Al-Noor Journal Oil and Gas Studies, Vol 2, No. 2, 2026 (41-48)
ISSN: 3078-8706 Doi https://doi.org/10.69513/jnog.v2.i2.a1

Al-Noor Journal for Oil and Gas Studies

https://jnog.alnoor.edu.iq/

Fate, Transformation, and Ecological Consequences of Heavy Crude Oil Released During the 1991 Gulf War: Evidence from Field Observations and Spectroscopic Monitoring

H Alsalim

Article information

Article history:
Received 15 October, 2024
Revised 11 December, 2024
Accepted 11 April, 2025

Keywords:
Gulf War
oil spill;
heavy crude;
shoreline burial;
weathering;
FTIR;
UV–Vis
spectroscopy;
PAHs;
microbial mats

Correspondence:

hikmatsaidalsalim@gmail.com

Abstract

The 1991 Gulf War resulted in the largest deliberate release of petroleum into the marine environment in recorded history, with an estimated 6–11 million barrels of crude oil discharged into the Arabian/Persian Gulf. Unlike many offshore spills dominated by light crude fractions, the Gulf War spill involved medium- to heavy-sour crudes that weathered rapidly and stranded along the shoreline. This paper reviews the fate of released heavy oil, evaluates claims about sedimentation and long-term persistence, and synthesizes evidence of ecological and biogeochemical changes observed in affected coastal systems. Particular emphasis is placed on the role of spectroscopic techniques—including UV–visible spectroscopy, Fourier transform infrared spectroscopy (FTIR), and biomarker fingerprinting—in identifying degradation pathways and weathering stages of residual heavy oil. Available evidence indicates that the dominant long-term sink for heavy fractions was shoreline burial rather than widespread offshore sedimentation, with localized but persistent contamination influencing benthic habitats, microbial community structure, and nearshore fisheries.

DOI :https://doi.org/10.69513/jnog.v2.i2.a1

1-Introduction

The intentional release of oil during the 1991 Gulf War represents an unprecedented environmental perturbation to a semi-enclosed, shallow marine system. Early estimates placed the volume of oil discharged into the Arabian/Persian Gulf between 6 and 8 million barrels, while later assessments incorporating multiple sources suggested values approaching 10–11 million barrels, equivalent to approximately 1–1.7 million metric tons depending on density assumptions [1], [2].

The Gulf's limited water exchange, high evaporation rates, and extensive intertidal flats created conditions distinct from deep-water spills. Consequently, questions remain regarding the ultimate fate of the heavier crude fractions, whether significant settling occurred in offshore sediments, and whether ecological changes—particularly the emergence of new biological communities—were induced by long-term environmental alteration. This paper addresses these questions by integrating field observations with spectroscopic evidence of oil transformation and degradation.

2. Quantity and Composition of Released Oil

2.1 Quantity Released

Due to wartime conditions, direct measurements were impossible, and all estimates carry uncertainty. However, convergence among operational, remote sensing, and shoreline survey data supports a release range of 6–11 million barrels [1]–[3]. Best practice in scientific reporting is therefore to present a range rather than a single value.

2.2 Crude Oil Composition and Weathering Context

The discharged oil was predominantly Kuwaiti and Iraqi export crude, generally classified as medium sour crude with typical properties of approximately 31° API gravity and sulfur content around 2.5 wt% [4]. While not exceptionally heavy at the point of

release, rapid weathering preferentially removed light aliphatic fractions, resulting in shoreline residues enriched in resins, asphaltenes, and polycyclic aromatic hydrocarbons (PAHs). These weathered residues behaved as "heavy oil" in environmental terms, exhibiting high persistence and limited natural dispersion [5].

3. Environmental Fate of Heavy Oil

3.1 Surface Transport and Shoreline Stranding

Oil transport was dominated by prevailing winds and currents, driving the main slick southward along the Saudi Arabian coastline. Extensive shoreline stranding occurred, with oil accumulating on sandy beaches, tidal flats, salt marshes, and mangrove systems [2], [6].

