COAL GAS ORIGINS AND EXPLORATION STRATEGIES ©

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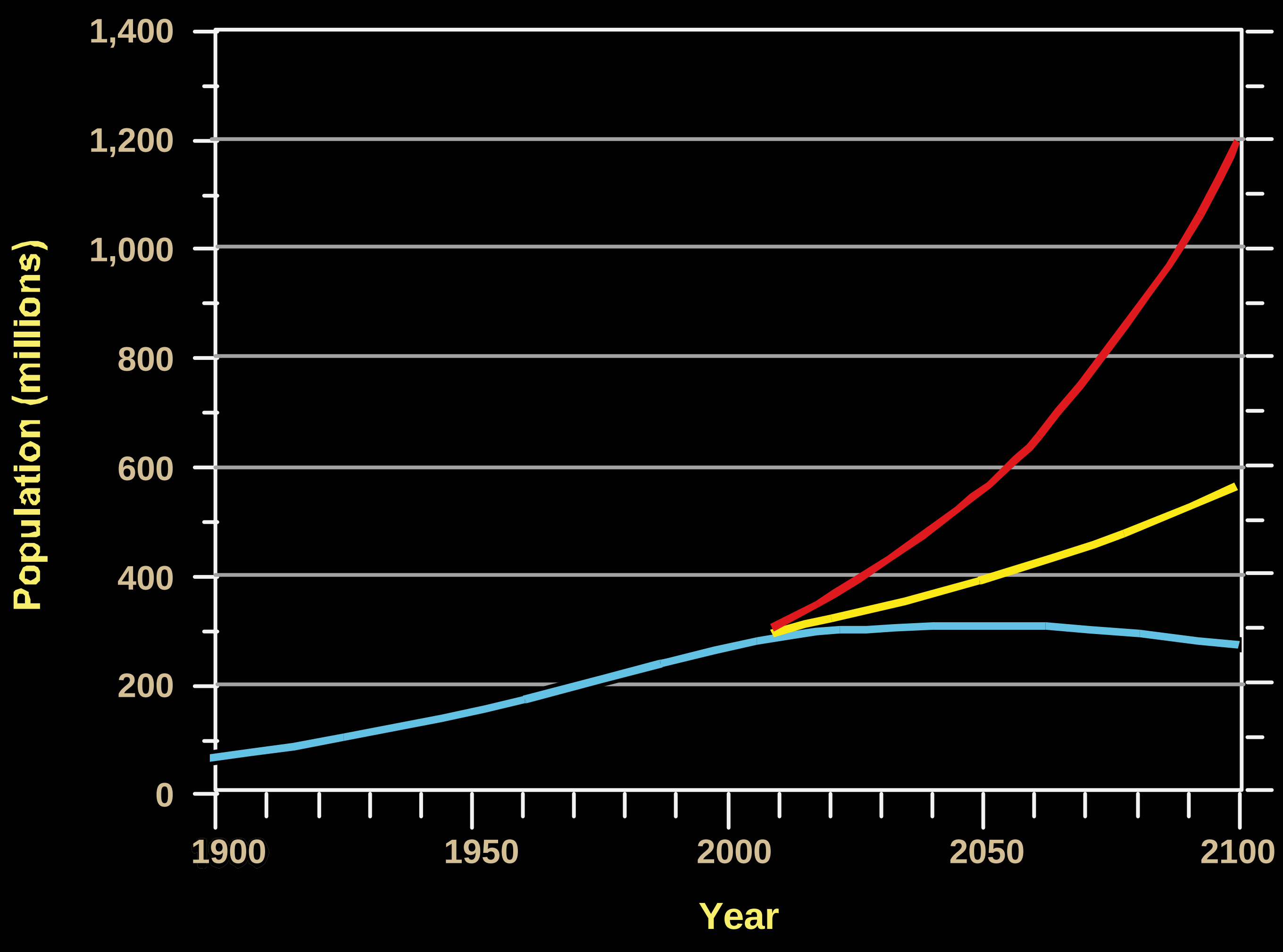
Mid-Continent Coalbed Methane Symposium

