

Pay Allocation and Reservoir Depletion Analysis Through Geochemical Technologies

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Understanding the relationship between source rocks and reservoirs in petroleum systems is a longstanding need for those in the oil and gas industry. As industry professionals continue to expand drilling in systems with stacked play, the need to understand the origin of the produced hydrocarbons increases, especially in unconventional systems. Geochemical technologies provide quantitative solutions to establish pay allocation with the same dataset providing ‘added value’ depletion analysis.

Pay allocation uses specified ratios of uncommon GC peaks in conjunction with common peaks (e.g., alkanes, toluene, etc.) to determine what percentage of a mixed origin sample comes from each of two or more end member oils. In essence, end members have chemical signatures that are unique to them, providing a “fingerprint” which can be quantified using GC peak ratios. By comparing the chemical fingerprints from mixed origin samples to pristine end members, the percentage of a given sample originating from each source can be quantified. Value is added when the same data set is subjected to depletion analysis, which allows for the determination of how hydrocarbon within a given reservoir compartment will alter over space and time. Depletion monitoring is based on the principle of fractionation, which is largely a function of relative mobility of molecular and isotopic components. The more mobile (volatile) phase is preferentially produced up the well bore, leaving a less mobile (residual) phase in the reservoir. In the depleted reservoir, the gas phase is observed to be compositionally wetter and isotopically heavier.

The collective pay allocation and depletion technologies benefit from being integrated into a 3D reservoir visualization, especially when interpreted with other geochemical, structural, and stratigraphic parameters. This provides dramatic cost-savings (i.e., over traditional production logging) while existing production is optimized, underdeveloped resources are identified, and critical well spacing issues are evaluated. By utilizing tools to understand depletion and pay allocation, companies will be better equipped to target future wells in more advantageous formations, understand the evolution of wells within fields, and avoid placing wells in depleted compartments. These tools combine techniques for traditional production logging with the added advantage of separating water from hydrocarbon flow from the well bore all while creating dramatic cost-savings and identifying under-developed resources.

Introduction

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Footnotes

¹ Kaufman, R. L., A. S. Ahmed, and R. L. Elsinger, 1990, Gas chromatography as a development and production tool for fingerprinting oils from individual reservoirs. Applications in the Gulf of Mexico: Gulf Coast Section of the Society of Economic Paleontologists and Mineralogists Foundation Annual Research Conference Proceedings, Austin, p. 263-282.

² Larter, S. R. and A. C. Aplin, 1995, Reservoir geochemistry: methods, applications, and opportunities, In: J. M. Cubitt, and W. A. England (eds.), The Geochemistry of Reservoirs: Geological Society, London, Special Publications, v. 86, p. 5-32.

³ Wavrek, D. A. and F. Mosca, 2004, Compositional grading in the oil column: advances from a mass balance and quantitative molecular analysis, In: J. M. Cubitt, W. A. England, and S. Larter (eds.), Understanding Petroleum Reservoirs: towards an Integrated Reservoir Engineering and Geochemical Approach: Geological Society, London, Special Publications, v. 237, p. 207-220.

⁴ Wavrek, D. A., D. D. Schelling, R. Sbarra, J. Vrona, and K. Johnson, 2010, Central Utah thrust belt discoveries – A tale of two hydrocarbon charges, AAPG Rocky Mountain Section Meeting, Durango, CO.

⁵ Wavrek, D. A., D. D. Schelling, R. Sbarra, D. Hall, D. Strickland, and A. Hansen, 2011, Identification and quantification of paleotrap during petroleum systems assessments, AAPG Annual Meeting Abstracts with Program, Houston, TX.

⁶ Wavrek, D. A. and S. Field, 2018, Novel insights to the unconventional reservoir: Unlocking the mystery of GOR variations, AAPG Annual Meeting, Salt Lake City, UT.

⁷ Wavrek, D. A. and S. Field, 2019, Sweet-n-sour: Application of the wellsite mass spectrometer in 3D unconventional resource development, AAPG Annual Meeting, San Antonio, TX.

⁸ Slack, M. N., 2019, South-Central Oklahoma SCOOP Plays: 3-D basin modeling insights to support select petroleum system elements and processes, Oklahoma City Geologic Society Invited Luncheon Speaker, Oklahoma City, Oklahoma.

⁹ Slack, M. N., C. W. Slack, and D. A. Wavrek, 2018, Strategies for effective petroleum systems analysis: SCOOP plays of Central-South Oklahoma, AAPG Annual Meeting, Salt Lake City, UT.

