New Insights into the Effective Petroleum Source Rocks in the Beaufort-Mackenzie Basin from an Integrated Molecular and Isotope Approach*

Maowen Li[1], Zhuoheng Chen[2], Dale Issler[2], Sneh Achal[2], Marina Milovic[2], and Rachel Robinson[2]

Search and Discovery Article #40669 (2010)
Posted December 31, 2010

*Adapted from oral presentation at AAPG International Conference and Exhibition, Calgary, Alberta, Canada, September 12-15, 2010

[1]Geological Survey of Canada, Calgary, AB, Canada (mali@nrcan.gc.ca)
[2]Geological Survey of Canada, Calgary, AB, Canada

Abstract

Oil industry routinely uses biomarker ratios and "fingerprints" to classify genetically related oils, to correlate oils with source rocks, and to identify petroleum source horizons and kitchens. This application is valuable in allowing explorationists to identify end member petroleum sources even in cases where the source rocks have not been penetrated. Without the knowledge of the concentrations of the biomarker classes in question among source rocks of different organic facies or thermal maturity, however, oil source determination using this approach may unwittingly relate an oil to the wrong source rock. The aim of this study was to refine the genetic classification of discovered oils in the Beaufort-Mackenzie Basin, through an integrated, quantitative, molecular and isotopic approach. Although our results generally support the oil classification scheme accepted widely by industry, the discrepancies observed in the molecular and isotopic signatures in many of the studied oils indicate that most of the earlier interpreted oil-source relationships are incorrect. For example, biomarker evidence suggests marine source rocks in Upper Cretaceous Smoking Hills/Boundary Creek Formations for the oils from the Kugpik, Imnak, Tuk and Mayogiak discoveries, in contrast to the stable carbon and hydrogen isotope values of individual n-alkanes in these oils which display clear affinity with the marine source rocks in the Upper Jurassic Husky Formation and Lower Cretaceous Kamik Formation but not with the presumed Upper Cretaceous source rocks. The presence of bisnorlupanes and oleananes and the distributions of regular steranes in most of the offshore Kugmallit-reservoired oils appear to suggest an immature Tertiary deltaic non-marine source. However, the presence of 24-n-propylcholestanes, a large unresolved complex mixture and the mismatch in the stereochemistry and relative distributions of regular steranes and diasteranes indicate that these oils have most likely been derived from a mature Upper Cretaceous marine source, undergone varying degrees of biodegradation, and subsequently mixed with new hydrocarbon fluids from the shallower Tertiary strata. Interpretation of the newly acquired geochemical data within the context of petroleum mass fractions provides important source rock information for exploration geologist to address trap filling issues.

References

Brooks, P.W., 1986, Biological Marker Geochemistry of Oils from the Beaufort-Mackenzie Region, Arctic Canada: Canadian Petroleum Geology, Bulletin v. 34/4, p. 490-505.

Curiale, J.A., 1991, The petroleum geochemistry of Canadian Beaufort Tertiary "non-marine" oils: Chemical Geology, v. 93/1-2, p. 21-45.

McCaffrey, M.A., J.E. Dahl, P. Sundararaman, J.M. Moldowan, and M. Schoell, 1994, Source rock quality determination from oil biomarkers; II, A case study using Tertiary-reservoired Beaufort Sea oils: AAPG Bulletin, v. 78/10, p. 1527-1540.

Snowdon, L.R., L.D. Stasiuk, R. Robinson, J. Dixon, J. Dietrich, and D.H. McNeil, 2004, Organic geochemistry and organic petrology of a potential source rock of early Eocene age in the Beaufort-Mackenzie Basin: Organic Chemistry, v. 35/9, p. 1039-1052.

New insights into the effective petroleum source rocks in the Beaufort-Mackenzie Basin from an integrated molecular and isotope approach

Earth Sciences Sector

Secure Canadian Energy Supply Program

Maowen Li
Zhuoheng Chen
Dale Issler
Sneh Achal
Marina Milovic
Rachel Robinson

Talk outline

- **Problem definition & objectives**
- Previous work
- A new integrated approach
- Key findings
- Implications

Problem definition

- Oil industry routinely uses biomarker “fingerprints” and stable carbon isotope ratios to classify genetically related oils, to correlate oils with source rocks, and to identify petroleum source horizons and kitchens

- The underlying concept for oil-oil and oil-source correlations is that certain compositional traits of migrated oil do not differ significantly from those of bitumen remianing in the source rock

- This application is valuable in allowing the identification of end member petroleum sources even in cases where the source rocks have not been penetrated

Geochemical correlation

- Requires parameters that
  - distinguish oils from different sources
  - are resistant to secondary processes (biodegradation, and thermal maturation)

- Rule of thumb
  - A positive correlation is not necessarily proof that samples are related (e.g. different source rocks can show similar geochemical characteristics)
  - But a negative correlation is strong evidence for lack of a relationship

- Other factors may obscure correlation efforts
  - in-migrated oil in source rock
  - mismatch in maturity in source rock-oil samples
  - limited number of source rock samples that may not be representative
  - contributions from more than one source
  - phase related compositional fractionation

Objectives

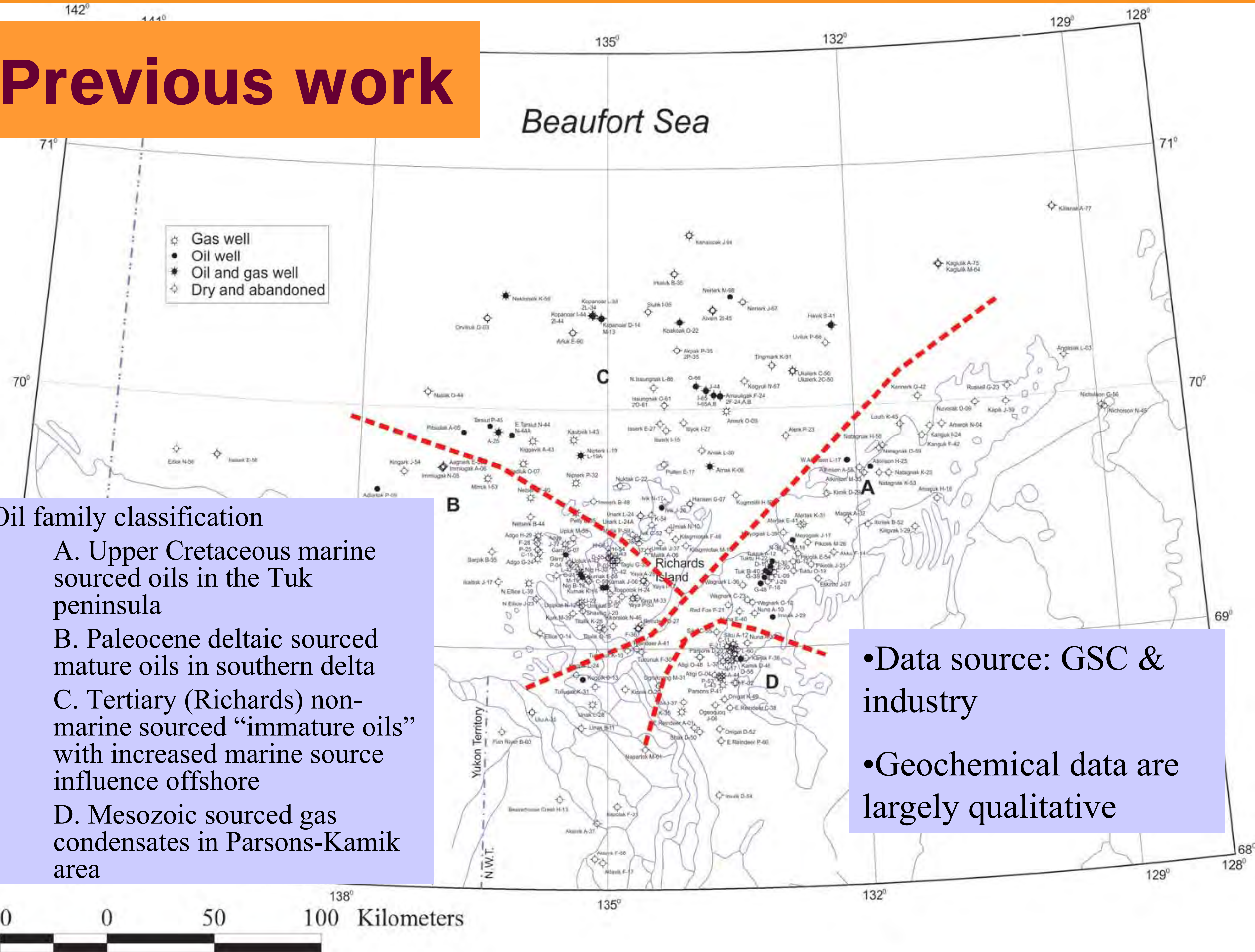
- Refine the genetic classification of discovered oils in the Beaufort-Mackenzie Basin, through an integrated, quantitative, molecular and isotopic approach