Tulsa, Oklahoma
November 7-9, 2004

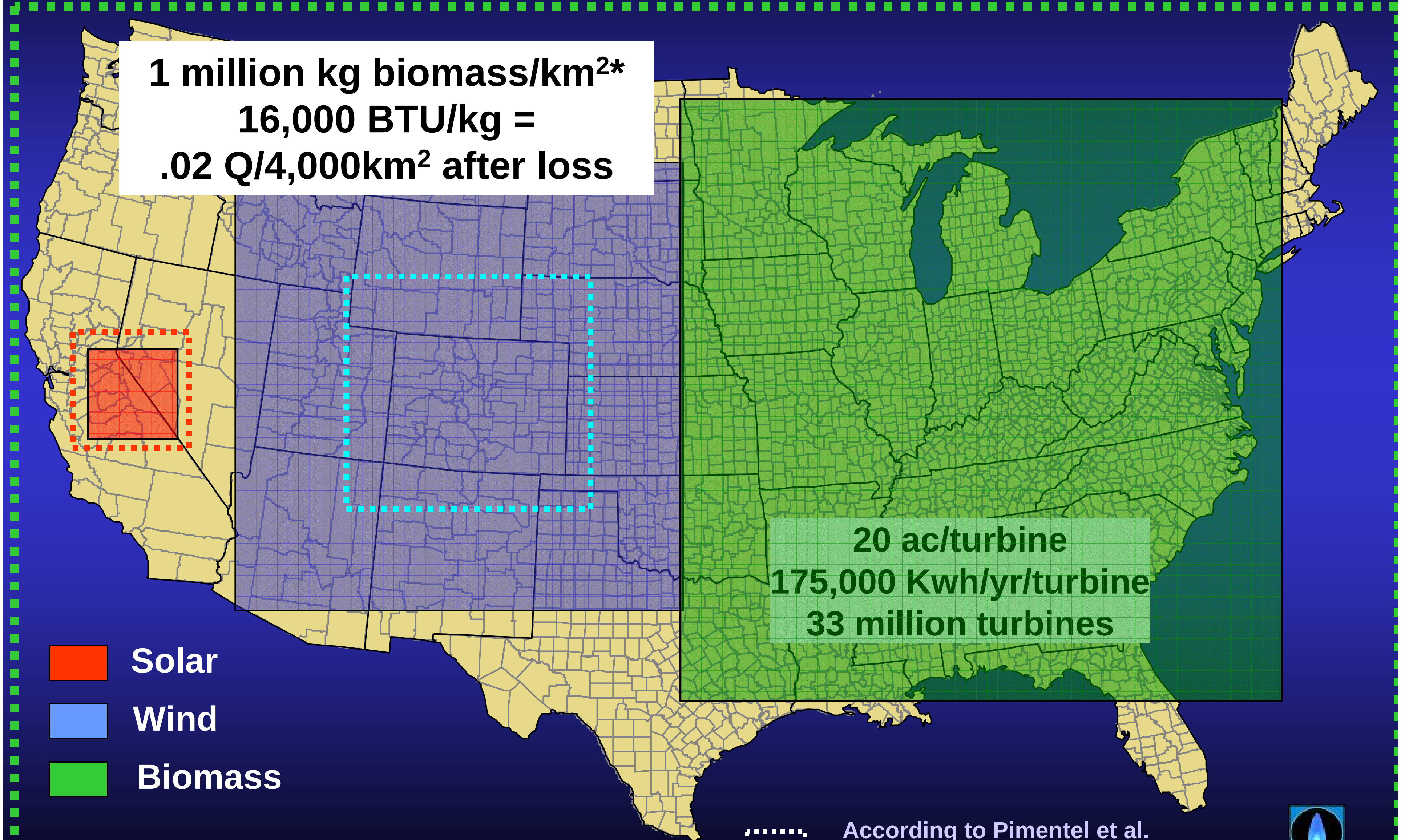


Data from U.S. Bureau of the Census; ftuture growth estimates
from U.S. Census Bureau publication NP-T1, February 2000; website
www.mnforsustain.org/united_states_population.htm


1. Energy
2. Water
3. Food
4. Environment
5. Poverty
6. Terrorism & War
7. Disease
2. Education
9. Democracy
10. Population
Tinker (2004) after Smalley (2003)

