OGIP Evaluation of Shale Gas and CBM with Basin Modeling and Gas Isotopes Interpretation*

Daniel Xia[1,2] and Yongchun Tang[1]

Search and Discovery Article #40842 (2011)
Posted November 30, 2011

*Adapted from presentation at AAPG Geoscience Technology Workshop, "International Shale Plays," Houston, Texas, October 11-12, 2011

[1]Power, Energy and Environmental Research Institute, Covina, California (Daniel_xia@peeri.org)
[2]GeoIsoChem Corporation

Abstract

Shale gas and coal-bed methane (CBM) are retained gas in source rocks. The application of basin modeling and gas isotopes will forecast OGIP, but the procedure is different from conventional gas. Using advanced chemistry of basin modeling, the distribution of expelled oil/gas, adsorbed gas, and free gas can be simulated. The kinetic parameters are based on the results of isobaric gold-tube source rock pyrolysis. In addition, the method to quantify the gas isotope fractionation by diffusion and adsorption/desorption during gas expulsion and production are established. With these methods, the prediction of OGIP and productivity of unconventional gas can be largely improved.

References

Braun, R.L., and A.J. Rothman, 1975, Oil-Shale pyrolysis: Kinetics and mechanism of oil production: Fuel, v. 54, p. 129-131.

Braun, R.L., and A.K. Burnham, 1987, Analysis of chemical reaction kinetics using a distribution of activation energies and simpler models: Energy and Fuels, v. 1, p. 153-161.

Tang, Y.C., P.D. Jenden, A. Nigrini, and S.C. Teerman, 1996, Modeling Early Methane Generation in Coal: Energy & Fuels, v. 10/3, p. 659-671.

Xia, X., and Y. Tang, in press, Isotope Fractionation of Methane during Natural Gas Flow with Coupled Diffusion and Adsorption/Desorption: Geochimica et Cosmochimica Acta.
http://www.sciencedirect.com/science/article/pii/S0016703711006016

AAPG GTW on Shale Plays, Oct. 2011, Houston

OGIP Evaluation of Shale Gas and CBM with Basin Modeling and Gas Isotopes Interpretation

Daniel Xia and Yongchun Tang

PEER Institute; GeoIsoChem Corp.

738 Arrow Grand Circle, Covina,
California 91722, U.S.A.

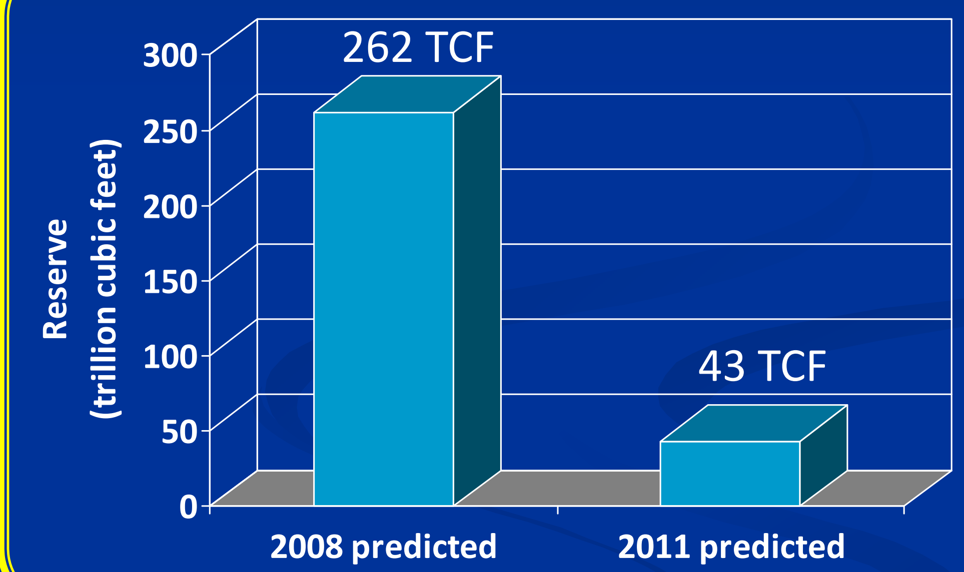
Daniel.xia@peeri.org

Original Gas in Place

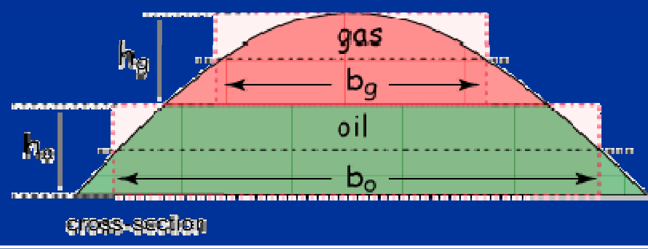
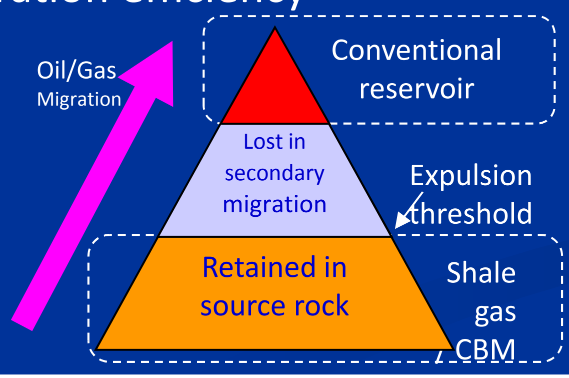
- Why to predict:
  - Geological risk
  - Economic risk

- How to predict:
  - Geochemistry
    + Basin Modeling

Change of Marcellus shale gas reserve assessment



Assessment method

	Conventional gas	Shale gas/CBM
From trap volume	Hydrocarbon Reserve = trap volume x porosity x hydrocarbon saturation 	Shale Gas Reserve = shale volume x shale density x gas content (in scf/ton) ■ Need core sample ■ Heterogeneity!
From generated amount (Basin Modeling)	Hydrocarbon Reserve = generated x expulsion ratio x migration efficiency 	?

Parameters and uncertainties in modeling

- For conventional gas

Hydrocarbon Reserve =

generated x expulsion ratio x migration efficiency

Determined by source rock conditions

Determined by geological background

= bulk source rock volume x source rock density x total organic matter content x genetic potential x transformation ratio

TOC, organic type, hydrocarbon potential, maturity

Parameters and uncertainties in modeling

- For shale gas

Hydrocarbon Reserve =

generated x (1 - expulsion ratio) ?