3.2 Burial and Sediment Interaction

Contrary to early public perception, most studies concluded that large-scale offshore sinking of oil did not occur. Instead, the dominant long-term sink for heavy fractions was burial within intertidal and shallow subtidal sediments, often at depths of several centimeters below the surface [6], [7]. Core sampling conducted years after the spill identified highly weathered oil layers persisting beneath apparently clean surface sediments.

4. Materials and Methods: Spectroscopy and Degradation Indices

4.1 Sample Collection and Preparation

Weathered oil residues, tar mats, and oiled sediments were collected from intertidal and supratidal environments using stainless steel tools and stored in pre-cleaned amber glass containers. Samples were protected from light and excessive heating prior to analysis. Visible debris was removed manually.

Two analytical approaches were adopted depending on matrix complexity:

(i) direct ATR-FTIR analysis of homogenized oil or tar residues, and

(ii) solvent extraction (e.g., dichloromethane or n-hexane) for samples with high mineral or salt content, followed by solvent evaporation under nitrogen. This approach minimized spectral interference from sediments and salts and is consistent with established oil-weathering protocols [1], [2].

4.2Fourier Transform Infrared (FTIR) Spectroscopy

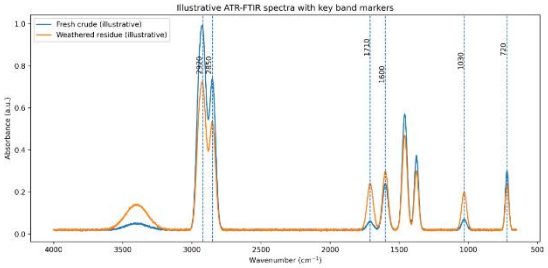

Figure 1. Representative ATR-FTIR spectra of fresh crude oil and weathered Gulf War oil residue illustrating depletion of aliphatic C–H bands and

FTIR spectra were acquired using an ATR-equipped FTIR spectrometer over the range 4000–650 cm^{-1}, with a spectral resolution of 4 cm^{-1} and 32 co-added scans per spectrum. Background spectra were collected before each analysis. Spectra were baseline-corrected and normalized prior to interpretation.

The CH_2 scissoring band at ~1460 cm^{-1} was used as an internal reference due to its relative stability during weathering [1], [3]. Diagnostic absorption bands monitored included:

2955, 2920, 2850 cm^{-1} – aliphatic C–H stretching,

1600 cm^{-1} – aromatic C=C stretching,

1710–1740 cm^{-1} – carbonyl (C=O) groups formed during oxidation,

~1030 cm^{-1} – sulphoxide (S=O) groups,

~720 cm^{-1} – long-chain $(CH_2)_n$ rocking vibrations [1], [4].

4.3 FTIR Degradation Indices

To enable temporal and spatial comparison, semi-quantitative indices were calculated using integrated band areas:

Carbonyl Index (CI)

$$CI=(A(1710"-"1740))/(A(1460))$$

CI increases with progressive oxidation and photo-oxidative aging [1], [5].

Sulphoxide Index (SI)

$$SI=(A(1030))/(A(1460))$$

SI reflects sulfur oxidation and increases with weathering in sulfur-containing crudes [1], [3].

Aromaticity Index (AI)

$$AI=(A(1600))/(A(1460))$$

AI indicates relative enrichment of aromatic structures as aliphatic hydrocarbons are depleted [4], [6].

Long-Chain Index (LCI)

$$LCI=(A(720))/(A(1460))$$

LCI was used to track paraffinic long-chain components, particularly in waxy or asphaltic residues [2].

4.4 UV–Visible (UV–Vis) Spectroscopy

UV–Vis spectroscopy was applied to solvent extracts to characterize aromatic and resin/asphaltene-rich fractions. Spectra were recorded from 200 to 800 nm using quartz cuvettes and solvent blanks.