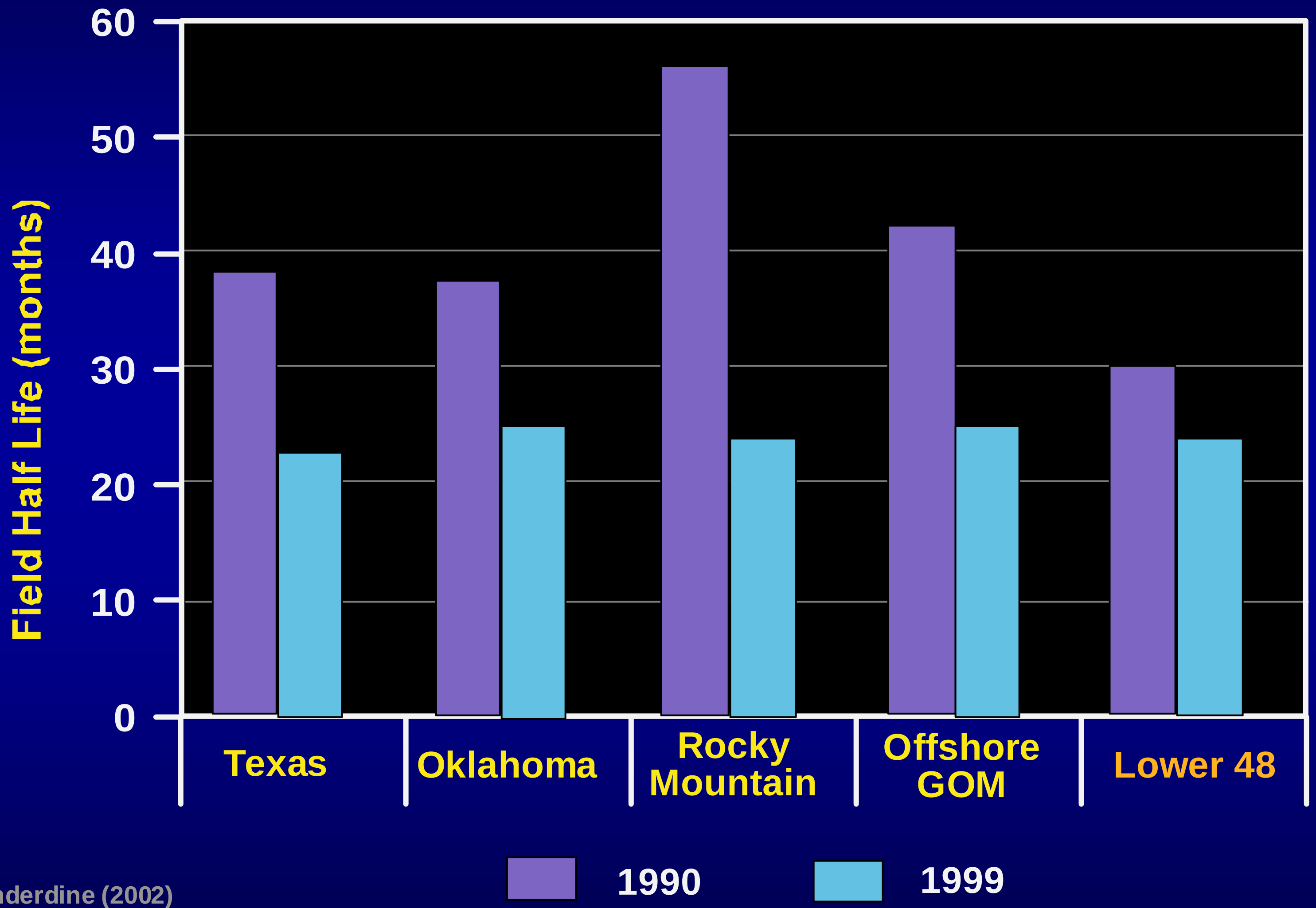
U.S. ENERGY COMPARISON

To Produce 20% of US Energy Demand (20 Quads per year)



Tinker RMS AAPG Keynote (2004)

NATURAL GAS DEPLETION RATES



Kenderdine (2002)