Methodology

The central tenet of a reservoir study (e.g., compartmentalization, depletion, allocation, etc.) is that homogenization of a hydrocarbon column is rapid, particularly in a high-quality well-connected reservoir, unless a barrier is present^{1,2}. The importance of evaluating the validity of this central tenet before a reservoir geochemistry study is attempted cannot be over-emphasized, as our experience indicates that the central tenet is often invalid. That is, the specific reservoir or compartment of interest may actually be in a state of disequilibrium due to a variety of natural and/or anthropogenic causes. For this reason, the initial step in the planning and preparation state of the reservoir workflow is to determine the equilibrium potential of the system. This is normally accomplished with a comprehensive synthesis of existing geological, geochemical, and engineering data associated with the hydrocarbon resources. The analysis of equilibrium potential provides critical input to the tool selection process, as each of the available tools has particular strengths and weaknesses in real world application. For example, a methodology that has demonstrated success in the North Sea may not be appropriate for application in the Gulf of Mexico due to different genetic reasons for the reservoir signals, as well as that form competing signals (i.e., noise). Failure to recognize and account for the competing signals invariably leads to erroneous results. The purpose of this presentation is to highlight methodologies used to recognize and quantify signals critical to determine correct pay allocation and recognize reservoir depletion.

Reservoir Geochemistry Workflow³

Plan & Prepare

1. Establish equilibrium potential
2. Define the scale
3. Think in terms of a mass balance
4. Anticipate molecular variation - cause and effect
5. Use all information to choose a proper tool



Analysis



Interpretation

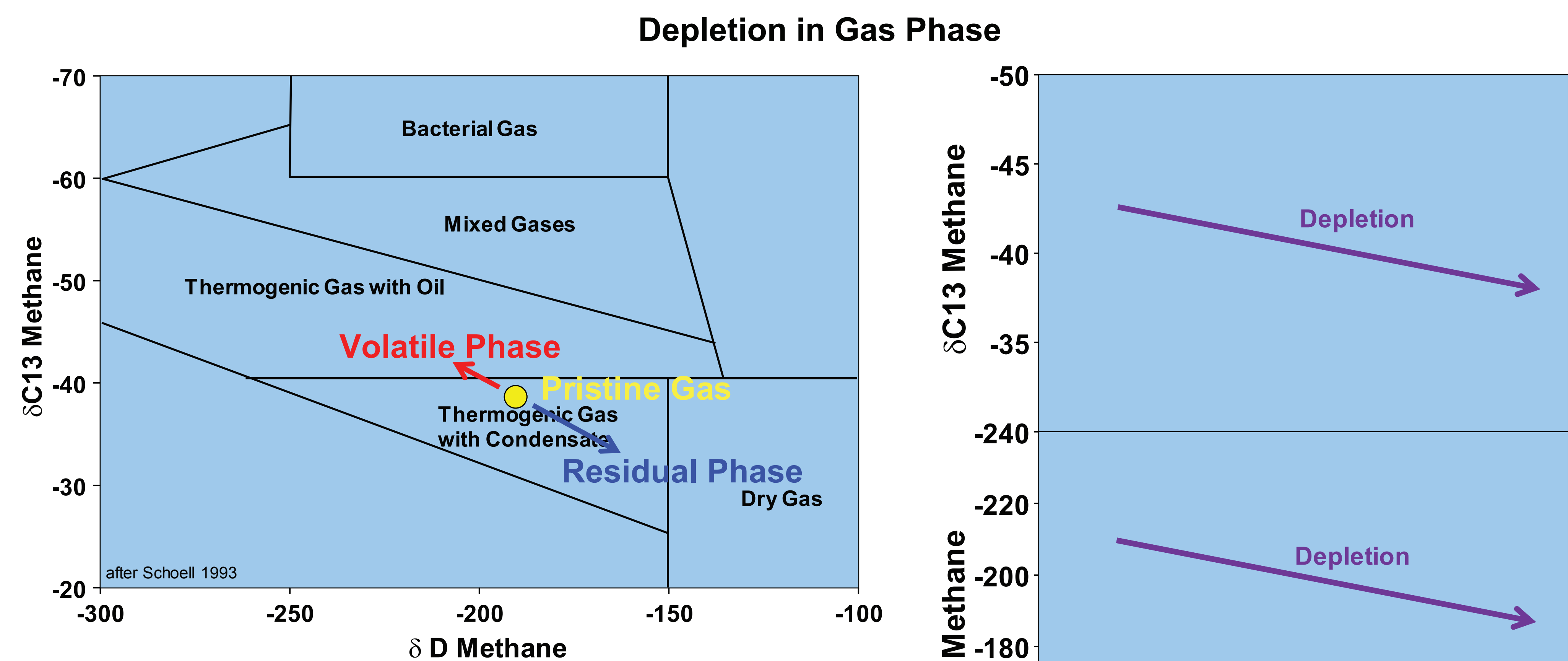
1. Tool selection - best practice
 - a. Whole Oil = general case
 - b. Saturate Fraction = special case
 - c. Aromatic Fraction = special case
 - d. CSIA or GC-IRMS = special case (esp. gas systems)
 - e. other special methods
2. Acquire data
 - a. QA / QC
 - b. replicates
 - c. digitization
 - d. outlier validation
3. Process & present data
 - a. Visual inspection
 - b. HCA / PCA
 - c. Star diagram construction