- Revise petroleum system models to assist oil industry to reassess petroleum resources, identify new exploration horizons, and finetune exploration programs

Talk outline

- Problem definition & objectives
- **Previous work**
- A new integrated approach
- Key findings
- Implications for exploration

Previous work



Oil family classification

- A. Upper Cretaceous marine sourced oils in the Tuk peninsula
- B. Paleocene deltaic sourced mature oils in southern delta
- C. Tertiary (Richards) non-marine sourced "immature oils" with increased marine source influence offshore
- D. Mesozoic sourced gas condensates in Parsons-Kamik area

- Data source: GSC & industry
- Geochemical data are largely qualitative

Talk outline

- Problem definition & objectives
- Previous work
- **A new integrated approach**
- Key findings
- Implications for exploration

A new integrated approach

- An extensive geological sample base, covering almost all DST oils from existing discoveries and source rock extracts
- Geochemical data
  - 200 oils:
    - Whole oil GC
    - Gasoline range hydrocarbons
    - Saturate and **aromatic** GC & GC/MS
  - 50 selected oils :
    - **Quantitative diamonoid, saturate and aromatic GC/MS, and GC/MS/MS**
    - **Bulk isotopes and saturate GC-ir-MS for both C and H**
- Consider all geochemical parameters within the context of mass fraction of the concerned components in the oil, for intra and inter-fraction consistency
- Constrain oil-source correlation models with integrated geological and geochemical data

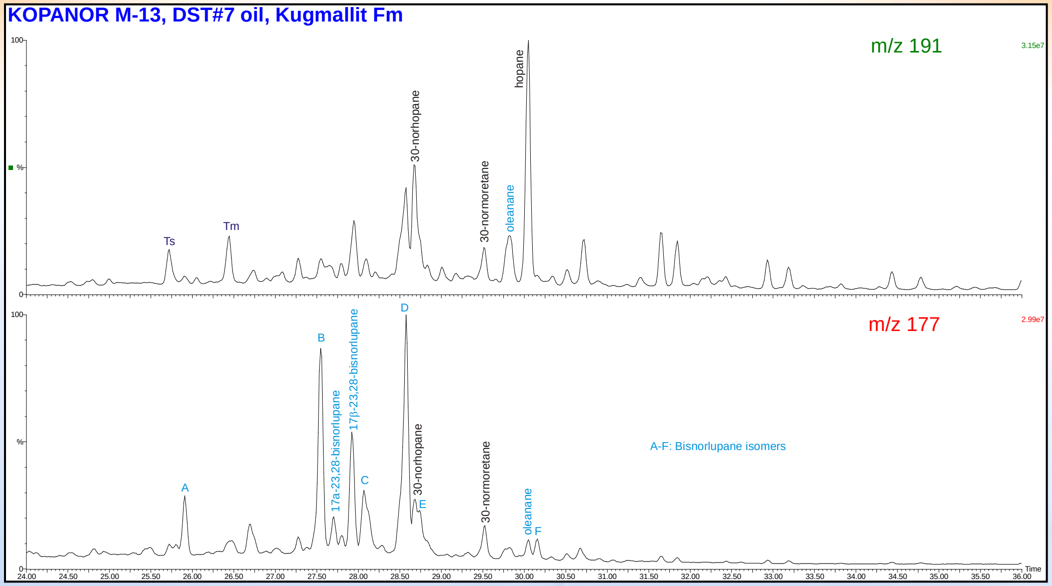
Talk outline

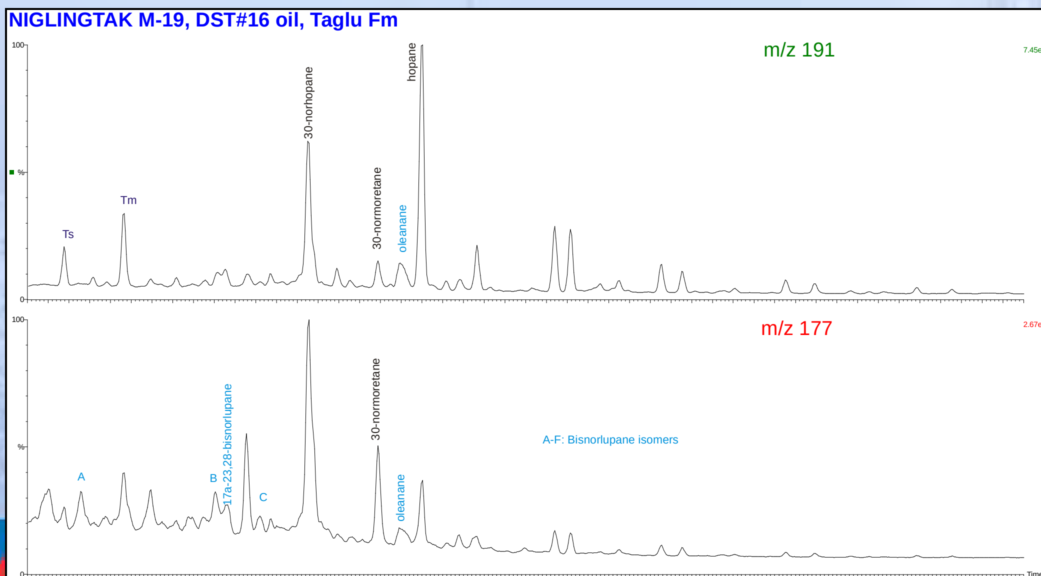
- Problem definition & objectives
- Previous work
- A new integrated approach
- **Key findings**
- Implications for exploration

Key findings

- Bisnorlupanes cannot be a Richards-specific source indicator
- Sterane distribution indicates significant mixing of a mature marine oil and immature terrigenic bitumen in offshore oils
- Conflicting molecular and isotopic signatures for oils in Tuk peninsula suggest multiple charge senarios

