Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems*

Kenneth Peters[1,2] and Andrew Murray[3]

Search and Discovery Article #42564 (2020)**
Posted October 26, 2020

*Adapted from oral presentation accepted for the 2020 AAPG Annual Convention and Exhibition online meeting, September 29 – October 1, 2020
 DOI:10.1306/42564Peters2020

[1]Geological Sciences Department, Stanford University, Stanford, CA,USA (kepeters@stanford.edu)
[2]Schlumberger (retired), Mill Valley, CA, USA
[3]Murray Partners PPSA Pty. Ltd., Perth, Australia

Abstract

Geochemical analyses of mixed petroleum commonly underestimate input from the more gas-prone source, e.g., inferred input from coaly Sleipner-Hugin source rock is anomalously low compared to that from the Draupne Formation in mixed fluids from the South Viking Graben (SVG; Patience, 2003; Cornford, 2018). We mathematically mixed various pairs of endmembers, including oil and gas condensate (<3,000 and >3,000 scf/bbl, respectively), which we deconvoluted by alternating least squares regression of compound ratios (ALS-R) and concentrations (ALS-C) in the traditional C_{15+} range. Results show that ALS-R underestimates input of gas condensate while ALS-C correctly predicts the relative contributions of both endmembers. Furthermore, hierarchical cluster analysis (HCA) of compound ratios to establish genetic families can be misleading. Mixtures having major proportions of gas condensate can cluster with those dominated by the oil endmember.

This work supports previous conclusions that ALS-C reliably predicts mix composition, while ALS-R does not (Peters et al., 2008). For example, ALS-R for mathematical mixtures of Draupne oil (SVG_o) and Sleipner-Hugin gas condensate (SVG_g) underestimates SVG_g by up to 82%. The 10:90 mix of SVG_o to SVG_g deconvolutes by ALS-R to 92:8 (severely underestimated SVG_g) and by ALS-C to 10:90. In the HCA dendrogram, mixtures with up to 75% SVG_g (GLR=1,070-9,734 scf/bbl) cluster with others dominated by SVG_o. A more distal cluster of mixtures contains 80-95% SVG_g (GLR=10,312-12,044 scf/bbl). The endmember SVG_g (0:100; GLR=12,622 scf/bbl) clusters as another distinct genetic group. Thus, many fluids assigned to the oil-prone source rock by HCA have strong input from the gas-prone endmember. Unfortunately, many publications use ALS-R to deconvolute mixtures (e.g., Justwan et al., 2006). The large range of GLR for the above mixtures (1,070-12,622 scf/bbl) is unrelated to differential biodegradation or thermal maturation.

In conclusion, compound ratios must cover the entire boiling range of mixed petroleum to avoid bias in HCA for genetic affinity of mixed oil and gas condensate. Deconvolution based on C_{15+} compound ratios underestimates input of gas condensate to such mixtures and compound concentrations are required.

Selected References

Cornford, C., 2018, Petroleum Systems of the South Viking Graben, *in* C.C. Turner and B.T. Cronin (eds.), Rift-Related Coarse-Grained Submarine Fan Reservoirs; The Brae Play, South Viking Graben, North Sea: American Association of Petroleum Geologists Memoir 115, p. 453-542.

Justwan, H., B. Dahl, and G.H. Isaksen, 2006, Geochemical Characterization and Genetic Origin of Oils and Condensates in the South Viking Graben, Norway: Marine and Petroleum Geology, v. 23/2, p. 213-239. doi:10.1016/j.marpetgeo.2005.07.003

Kaufman, R.L., A.S. Ahmed, and R.J. Elsinger, 1990, Gas Chromatography as a Development and Production Tool for Fingerprinting Oils from Individual Reservoirs: Applications in the Gulf of Mexico, *in* D. Schumacker and B.F. Perkins (eds.): Proceedings of the 9th Annual SEPM Research Conference, New Orleans, p. 263-282.

McCaffrey, M.A., D.S. Ohms, M. Werner, C.L. Stone, D.K. Baskin, and B.A. Patterson, 2011, Geochemical Allocation of Commingled Oil Production or Commingled Gas Production: Society of Petroleum Engineers Western North American Region Meeting, 7-11 May, Anchorage, Alaska, USA, SPE 144618-MS, 19 p. doi.org/10.2118/144618-MS

Murray, A.P., and K.E. Peters, 2020, Quantifying Multiple Source Rock Contributions to Petroleum Fluids: Bias in Using Compound Ratios and Neglecting the Gas Fraction: American Association of Petroleum Geologists Bulletin, in press.

Patience, R.L., 2003, Where Did All the Coal Gas Go?: Organic Geochemistry, v. 34, p. 375-387.

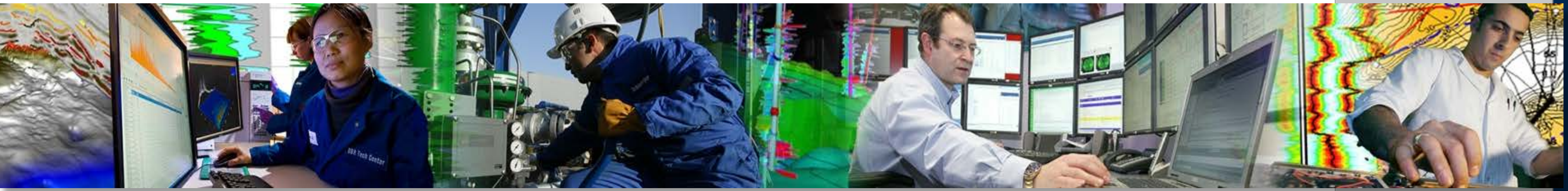
Peters, K.E., L.S. Ramos, J.E. Zumberge, Z.C. Valin, and K.J. Bird, 2008, De-Convoluting Mixed Crude Oil in Prudhoe Bay Field, North Slope, Alaska: Organic Geochemistry, v. 39/6, p. 623-645. doi.org/10.1016/j.orggeochem.2008.03.001

Theme 3: Fluid-Rock and Fluid-Fluid Interaction

ACE 2020 7-10 JUNE HOUSTON
AAPG ANNUAL CONVENTION & EXHIBITION

SEPTEMBER 30, 2020
VIRTUAL AAPG

Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems



Kenneth Peters[1,2] and Andrew Murray[3]

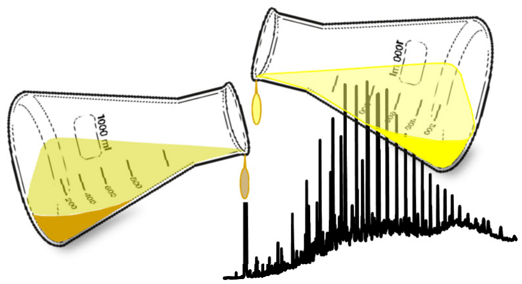
[1] Stanford University, Geological Sciences Department, Stanford, California; kepeters@stanford.edu
[2] Schlumberger (retired), Mill Valley, CA 94941
[3] Murray Partners PPSA Pty. Ltd., Perth, Australia; amurraypartners@gmail.com

Purpose and Methods

- What is the impact of mixed light and heavy petroleum on fluid-source assignment and predicted gas-liquid ratio (GLR)?
- Biomarker concentrations for four pairs of petroleum fluids having endmember GLRs from ~100 to ~50,000 scf/bbl were mathematically mixed in 5% increments.
- Each series of mixtures was evaluated for genetic affinity by hierarchical cluster analysis (HCA) and for source allocation by alternating least squares regression of compound ratios (ALS-R) and concentrations (ALS-C).

<u>**17 independent source-related variables**</u>

Pr/Ph, C_{19}/C_{23}, C_{22}/C_{21}, C_{24}/C_{23}, C_{26}/C_{25}, Tet/C_{23}, $C_{27}T/C_{27}$, C_{28}/H, C_{29}/H, X/H, C_{31}/R, St/H, %C_{27}, %C_{28}, %C_{29}, S1/S6, Ol/H



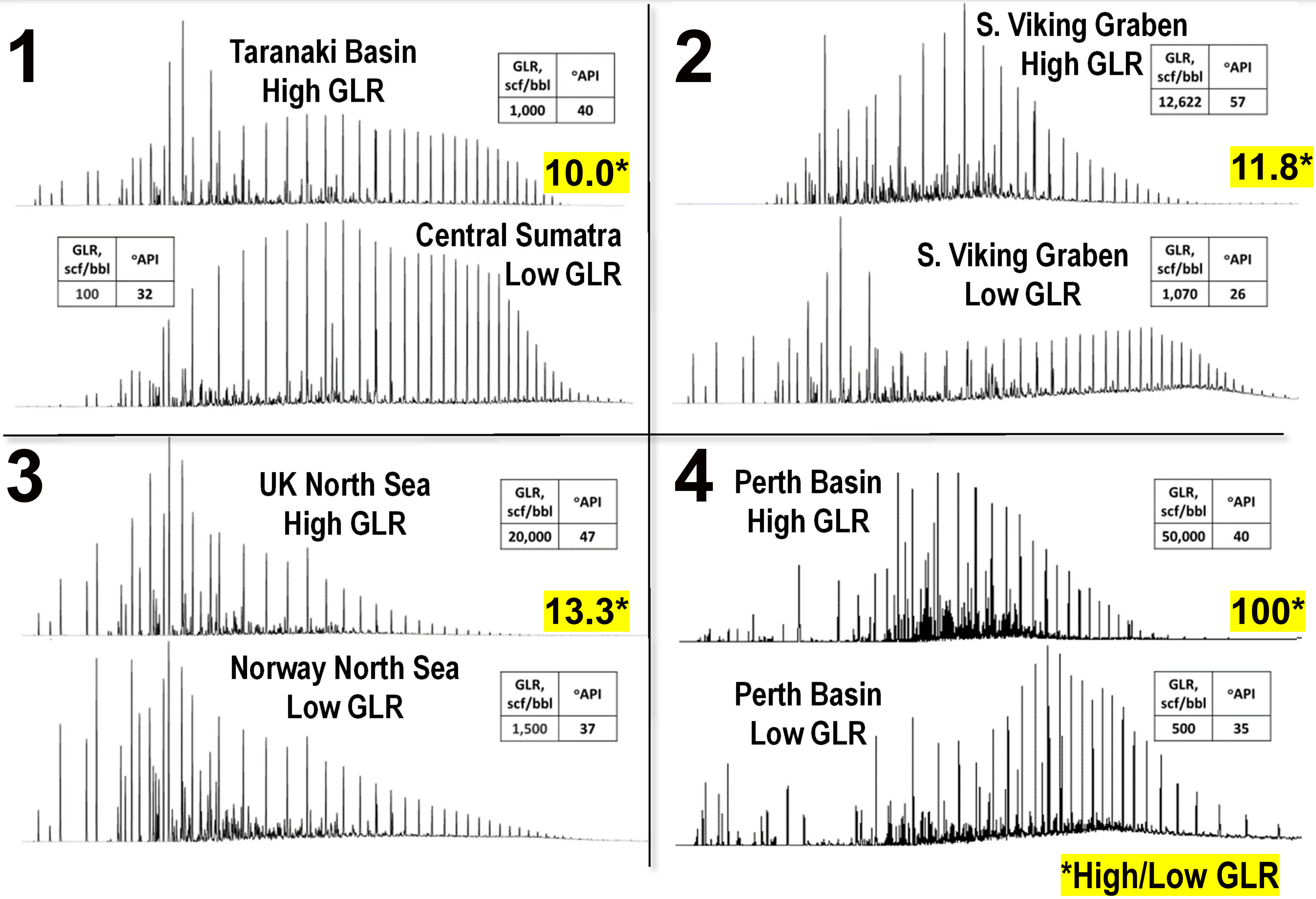
Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