Too rough!

= bulk source rock volume x source rock density x total organic matter content x genetic potential x transformation ratio

TOC, organic type, hydrocarbon potential, maturity

Model coupling generation/expulsion

- Kerogen cracking, oil cracking and oil/gas expulsion should be considered simultaneously

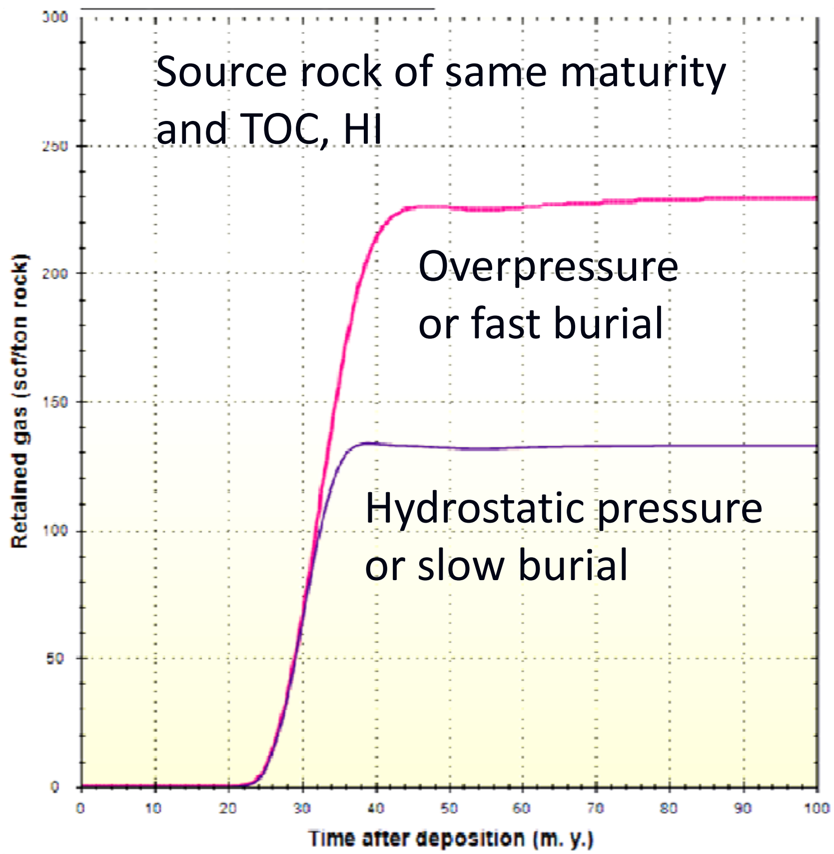
Retained = Generated – Cracked – Expelled

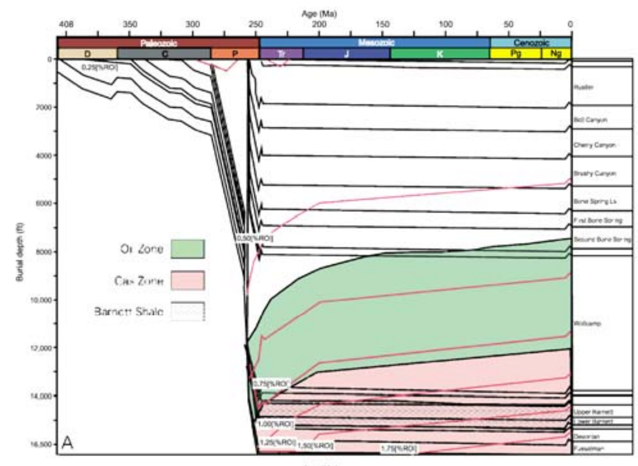
Kinetic description

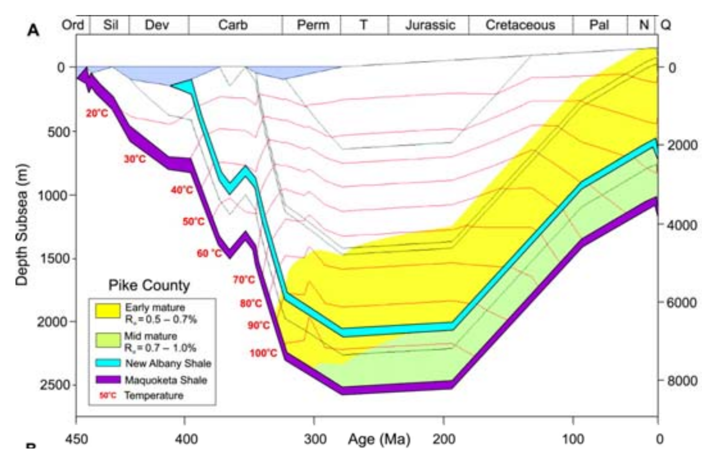
- Expulsion due to exceeding threshold:
  - Free gas:
    Equation of state
  - Adsorbed gas:
    Adsorption thermodynamics
- Expulsion due to dissipation

Coupled kinetics + dynamics

How expulsion counts





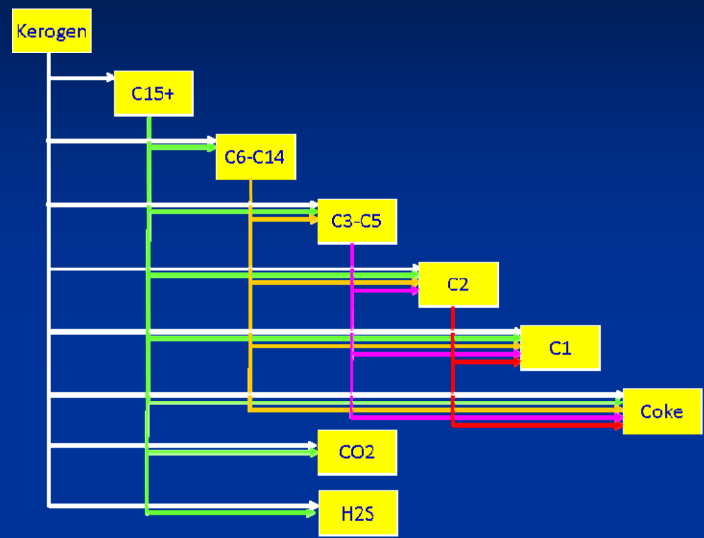


Risk of high maturity

- Pure "generation" simulation may over-estimate OGIP at high maturity
  - Reason: cumulative generated amount increases monotonically with maturity