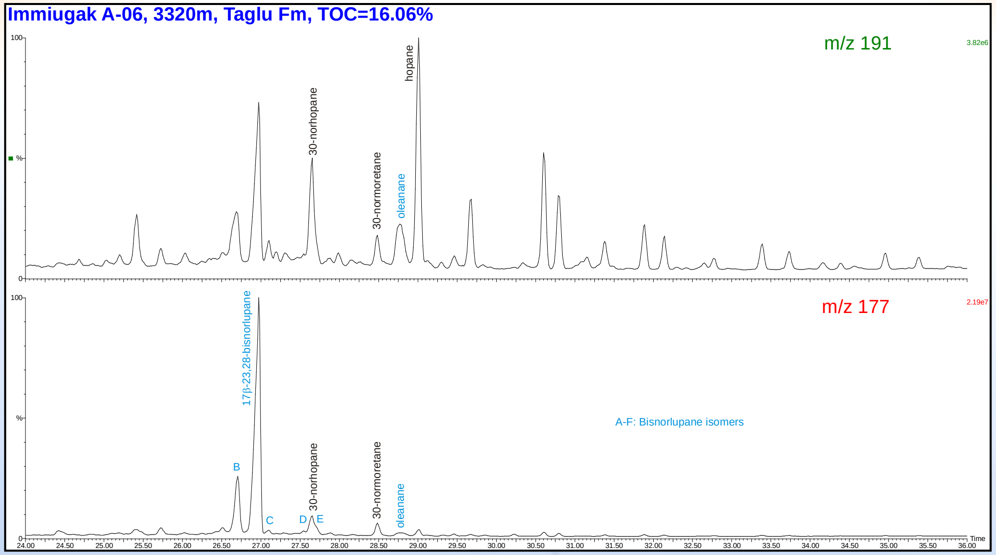
Bisnorlupanes as source-specific indicator?

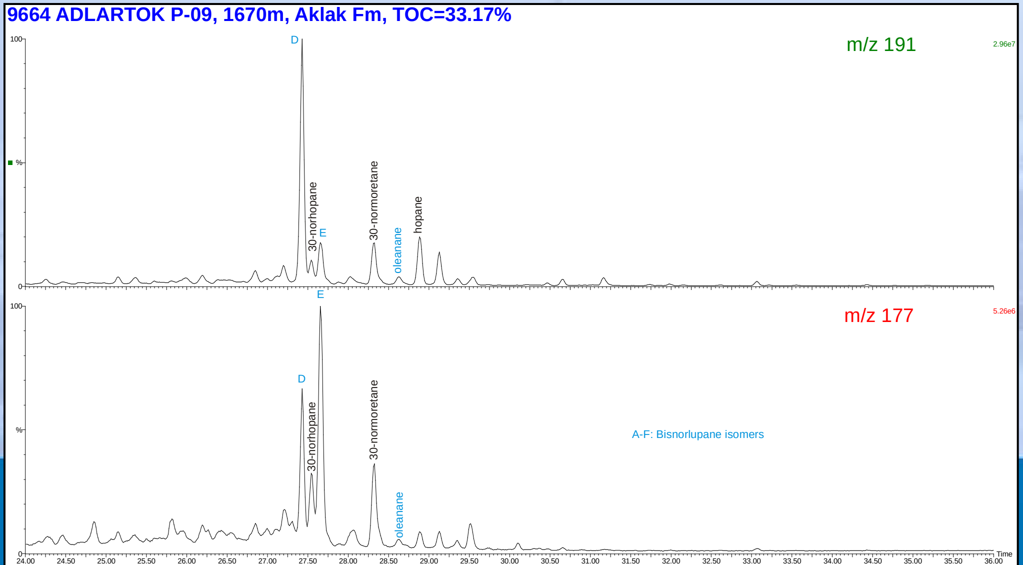




- Earlier studies (Brooks , 1986) detected these compounds only in the Richards Fm, based on limited sample coverage
- Curiale (1991) proposed two genetic groups of Tertiary reservoired oils
  - Richards sourced oils in Kugmallit/Richards reservoirs offshore
  - Paleocene sourced oils in the Reindeer/Moose Channel reservoirs in southern delta (lack of lupanoids but contain 28,30-bisnorhopanes and oleananes)

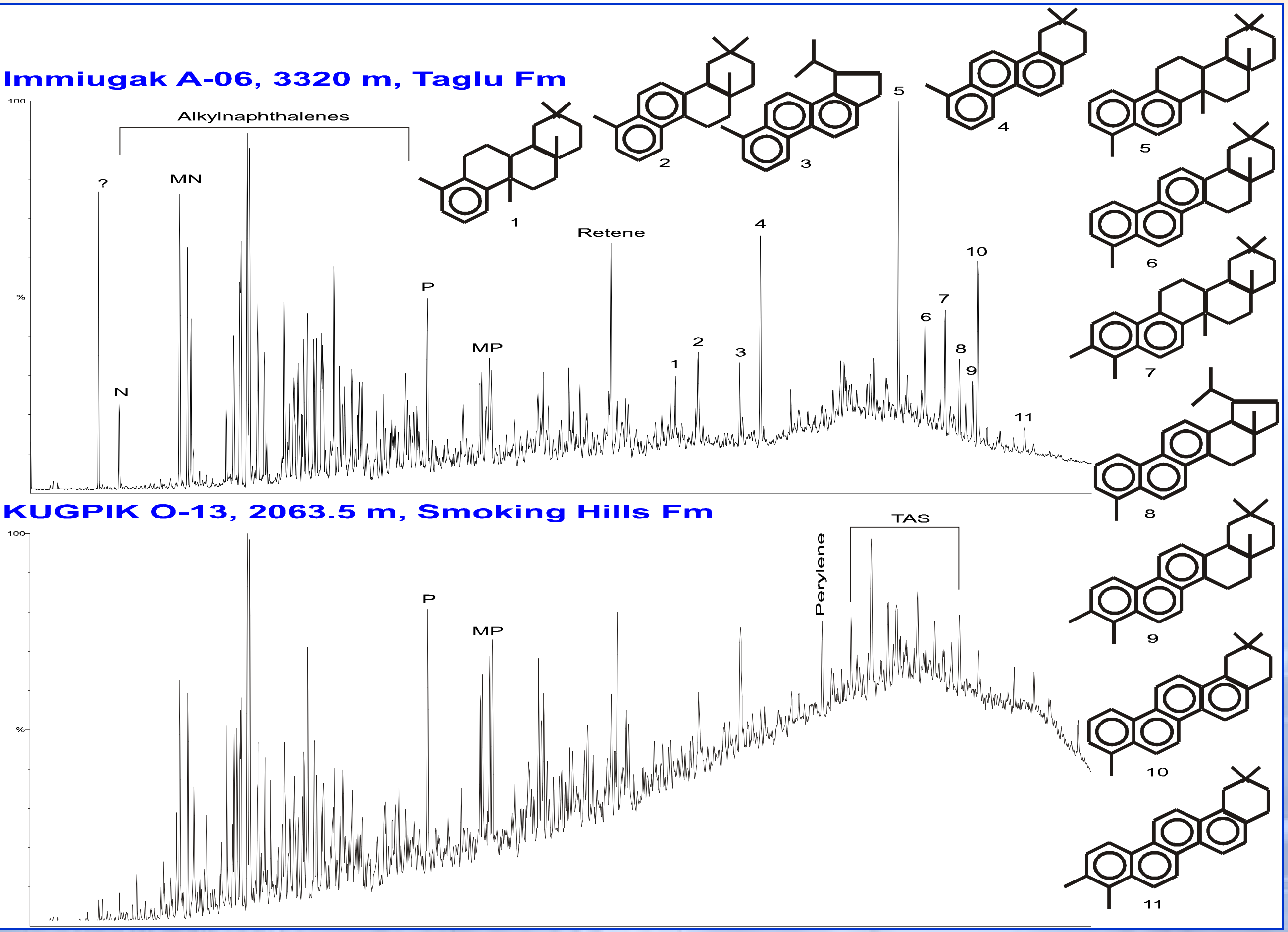
Bisnorlupanes as source-specific indicator?





- Detected in the Taglu coals and shales (Snowdon et al., 2004)
- Also in Aklak, Richards and Kugmallit samples analyzed here

Bisnorlupanes as source-specific indicator?