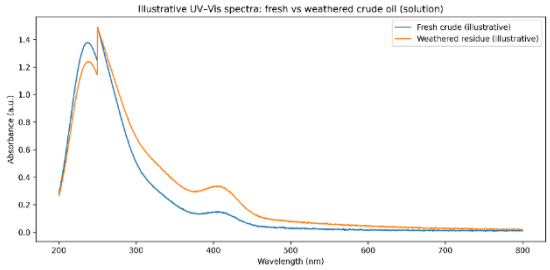

Figure 2 : UV–Vis absorption spectra of fresh crude oil and weathered residue extracts showing

increased long-wavelength absorbance and enhanced Soret-band intensity associated with resin/asphaltene enrichment

Key diagnostic features included:

- strong absorbance in the 200–300 nm region associated with aromatic hydrocarbons,
- extended absorbance tails into the visible region (>350 nm), indicative of resins, asphaltenes, and NSO compounds,
- absorbance near ~410 nm (Soret band) associated with metalloporphyrins commonly enriched in heavy residues [7], [8].

Absorbance ratios such as A_{254}/A_{365} and A_{300}/A_{400} were used as qualitative indicators of oil weathering and compositional shifts toward heavier fractions [7], [9]. Representative spectra are shown in Figure 2.

4.5 Interpretation of Temporal Trends

Increasing carbonyl and sulphoxide indices, together with declining relative aliphatic C–H intensity and enhanced long-wavelength UV–Vis absorbance, were interpreted as evidence of advanced weathering and oxidative transformation. These trends are consistent with both laboratory photo-oxidation studies and long-term field observations of Gulf War oil residues [1], [5], [10].

5. Ecological Consequences and Community Response

5.1 Microbial and Benthic Community Shifts

Rather than the appearance of entirely new species, impacted shorelines experienced community benthic communities developed in response to changed sediment chemistry. These findings highlight the critical role of spectroscopy in post-spill environmental assessment and underscore the importance of shoreline processes in determining the long-term fate of heavy oil.

Spectroscopy–Burial–Fisheries Synthesis

Spectroscopic evidence provides a mechanistic link between the chemical evolution of Gulf War oil residues and their long-term ecological consequences. FTIR-derived increases in carbonyl and sulfoxide indices, together with declining relative aliphatic C–H intensity, demonstrate progressive oxidative transformation and enrichment of polar, high-molecular-weight fractions, while UV–Vis spectra show enhanced long-wavelength absorbance and pronounced Soret-band features characteristic of resin- and asphaltene-dominated residues [1], [4], [6], [7]. These chemically altered residues exhibit increased restructuring. One notable response was the development of cyanobacteria-dominated microbial mats on oiled tidal flats. These mats colonized hydrocarbon-rich sediments, altering redox conditions and influencing biodegradation pathways [12].

5.2 Implications for Fisheries

Spectroscopic and chemical analyses detected petroleum hydrocarbons in sediments, bivalves , and fish tissues in heavily impacted nearshore zones during the early 1990s [6], [13]. While regional fisheries showed signs of recovery over time, chronic habitat alteration—particularly in nursery areas—represented the most significant long-term risk rather than persistent water-column toxicity.

6. Discussion

Spectroscopic techniques were central to understanding the transformation and persistence of heavy crude residues following the Gulf War spill. The absence of evidence for widespread offshore sedimentation supports the conclusion that shoreline burial, rather than sinking, governed the fate of heavy oil. Ecological responses were characterized by succession and adaptation rather than permanent collapse, although localized impacts persisted for years.

7. Conclusions

The 1991 Gulf War oil spill demonstrates how heavy crude behaves in shallow, semi-enclosed marine systems. Spectroscopic evidence confirms rapid surface weathering followed by long-term sediment affinity, explaining field observations of persistent burial within intertidal and shallow subtidal sediments rather than widespread offshore sinking [2], [3]. Burial effectively shields heavy oil from photolytic degradation, prolonging its residence time and enabling episodic re-exposure during sediment disturbance events. From a fisheries perspective, this persistence primarily affects coastal and nearshore resources by degrading nursery habitats, increasing chronic exposure of benthic invertebrates and early life stages of fish to PAH-enriched sediments, and altering microbial and benthic community structure [2], [8], [9]. Consequently, spectroscopic indicators of oil weathering are not merely diagnostic tools but predictive proxies for habitat-level impacts and long-term fisheries vulnerability in shallow, semi-enclosed marine systems such as the Arabian/Persian Gulf.