Presenter's notes:

	black oil	volatile oil		gas condensate
GLR	<2000	2000-3000		>3000 scf/bbl
API	<40	40-45	45-50	

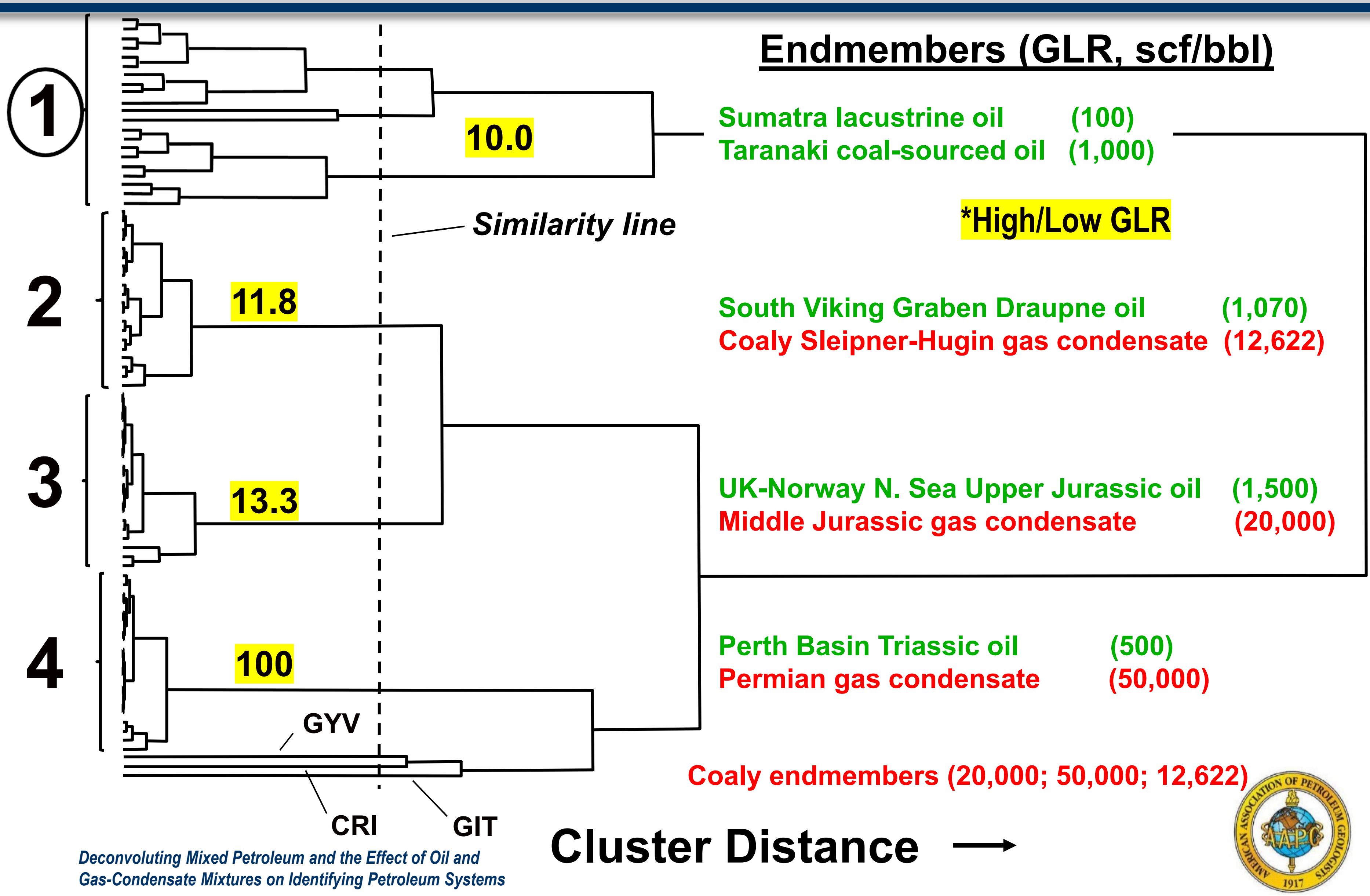
ALS refers to an algorithm to estimate the contributions from mixed sources, projecting that estimate onto the original data to produce an estimate of the chromatographic pattern in each of the component oils. Users modify the projected chromatogram to add constraints that are not possible (e.g., no negative peaks) to form a revised estimate of a logical set of chromatographic patterns, then reverse the process to estimate a new set of concentrations across all oils, then add a constraint (i.e., no negative concentrations and add up to 100%) and repeat: therefore “alternating”.

GCs and Gas-Liquid Ratios Differ for the Endmembers



Presenter's notes: GOR = gas-oil ratio; <3,000 = oil (<45 API), 3,000-100,000 = gas condensate
Therefore we will use GLR to include gas condensates.

HCA of Four Binary Petroleum Mixtures is Misleading



Presenter's notes: Four sets of binary mixtures were obtained by mathematically mixing whole fluid concentrations of compounds for the two endmembers. Seventeen biomarker ratios calculated for each mixture were used to construct the HCA dendrogram, traditionally used to identify genetic affinities. The cluster analysis suggests at least four genetic oil families and three outliers based on the vertical similarity line.

Note that the cluster distances between samples in each binary mix decrease as the difference in GLR between endmembers increases. This occurs because with higher GLR of the gas condensate, the relative influence of the oil on cluster distance increases.

For HCA: autoscale preprocessing, Euclidean distance, incremental linkage
GOR = gas-oil ratio; <3,000 = oil (<45o API), 3,000-100,000 = gas condensate
Therefore we will use GLR to include gas condensates.

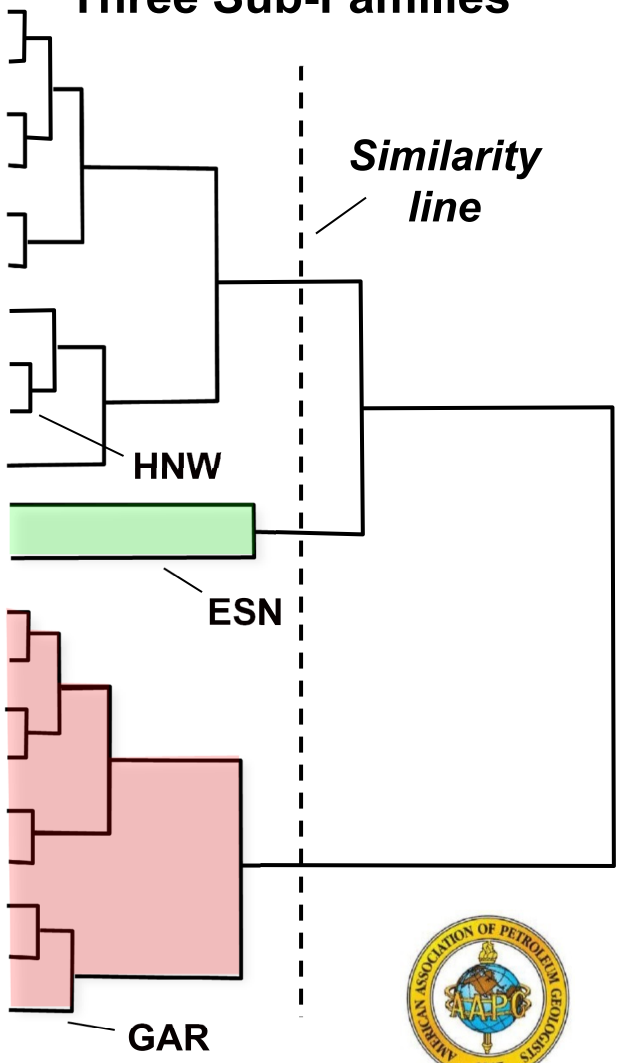
Families with and without noise are identical, although cluster distances are slightly greater between families without added noise.

ALS-C Reliably Deconvolutes Mixtures; ALS-R Does Not

Pair 1	Math Mix, %		ALS-R, %		ALS-C WL, %		ALS-C WF, %		GLR, scf/bbl
	Suma	Tara	Suma	Tara	Suma	Tara	Suma	Tara	
ESN	100	0	100.0	0.0	100.0	0.0	100.0	0.0	100
HKS	95	5	83.6	16.4	95.8	4.2	95.0	5.0	145
GLS	90	10	66.7	33.3	91.4	8.6	90.0	10.0	190
XOY	85	15	57.0	43.0	87.1	12.9	85.0	15.0	235
IKL	80	20	50.2	49.8	82.6	17.4	80.0	20.0	280
HNW	75	25	45.1	54.9	78.1	21.9	75.0	25.0	325
HNH	70	30	40.9	59.1	73.5	26.5	70.0	30.0	370
HDH	65	35	37.4	62.6	68.8	31.2	65.0	35.0	415
HDD	60	40	34.3	65.7	64.0	36.0	60.0	40.0	460
GKV	55	45	31.5	68.5	59.2	40.8	55.0	45.0	505
GFJ	50	50	28.9	71.1	54.3	45.7	50.0	50.0	550
ZSE	45	55	26.4	73.6	49.3	50.7	45.0	55.0	595
XUP	40	60	24.0	76.0	44.2	55.8	40.0	60.0	640
IBA	35	65	21.5	78.5	39.0	61.0	35.0	65.0	685
BOX	30	70	19.1	80.9	33.7	66.3	30.0	70.0	730
ZAG	25	75	16.6	83.4	28.4	71.6	25.0	75.0	775
GRH	20	80	13.9	86.1	22.9	77.1	20.0	80.0	820
GKT	15	85	11.1	88.9	17.3	82.7	15.0	85.0	865
GKN	10	90	8.1	91.9	11.7	88.3	10.0	90.0	910
GEI	5	95	4.7	95.3	5.9	94.1	5.0	95.0	955
GAR	0	100	0.9	99.1	0.0	100.0	0.0	100.0	1,000

Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

HCA Suggests Three Sub-Families



Presenter's notes: ALS-R underestimates Sumatra oil by up to 30%!