- High maturity may indicate
  - Decreased porosity
  - Higher expulsion efficiency
    - Increased diffusivity
    - Tectonics
  - Examples (CBM in China; Cambrian shale)

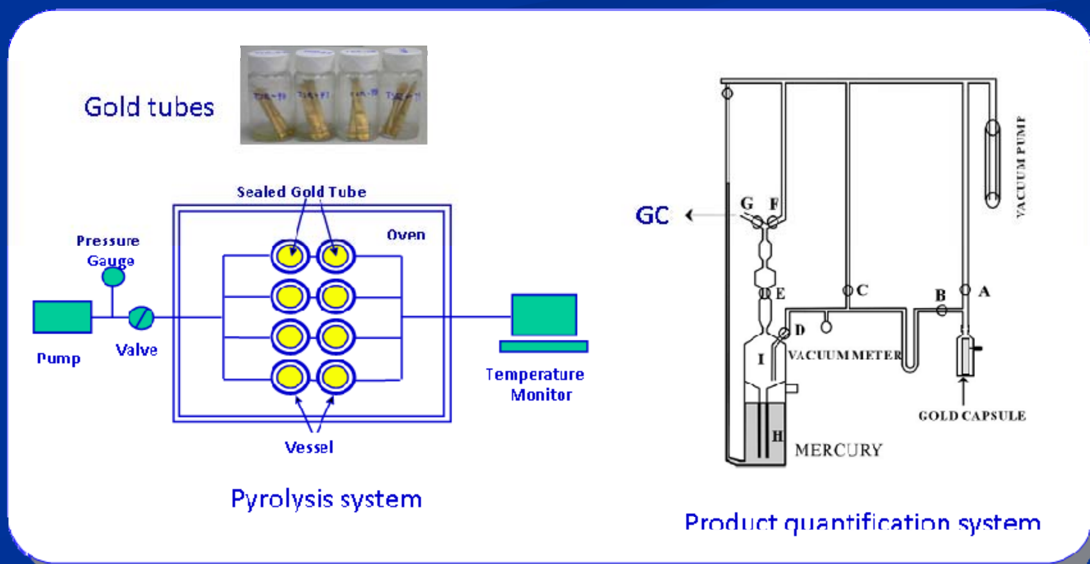
Model and calibration



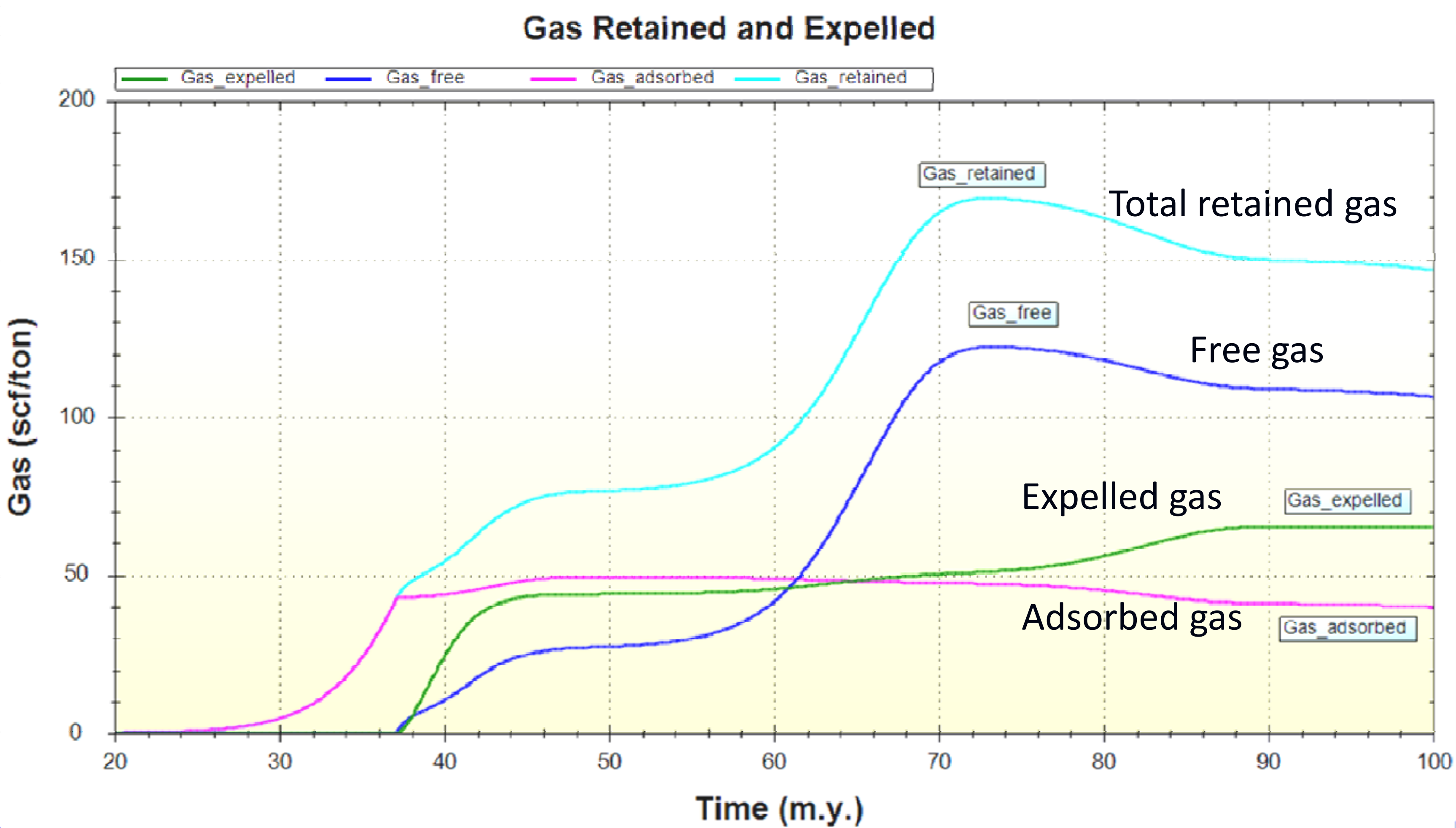
- Extended kinetic model:
  - Parallel first order reactions
    - Braun et al., Fuel, 1975, 54, 129
    - Braun et al., Energy and Fuels, 1987, 1, 452
  - Species: retained (free +adsorbed) + expelled