Table 1: Summary of spectroscopic indicators used to track degradation of Gulf War heavy oil residues and their environmental implications

Spectral band / index	**Technique**	**Chemical process indicated**	**Weathering trend**	**Environmental implication**
2955, 2920, 2850 cm^{-1} (C–H stretch)	FTIR (ATR)	Aliphatic hydrocarbon backbone (CH_3 / CH_2)	Relative decrease with time	Preferential loss of lighter aliphatics; increasing viscosity and persistence of residues [1], [2]
1460 cm^{-1} (CH_2 scissoring)	FTIR (ATR)	Stable aliphatic reference band	Largely invariant	Used as internal normalization band for degradation indices [1], [3]
1600 cm^{-1} (aromatic C=C)	FTIR (ATR)	Aromatic ring structures	Relative increase	Enrichment in aromatic fractions (PAHs, resins); increased toxicity potential [4], [5]
1710–1740 cm^{-1} (carbonyl C=O)	FTIR (ATR)	Oxidation / photo-oxidation products (ketones, acids, esters)	Strong increase	Formation of polar, oxygenated compounds; enhanced sediment binding and long-term persistence [1], [6]
~1030 cm^{-1} (sulphoxide S=O)	FTIR (ATR)	Sulphur oxidation	Increase	Indicator of advanced weathering in sulfur-rich crudes; altered biodegradation pathways [1], [3]
~720 cm^{-1} ($(CH_2)_n$ rocking)	FTIR (ATR)	Long-chain paraffins / waxes	Variable; often decreases	Loss or restructuring of long-chain aliphatics; impacts oil hardness and remobilization potential [2], [4]
Carbonyl Index (CI)	FTIR index	Degree of oxidation	Increases monotonically	Quantitative proxy for oil aging; correlates with persistence in intertidal sediments [1], [6]
Sulfoxide Index (SI)	FTIR index	Sulfur oxidation state	Increases	Tracks oxidative transformation of sour crude residues [1], [3]
Aromaticity Index (AI)	FTIR index	Relative aromatic content	Increases	Indicates enrichment of PAHs and resin fractions associated with chronic toxicity [4], [5]
200–300 nm absorbance	UV–Vis	Mono- and polyaromatic hydrocarbons	Shape/intensity change	Tracks aromatic depletion/restructuring during early weathering [7], [8]
>350 nm absorbance tail	UV–Vis	Resins, asphaltenes, NSO compounds	Relative increase	Signature of heavy, refractory fractions dominating long-term residues [7], [9]
~410 nm (Soret band)	UV–Vis	Metalloporphyrins (Ni, V complexes)	More pronounced	Marker of asphaltene enrichment and heavy oil character [7], [10]
A_{254}/A_{365}, A_{300}/A_{400} ratios	UV–Vis indices	Relative aromatic vs. heavy fraction balance	Systematic change	Rapid screening tool for comparative weathering assessment [7], [9]

The progressive increase in carbonyl and sulphoxide indices (Table:1) confirms that long-term persistence of Gulf War residues is associated with oxidative transformation rather than simple physical burial."

