Study on Oil-Source Correlation Methods of Severely Biodegraded Oils in Bozhong Subbasin, Bohai Bay Basin, China*

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Abstract

There are three organic-rich, oil-prone source rock intervals in Bozhong Subbasin, Bohai Bay Basin: the third and the first members of Shahejie Formation, and the Dongying Formation. Most oils with burial depths less than 2,000m (6,562ft) are severely biodegraded as evidenced by the occurrence of 25-norhopanes. To recognize the source of the biodegraded oils, biomarker characteristics of the three source rock intervals are identified and several oil-source correlation methods are applied.

The upper Eocene third member of Shahejie Formation (E2s3) is dominated by semi-deep and deep lacustrine facies mudstone with highest TOC contents and hydrocarbon indices, and it has low gammacerane, C₁₉ tricyclic terpane and C₂₄ tetracyclic terpane contents, and high 4,23,24-trimethyl triaromatic dinosterane and 4-methyl-24-ethyl triaromatic sterane contents, indicating light saline water and blooming dinoflagellates paleoenvironment. The lower Oligocene first member of Shahejie Formation (E3s1) is saline lacustrine facies mudstone, lime mudstone and limestone with relatively high TOC contents and hydrocarbon indices. It has high gammacerane and 4,23,24-trimethyl triaromatic dinosterane contents, low C₁₉ tricyclic terpane, C₂₄ tetracyclic terpane and 4-methyl-24-ethyl triaromatic sterane contents. The upper Oligocene Dongying Formation (E3d) is semi-deep and deep lacustrine facies mudstone in its lower part, with relatively high contents of vitrinite and nonfluorescent amorphous organic matter and classified as mixed type I and III kerogens. It has low gammacerane and 4-methyl triaromatic sterane homologues contents, high C₁₉ tricyclic terpane and C₂₄ tetracyclic terpane contents, indicating fresh water, freshwater algae dominated and partially terrigenous organisms input paleoenvironment.

Carbon isotope of whole oil, 4-methyl triaromatic sterane homologues, gammacerane, C₁₉ tricyclic terpane, C₂₄ tetracyclic terpane, carbazole, and crude oil density and viscosity are used to determine the source of severely biodegraded oils. The biodegradation has little effect to carbon isotope of whole oil. The whole oil carbon isotopes from E2s3 and E3d source rock intervals are heavier than -27‰ and lighter than -28‰ respectively in east Bozhong Subbasin, and that from E3s1 source rock interval are intervenient. 4-methyl triaromatic sterane homologues discussed above can distinguish oils from the three source rock intervals, and they are seldom influenced by biodegradation.
Selected References


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**Double dynamics: regional compression and mantle uplift**

**Bozhong Subbasin: incised by multi-basement faults**

Tang Liangjie, 2009
Three major source rocks: $E_2 s_3$, $E_3 s_1$ and $E_3 d$. The upper, the less important.
Neogene Guantao and Minghuazhen Formation develops shallow water delta facies

Neogene is the major reservoir in Bozhong Subbasin, bearing huge heavy oil reserves.
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Light saline lacustrine facies

Excellent source rock thickness: up to 400m; TOC: up to 4%

Low Gammacerane; low diasteranes, low C\textsubscript{19} tricyclic terpane and C\textsubscript{24} tetracyclic terpane; high 4-methyl steranes, high C\textsubscript{27}-C\textsubscript{29} triaromatic steranes
🔹 Saline water lacustrine facies
🔹 Excellent source rock thickness: up to 250m; TOC: up to 3.5%
🔹 High Gammacerane; low diasteranes, low C₁₉ tricyclic terpane and C₂₄ tetracyclic terpane, low 4-methyl steranes, low 4-methyl triaromatic steranes and 4-methyl-24-ethyl triaromatic steranes; high 4,23,24-trimethyl triaromatic dinosteranes