Principles

The principles used to develop tools for depletion analysis in hydrocarbon reservoirs are based on fractionation, both gas and liquid phases. The gas phase is summarized as the volatile phase being compositionally drier and isotopically lighter, whereas the inverse is true of the residual phase. The volatile liquid phase follows the same principles, but on fractionation within the C7 molecules and oil phases separate along similar principles. More subtle molecular variations have been documented in compositional grading in the oil column³. Important advances in the gas phase dates back 20 years when PSI studies of developing methods to quantitate the lost gas from core material being recovered for coal bed methane and shale gas projects. That is, using a combination of drilling mud gas (i.e., mud log as well as isotubes), produced gas, and desorption gas to calculate the lost gas as a mass balance exercise. Other seminal work was done in the mass balance of compositionally graded oil columns such as the oil accumulations in the southern Apennines of Italy that are up to 1000 m thick (i.e., 3281 ft)³. Practical applications of the PSI mass balance methodologies include interpretation of oil shows (i.e., including fluid inclusions), paleotrap accumulations^{4,5}, top seal integrity versus leakage^{6,7,8,9}, and reservoir depletion in tight reservoirs and unconventional resources. The principles are likewise critical to the practice of pay allocation, as pay allocation technologies often detect the depletion signal, resulting in erroneous results when not recognized but applied across an asset. Hence, this point demonstrates the importance of adhering to the workflow program outline above.