Close system, isobaric pyrolysis (gold tube pyrolysis)

Tang et al., Energy and Fuels, 1996, 10, 659

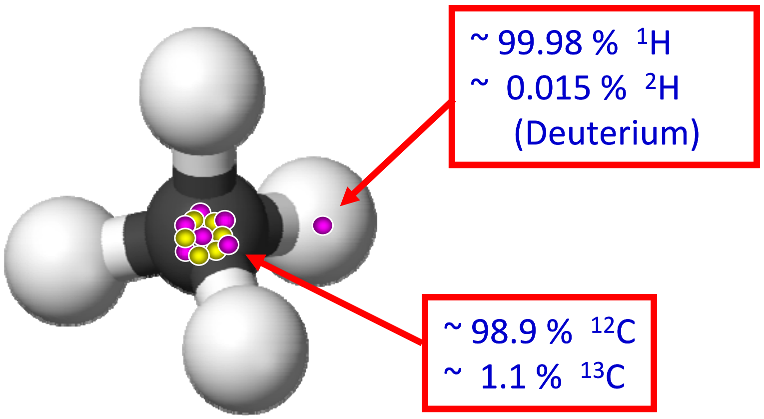


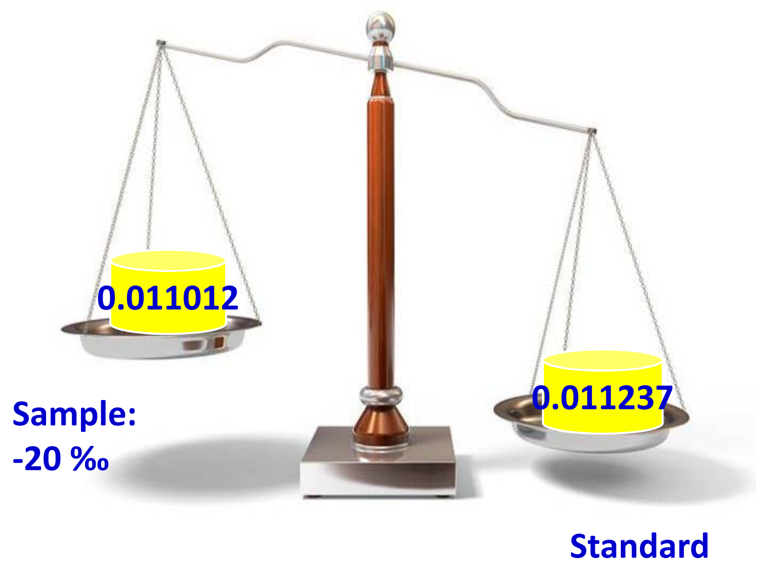
Example



Gas Retained and Expelled
Gas_expelled
Gas_free
Gas_adsorbed
Gas_retained
Total retained gas
Free gas
Expelled gas
Adsorbed gas
Gas (scf/ton)
Time (m.y.)
0
50
100
150
200
20
30
40
50
60
70
80
90
100

Application of gas isotope data





$$\delta^{13}C = \left[\frac{\left(^{13}C/^{12}C\right)_{sample}}{\left(^{13}C/^{12}C\right)_{standard}} - 1 \right] \times 1000, \text{ with } \left(^{13}C/^{12}C\right)_{PDB} = 0.011\ 237$$

$$\delta^{2}H = \left[\frac{\left(^{2}H/^{1}H\right)_{sample}}{\left(^{2}H/^{1}H\right)_{standard}} - 1 \right] \times 1000, \text{ with } \left(^{2}H/^{1}H\right)_{SMOW} = 0.000\ 155\ 8$$

How ^{12}C and ^{13}C atoms act differently?

- Generation:

  $^{12}C - ^{12}C$ bonds more active than $^{12}C - ^{13}C$ bonds

  → ^{13}C more rich in late products

- Migration / production / lab degassing:

  $^{12}CH_4$ more easy to diffuse than $^{13}CH_4$

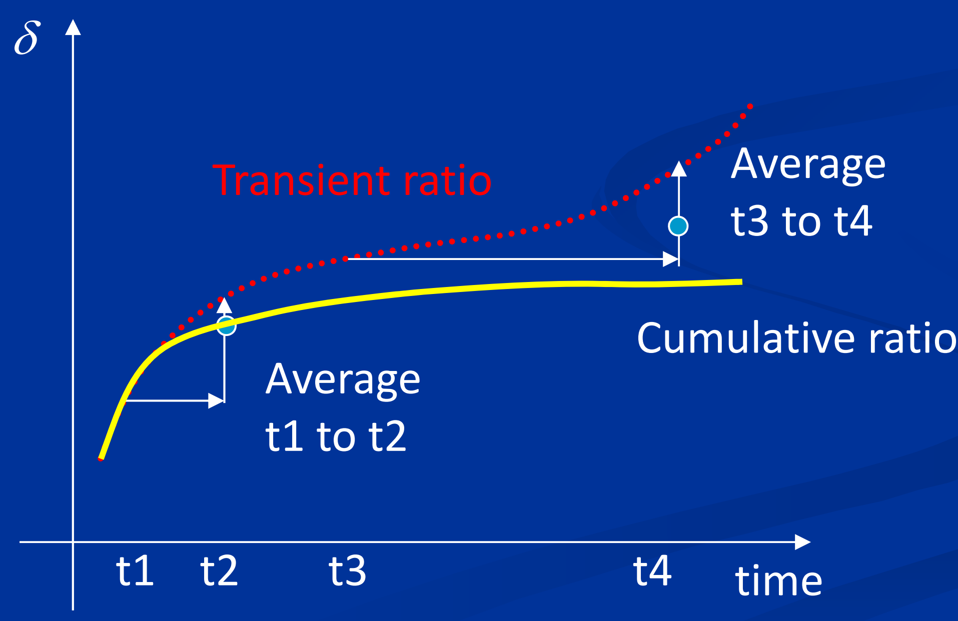
  → $^{13}CH_4$ more rich in late producing gas

What influences gas isotopic ratio?

- Kinetic isotope fractionation (generation)
  - Early products more “light” than late products
- Isotopic ratio of precursors (kerogen/oil; kerogen type, organic facies, and age)
  - “Light” precursors form “light” products (under same maturity)
- Mass transport (weak under geological conditions)
- <u>Accumulation extent</u>!