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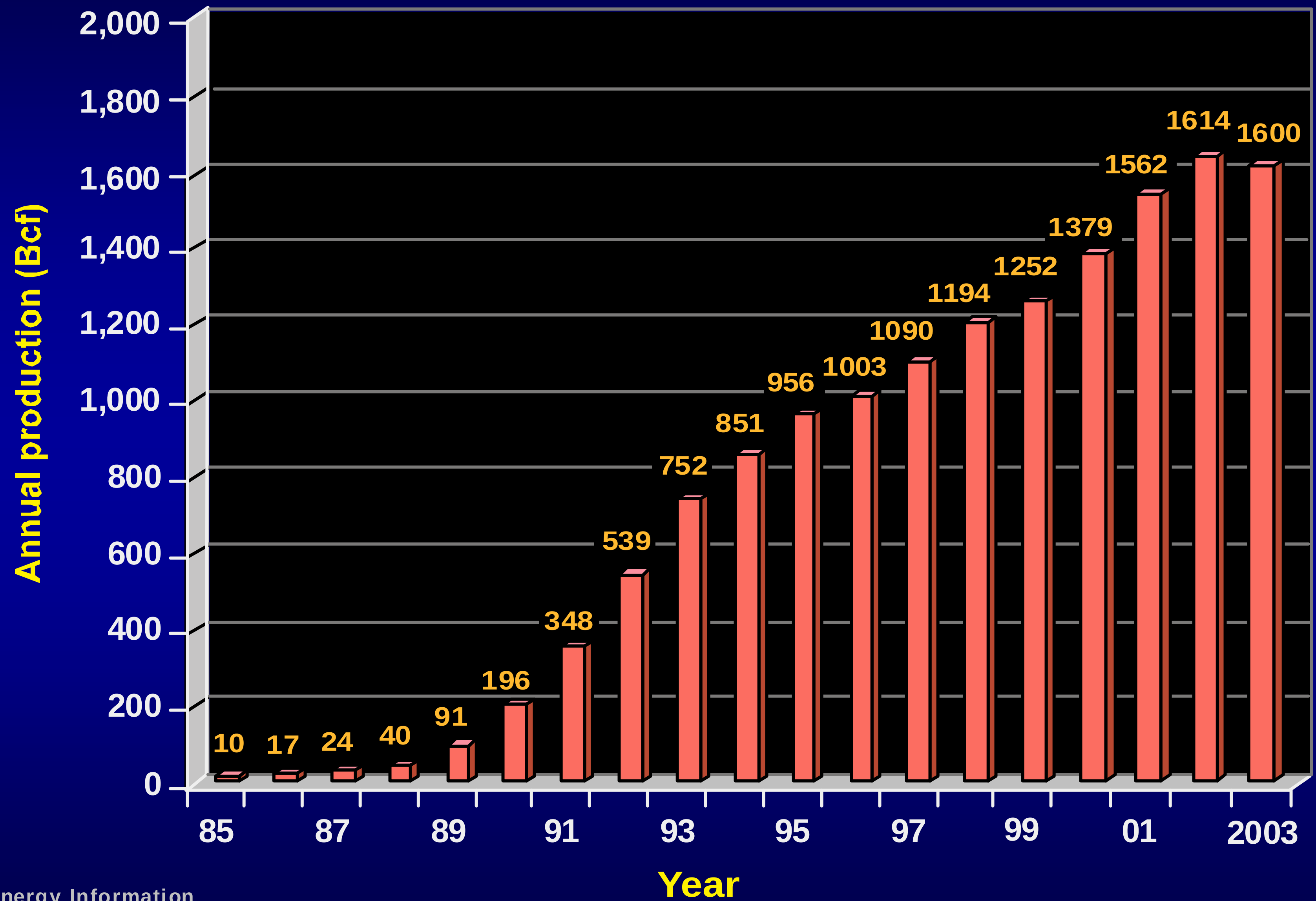
COALBED METHANE PRODUCTION IN U.S.



Energy Information Administration (1992, 1995,1999, 2002, 2004)