- The detection of many related aromatic derivatives suggests that they are likely present throughout the Tertiary strata
- Useful for distinguishing from older sources, but not among various Tertiary sources

Key findings

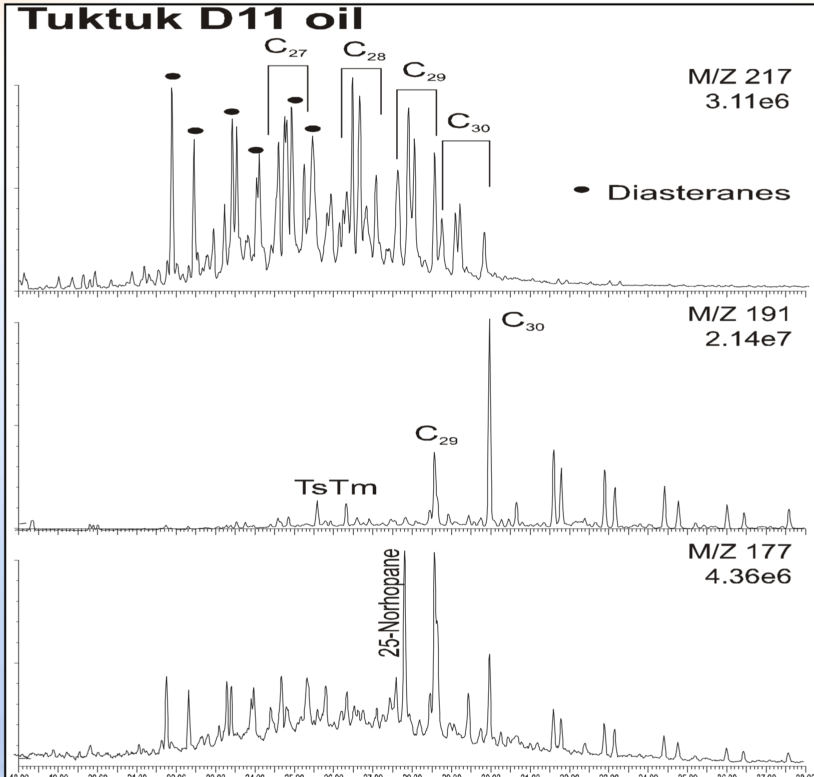
- Bisnorlupanes cannot be a Richards-specific source indicator
- **Sterane distribution indicates significant mixing of a mature marine oil and immature terrigenic bitumen in offshore oils**
- Conflicting molecular and isotopic signatures for oils in Tuk peninsula suggest multiple charge senarios

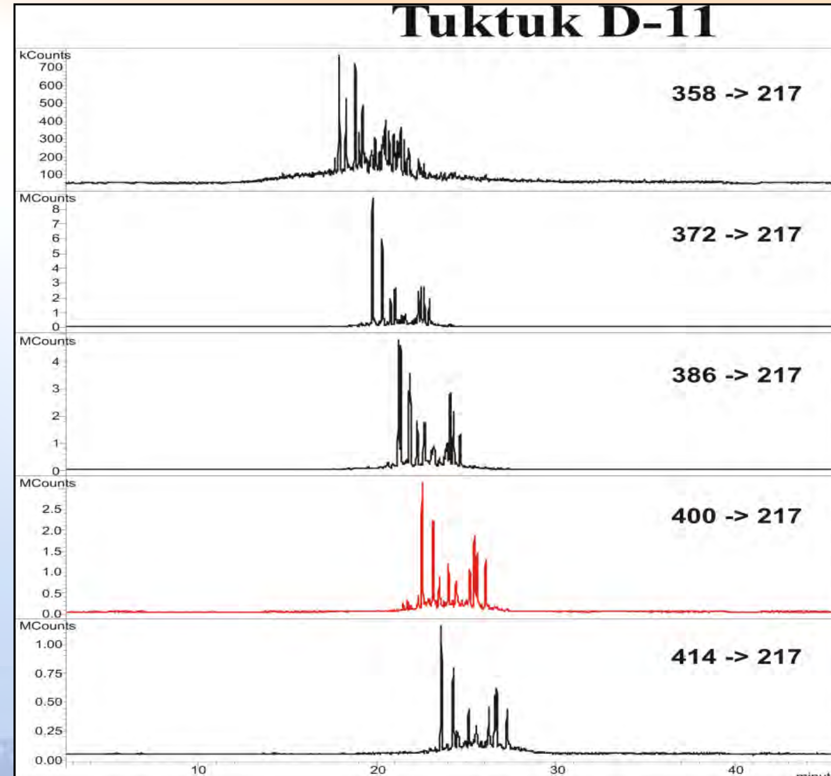
Lateral change in sterane distribution

- The relative abundances of C_{30}, C_{28} over C_{29} steranes in Tertiary reservoired oils increases toward offshore
- This was interpreted to indicate that one or more of the Tertiary deltaic sequences become substantially more oil-prone in the distal part of the delta and generated most of the oils in the offshore parts of the basin
- Potential contribution of pre-Tertiary marine source to Tertiary reservoired oils and possible migration-contamination effects was discounted based on some isotope evidence

(*McCaffrey et al., 1994)*

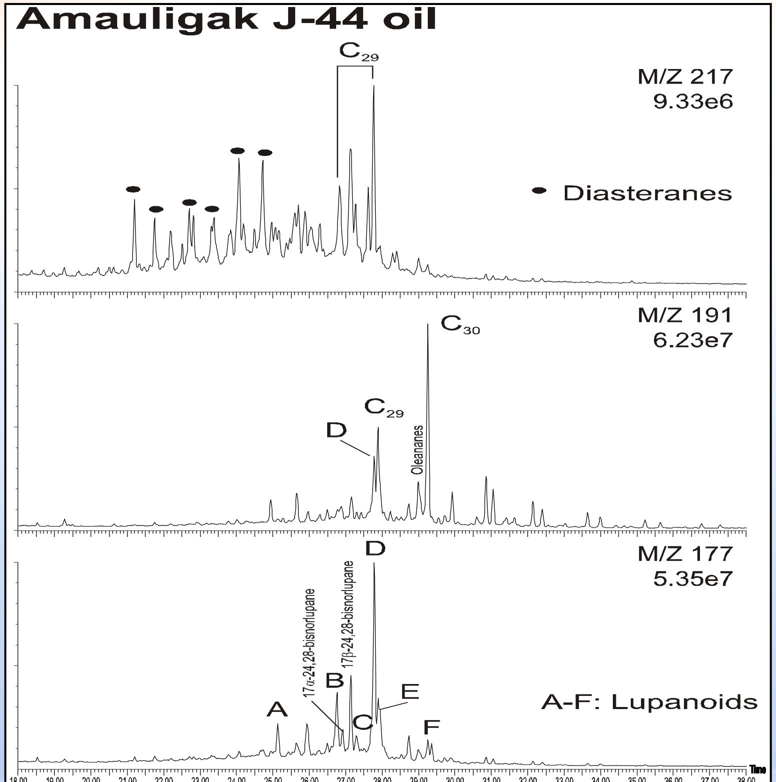
Biomarkers for oils in the Tuk Peninsula