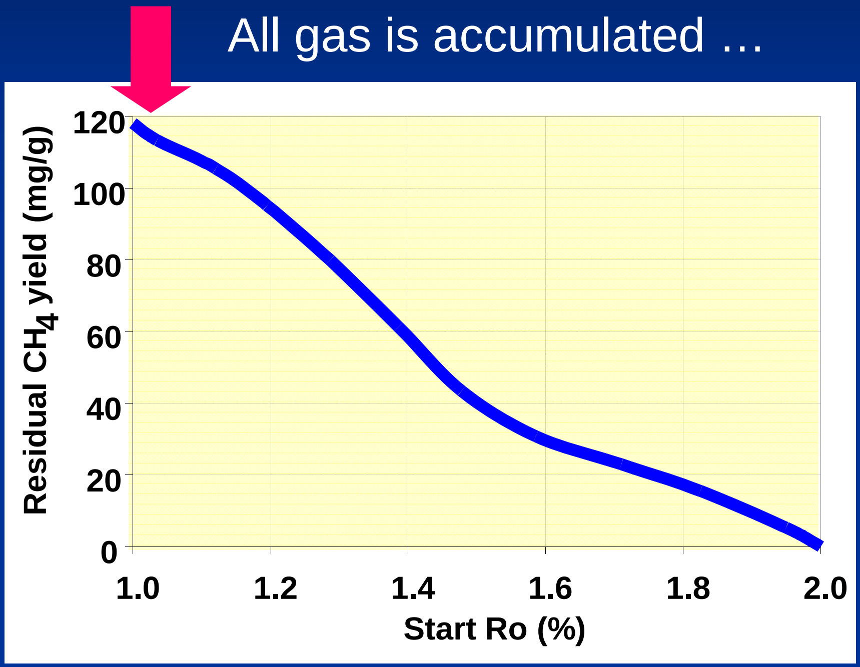
Cumulative vs. instantaneous

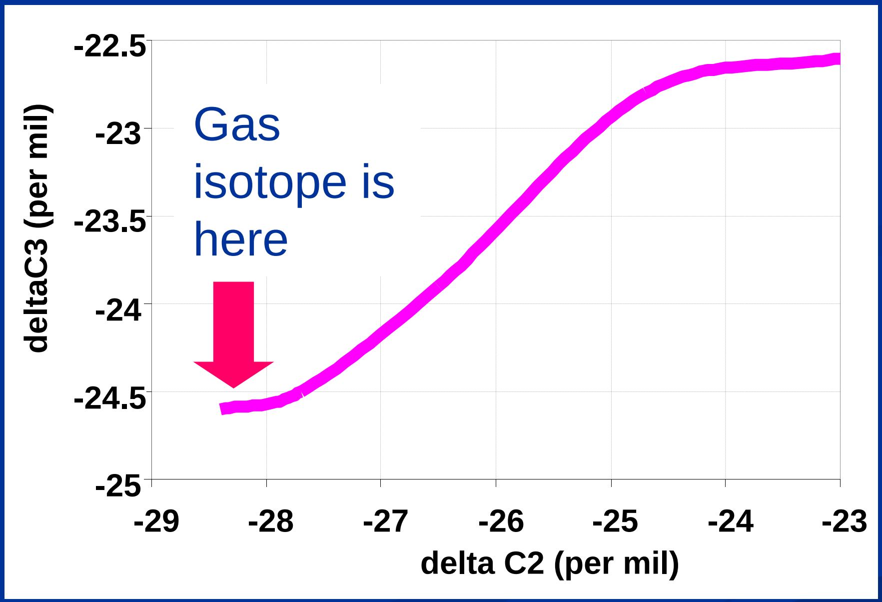
- Gas isotope ratio changes with time (organic matter maturity), thus its "average" value depends on time interval!
- Less cumulative reservoir → less negative isotope