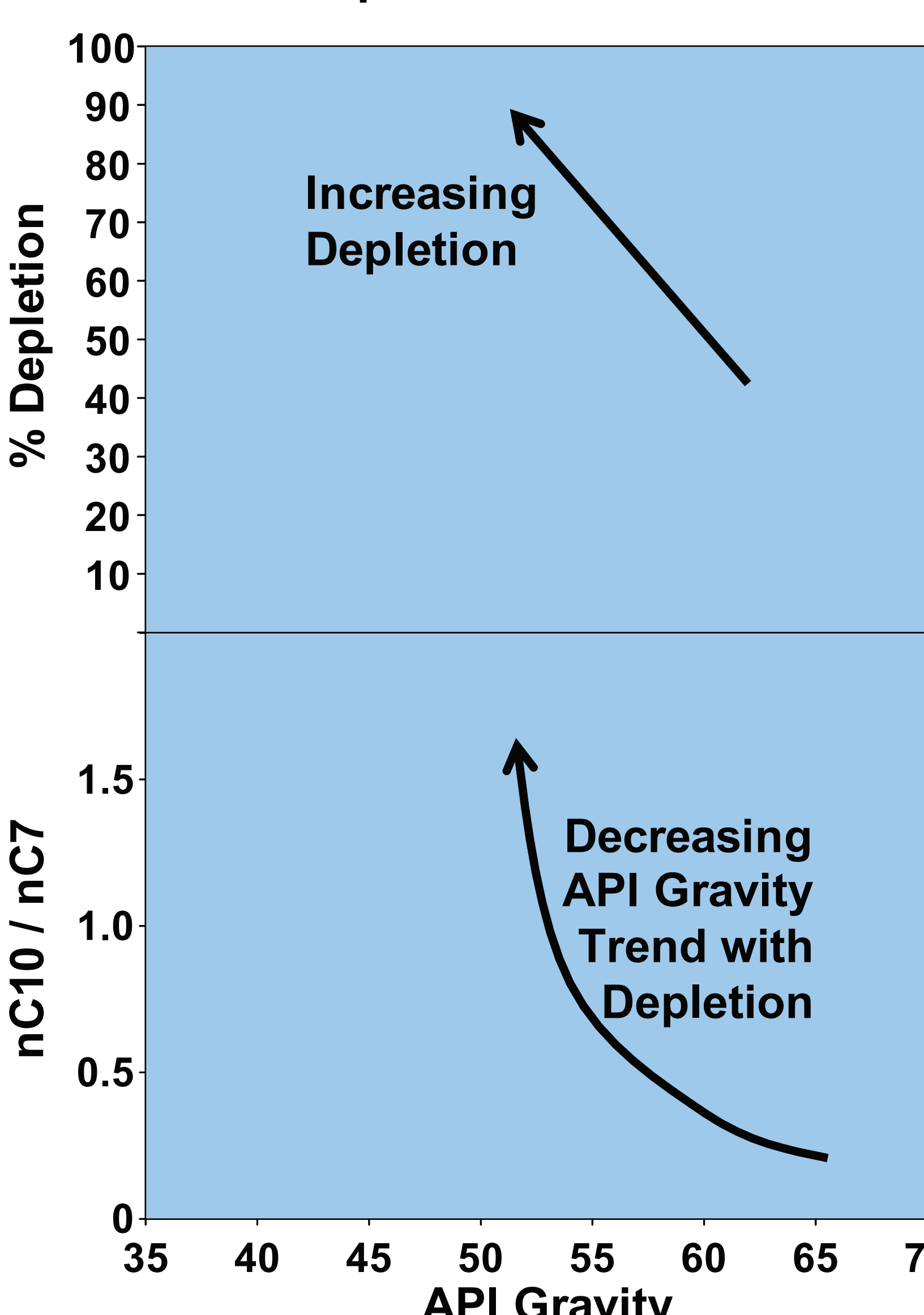
Results - Depletion

The principles of depletion monitoring developed at PSI over the past two decades is based on the gas and oil phases responding to fractionation. In brief, the depletion trend will respond to the relative mobility of the hydrocarbon molecular fractions and isotopes, as well as the inorganic components (e.g., inert gases). As a result, there will be more mobile (volatile) components preferentially produced up the wellbore, leaving a less mobile (residual) phase in the reservoir. In the depleted reservoir, the gas phase will be compositionally wetter and isotopically heavier. In the depleted reservoir, the oil phase will be lower API and GOR, as well as enriched in sulfur, metals, and asphaltenes. Between compound classes of a given carbon number, the fractionation behavior is interpreted to be a function of the surface charge between the specific molecule and the matrix fluid³. Within the routinely analyzed biomarker fraction, fractionation