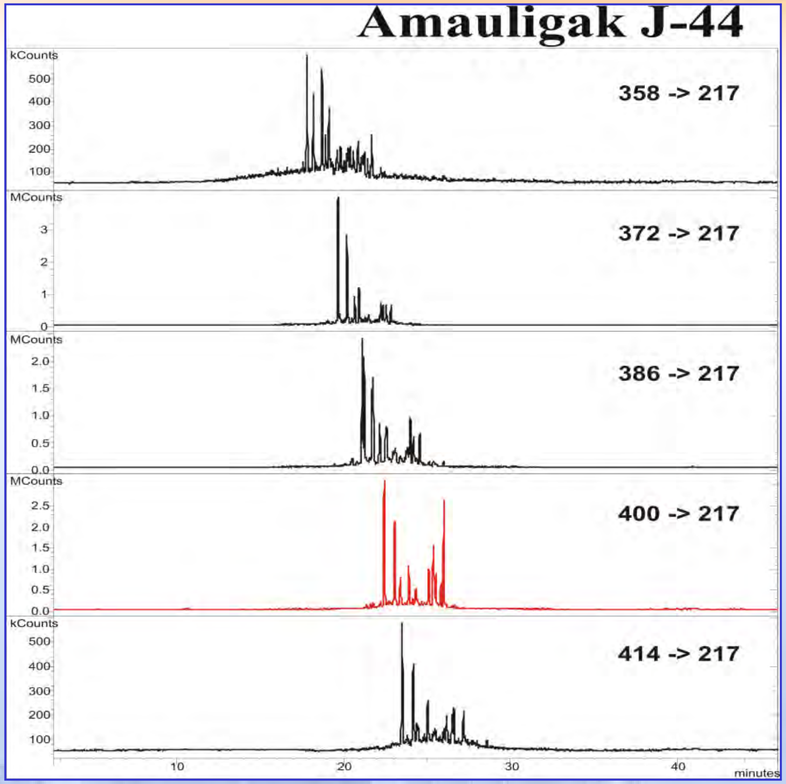




- Sterane distributions characteristic of marine source rocks in the Upper Cretaceous Smoking Hills/Boundary Creek Fm
- Consistent stereochemistry for C_{26} to C_{30} steranes with clear marine source contribution

Biomarkers for offshore oils

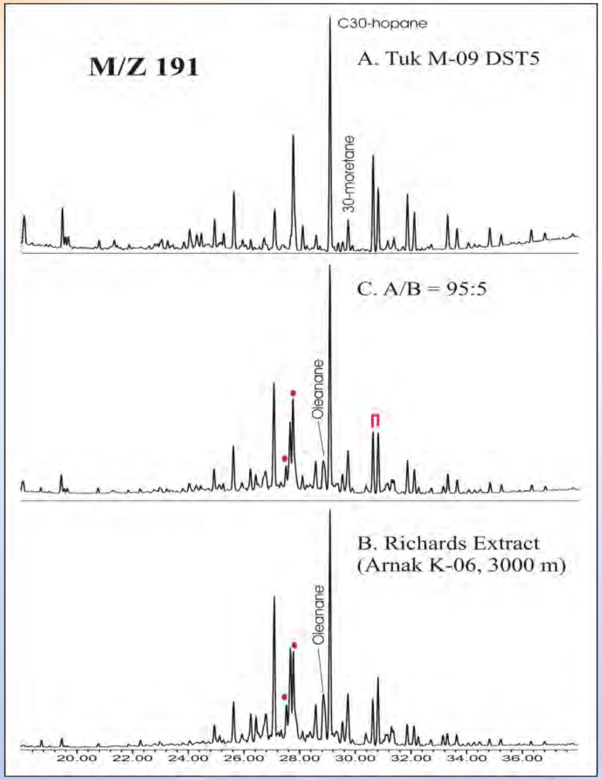


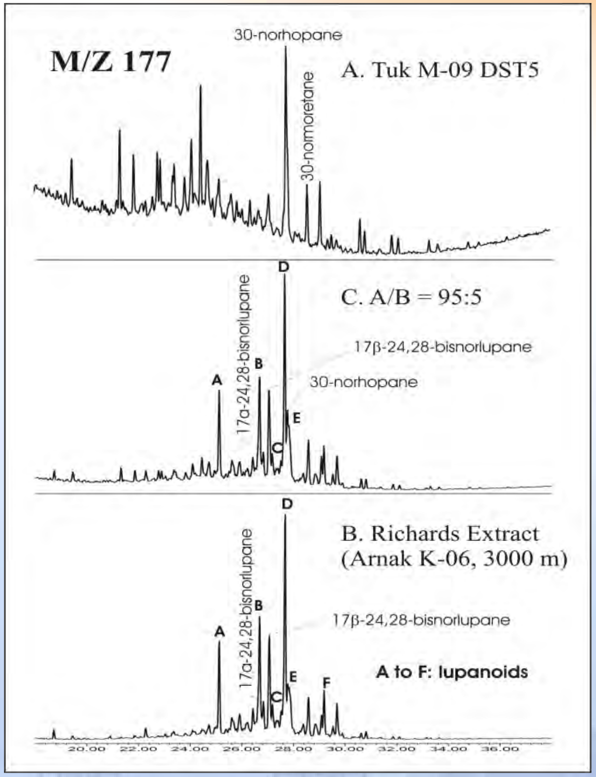


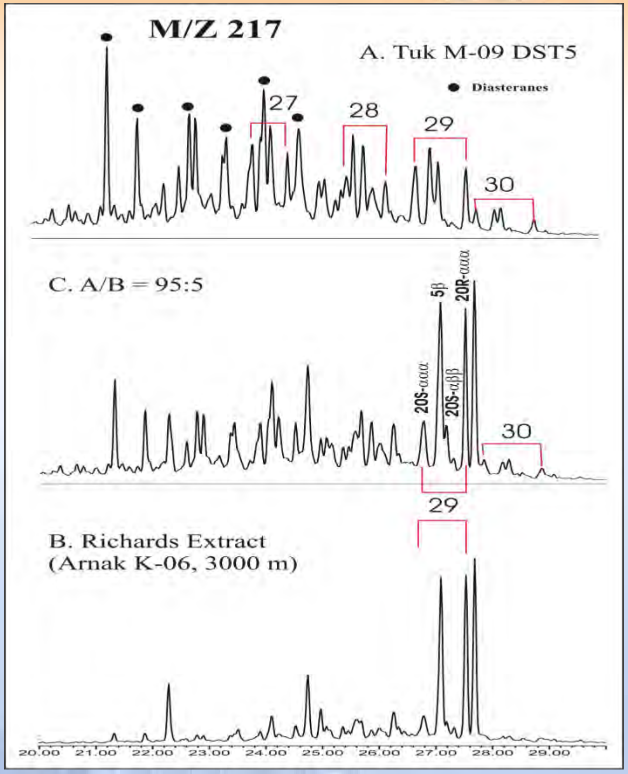
- Abundant higher plant markers in the GC/MS data of Paleogene oils appears to suggest a dominant deltaic coaly source with relatively low thermal maturity

- GC/MS/MS data reveal that the steranes are in fact a mixture of immature terrestrially-derived C_{29} steranes superimposed on a group of C_{26} to C_{30} steranes with mature structural configurations likely from the Upper Cretaceous marine source