Mass balance (WL and WF): To calculate whole-liquids concentrations, ppm values from Geomark RFDbase were corrected to the saturates concentration using the P/N ratio, then corrected to the concentration in the C_{15+} fraction using %saturates (relative to total saturates, aromatics, resins, and asphaltenes), and finally corrected to the C_{6+} concentration using the %loss upon topping (i.e., C_6-C_{15}). The whole-fluid concentration (C_{1+}) can then be calculated by using the GLR (m/m).

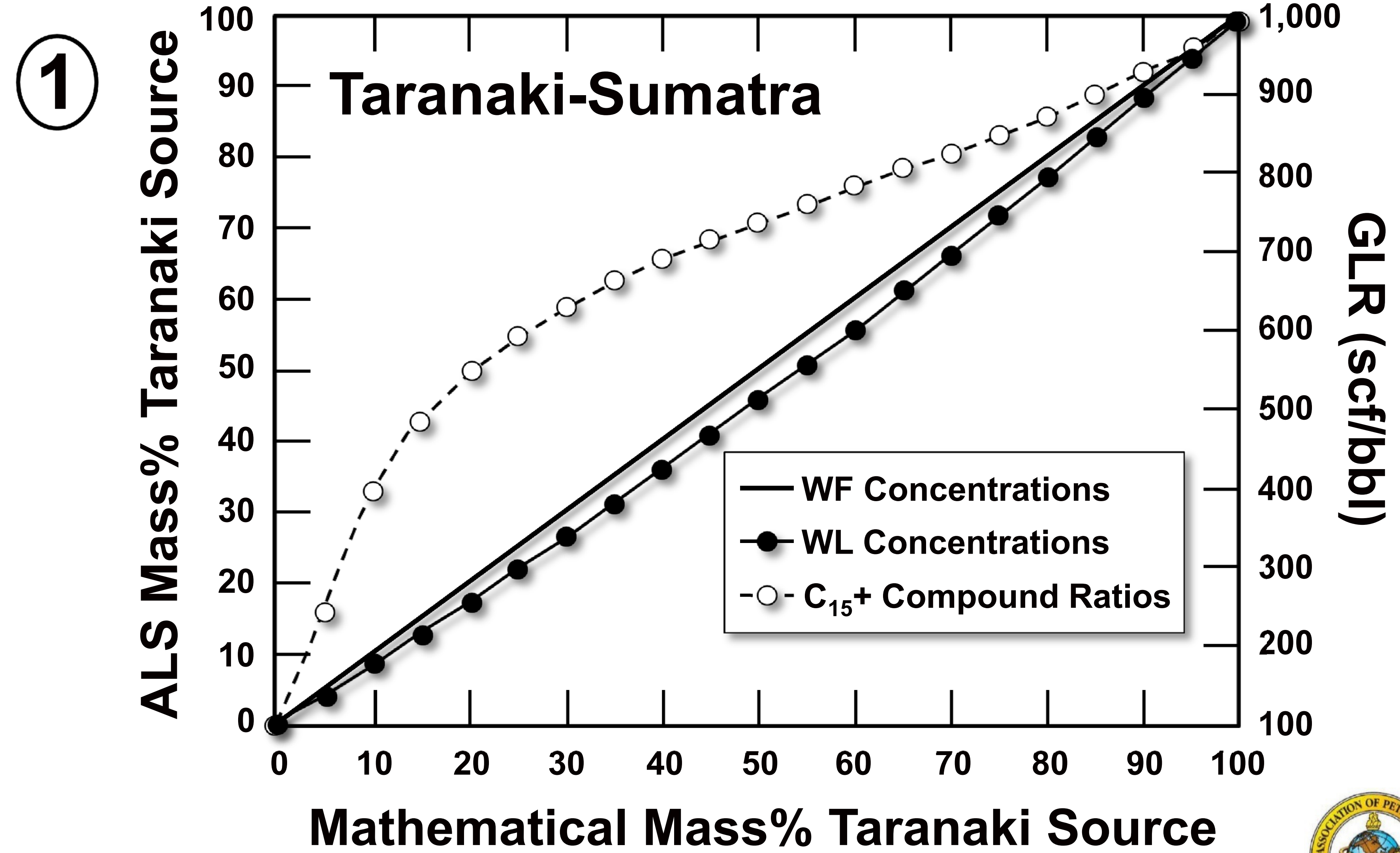
These results confirm Peters et al. (2008), where ALS-C gives reliable predictions of mix composition, while ALS-R does not.

Note that the vertical order of individual samples or sub-families on a dendrogram can change by rotation around the horizontal tie line that connects them. Only cluster distance is important. For example, the sub-family that includes ESN could rotate to the top of the dendrogram over the sub-family that contains HNW around the horizontal tie between them.

For ALS: Variance scale preprocessing, 21 samples, 25 independent variables:

Pr, Ph, C_{19} Tri, C_{23} Tri, C_{22} Tri, C_{21} Tri, C_{24} Tri, C_{26} Tri, C_{25} Tri, Tet, C_{27} Tri, C_{27}H(Tm), C_{28}H, 29H, C_{30}H, X, C_{31}R, Steranes, Hopanes, C_{27} Ster, C_{28} Ster, C_{29} Ster, S1, S6, Ol

ALS-R Overestimates Taranaki Coaly Input and GLR



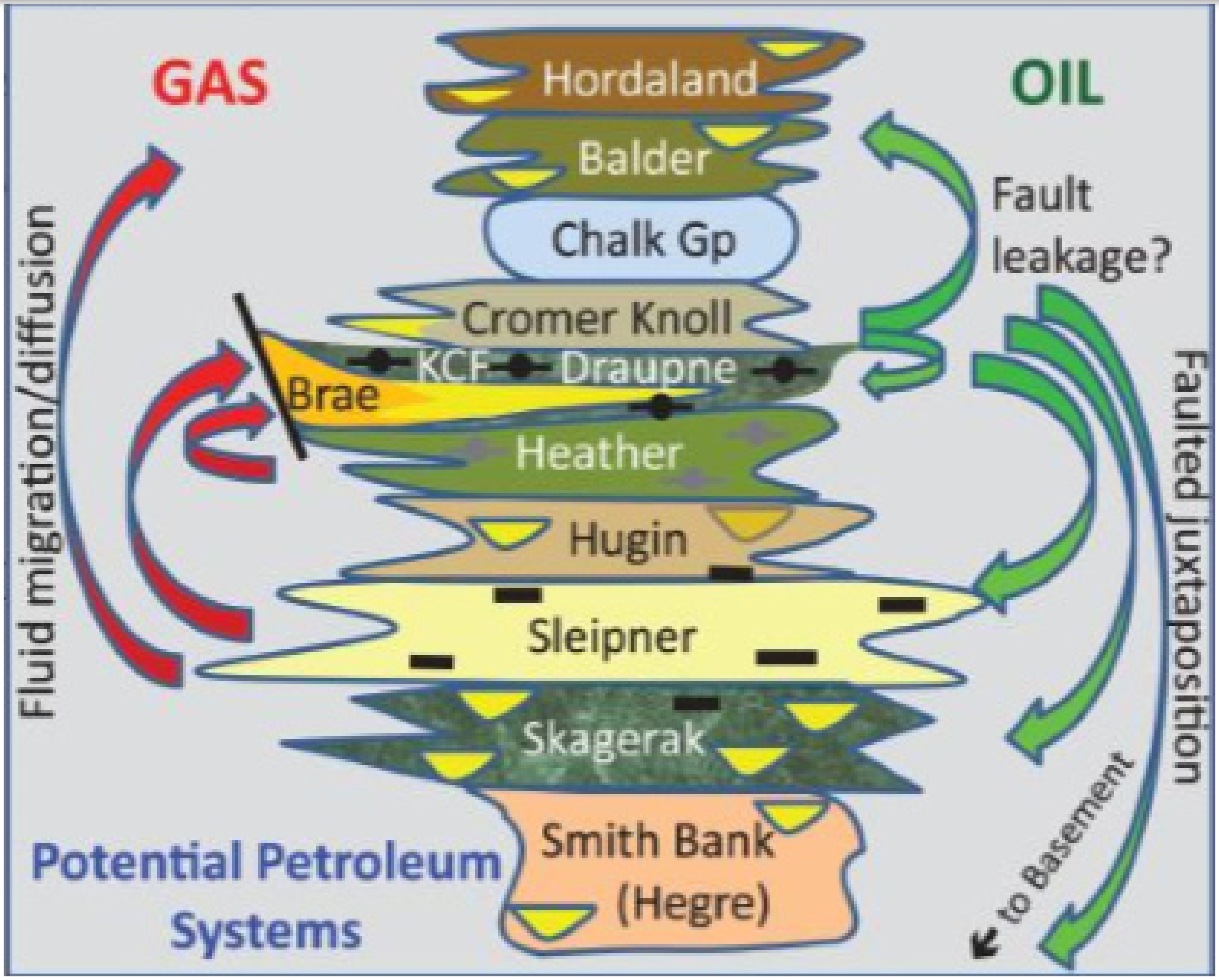
Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

Presenter's notes: ALS-R underestimates Sumatra oil by up to 30%! At 30% math mass% Taranaki, ALS-R predicts GLR of ~600 scf/bbl, but it should be ~300 scf/bbl.