occurs mainly according to molecular weight, with higher carbon numbers being enhanced in the residual fraction. This latter effect will also make the sample erroneously appear to have been subjected to a lower degree of thermal stress. The principles apply to both unconventional and conventional resources, and provide an explanation for 'scatter' in routine geochemical studies. The depletion artifact is more prevalent in unconventional reservoirs which can be monitored with time-lapse geochemistry methods. New wells in maturing (i.e., depleted) fields will start their life from an incremental degree of depletion.



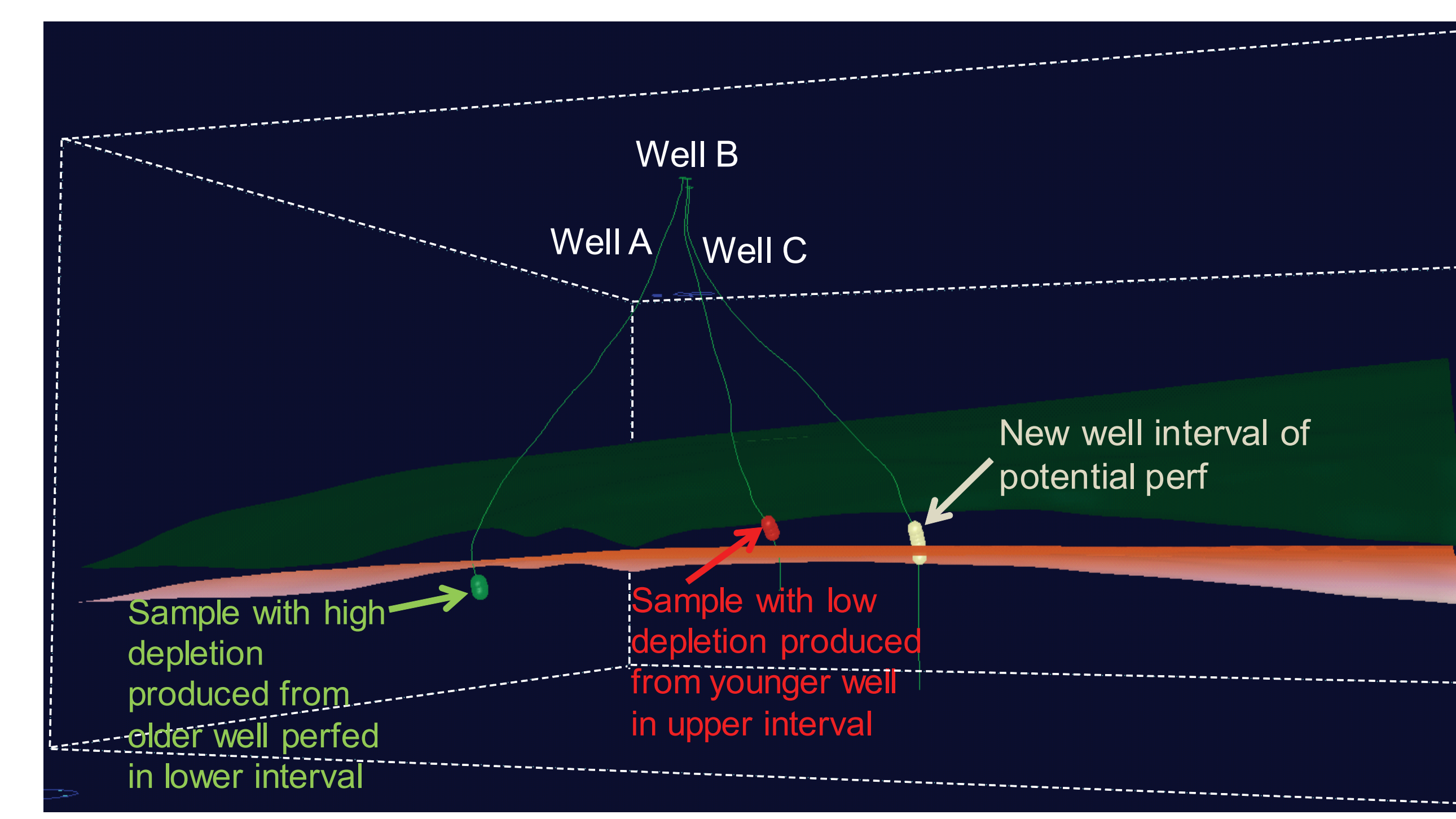
Main Point: Measured variations in gas phase components can differentiate the expected pristine gas signature from the isotopically heavy depleted residual phase and the isotopically lighter volatile phase. The depletion artifact can introduce an extra degree of variation in natural datasets, especially for the methane molecule.