Lab mixing results & mass balance



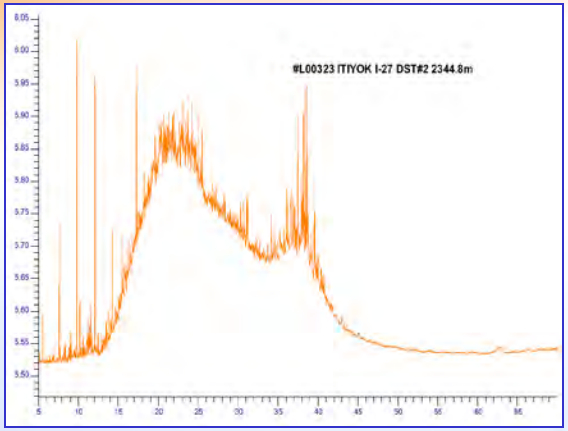


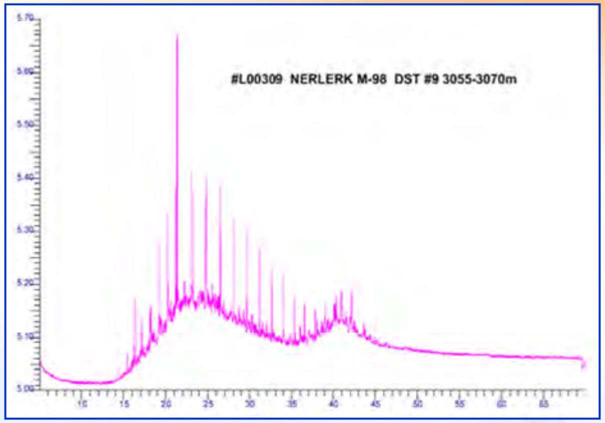


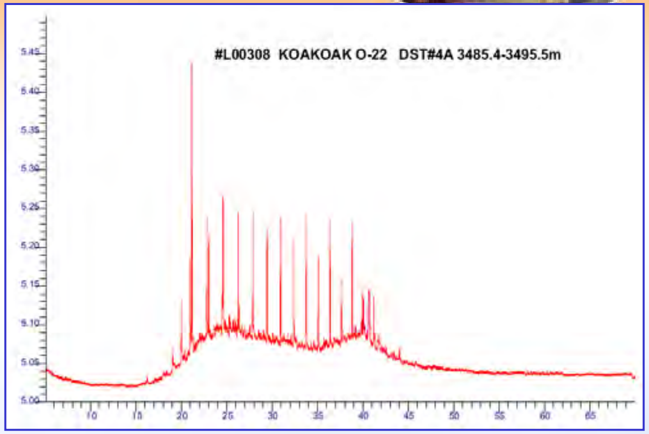
- **Addition of only 5% of the immature intra-reservoir deltaic source rock extract would turn a mature Upper Cretaceous marine oil into an "immature oil" with an apparent coaly source**

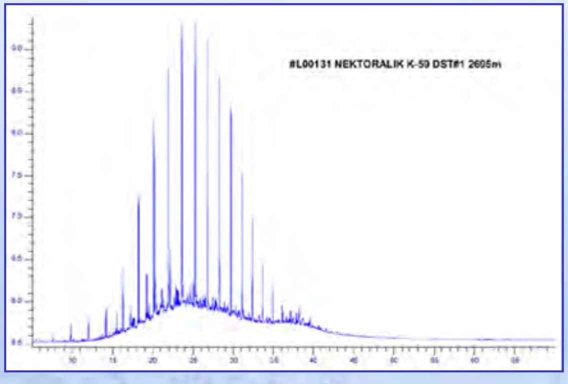
- **This suggests that the presence of abundant higher plant markers in the oil is a necessary but not sufficient indicator for the Paleogene deltaic source, thus potential marine source rocks in the Mesozoic may have been overlooked**

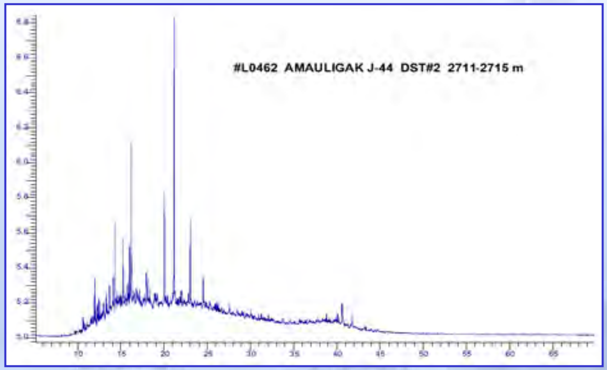
Possible mixing scenarios for offshore oils

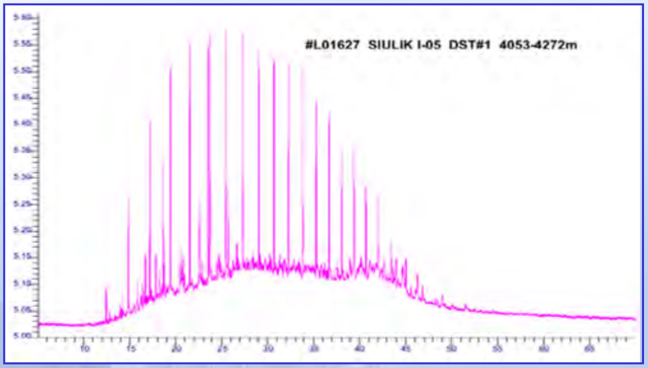










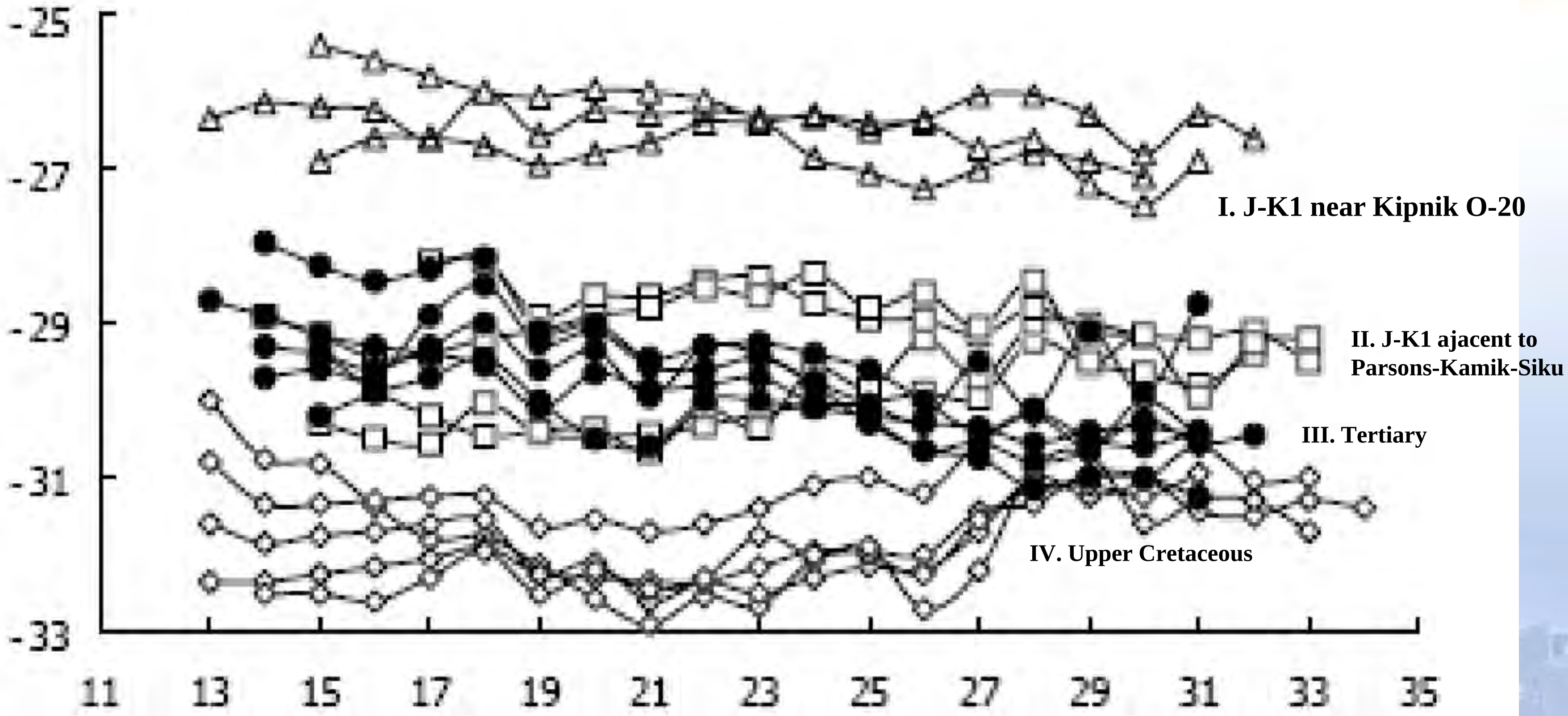


- Most of the offshore oils consist of a series of n-alkanes sitting on top of a UCM
- Strong evidence for more than one oil charge