Oil-oil mixtures: Biomarkers are more abundant in the Taranaki than the Sumatra oil, which results in the unusual case where Taranaki input and GLR are overestimated by ALS-R. Normally, coaly input and GLR for an oil-gas condensate mixture are underestimated by ALS-R.

Mass balance (WL and WF): To calculate whole-liquids concentrations, ppm values from Geomark RFDbase were corrected to the saturates concentration using the P/N ratio, then corrected to the concentration in the C_{15+} fraction using %saturates (relative to total saturates, aromatics, resins, and asphaltenes), and finally corrected to the C_{6+} concentration using the %loss upon topping (i.e., C_6-C_{15}). The whole-fluid concentration (C_{1+}) can then be calculated by using the GLR (m/m).

South Viking Graben: *Where Did All the Coal Gas Go?*



SVG oil

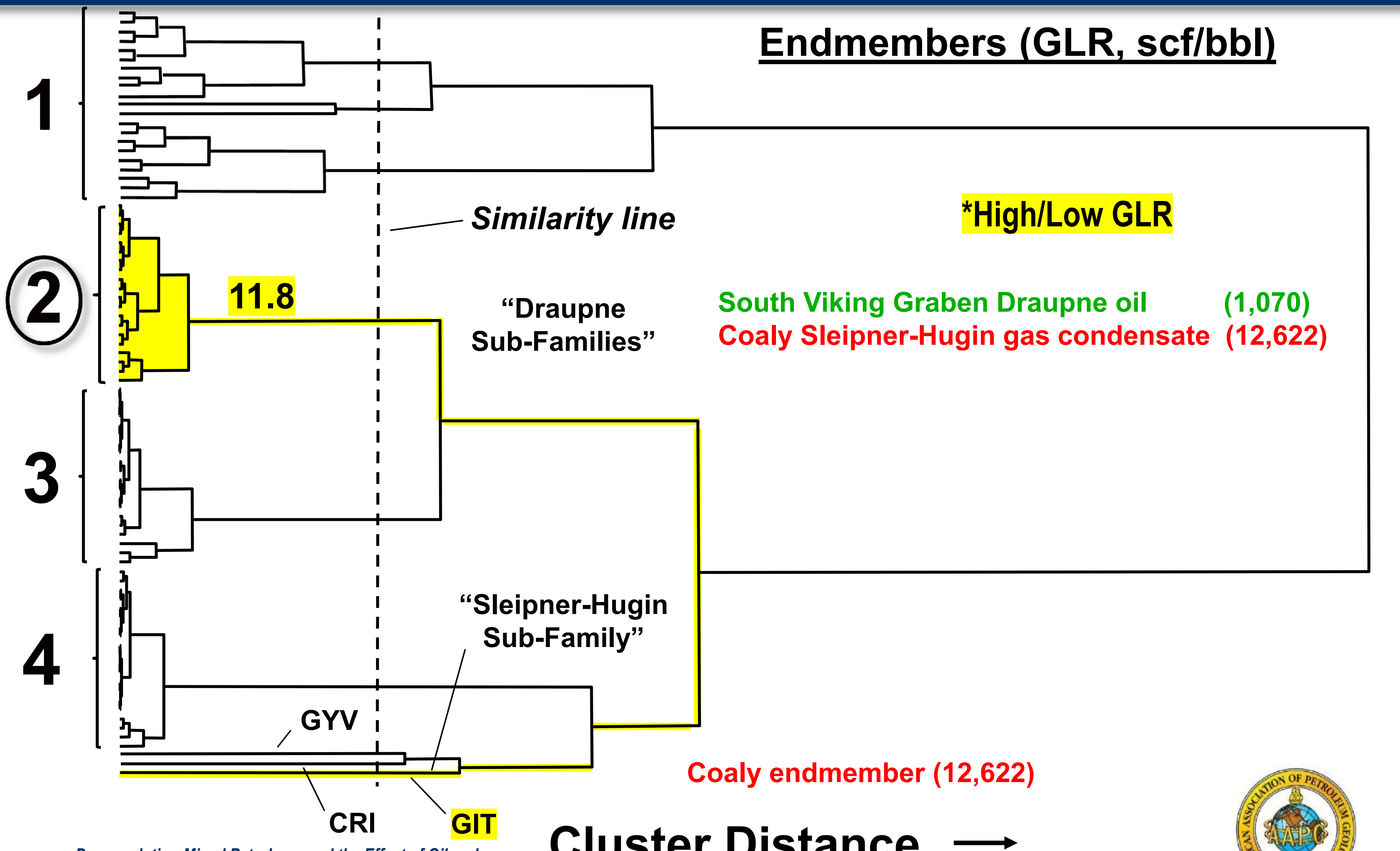
SVG gas

From Cornford (2018)

Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

Presenter's notes: South Viking Graben: Draupne (low GLR), coaly Sleipner-Hugin (high GLR)
North and Central Graben: Kimmeridge Clay (low GLR), coaly Pentland (high GLR)
Mid-Norway: Spekk (low GLR), coaly Åre (high GLR)

HCA is Biased for the Low vs. High GLR Endmember



Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

Presenter's notes: Only the endmember Sleipner-Hugin gas condensate plots separately. All other mixtures (up to 95% Sleipner-Hugin) plot in the HCA near the Draupne endmember, i.e., the 'Draupne Sub-Families' contain up to 95% Sleipner-Hugin input.

Note that the cluster distances between samples in each binary mix decrease as the difference in GLR between endmembers increases. This occurs because with higher GLR of the gas condensate, the relative influence of the oil on cluster distance increases.

HCA is biased for the low GLR endmember because biomarker concentrations are generally higher than the high GLR endmember. However, this does not apply to the Taranaki-Sumatra mixed series because the low GLR endmember (Taranaki) has higher biomarker concentrations than the high GLR endmember.

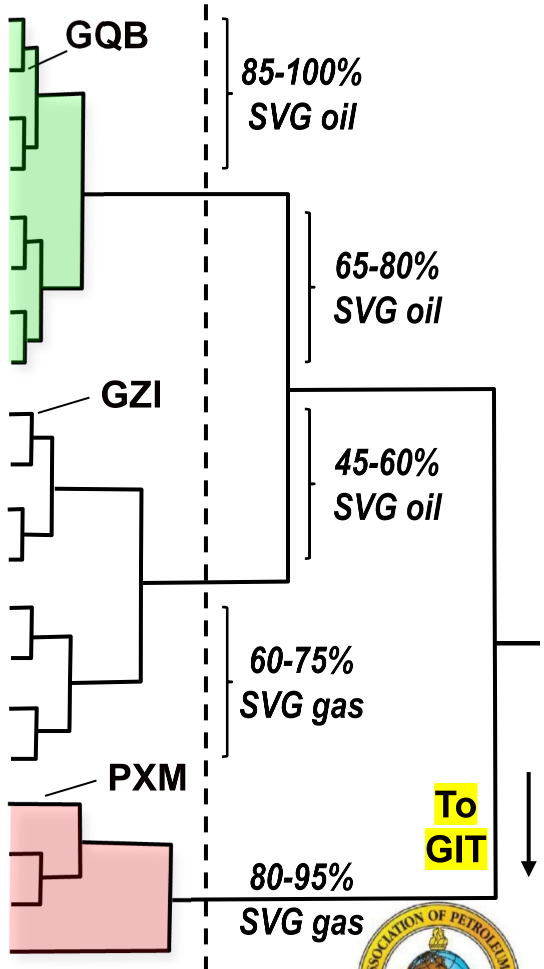
GOR = gas-oil ratio; <3,000 = oil (<45o API), 3,000-100,000 = gas condensate
Therefore we will use GLR to include gas condensates.

ALS-R Underestimates Sleipner-Hugin Coaly Endmember

Pair 2	Math Mix, %		ALS-R, %		ALS-C WL, %		ALS-C WF, %		GLR, scf/bbl
	SVG oil	SVG gas	SVG oil	SVG gas	SVG oil	SVG gas	SVG oil	SVG gas	
GQB	100	0	99.8	0.2	100.0	0.0	100.0	0.0	1,070
ZMC	95	5	99.7	0.3	98.3	1.7	95.0	5.0	1,648
XEO	90	10	99.6	0.4	96.5	3.5	90.0	10.0	2,225
XER	85	15	99.5	0.5	94.6	5.4	85.0	15.0	2,803
GLX	80	20	99.3	0.7	92.5	7.5	80.0	20.0	3,380
GNF	75	25	99.2	0.8	90.2	9.8	75.0	25.0	3,958
GNH	70	30	99.0	1.0	87.8	12.2	70.0	30.0	4,536
GNK	65	35	98.9	1.1	85.1	14.9	65.0	35.0	5,113
GPJ	60	40	98.7	1.3	82.2	17.8	60.0	40.0	5691
GPK	55	45	98.4	1.6	79.0	21.0	55.0	45.0	6,268
GPL	50	50	98.2	1.8	75.4	24.6	50.0	50.0	6,846
GZI	45	55	97.9	2.1	71.5	28.5	45.0	55.0	7,424
BUZ	40	60	97.6	2.4	67.2	32.8	40.0	60.0	8,001
ATW	35	65	97.2	2.8	62.3	37.7	35.0	65.0	8,579
CKM	30	70	96.7	3.3	56.8	43.2	30.0	70.0	9,156
GKQ	25	75	96.1	3.9	50.6	49.4	25.0	75.0	9,734
HDT	20	80	95.2	4.8	43.4	56.6	20.0	80.0	10,312
NYM	15	85	93.9	6.1	35.1	64.9	15.0	85.0	10,889
PXM	10	90	91.7	8.3	25.4	74.6	10.0	90.0	11,467
GIR	5	95	86.2	13.8	13.9	86.1	5.0	95.0	12,044
GIT	0	100	0.0	100.0	0.0	100.0	0.0	100.0	12,622

Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

South Viking Graben Sub-Families



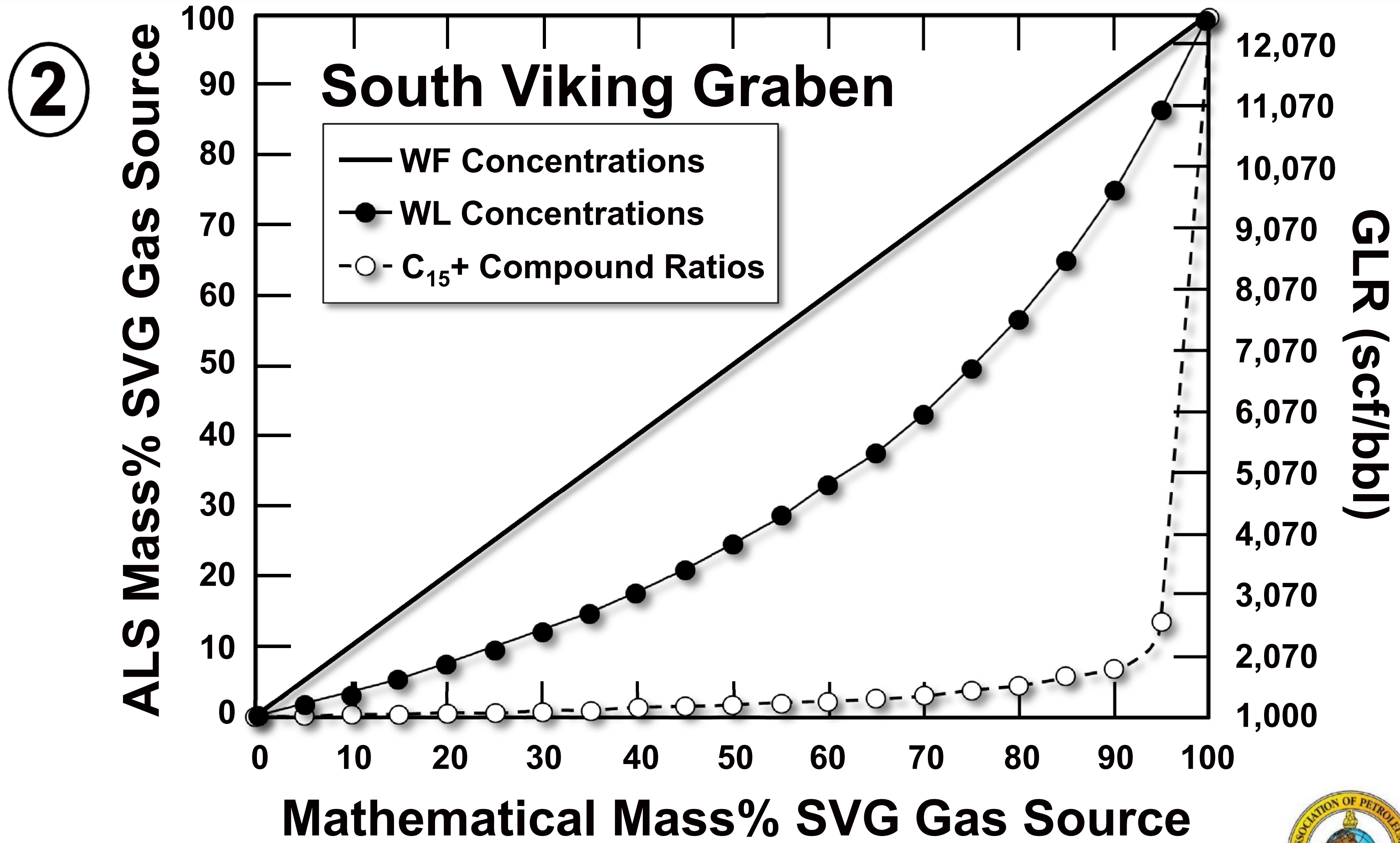
Presenter's notes: Only the endmember Sleipner-Hugin gas condensate plots separately. All other mixtures (up to 95% Sleipner-Hugin) plot in an area of the HCA dendrogram near the Draupne endmember. ALS-R underestimates SVG gas by as much as 82% (PXM), whereas ALS-C correctly deconvolutes all artificial mixtures.

GLR increases from pure Upper Jurassic Draupne oil to pure Middle-Upper Jurassic coaly Sleipner-Hugin gas condensate in the South Viking Graben. GLR oil <3000 sf/bbl; GLR gas condensate = 3000-15,000 scf/bbl.

As shown on the HCA, mixtures with up to 75% SVG gas might be considered to cluster with mixtures dominated by SVG oil.

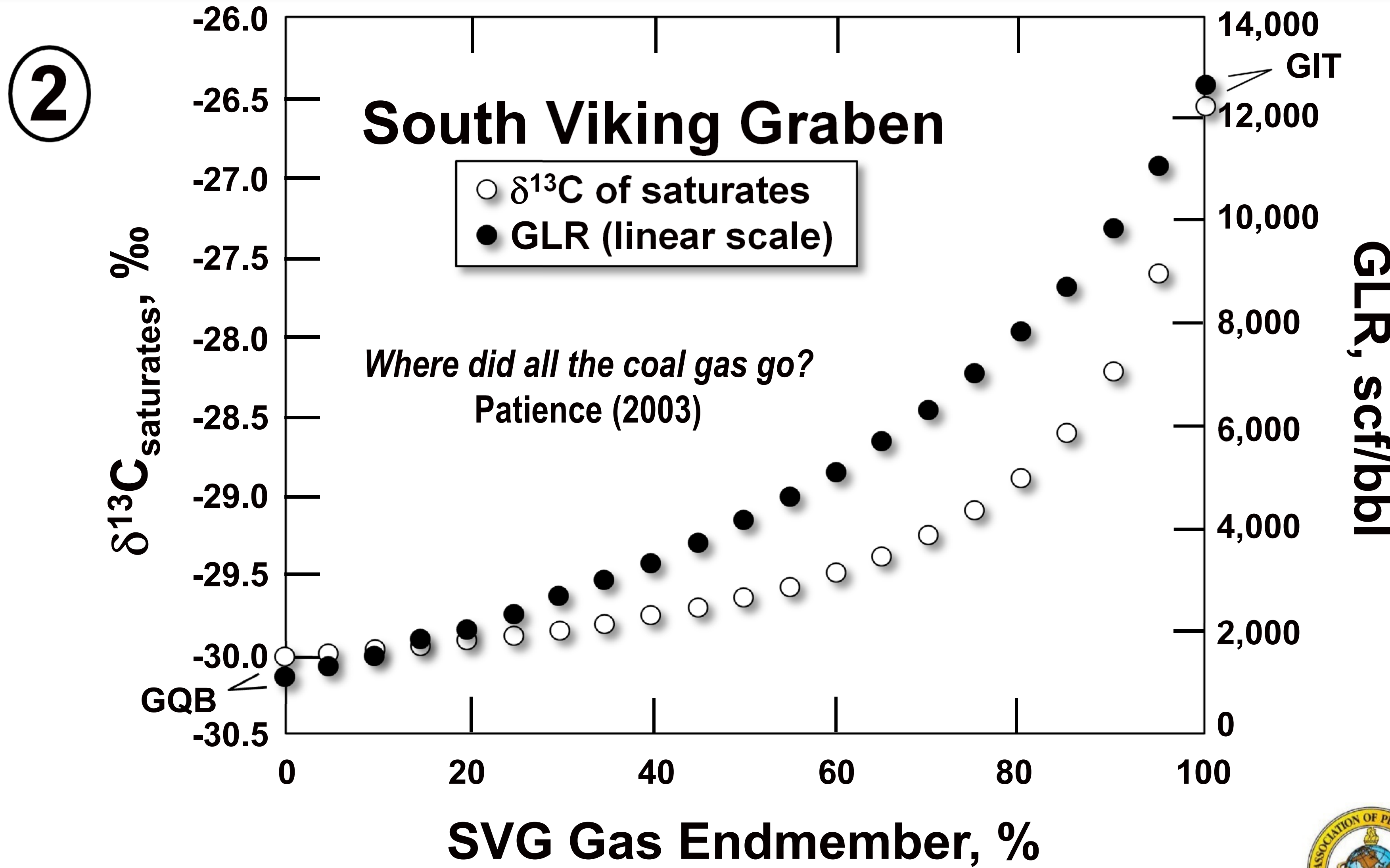
The coaly source rock of the Middle Jurassic petroleum system in the greater North Sea is included in the Bryne/Lulu Formations in Denmark, the Pentland Formation in the UK, and the Sleipner and Hugin formations in Norway.

ALS-R Underestimates Sleipner-Hugin Coaly Input, GLR



Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

Isotopes are Also Biased for the Low GLR Endmember



Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

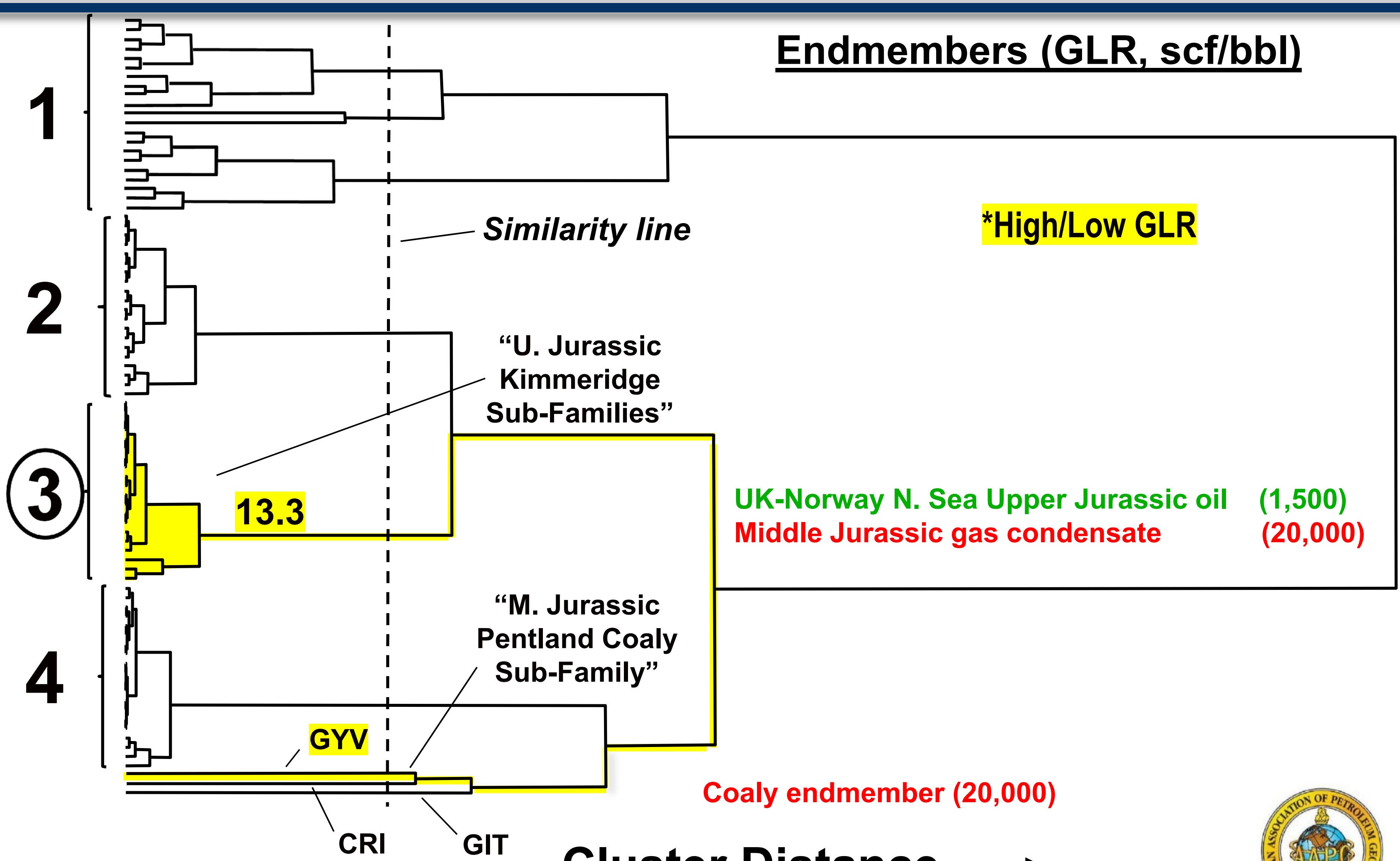
Presenter's notes: Calculated d^{13}C for the mixtures closely resemble the SVG oil endmember (Draupne; -30.02‰) until the SVG gas endmember (Sleipner-Hugin) contributes more than ~80% by mass to the mixture. This provides an explanation for the question *"Where did all the coal gas go?"*. Note that GLR increases more rapidly than d^{13}C, so that **mixtures thought to be primarily SVG oil will show unexpectedly high GLR.**