PL3-1-1 oil from E₃s₁ source rock

m/z 191

m/z 217

m/z 191

m/z 245

C₁₉ TT

C₂₃ TT

C₂₆ TT

C₂₄ Te

C₂₇ diasteranes

4-MS

Ga

NL: 4.27E4
m/z = 190.50-191.50
F: MS
geoa09127
6 2256.5 oil

NL: 5.38E3
m/z = 216.50-217.50
F: MS
geoa09127
6 2256.5 oil

NL: 5.88E3
Base Peak
m/z = 244.50-245.50
F: MS
geoa09127
6 2256.5 oil

NL: 2.58E4
Base Peak
m/z = 230.50-231.50
F: MS
geoa09127
2256.5 oil

NL: 6.66E2
m/z = 216.50-217.50
F: MS
geoa09127
6 2256.5 oil
◆ Fresh water lacustrine facies
◆ Excellent source rock thickness: up to 450m; TOC: up to 3%
◆ Low Gammacerane; high diasteranes, high C_{19} tricyclic terpane and C_{24} tetracyclic terpane; low 4-methyl steranes, low C_{27}-C_{29} triaromatic steranes
oil from $E_3 s_1$ SR

oil from $E_3 d$ SR

oil from mostly $E_2 s_3$, partly $E_3 s_1$ SR

$E_2 s_3$, $E_3 s_1$, $E_3 d$ effective SR

$E_3 s_1$, $E_3 d$ effective SR

Study Area, east of Bozhong Subbasin

Penglai9-1 oilfield

Penglai19-3 oilfield

South Sag of Bodong Depression
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1. Geological background

2. Biomarker characteristics of three kinds of oils

3. Oil-source correlation of severely biodegraded oils
Penglai9-1 oilfield: Mesozoic granite buried hill and Neogene sandstone reservoirs, 7-8 level of oil biodegradation

- **Direction**: Bodong or Miaoxi?
- **Source rock**: $E_2 s_3$, $E_3 s_1$, $E_3 d$?
- **Difference**: Mz hill and Neogene?
Oil-source Correlation Methods of Severely Biodegraded Oils

◆ Carbon isotope of whole oil: affected little by biodegradation
◆ Aromatic hydrocarbon: C_{27}-C_{29} triaromatic steranes
◆ Saturated hydrocarbon: Gammacerane
◆ Non-hydrocarbon: carbazole absolute concentration and kinds
◆ Crude oil properties: density and viscosity
Carbon Isotope of Whole Oil (CIWO)

Saturated hydrocarbon
Aromatic hydrocarbon
Non-hydrocarbon
Asphaltenes

δ\textsuperscript{13}C (‰)

-28 -27 -26

depth (m)

δ\textsuperscript{13}C CIWO ‰(PDB)

Gang Wenzhe et al, 2011

δ\textsuperscript{13}C‰(PDB)

-31 -29 -27 -25 -23

-31 -29 -27 -25 -23

-28 -27.5 -27

-28 -27.5 -27

-28 -27.5 -27

-28 -27.5 -27

PL9-1
PL9-1-2
PL9-1-3
PL9-1-4
PL9-1-5
PL9-1-6
PL9-1-7
PL9-1-8
PL9-1-9
PL9-1-11
PL9-1-12
PL9-1-14
C_{27}-C_{29} 4-methyl Triaromatic Sterane Homologues

1. 4,23,24-trimethyl triaromatic dinosteranes (C_{29}), TADS;
2. 4-methyl-24-ethyl triaromatic steranes (C_{29}), 4-M-24-ETAS;
3. 3-methyl-24-ethyl triaromatic steranes (C_{29});
4. 3-methyl-24-methyl triaromatic steranes (C_{28});
5. 4-methyl triaromatic steranes (C_{27}), 4-MTAS;
6. 3-methyl triaromatic steranes (C_{27}), 3-MTAS;

◆ Aromatization possible products of 4-methyl sterane homologues

4,23,24-trimethyl triaromatic dinosteranes originating from dinoflagellates adapt to saline water, while 4-methyl triaromatic steranes and 4-methyl-24-ethyl triaromatic steranes originating from dinoflagellates adapt to slight saline water.