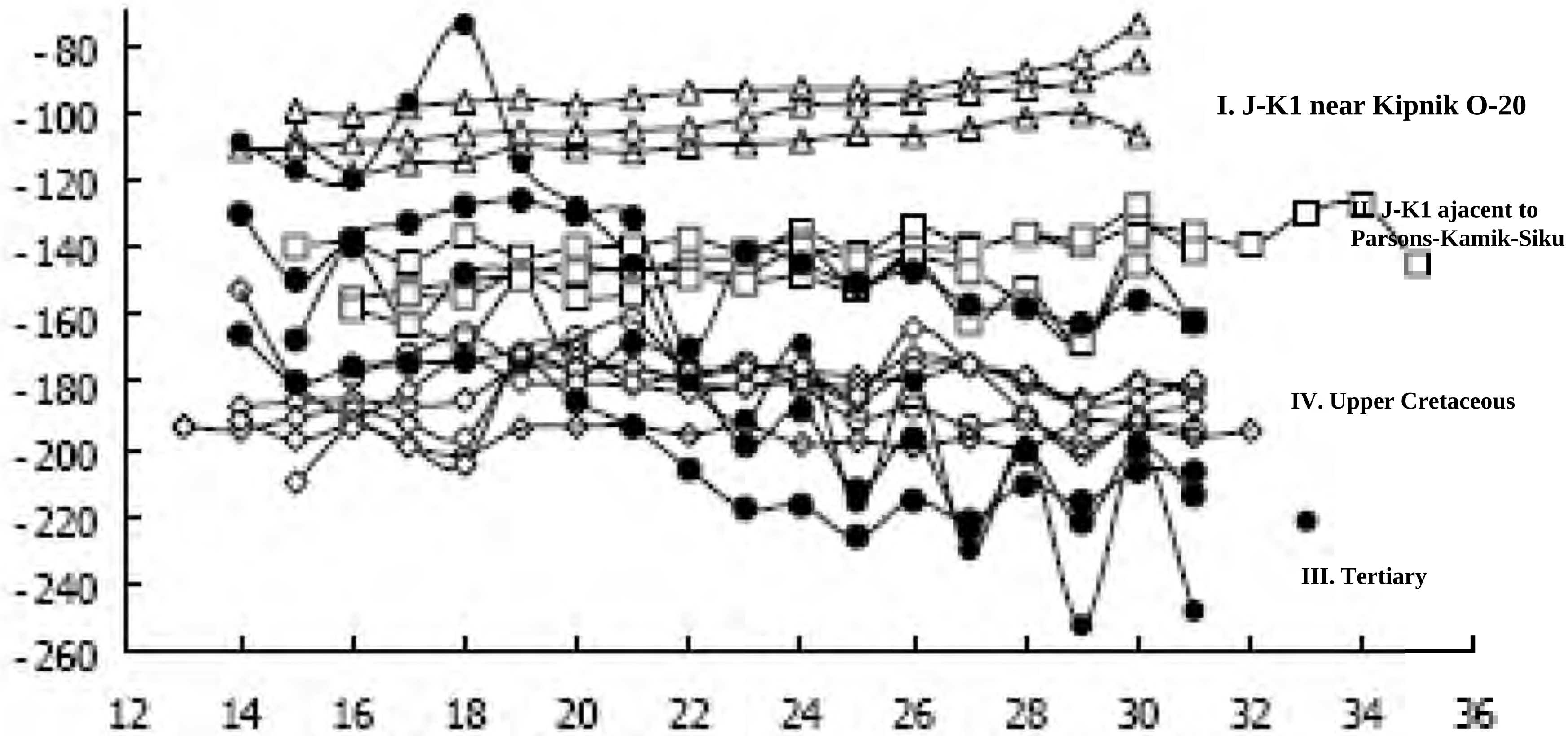
Key findings

- Bisnorlupanes cannot be a Richards-specific source indicator
- Sterane distribution indicates significant mixing of a mature marine oil and immature terrigenic bitumen in offshore oils
- **Conflicting molecular and isotopic signatures for oils in Tuk peninsula suggest multiple charge scenarios**