Indicated by isotope ratio

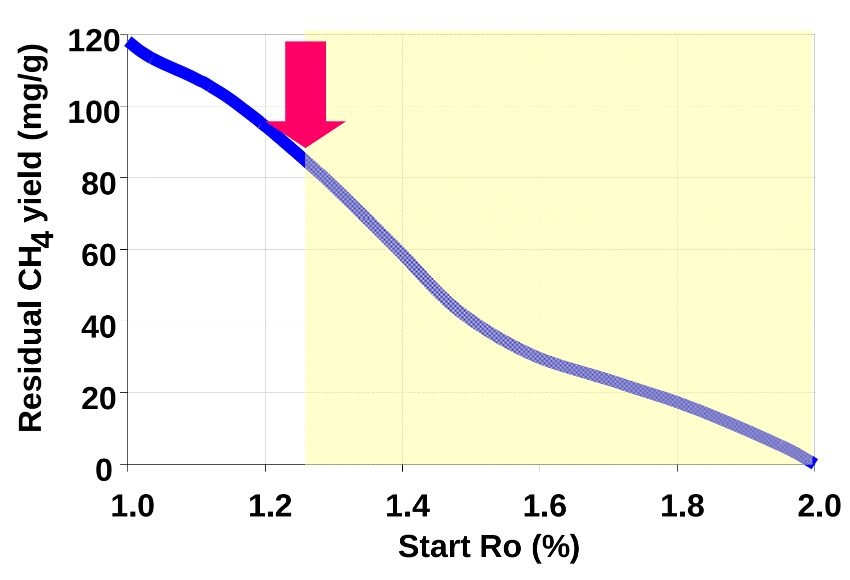
All gas is accumulated …

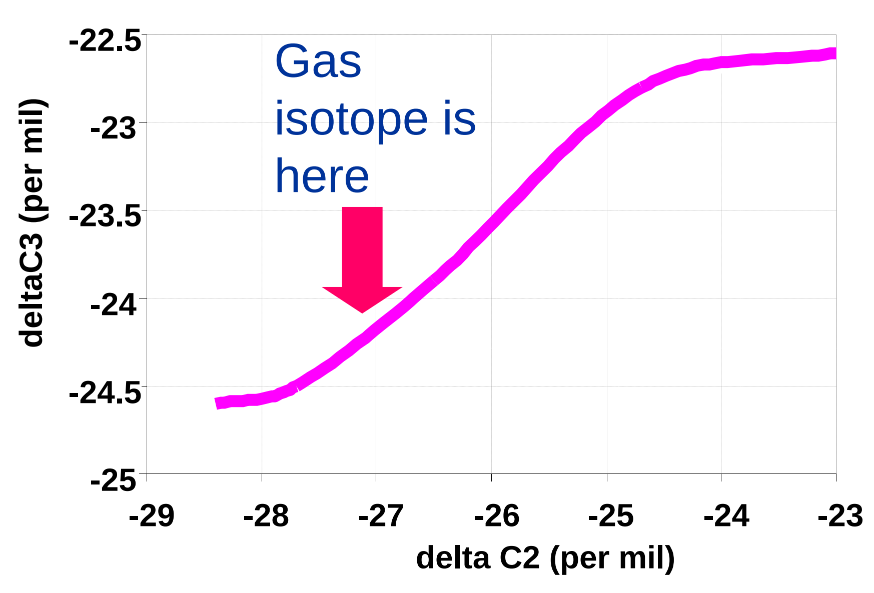




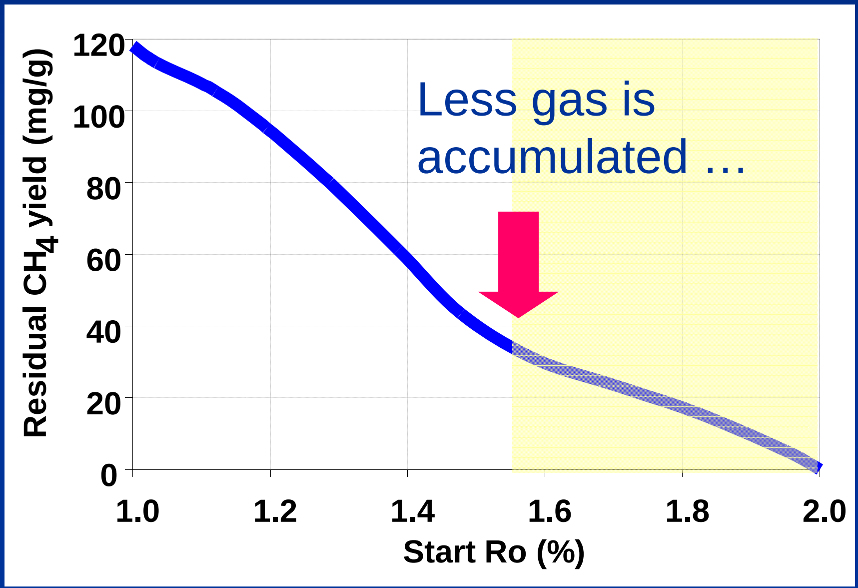
Indicated by isotope ratio

Most gas is accumulated …

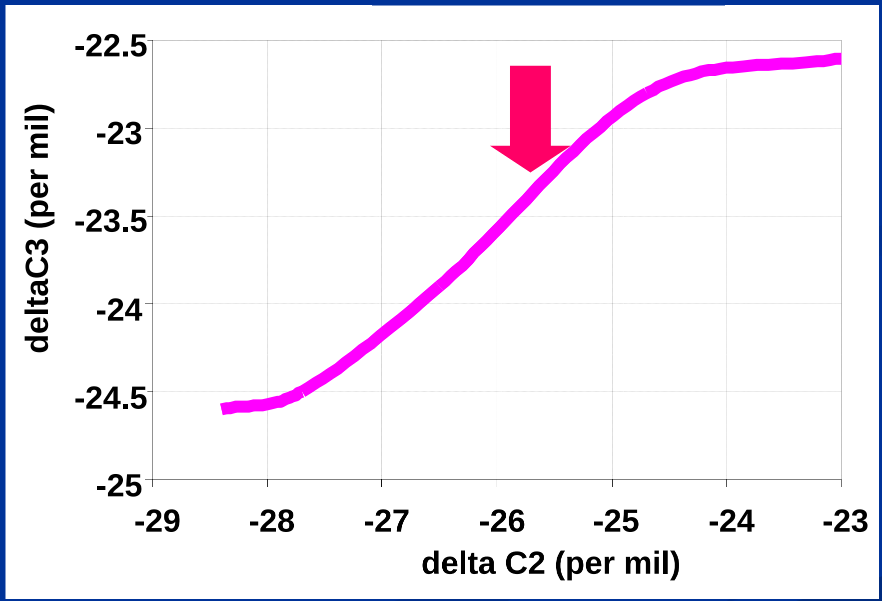




Indicated by isotope ratio



Gas isotope is here



Using gas isotopes for early prediction

Kinetic model
Calibrated with
source rock
pyrolysis

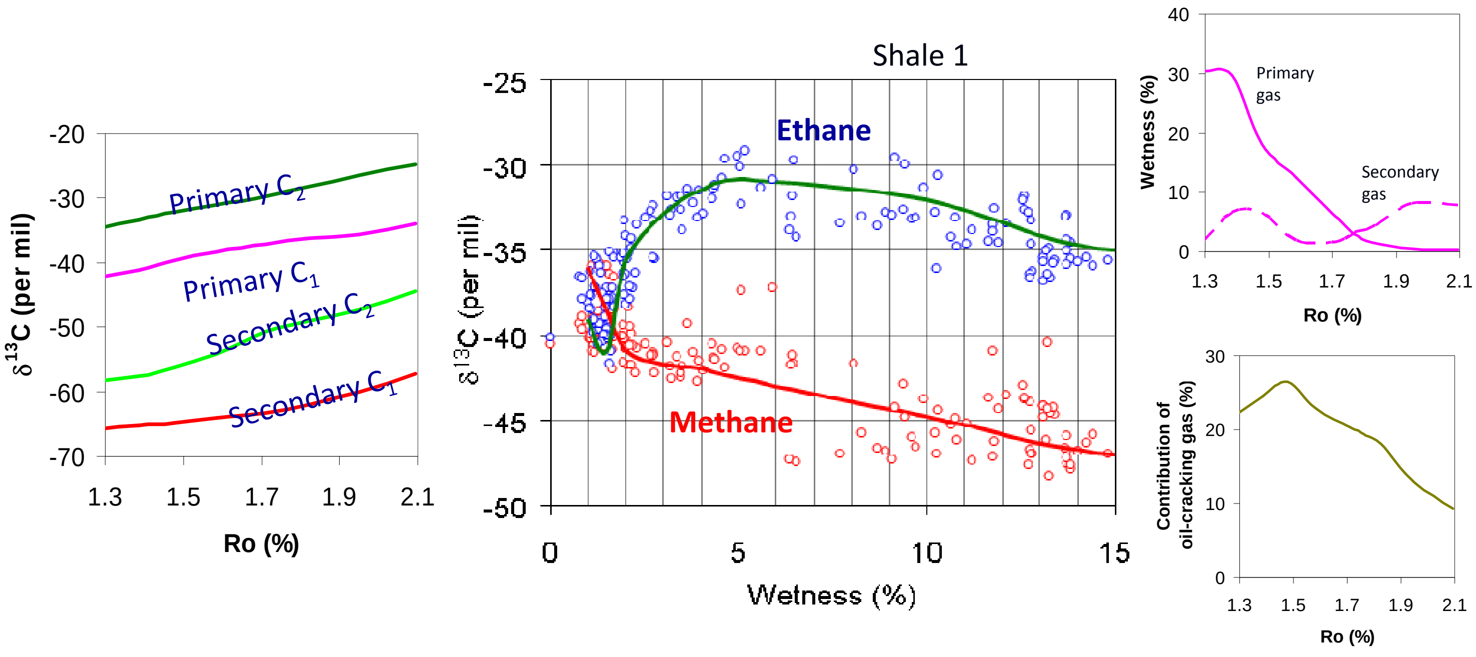
Interpretation of
gas isotope data

Projecting to geological conditions:
Relation between isotope and fluid
yield, composition and properties

t	T	Ro	Isotope: instantaneous	Isotope: Cumulative	C_1	C_2	C_{3-5}	Light oil	Heavy oil	SARA	GOR	API

A complicated case in shale gas: "rollover"

- "Rollover" of ethane isotopic composition
  - Explainable with mixing of gas converted from oil



More kinetic processes in geochemistry…