The GLR curve (black dots) plots ALS-C WL vs. GLR predicted assuming a linear relationship between mathematical SVG-gas vs. GLR (see Excel).

Our results differ substantially from Justwan et al. (2006) who based their interpretations on biomarker and isotope analyses of the C_{15+} fraction for crude oils *and condensates* from the South Viking Graben.

Justwan H. et al., 2006. Geochemical characterization and genetic origin of oils and condensates in the South Viking Graben, Norway. Marine and Petroleum Geology 23, 213-239.

HCA is Biased for the Low vs. High GLR Endmember



Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

Cluster Distance →

Presenter's notes: HCA is biased for the low GLR endmember because biomarker concentrations are generally higher than the high GLR endmember. However, this does not apply to the Taranaki-Sumatra mixed series because the low GLR endmember (Taranaki) has higher biomarker concentrations than the high GLR endmember.

Note that the cluster distances between samples in each binary mix decrease as the difference in GLR between endmembers increases. This occurs because with higher GLR of the gas condensate, the relative influence of the oil on cluster distance increases.

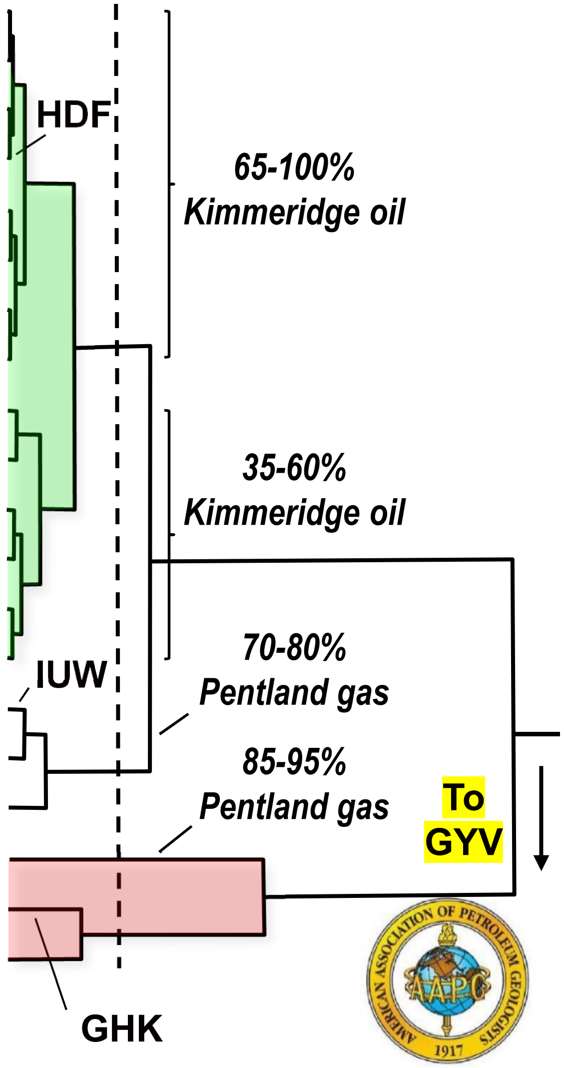
Families with and without noise are identical, although cluster distances are slightly greater between families without added noise.

ALS-R Underestimates M. Jurassic Pentland Endmember

Pair 3	Math Mix, %		ALS-R, %		ALS-C WL, %		ALS-C WF, %		GLR, scf/bbl
	UJ oil	MJ gas	UJ oil	MJ gas	UJ oil	MJ gas	UJ oil	MJ gas	
HDF	100	0	100.0	0.0	100.0	0.0	100.0	0.0	1,500
WUT	95	5	99.9	0.1	98.7	1.3	95.0	5.0	2,425
XJM	90	10	99.9	0.1	97.4	2.6	90.0	10.0	3,350
GHA	85	15	99.8	0.2	95.9	4.1	85.0	15.0	4,275
FQU	80	20	99.7	0.3	94.3	5.7	80.0	20.0	5,200
FXU	75	25	99.6	0.4	92.5	7.5	75.0	25.0	6,125
GJI	70	30	99.4	0.6	90.6	9.4	70.0	30.0	7,050
GLU	65	35	99.3	0.7	88.4	11.6	65.0	35.0	7,975
GNR	60	40	99.1	0.9	86.1	13.9	60.0	40.0	8,900
GQM	55	45	98.9	1.1	83.4	16.6	55.0	45.0	9,825
GQV	50	50	98.7	1.3	80.4	19.6	50.0	50.0	10,750
GUR	45	55	98.4	1.6	77.1	22.9	45.0	55.0	11,675
HNR	40	60	98.0	2.0	73.3	26.7	40.0	60.0	12,600
HNV	35	65	97.6	2.4	68.9	31.1	35.0	65.0	13,525
IUW	30	70	97.0	3.0	63.8	36.2	30.0	70.0	14,450
GBC	25	75	96.2	3.8	57.8	42.2	25.0	75.0	15,375
GDN	20	80	95.0	5.0	50.7	49.3	20.0	80.0	16,300
GDP	15	85	93.2	6.8	42.1	57.9	15.0	85.0	17,225
GHK	10	90	89.9	10.1	31.4	68.6	10.0	90.0	18,150
GPR	5	95	81.9	18.1	17.8	82.2	5.0	95.0	19,075
GYV	0	100	0.0	100.0	0.0	100.0	0.0	100.0	20,000

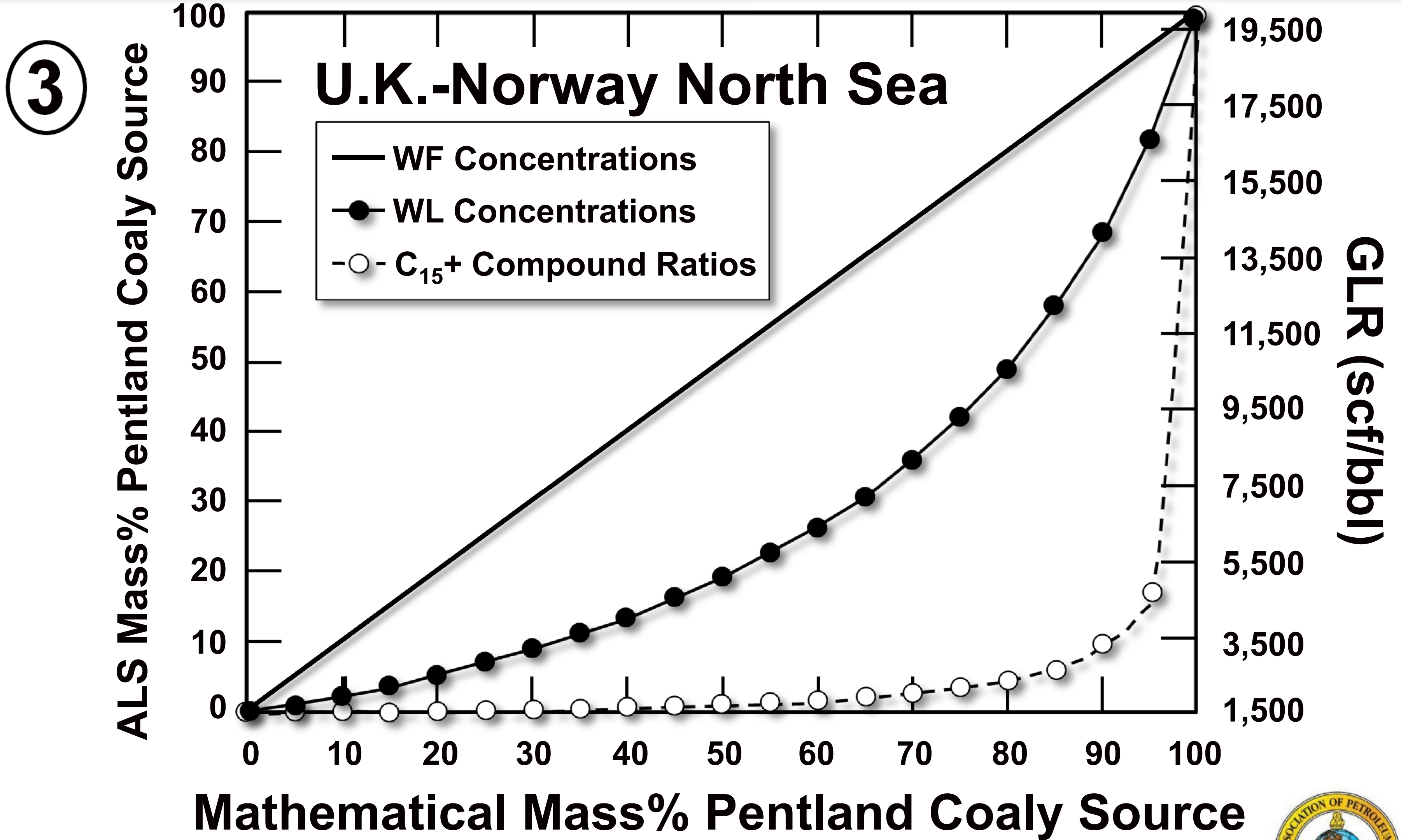
Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