Depletion in Oil Phase



Main Point: As oil reservoirs become more depleted, they decrease in API gravity and GOR. Within the biomarker fraction, the depleted reservoir will be selectively enriched in the higher molecular weight members.

3D Applications for Depletion

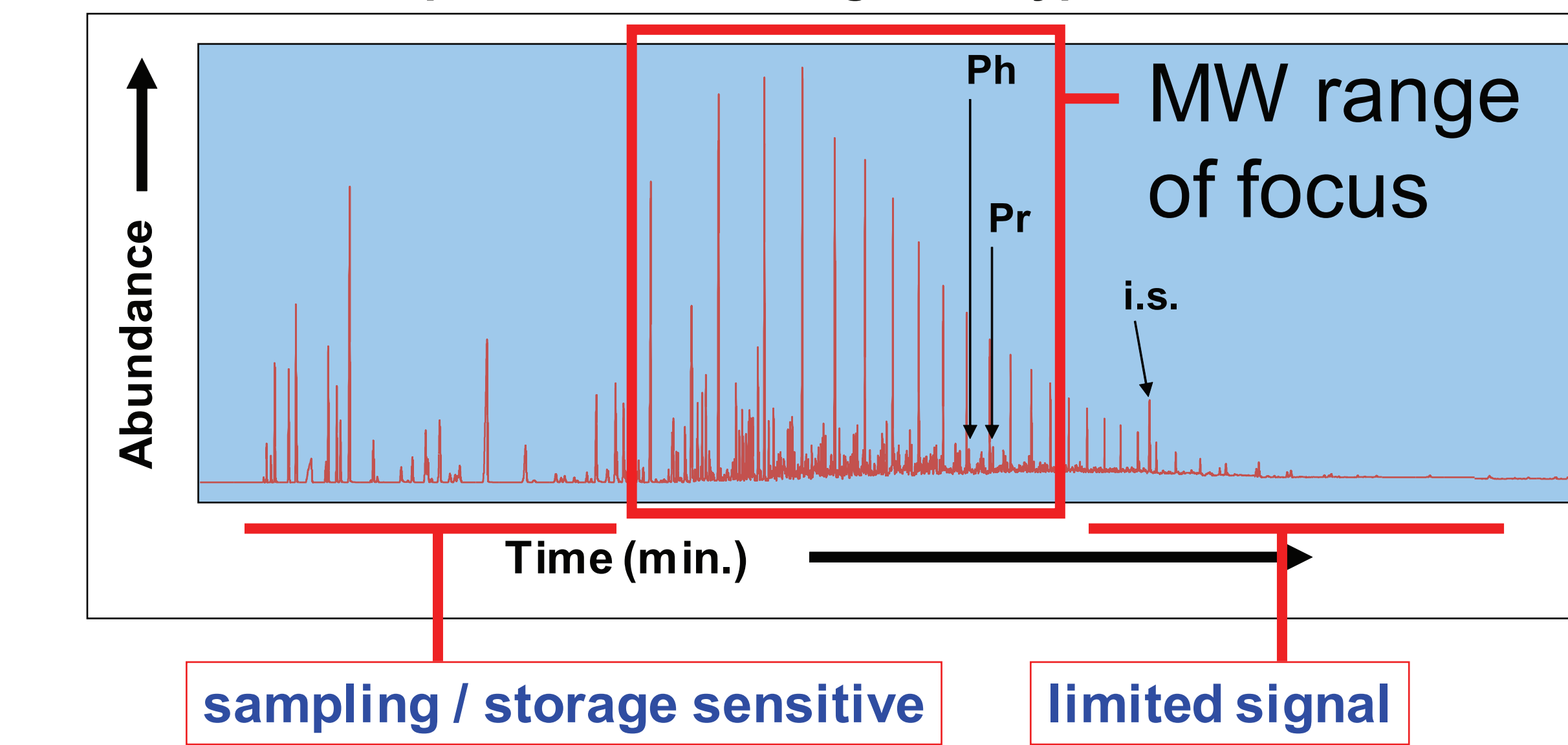


Main Point: Reservoir and/or compartment depletion can be evaluated during development completions. Note that new wells in the unconventional resource will have an incremental depletion.

Results - Allocation

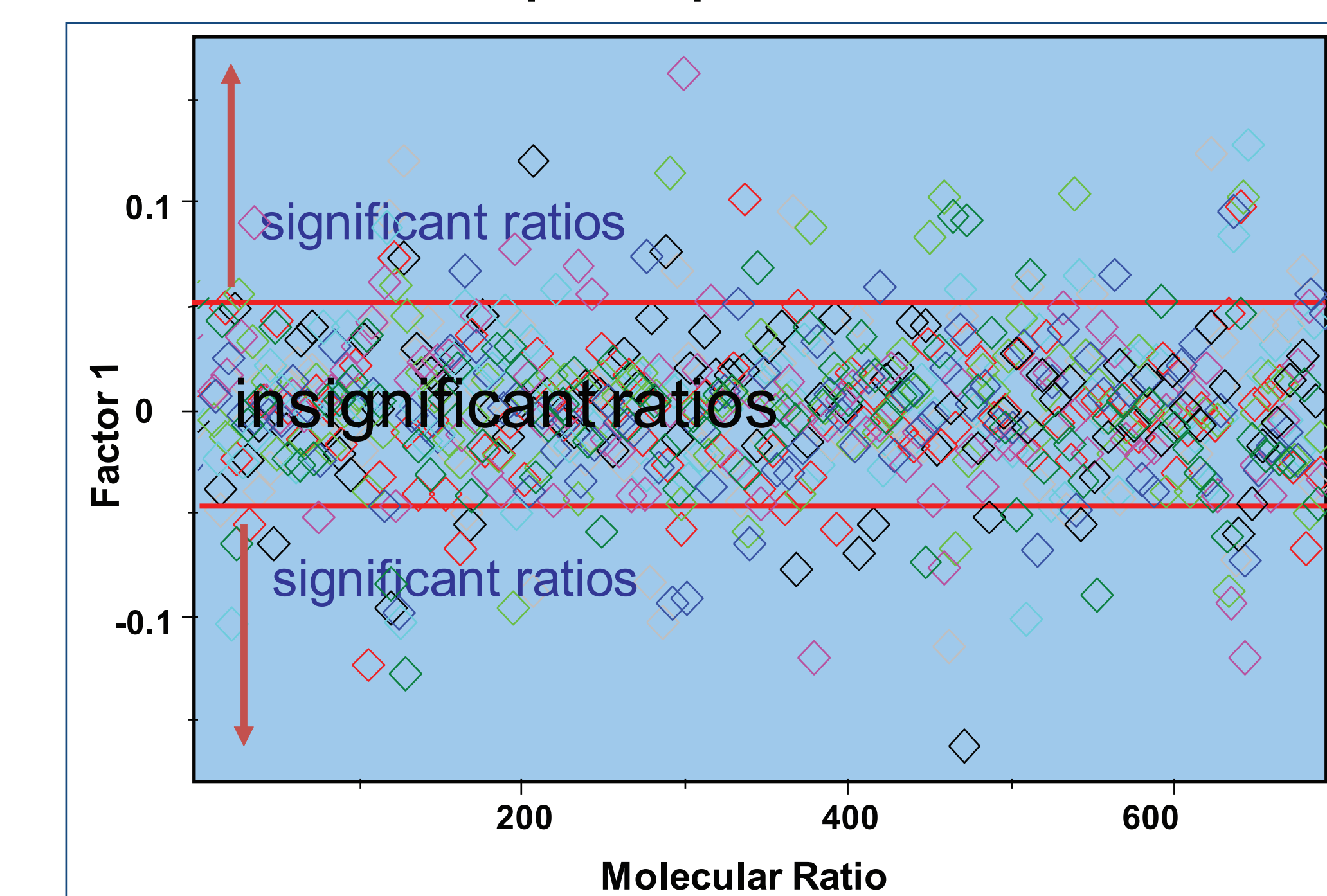
The principle of allocation uses specified ratios of uncommon GC peaks in conjunction with common peaks (e.g., alkanes, toluene, etc.) to determine what percentage of a mixed origin sample comes from each of two or more end member oils. Peak selection is a critical process. For example, a protocol that solely focuses on identifying differences will bias the peak selection to secondary alteration processes such as depletion, which will yield erroneous allocation percentages. The PSI protocol uses a hybrid of techniques that identify differences, but those differences are subsequently deconvoluted with PCA and HCA methods. In essence, end members have chemical signatures that are unique to them, providing a "fingerprint" which can be quantified using GC peak ratios. By comparing the chemical fingerprints from mixed origin samples to pristine end members, we can determine the percentage of a given sample originating from each source.