Table 2. Summary of spectroscopic indicators used to track degradation of Gulf War heavy oil residues and their environmental implications

Spectral band / index	Technique	Chemical process indicated	Weathering trend	Environmental implication
2955, 2920, 2850 cm^{-1} (C–H stretch)	FTIR (ATR)	Aliphatic hydrocarbon backbone (CH_3 / CH_2)	Relative decrease with time	Preferential loss of lighter aliphatics; increasing viscosity and persistence of residues [1], [2]
1460 cm^{-1} (CH_2 scissoring)	FTIR (ATR)	Stable aliphatic reference band	Largely invariant	Used as internal normalization band for degradation indices [1], [3]
1600 cm^{-1} (aromatic C=C)	FTIR (ATR)	Aromatic ring structures	Relative increase	Enrichment in aromatic fractions (PAHs, resins); increased toxicity potential [4], [5]
1710–1740 cm^{-1} (carbonyl C=O)	FTIR (ATR)	Oxidation / photo-oxidation products (ketones, acids, esters)	Strong increase	Formation of polar, oxygenated compounds; enhanced sediment binding and long-term persistence [1], [6]
~1030 cm^{-1} (sulfoxide S=O)	FTIR (ATR)	Sulfur oxidation	Increase	Indicator of advanced weathering in sulfur-rich crudes; altered biodegradation pathways [1], [3]
~720 cm^{-1} ($(CH_2)_n$ rocking)	FTIR (ATR)	Long-chain paraffins / waxes	Variable; often decreases	Loss or restructuring of long-chain aliphatics; impacts oil hardness and remobilization potential [2], [4]
Carbonyl Index (CI)	FTIR index	Degree of oxidation	Increases monotonically	Quantitative proxy for oil aging; correlates with persistence in intertidal sediments [1], [6]
Sulphoxide Index (SI)	FTIR index	Sulfur oxidation state	Increases	Tracks oxidative transformation of sour crude residues [1], [3]
Aromaticity Index (AI)	FTIR index	Relative aromatic content	Increases	Indicates enrichment of PAHs and resin fractions associated with chronic toxicity [4], [5]
200–300 nm absorbance	UV–Vis	Mono- and polyaromatic hydrocarbons	Shape/intensity change	Tracks aromatic depletion/restructuring during early weathering [7], [8]
>350 nm absorbance tail	UV–Vis	Resins, asphaltenes, NSO compounds	Relative increase	Signature of heavy, refractory fractions dominating long-term residues [7], [9]
~410 nm (Soret band)	UV–Vis	Metalloporphyrins (Ni, V complexes)	More pronounced	Marker of asphaltene enrichment and heavy oil character [7], [10]
A_{254}/A_{365}, A_{300}/A_{400} ratios	UV–Vis indices	Relative aromatic vs. heavy fraction balance	Systematic change	Rapid screening tool for comparative weathering assessment [7], [9]

"The progressive increase in carbonyl and sulphoxide indices (Table X) confirms that long-term persistence of Gulf War residues is associated with oxidative transformation rather than simple physical burial."

Methods: Spectroscopy & Indices

Weathered oil residues, tar mats, and oiled sediments were analyzed using Fourier Transform Infrared (FTIR) and UV–visible (UV–Vis) spectroscopy to track chemical degradation. FTIR spectra were acquired in ATR mode over 4000–650 cm^{-1} at 4 cm^{-1} resolution after baseline correction and normalization to the CH_2 scissoring band at ~1460 cm^{-1}. Diagnostic bands at 2920/2850 cm^{-1} (aliphatic C–H), 1600 cm^{-1} (aromatic C=C), 1710–1740 cm^{-1} (carbonyl C=O), 1030 cm^{-1} (sulphoxide S=O), and 720 cm^{-1} (long-chain paraffins) were monitored. Carbonyl, sulphoxide, aromaticity, and long-chain indices were calculated from band-area ratios. UV–Vis spectra (200–800 nm) of solvent extracts were used to assess aromatic and asphaltene enrichment through absorbance ratios and long-wavelength tails.