Source rocks: Stable carbon isotopes

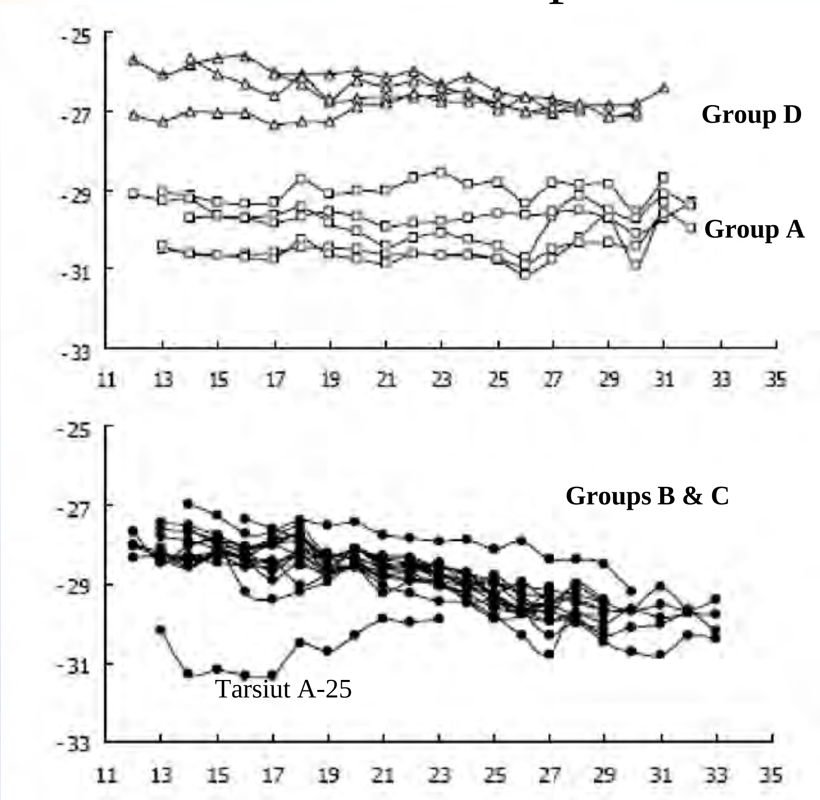


Source rocks: Hydrogen isotopes

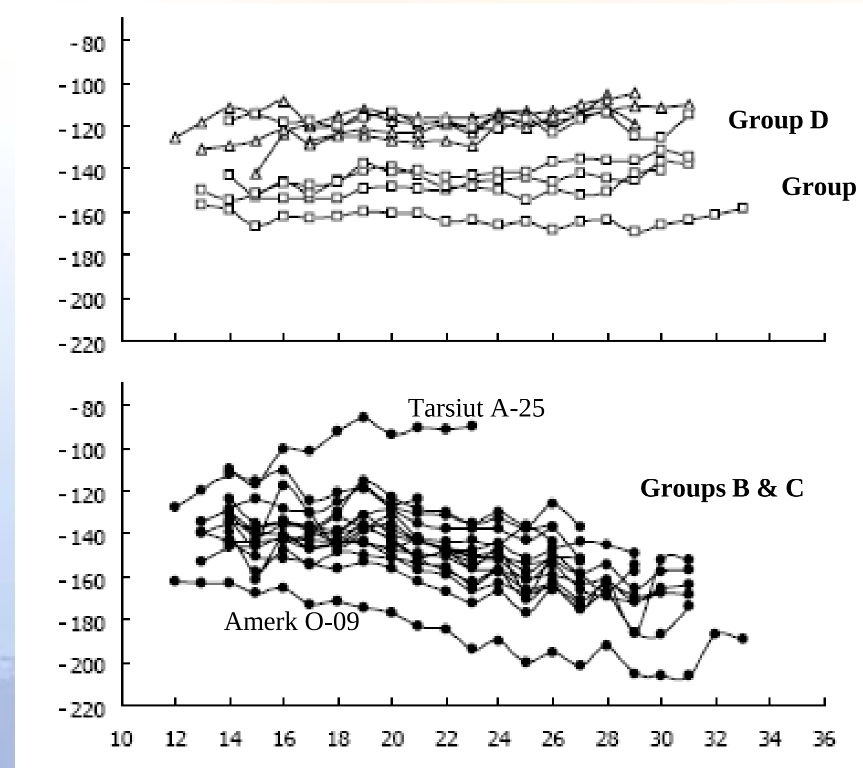


Oil grouping based on δ13C and δD values of individual n-alkanes

Stable carbon isotope



Hydrogen isotope

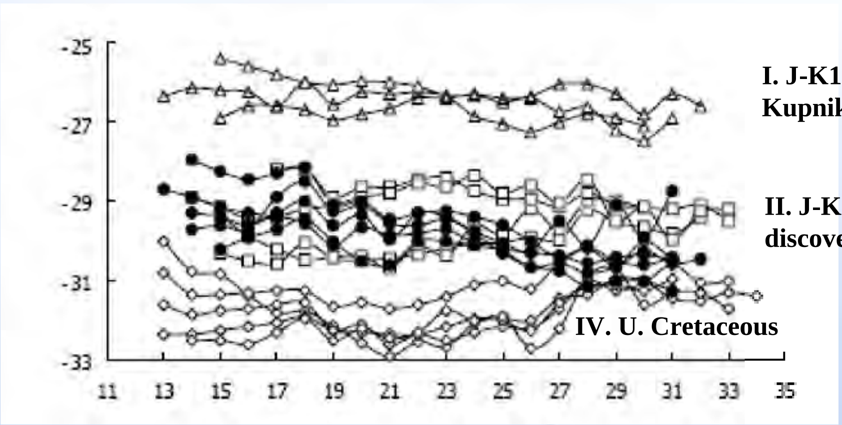


Oils in the study area can be classified into three groups

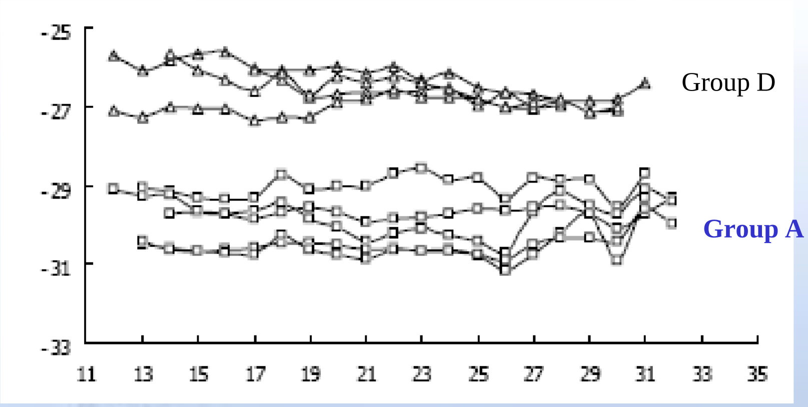
Group A oils

Stable carbon isotope

Source rocks



Oils

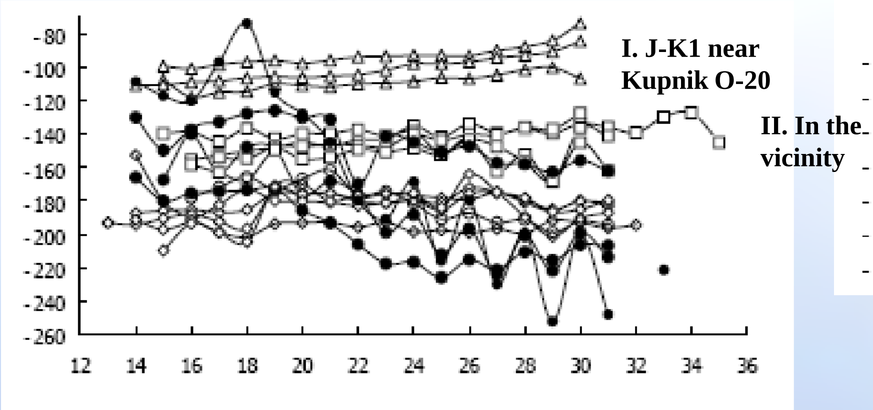


- N-alkanes in the oils show δ13C range in between those of Upper Cretaceous and older source rocks
- Good correlation with the Upper Cretaceous source rocks using biomarker distribution may underestimate the potential contribution from older source rocks

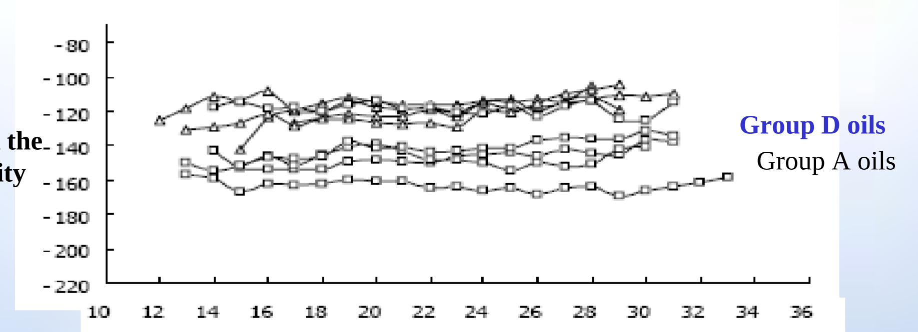
Group A oils

Hydrogen isotope

Source rocks



Oils



- **N-alkanes in the oils also show intermediate δD range, indicating potential underestimation of older and more mature source contribution**

Talk outline

- Problem definition & objectives
- Previous work
- A new integrated approach
- Key findings
- **Implications for exploration**

Implications for exploration

- Although our results generally support the end member oils identified previously by industry, the discrepancies observed in the molecular and isotopic signatures in many of the studied oils indicate that most of the earlier interpreted oil-source relationships are incorrect

- In the Tuk peninsula, biomarkers suggests marine Upper Cretaceous sourced oils, but isotope values of individual n-alkanes in the oils display clear affinity with the marine source rocks in the Upper Jurassic - Lower Cretaceous strata, thus older Mesozoic source rocks in the deeper grabens may have far more important contribution than presently recognized

Implications for exploration

- In the offshore area, integrated molecular and isotopic approach reveals that the oils have most likely been derived from a mature Upper Cretaceous marine source, undergone varying degrees of biodegradation, and subsequently mixed with new hydrocarbon fluids from the shallower Tertiary strata

- Interpretation of the newly acquired geochemical data within the context of petroleum mass fractions provides important petroleum source information that requires the revision of the current seismic formation top picks, burial history models and trap filling concepts

Thank you very much!