Example Gas Chromatogram - Typical Raw Data



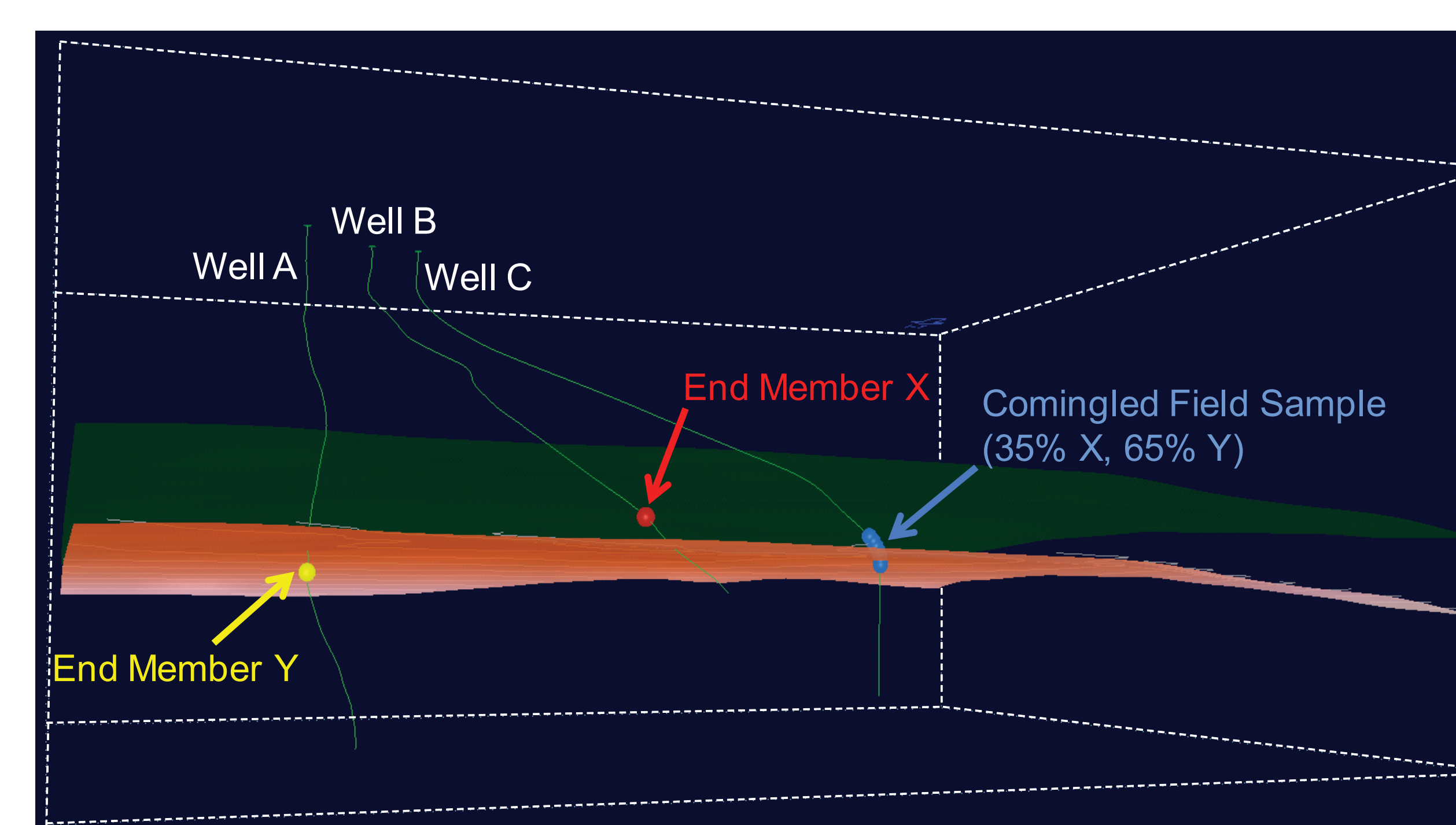
Main Point: Gas chromatograph peaks of consideration for allocation should fall in the identified MW range of focus to avoid bias due to secondary alteration processes or limited signal.