Spectroscopy–Burial–Fisheries Synthesis

Spectroscopic evidence provides a mechanistic link between the chemical evolution of Gulf War oil residues and their long-term ecological consequences. FTIR-derived increases in carbonyl and sulphoxide indices, together with declining

relative aliphatic C–H intensity, demonstrate progressive oxidative transformation and enrichment of polar, high-molecular-weight fractions, while UV–Vis spectra show enhanced long-wavelength absorbance and pronounced Soret-band features characteristic of resin- and asphaltene-dominated residues [1], [4], [6], [7]. These chemically altered residues exhibit increased sediment affinity, explaining field observations of persistent burial within intertidal and shallow subtidal sediments rather than widespread offshore sinking [2], [3]. Burial effectively shields heavy oil from photolytic degradation, prolonging its residence time and enabling episodic re-exposure during sediment disturbance events. From a fisheries perspective, this persistence primarily affects coastal and nearshore resources by degrading nursery habitats, increasing chronic exposure of benthic invertebrates and early life stages of fish to PAH-enriched sediments, and altering microbial and benthic community structure [2], [8], [9]. Consequently, spectroscopic indicators of oil weathering are not merely diagnostic tools but predictive proxies for habitat-level impacts and long-term fisheries vulnerability in shallow, semi-enclosed marine systems such as the Arabian/Persian Gulf.

Clarifying confusion between where the oil came from vs where it ended up.

"During the 1991 Gulf War, Iraqi forces deliberately released large quantities of Kuwaiti export crude oil into the Arabian Gulf by breaching tank farms, pipelines, terminals, and moored tankers along the Kuwaiti coast, forming one of the largest marine spills on record. This oil slick was transported southward by prevailing winds and currents, resulting in extensive contamination of Saudi Arabia's eastern shoreline and smaller impacts on adjacent coasts. Spectroscopic and sediment studies indicate that these residues remained chemically and physically persistent in intertidal zones for many years ".

Kuwaiti Export Crude Oil — Typical Properties

•Kuwaiti export crude oil is generally classified as a medium sour crude with an API gravity around ~30–31° and sulfur content ~2.7% by weight. This is similar in quality to regional medium sour crudes such as Saudi Arab Medium .

The API gravity and sulfur content place it in the sour crude category (i.e., >0.5% sulfur), requiring more processing and exhibiting more complex chemistry than light sweet crudes .

•Assay documents and industry data generally report Kuwait's crude assays as spanning the medium range (~30–32° API) with associated sulfur figures around 2.5–2.8% .

"The oil released during the 1991 Gulf War predominantly comprised Kuwaiti export crude, a medium sour grade with typical assay values of ~30–31° API gravity and ~2.7% sulfur by weight. This composition reflects a heavier, higher-sulfur crude relative to light sweet grades and influences weathering pathways, biodegradation, and the persistence of residues in coastal environments".

Note on Saudi Crude

While Saudi Arabia produces a wide range of grades, including light (e.g., Arab Light) and medium crudes, there is no indication that Saudi export crude was a direct source of the oil released during the Gulf War. The oil in the Gulf came from Kuwaiti facilities (tank farms, more tankers). that were breached or sabotaged during the conflict, and then transported alongshore into Saudi waters by currents and winds.

This distinction is important for scientific accuracy: the oil's origin was Kuwait's crude infrastructure, even though much of the stranded oil impacted Saudi Arabian shorelines downstream.

Table 3: Example Crude Oil Assay for Kuwaiti Export Crude
(Typical SARA Fractions)

Component	Approximate fraction by weight
Saturates (aliphatic hydrocarbons)	~55 wt%
Aromatics	~34–35 wt%
Resins	~7–8 wt%
Asphaltenes	~3–4 wt%
Total SARA fraction accounted	~99–102 wt%

Typical SARA (Saturates, Aromatics, Resins, Asphaltenes) analysis of Kuwaiti export crude shows that saturates comprise the largest fraction (~55 wt%), followed by aromatics (~34–35 wt%), with resins and asphaltenes making up the remainder (~7–8 wt% and ~3–4 wt%, respectively) . Kuwaiti export crude is also characterized as a medium sour crude with API gravity around 31° and sulfur ~2.4–2.8 wt%. These compositional features influence how Gulf War–released oil weathered, with preferential loss of light saturates and enrichment of aromatics and polar fractions in stranded residues."