U.K.-Norway North Sea Sub-Families

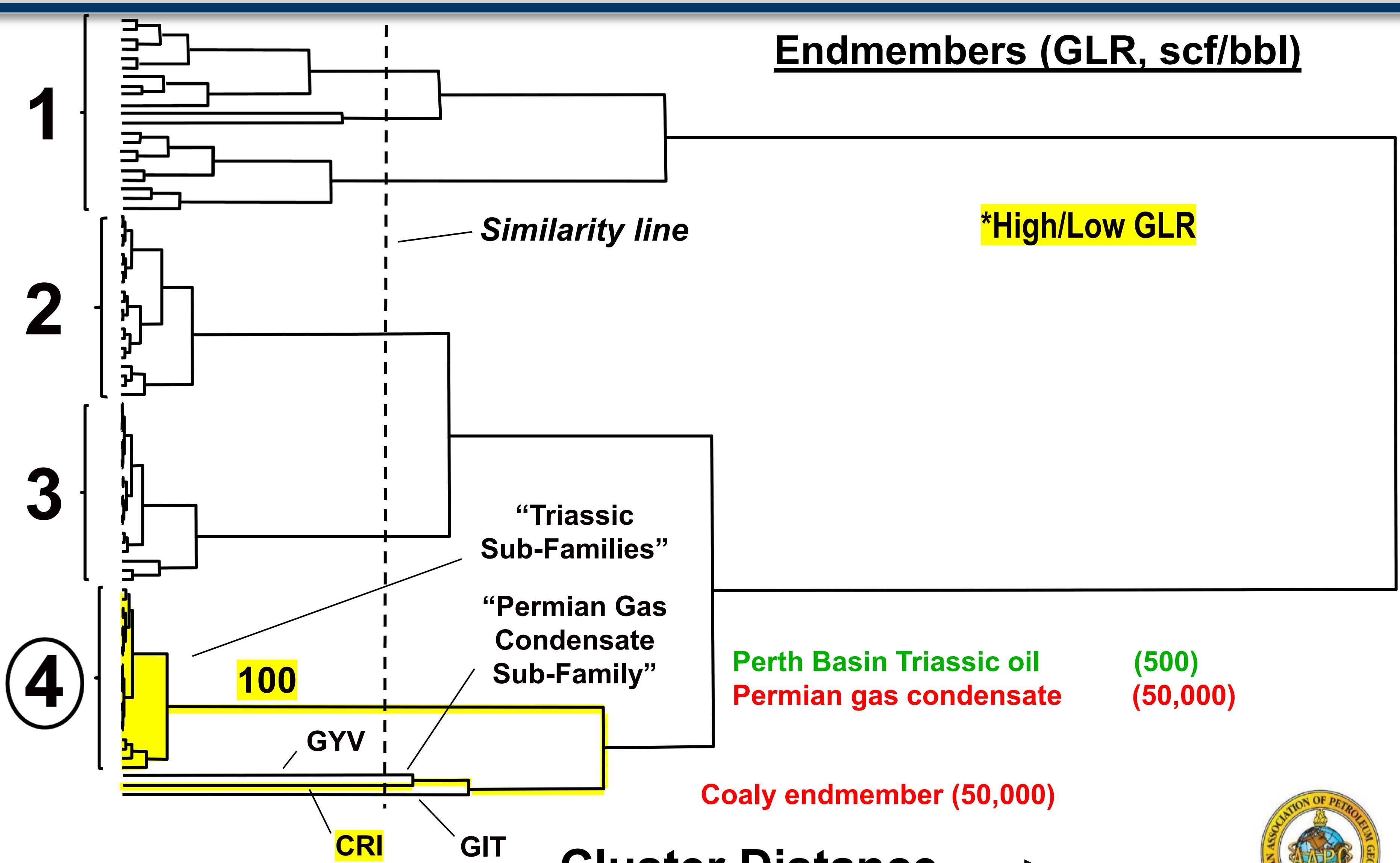


Presenter's notes: ALS-R underestimates Middle Jurassic Pentland gas condensate by up to 80%, i.e., ALS-R is biased for the low GLR endmember Kimmeridge oil.

ALS-R Underestimates Pentland Coaly Input and GLR



HCA is Biased for the Low vs. High GLR Endmember



Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

Presenter's notes: The fourth binary mixture from the Perth basin includes endmembers showing the greatest difference in GLR (500 vs. 50,000 scf/bbl). This results in a very tight cluster for all mixtures near the Triassic oil endmember on the HCA dendrogram, except for the Permian (coaly) endmember (CRI).

For HCA: autoscale preprocessing, Euclidean distance, incremental linkage
GOR = gas-oil ratio; <3,000 = oil (<45o API), 3,000-100,000 = gas condensate
Therefore we will use GLR to include gas condensates.

Note that the cluster distances between samples in each binary mix decrease as the difference in GLR between endmembers increases. This occurs because with higher GLR of the gas condensate, the relative influence of the oil on cluster distance increases.

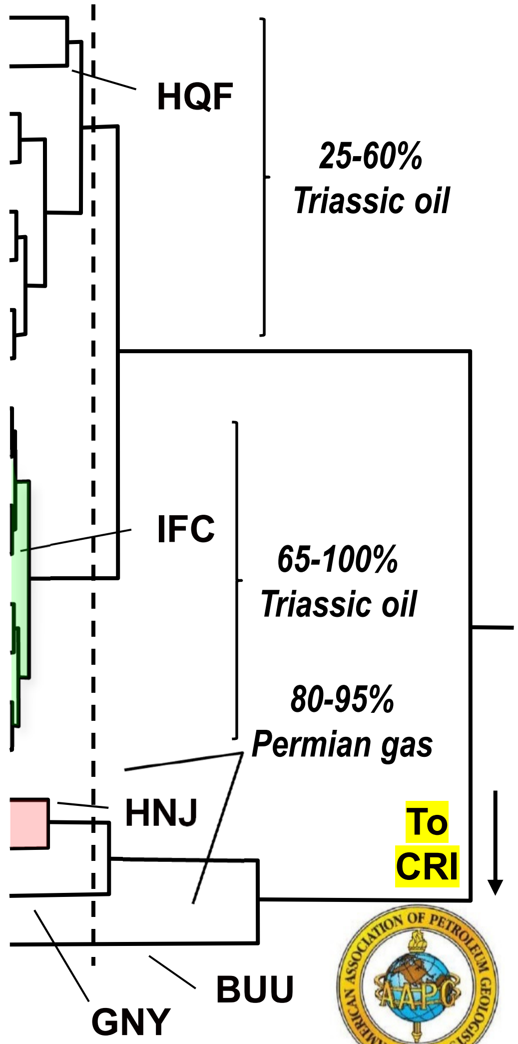
Families with and without noise are identical, although cluster distances are slightly greater between families without added noise.

ALS-R Severely Underestimates Permian Gas Condensate

Pair 4	Math Mix, %		ALS-R, %		ALS-C WL, %		ALS-C WF, %		GLR, scf/bbl
	Tri oil	Per gas	Tri oil	Per gas	Tri oil	Per gas	Tri oil	Per gas	
IFC	100	0	100.0	0.0	100.0	0.0	100.0	0.0	500
JAS	95	5	100.0	0.0	99.5	0.5	95.0	5.0	2,975
MED	90	10	100.0	0.0	99.0	1.0	90.0	10.0	5,450
GDX	85	15	99.9	0.1	98.3	1.7	85.0	15.0	7,925
GFE	80	20	99.9	0.1	97.7	2.3	80.0	20.0	10,400
GHO	75	25	99.9	0.1	96.9	3.1	75.0	25.0	12,875
GHU	70	30	99.9	0.1	96.1	3.9	70.0	30.0	15,350
GHV	65	35	99.8	0.2	95.1	4.9	65.0	35.0	17,825
GHZ	60	40	99.8	0.2	94.0	6.0	60.0	40.0	20,400
GNI	55	45	99.8	0.2	92.8	7.2	55.0	45.0	22,775
GPW	50	50	99.7	0.3	91.3	8.7	50.0	50.0	25,250
GXK	45	55	99.7	0.3	89.6	10.4	45.0	55.0	27,725
IZZ	40	60	99.6	0.4	87.5	12.5	40.0	60.0	30,200
KYI	35	65	99.5	0.5	85.0	15.0	35.0	65.0	32,675
UIX	30	70	99.4	0.6	81.8	18.2	30.0	70.0	35,150
HQF	25	75	99.2	0.8	77.8	22.2	25.0	75.0	37,625
HNJ	20	80	99.0	1.0	72.4	27.6	20.0	80.0	40,100
GNJ	15	85	98.7	1.3	64.9	35.1	15.0	85.0	42,575
GNY	10	90	98.0	2.0	53.8	46.2	10.0	90.0	45,050
BUU	5	95	96.5	3.5	35.6	64.4	5.0	95.0	47,525
CRI	0	100	0.0	100.0	0.0	100.0	0.0	100.0	50,000