- Variation of capacity to adsorbed gas
  - → OGIP
- Clay mineral conversion
  - → Reservoir properties
- Water generation and consumption
  - → Water saturation
  - → Rock resistivity
- Graphitization of kerogen and pyrobitumen
  - → Rock resistivity

Gas isotopes for production

- Principles: continuum flow model

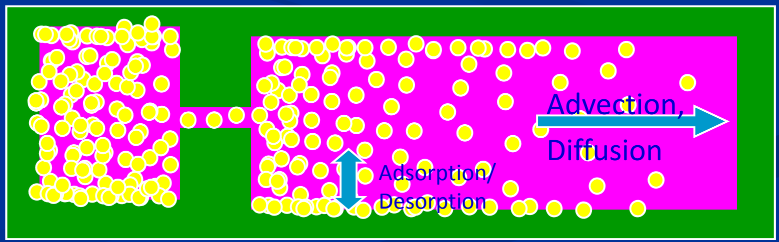
  Xia and Tang, 2011, Geochimica et Cosmochimica Acta (in press)

$$\varphi\frac{\partial c}{\partial t}=-\frac{1}{r^m}\frac{\partial}{\partial r}\left(r^m D\frac{\partial c}{\partial r}\right)-\left(1-\varphi\right)n_A\frac{\partial \vartheta}{\partial t}$$

Diffusion and Advection

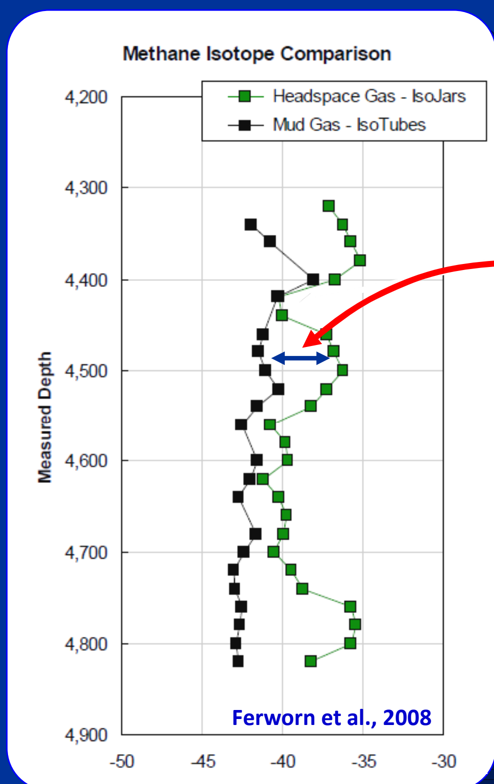
Adsorption /desorption

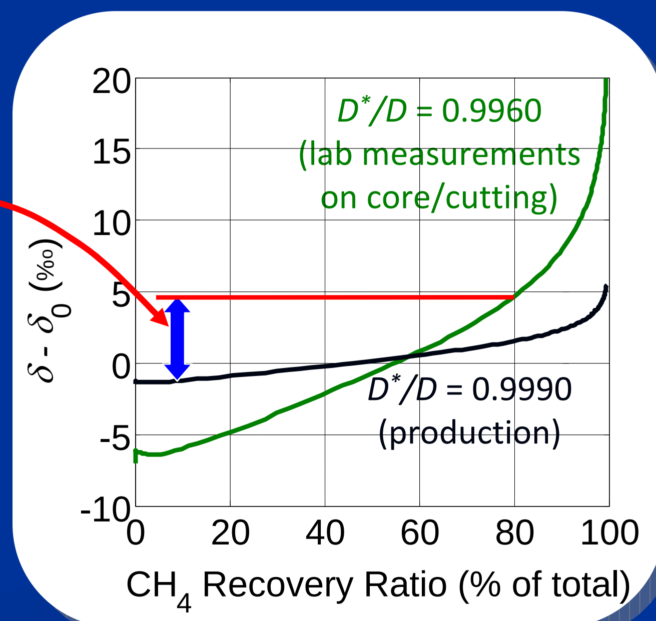
- Gas distribution in different space
  - Adsorbed gas vs. Free gas
  - Gas in different-sized pores
- Production monitoring
  - Productivity prediction