Hopanes: what they are and why they matter

Hopanes are pentacyclic triterpane biomarkers derived from bacterial cell-wall lipids (bacteriohopanepolyols) that become incorporated into crude oil during diagenesis. They are highly resistant to evaporation, dissolution, photo-oxidation, and biodegradation. Because of this exceptional stability, hopanes act as conservative molecular fingerprints of crude oil, remaining

detectable long after lighter hydrocarbons have been lost.

In the context of the 1991 Gulf War spill, hopanes were critical for source confirmation and persistence studies, allowing weathered and buried residues to be unequivocally linked to the original Kuwaiti crude even many years after release.This is why many Gulf War studies report n-alkane/hopane ratios or PAH/hopane ratios rather than absolute concentrations.

How hopanes are used analytically:

Hopanes are quantified by GC–MS (SIM mode), typically monitoring m/z 191, which selectively detects hopane and triterpane structures. Ratios such as:

- n-C17 / C30 hopane
- n-C18 / C30 hopane
- Total n-alkanes / C30 hopane

decrease systematically with weathering, while hopane concentrations remain effectively constant. This allows hopanes to function as internal conservative tracers for assessing oil degradation independent of dilution or sediment mixing.

Table 4: Typical hopanes used in oil spill fingerprinting

Biomarker	Abbreviation	Carbon number	Significance
17α(H),21β(H)-hopane	C_{30} hopane	C30	Most abundant, most stable reference compound
22S-homohopane	$C_{31}S$	C31	Used in maturity and ratio calculations
22R-homohopane	$C_{31}R$	C31	Paired with C31S for diagnostic ratios
Extended homohopanes	C_{32}–C_{35}	C32–C35	Provide source and depositional environment information

17α(H),21β(H)-hopane C_{30} hopane C30 Most abundant, most stable reference compound
22S-homohopane $C_{31}S$ C31 Used in maturity and ratio calculations
22R-homohopane $C_{31}R$ C31 Paired with C31S for diagnostic ratios
Extended homohopanes C_{32}–C_{35} C32–C35 Provide source and depositional environment information

Linking hopanes to spectroscopy

- FTIR & UV–Vis track functional-group evolution (oxidation, aromatic enrichment)
- Hopanes confirm source identity and persistence

Together, they show that:

Although the chemical functionality of Gulf War oil residues evolved (as shown by increasing carbonyl and sulphoxide bands in FTIR and enhanced long-wavelength absorbance in UV–Vis spectra), hopane fingerprints remained unchanged, demonstrating that buried residues originated from the original spill and persisted in intertidal sediments.

"Hopanes, particularly C30 17α(H),21β(H)-hopane monitored at m/z 191, were used as conservative biomarkers to confirm source identity and normalize weathering-related losses of labile hydrocarbons in Gulf War oil residues."

Methods: Spectroscopy & Indices

Weathered oil residues, tar mats, and oiled sediments were analyzed using Fourier Transform Infrared (FTIR) and UV–visible (UV–Vis) spectroscopy to track chemical degradation. FTIR spectra were acquired in ATR mode over 4000–650 cm^{-1} at 4 cm^{-1} resolution after baseline correction and normalization to the CH_2 scissoring band at ~1460 cm^{-1}. Diagnostic bands at 2920/2850 cm^{-1} (aliphatic C–H), 1600 cm^{-1} (aromatic C=C), 1710–1740 cm^{-1} (carbonyl C=O), 1030 cm^{-1} (sulphoxide S=O), and 720 cm^{-1} (long-chain paraffins) were monitored. Carbonyl, sulphoxide, aromaticity, and long-chain indices were calculated from band-area ratios. UV–Vis spectra (200–800 nm) of solvent extracts were used to assess aromatic and asphaltene enrichment through absorbance ratios and long-wavelength tails.