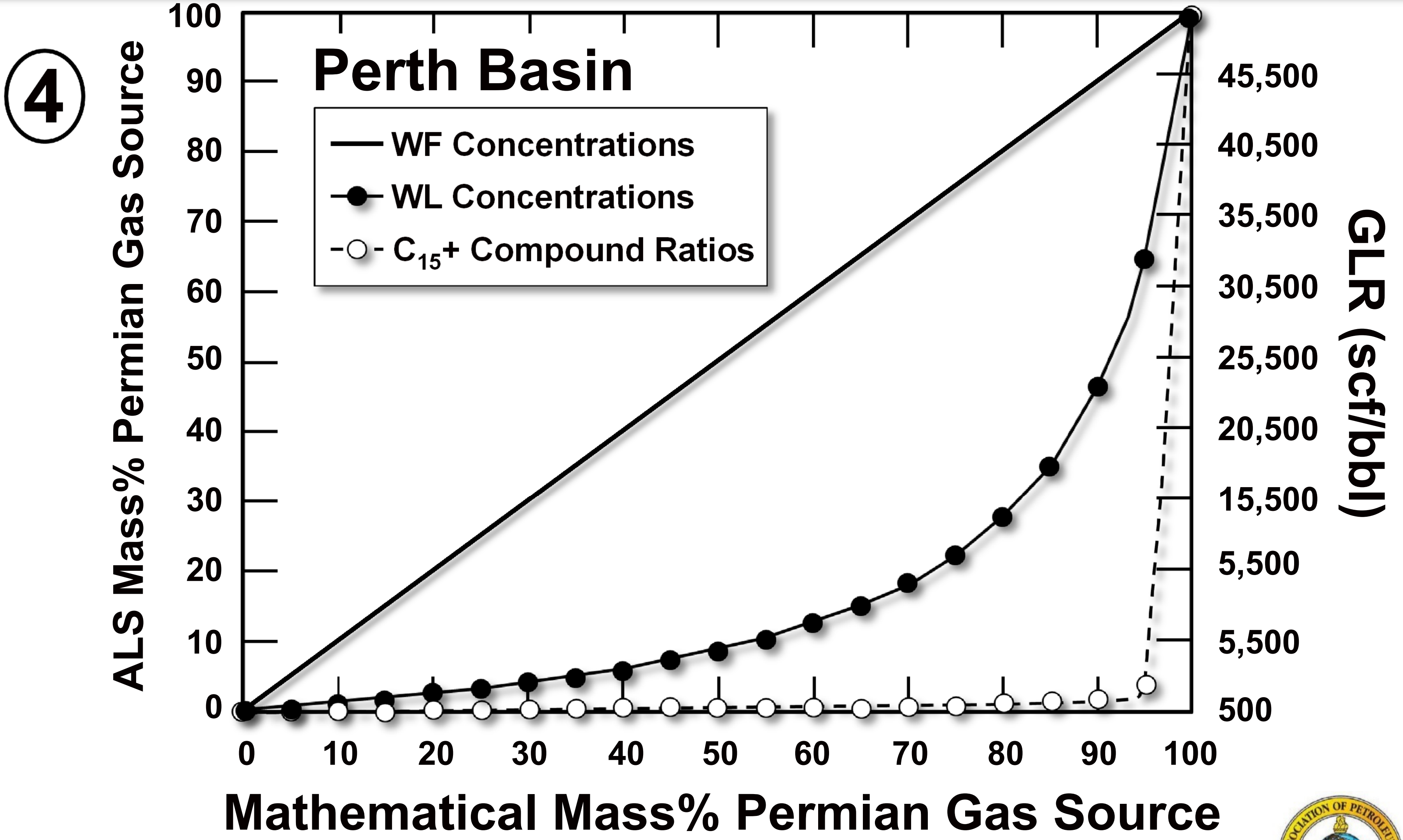
Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

Perth Basin Sub-Families



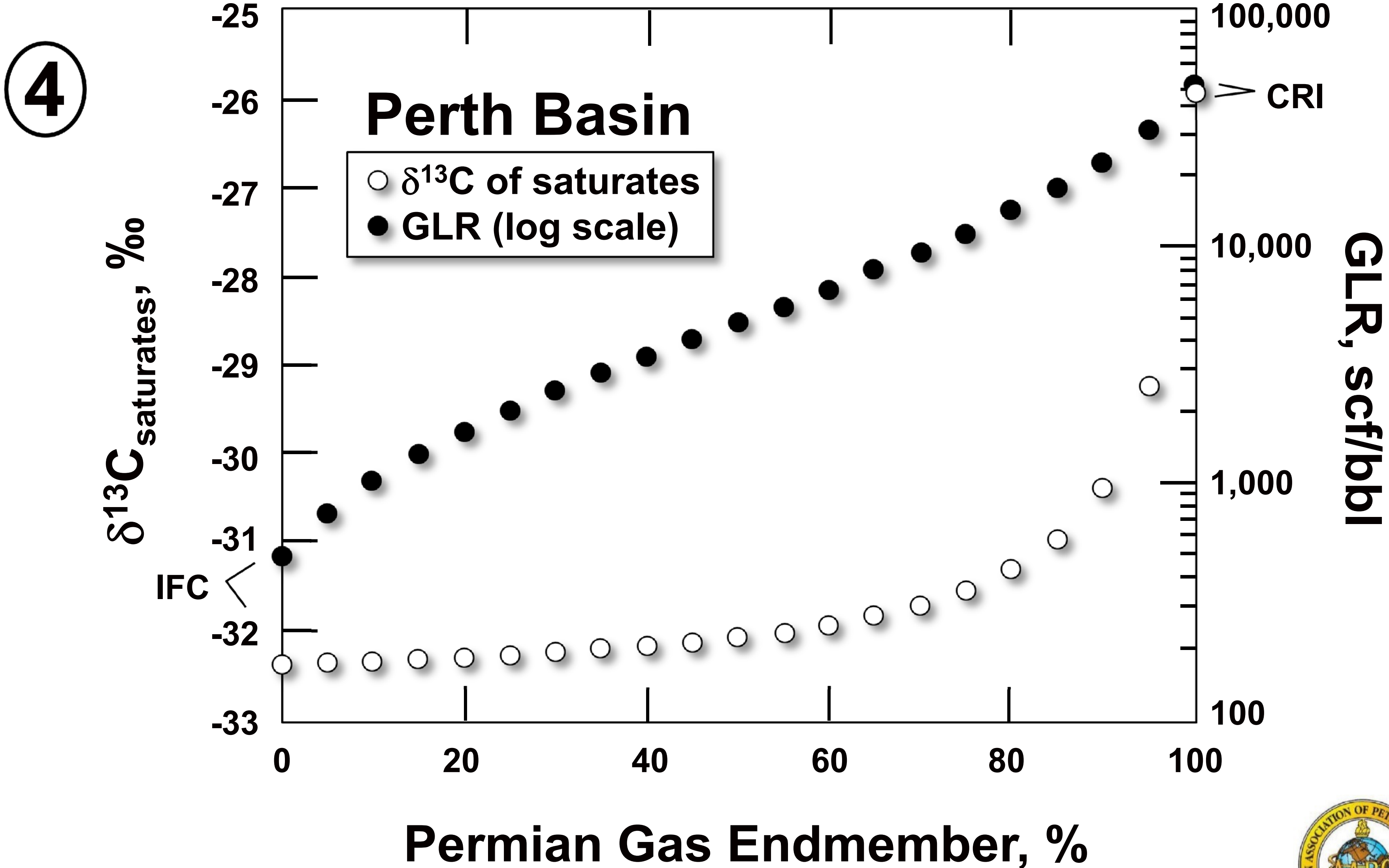
Presenter's notes: ALS-R underestimates the contribution of Permian gas condensate to the binary mixtures by up to 88% (GNY).

ALS-R Underestimates Coaly Permian Input and GLR



Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

Isotopes are Also Biased for the Low GLR Endmember



Deconvoluting Mixed Petroleum and the Effect of Oil and Gas-Condensate Mixtures on Identifying Petroleum Systems

Presenter's notes: Calculated d^{13}C for the mixtures closely resemble the Triassic oil endmember (-32.38‰) until the gassy Permian endmember contributes more than ~80% by mass to the mixture. Note that GLR (log scale) increases much more rapidly than d^{13}C , so that mixtures thought to be primarily Triassic oil based on ALS-R (ratios) will show unexpectedly high GLR.

Conclusions for Binary Mixtures of Petroleum

- HCA of compound ratios identifies genetic fluid families through a range of molecular weight but can be misleading for mixtures of endmembers with distinct compound concentrations or GLRs.
- ALS-R *can* deconvolute oil-oil mixtures having similar GLRs, but mixtures having different GLRs, compound ratios, and concentrations mix in non-linear fashion.
- ALS-R fails to deconvolute mixtures of oil and gas condensate; underestimates GLR and the contribution from gas-condensate.
- ALS-C deconvolutes mixtures (two or more endmembers), but GCMS quantification requires internal standards. ALS-C whole fluid (C_1+) is more accurate than ALS-C whole liquid (C_6+).
- Many interpreters use ALS-R to deconvolute mixtures, thus yielding inaccurate results.

Presenter's notes: Precision (repeatability) vs. accuracy

Selected References

Cornford C., 2018. Petroleum systems of the South Viking Graben, *in* C.C. Turner, B.T. Cronin, eds., Rift-related Coarse-grained Submarine Fan Reservoirs; the Brae Play, South Viking Graben, North Sea. *AAPG Memoir* 115, 453-542.

Kaufman R.L. et al., 1990. Gas chromatography as a development and production tool for fingerprinting oils from individual reservoirs: applications in the Gulf of Mexico, *in* D. Schumacker, B.F. Perkins, eds., *Proc. 9th Annual SEPM Research Conf.,* New Orleans, p. 263-282.

McCaffrey M.A. et al., 2011. Geochemical allocation of commingled oil production or commingled gas production. *Society of Petroleum Engineers, SPE* 144618, 1-19.

Murray A.P., K.E. Peters, 2020 in press. Quantifying multiple source rock contributions to petroleum fluids: bias in using compound ratios and neglecting the gas fraction. *AAPG Bulletin*.

Patience R.L., 2003. Where did all the coal gas go? *Organic Geochemistry* 34, 375-387.

Peters K.E. et al., 2008. De-convoluting mixed crude oil in Prudhoe Bay field, North Slope, Alaska. *Organic Geochemistry* 39, 623-645.

Different Basins, Same Rift *and* Bias Against Coal Gas

	Mixture	Field	GLR, scf/bbl	Source Rock
2	South Viking Graben	Sleipner Ost (Norway)	12,622	M. Jur. Sleipner-Hugin
		Sleipner Vest (Norway)	1,070	U. Jurassic Draupne
3	North and Central Viking Graben	Agat (Norway)	20,000	M. Jurassic Pentland
		Beryl (U.K.)	1,500	U. Jur. Kimmeridge Clay