Difference between mud gas and headspace gas

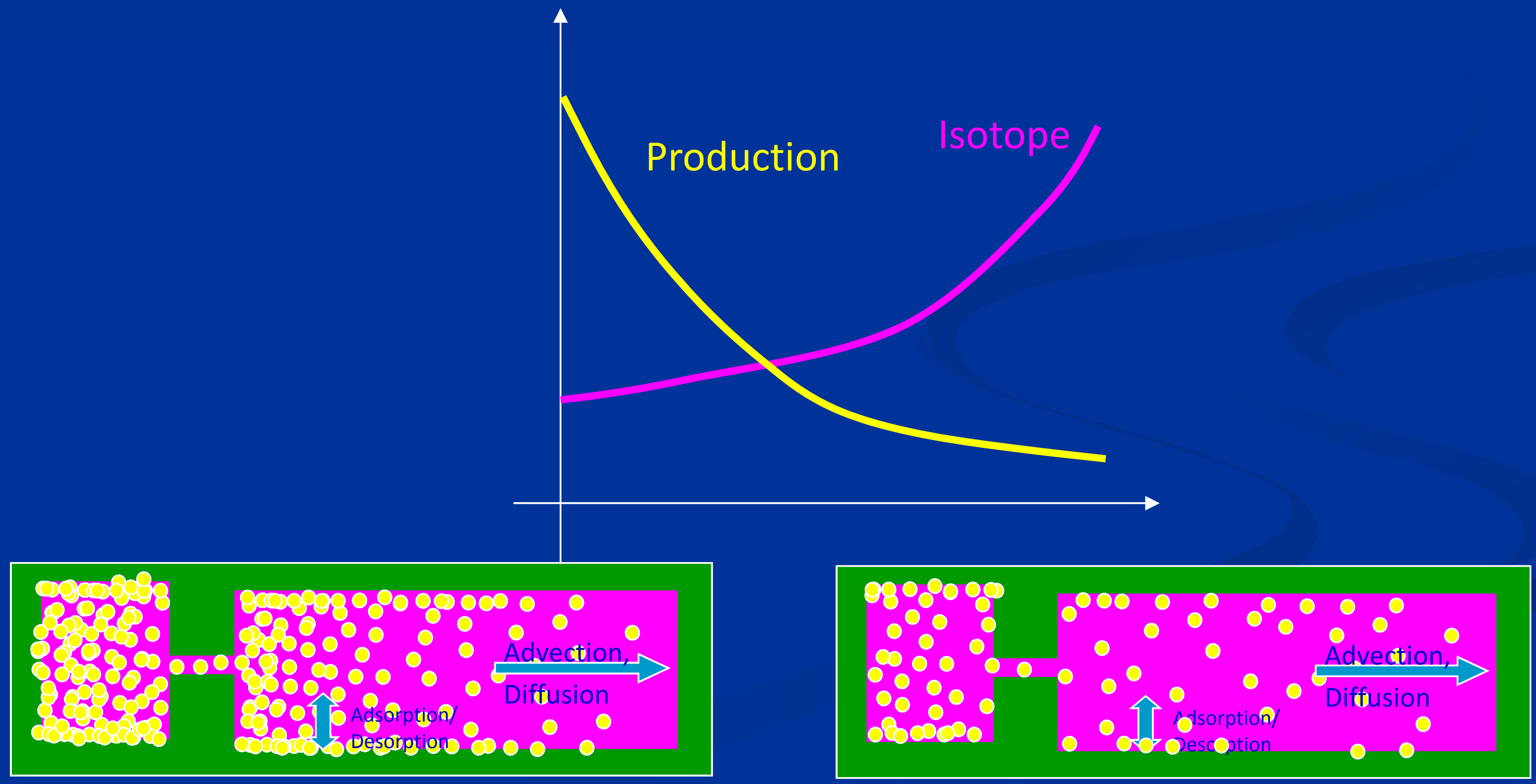
- Fractionation due to diffusion
- May reflect reservoir property
  - May be influenced by sampling and measurement conditions





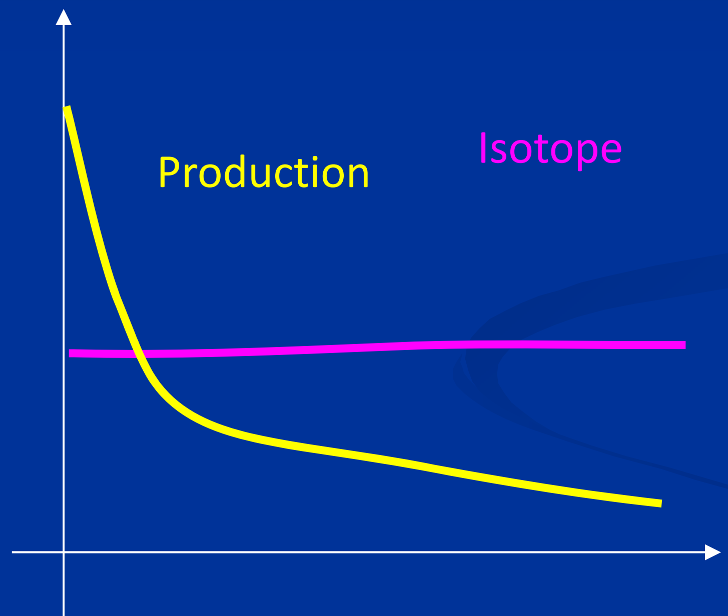
Application in production monitoring

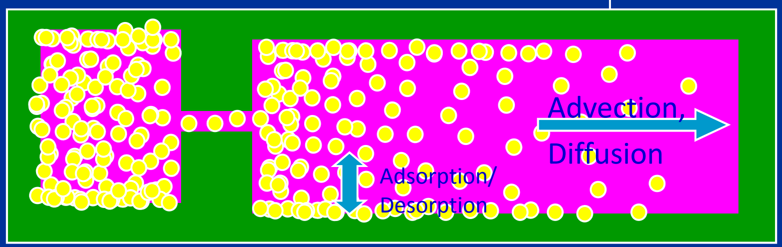
- Diagnosis of production decline
  - Depletion
  - Prediction of productivity

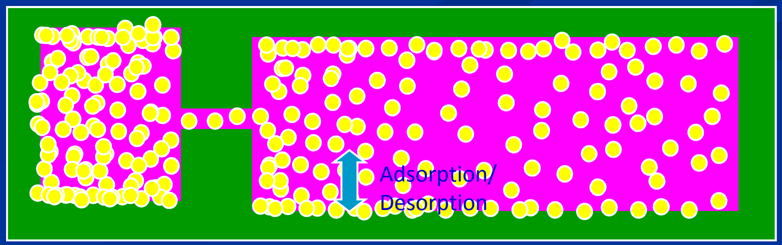


Application in production monitoring

- Diagnosis of production decline
  - Engineering problem







Summary

- OGIP is not only a function of source rock organic geochemical property; generation and expulsion need to couple
- Gas isotopes include plenty of information on reservoir property, but interpretation should not be over-simplified