Sample Output from PCA



Main Point: Statistical methods can be utilized to identify ratios of significance for allocation analysis.

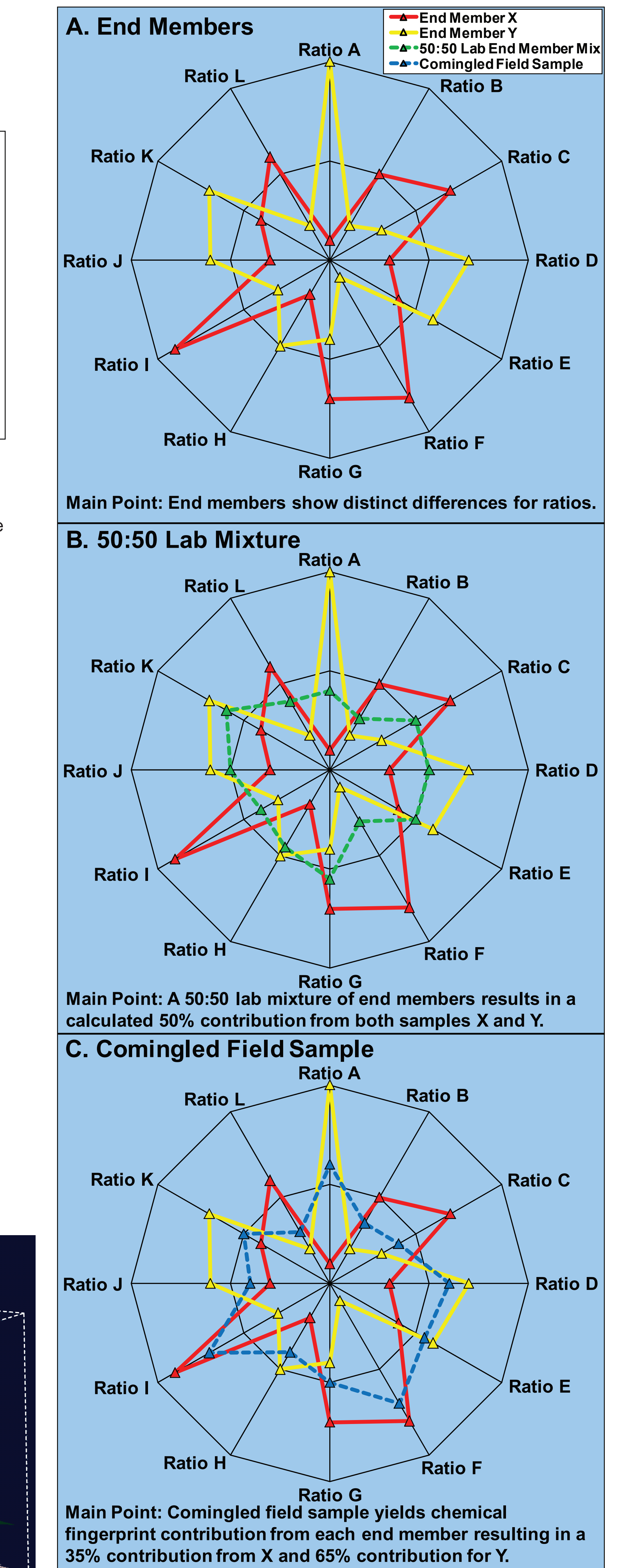
3D Applications for Allocation



Main Point: 3D analysis of allocation data can provide valuable visualization for the resource asset.

Successful allocation studies should meet these conditions:

- End members have one end of a range of chemical composition
- Each end member present in the system must be defined and analyzed to be included in the interpretation
- Any other end member contributions should be negligible
- Comingled samples receive 100% of their contributions from some combination of the defined end-members



Main Point: End members show distinct differences for ratios.

Main Point: A 50:50 lab mixture of end members results in a calculated 50% contribution from both samples X and Y.

Main Point: Comingled field sample yields chemical fingerprint contribution from each end member resulting in a 35% contribution from X and 65% contribution for Y.