C_{27}-C_{29} 4-methyl triaromatic sterane homologues can distinguish oils from E_{2}s_{3}, E_{3}s_{1}, and E_{3}d source rocks. Oils of Penglai9-1 buried hill are mainly from E_{2}s_{3} and E_{3}s_{1} source rocks; Oils of Penglai9-1 Neogene are mainly from E_{3}s_{1} source rock, and some are from E_{3}d source rock.
Oils of Penglai9-1 Buried Hill are from $E_2S_3$ and $E_3S_1$ Source Rocks

PL9-1-2 Mz buried hill oil
PL9-1-4 Mz buried hill oil
PL9-1-8 Mz buried hill oil

PL13-2-D29 Neogene oil is from $E_2S_3$ and $E_3S_1$ source rocks of Bodong Depression

PL19-3-D29 Neogene oil is from $E_2S_3$ source rock

PL15-2-1 Neogene oil is from $E_3S_1$ source rock of Miaoxi Depression

PL15-2-1D Neogene oil is from $E_2S_3$ and $E_3S_1$ source rocks of Bodong Depression
Oils of Penglai9-1 Neogene are Mainly from E₃s₁ Source Rock

PL9-1-2 Neogene oil
PL9-1-2 Neogene oil
PL9-1-3 Neogene oil
PL9-1-4 Neogene oil
PL3-1-1 Neogene oil is from E₃s₁ source rock of Bodong Depression
PL3-1-1 Neogene oil is from E₃s₁ source rock of Miaoxi Depression

PL15-2-1 Neogene oil is alike
PL15-2-1 Neogene oil is alike
PL15-2-1 Neogene oil is alike
PL15-2-1 Neogene oil is alike

Oils of Penglai9-1 Neogene are Mainly from E₃s₁ Source Rock
**Buried hill oils:** mainly from $E_2 s_3$ and $E_3 s_1$ SR, some are from $E_3 d$ SR

**North Neogene oils:** from $E_2 s_3$ and $E_3 s_1$ SR

**Middle Neogene oils:** mainly from $E_3 s_1$ SR

**South Neogene oils:** from $E_3 s_1$ and/or $E_3 d$ SR
Gammacerane Abundance: Buried Hill Oils Lower than Neogene Oils

- m/z 191
- C_{30}H
- C_{29}25-nH
- C_{29}Ts
- Ga
- C_{19}TT
- C_{23}TT
- C_{24}Te
- C_{26}TT

- Ga/C_{30}H
- Ga/C_{29}Ts
- C19TT/C23TT
- C24Te/C26TT

- m/z 191
- Base Peak
- m/z=
- 190.50-
- 191.50 F:
- MS
- gaea101320
- 1281-1360

- Relative Abundance
- Time (min)
- 0 10 20 30 40 50 60 70 80 90 100

- 0 20 40 60 80 100

- 0.0 0.4 0.8 1.2 1.6

- 0.0 0.4 0.8 1.2 1.6

- 0.0 0.1 1 10

- + oils from Penglai9-1 buried hill
- + oils from Penglai9-1 Neogene

- + C19TT/C23TT
- + C24Te/C26TT

- + Ga/C_{30}H
- + Ga/C_{29}Ts

- + C_{29}25-nH/C_{30}H

- + C_{19}TT/C_{23}TT
- + C_{24}Te/C_{26}TT

- + C_{29}25-nH/C_{30}H

- + Ga/C_{30}H

- + Ga/C_{29}Ts

- + C_{29}25-nH/C_{30}H

- + C_{29}25-nH/C_{30}H
Absolute abundance of carbazole decreasing
N shielded type (1,8-dimethy carbazole) relative abundance increasing

Wang Tieguan, 2011
Crude Oil Density and Viscosity Variation of Penglai9-1 Buried Hill

Crude Oil Density and Viscosity Variation of Penglai9-1 Neogene

Mz buried hill

Neogene

PL9-1-14 PL9-1-5 PL9-1-1 PL9-1-2 PL9-1-4

PL9-1-14 PL9-1-5 PL9-1-1 PL9-1-2 PL9-1-4

PL9-1-3 PL9-1-1 PL9-1-2 PL9-1-4

PL9-1-3 PL9-1-1 PL9-1-2 PL9-1-4
Petroleum System:

- Effective source rock?
- Source rock distribution?
- Migration pathway?
- Reservoir model?
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