <sub>23</sub>	10.7	2.35
2,3,4-TMP	nC <sub>24</sub>	8	1.77
Toluene	nC <sub>25</sub>	7.2	1.6
3-Mheptane	nC <sub>26</sub>	5	1.11
2,2,5-TMP	nC <sub>27</sub>	4	0.89
Cycloheptane	nC <sub>28</sub>	3.2	0.72
<i>n</i> -Octane	nC <sub>29</sub>	3.14	0.7
Ethylbenzene	nC <sub>30</sub>	2.1	0.47
<i>m</i> -Xyle/pXyl	nC <sub>21</sub>	1	0.22
<i>o</i> -Xylene	nC <sub>32</sub>	0.2	0.045
<i>n</i> -Nonane	nC <sub>33</sub>	–	–

Percentage area = area of peak A/(area of peak A + total peak area) × 100



**Fig. 7** Gas chromatogram for sample Ea

9006 UNN/SUN 5 WHOLE OIL GC (6,1)



**Table 7** Integrated and percentage areas of Ea oil component

Name	Hydrocarbon	Ea oil	
		Integrated area (IA)	Percentage area (PA)
<i>n</i> -Hexane	nC <sub>10</sub>	1.31	0.3
2,4-DMP	nC <sub>11</sub>	2.63	0.6
Benzene	nC <sub>12</sub>	11.01	2.46
Cyclohexane	nC <sub>13</sub>	14	3.11
2-Mhexane	nC <sub>14</sub>	72.32	14.23
2,3-DMP	nC <sub>15</sub>	44.31	9.23
1,1-DMP	nC <sub>16</sub>	48.58	10.03
3-Mhexane	nC <sub>17</sub>	49.58	10.21
1- <i>c</i> -3-DMCP	nC <sub>18</sub>	15.689	3.47
Phytane	ph	18.26	4.02
1- <i>t</i> -2-DMCP	nC <sub>19</sub>	20	4.38
2,2,4-TMP	nC <sub>20</sub>	18.06	3.98
<i>n</i> -Heptane	nC <sub>21</sub>	14.93	3.31
McycloHexa	nC <sub>22</sub>	14.12	3.14
2,5DMHexa	nC <sub>23</sub>	13.52	3.01
2,3,4-TMP	nC <sub>24</sub>	11.87	2.65
Toluene	nC <sub>25</sub>	10.72	2.4
3-Mheptane	nC <sub>26</sub>	8.4	1.89
2,2,5-TMP	nC <sub>27</sub>	6.97	1.57
Cycloheptane	nC <sub>28</sub>	4.34	0.99
<i>n</i> -Octane	nC <sub>29</sub>	3.87	0.88
Ethylbenzene	nC <sub>30</sub>	2.57	0.59
<i>m</i> -Xyle/pXyl	nC <sub>31</sub>	0.943	0.22
<i>o</i> -Xylene	nC <sub>32</sub>	27.89	6.01
<i>n</i> -Nonane	nC <sub>33</sub>	–	–

Percentage area = area of peak A/(area of peak A + total peak area) × 100

Similarly, the value of xylene (m&p) to *n*-octane of the sample is very low (0.31). These calculated values show that the aromatics which are more resistant to biodegradation have been greatly degraded, hence under sulfate-reducing conditions (Margesin and Schinner 2001).

The Ea crude oil sample shows that the light fractions up to C<sub>9</sub> have been removed completely. There is also moderate depletion of the fractions (C<sub>11</sub>–C<sub>13</sub>) in the reservoir and slight decrease in the cycloalkanes fractions (Fig. 7). The 3-methylhexane component remains the most abundant hydrocarbon compound in the oil samples (Tables 3, 4, 5, 6, 7). The pristane has been removed completely, while the value of phytane to nC<sub>18</sub> is relatively high (1.16), showing that the oil had undergone moderate biodegradation. The aromatic content of the oil calculated with the ratio of benzene to *n*-hexane and toluene to *n*-heptane are 8.2 and 0.73, respectively (Table 2). These relatively high values suggest two possible secondary processes that occurred in the oil reservoir: Either that the light-end hydrocarbon compounds in the oil have been attacked and depleted by degrading anaerobic bacteria present in the deep reservoir or that the volatile hydrocarbons have been lost through evaporative fractionation or phase separation. The extent of biodegradation in this oil is ranked moderate because the isoalkanes, including the isoprenoid pristane, and cycloalkanes have been degraded.

## Conclusions

In this study, the whole oil gas chromatograms of the five oil samples show that they are at different levels of degradation. The results show that crude oil samples from Fs, Bs and Qe fields had undergone extensive to heavy degradation while those from Ai and Ea fields had undergone slight to moderate degradation. In this study, the analyses show that virtually all the oil samples used have been degraded. The *n*-paraffins have been degraded and reduced consistently in all the samples. This is confirmed by the low values of the paraffinic content in the samples. Although the fractions (C<sub>14</sub>–C<sub>18</sub>) have been reduced slightly, the 3-Methylhexane component has been observed to show strong resistance to the bacterial attack, and hence it remains the most abundant hydrocarbon component in the samples. These levels of biodegradation could be caused by degrading anaerobic bacteria present in the deep reservoir and/or by the influx of meteoric water, especially for the Bs crude, which is from an onshore field.

As these degrees of biodegradation continue to deplete the light hydrocarbon components, the residual heavy

components such as sulfur and asphaltenes are gradually concentrated, while the API gravity is consequently lowered. These effects will dramatically affect the fluid properties and hence the value and producibility of the oil accumulations in the basin.

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