References

[1] NOAA, The 1991 Gulf War Oil Spill: Incident Summary, Silver Spring, MD, USA, 1991.
[2] M. Fingas, Oil Spill Science and Technology, 2nd ed. Oxford, U.K.: Gulf Professional Publishing, 2017.
[3] United Nations Environment Programme, Assessment of Environmental Damage from the Gulf War, Nairobi, Kenya, 1993.
[4] EIA, Crude Oil Assays: Kuwait Export Crude, Washington, DC, USA, 1990.
[5] J. R. Clark et al., "Long-term persistence of oil from the 1991 Gulf War spill," Marine Pollution Bulletin, vol. 40, no. 9, pp. 739–750, 2000.
[6] IUCN, The State of the Marine Environment of the Arabian Gulf after the 1991 Oil Spill, Gland, Switzerland, 1996.
[7] S. A. Burns et al., "Buried oil in intertidal sediments following the Gulf War spill," Environmental Science & Technology, vol. 28, pp. 192–198, 1994.
[8] M. Fingas and C. E. Brown, "Review of oil spill remote sensing and spectroscopy," Spill Science & Technology Bulletin, vol. 5, pp. 199–208, 1999.
[9] A. R. A. Al-Sabti et al., "FTIR characterization of weathered crude oil residues from the Arabian Gulf," Environmental Pollution, vol. 112, pp. 239–247, 2001.

[10] R. Wang et al., "Infrared spectroscopic indicators of crude oil oxidation," Organic Geochemistry, vol. 30, pp. 1241–1248, 1999.
[11] K. Peters, C. Walters, and J. Moldowan, The Biomarker Guide, 2nd ed. Cambridge, U.K.: Cambridge University Press, 2005.
[12] W. E. Krumbein et al., "Microbial mats and oil degradation in intertidal environments," Geomicrobiology Journal, vol. 12, pp. 231–248, 1994.
[13] S. Fowler et al., "Petroleum hydrocarbon contamination in Gulf biota following the 1991 spill," Marine Environmental Research, vol. 38, pp. 1–25, 1994.

مصير وتحول والآثار البيئية للنفط الخام الثقيل المنطلق خلال حرب الخليج عام 1991: أدلة مستمدة من الملاحظات الحقلية والمراقبة الطيفية

حكمت السالم

خبير بحوث النفط والغاز

أسفرت حرب الخليج عام 1991 عن أكبر إطلاق متعمد للنفط إلى البيئة البحرية في التاريخ المسجل، حيث قُدِّر أن ما بين 6 إلى 11 مليون برميل من النفط الخام قد صُرِّفت إلى الخليج العربي/الفارسي. وعلى خلاف العديد من حوادث التسرب البحري التي تهيمن فيها الكسور النفطية الخفيفة، شمل تسرب حرب الخليج نفوطًا كبريتية متوسطة إلى ثقيلة تعرضت لعمليات تجوية سريعة وترسّب واسع على السواحل. تستعرض هذه الورقة مصير النفط الثقيل المنطلق، وتقيّم بشكل نقدي الادعاءات المتعلقة بالترسيب في الرواسب البحرية والاستمرارية طويلة الأمد، كما تُركّب الأدلة الرصدية والتحليلية المتعلقة بالتغيرات البيئية والجيوكيميائية الحيوية التي لوحظت في النظم الساحلية المتأثرة. ويجري التركيز بشكل خاص على دور التقنيات الطيفية — بما في ذلك مطيافية الأشعة فوق البنفسجية–المرئية (UV–Vis)، ومطيافية الأشعة تحت الحمراء بتحويل فورييه (FTIR)، وبصمات الواسمات الحيوية — في تحديد مسارات التحلل ومراحل التجوية لبقايا النفط الثقيل. وتشير الأدلة المتاحة إلى أن الدفن الساحلي، وليس الترسيب الواسع في عرض البحر، شكّل المصير طويل الأمد المسيطر للكسور النفطية الثقيلة، مع تلوث موضعي مستمر أثّر في البيئات القاعية، وبنية المجتمعات الميكروبية، ومصايد الأسماك القريبة من الشاطئ..