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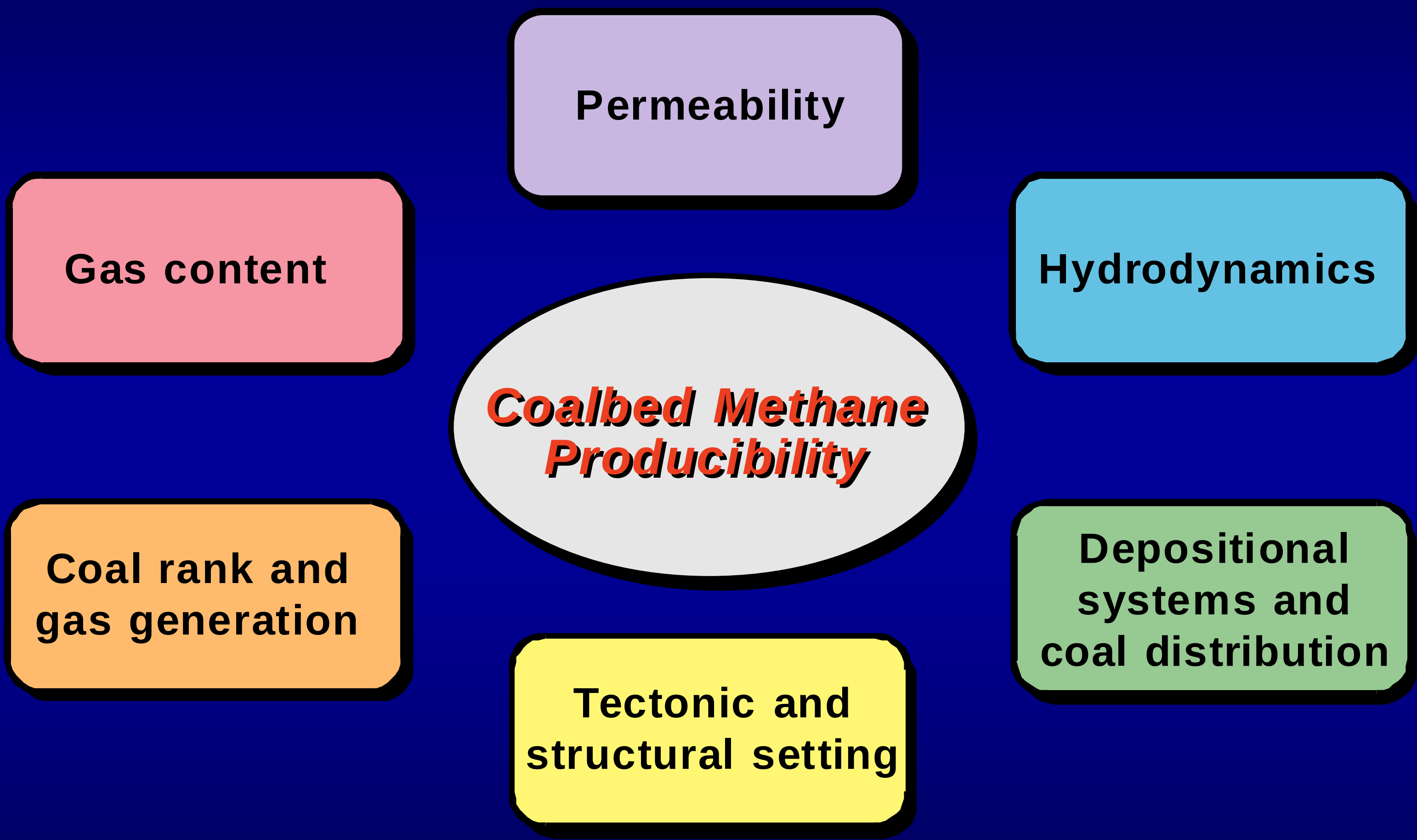
COALBED METHANE EXPLORATION MODEL



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EVALUATION OF GAS CHEMISTRY

- Gas chromatographic analyses provides information about gas chemistry; percentages of hydrocarbons, carbon dioxide, nitrogen, hydrogen, oxygen, etc. provided.

- Gas compositional analyses (gas chemistry) can be used in the classification of gases and to determine gas origins using a variety of calculated parameters including the gas dryness index and carbon dioxide content.

- Gas compositional analyses provide BTU content data of gases; higher BTU (wetter) gases demand a higher selling price, whereas low-BTU gases (carbon dioxide or nitrogen-rich) yield lower gas prices.

- The isotopic composition of gases, particularly the $\delta^{13}C$ and δD values of hydrocarbon gases and carbon dioxide, as well as isotopic data from formation waters can be used to determine gas origins and possible migration pathways.

- In some cases $\delta^{13}C$ isotopic values of gases can be used to estimate distance of migration.

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GAS DRYNESS INDEX (HYDROCARBONS ONLY)

$$GDI = \frac{C_1}{C_1 - C_5}$$

> 0.99	Very dry
0.94 to 0.99	Dry
0.86 to 0.94	Wet
≤ 0.86	Very wet

Scott et al. (1991)

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CARBON DIOXIDE CONTENT
(percent)

> 10	Very high
6 to 10	High
2 to 6	Moderate
≤2	Low

Hanson (1990)

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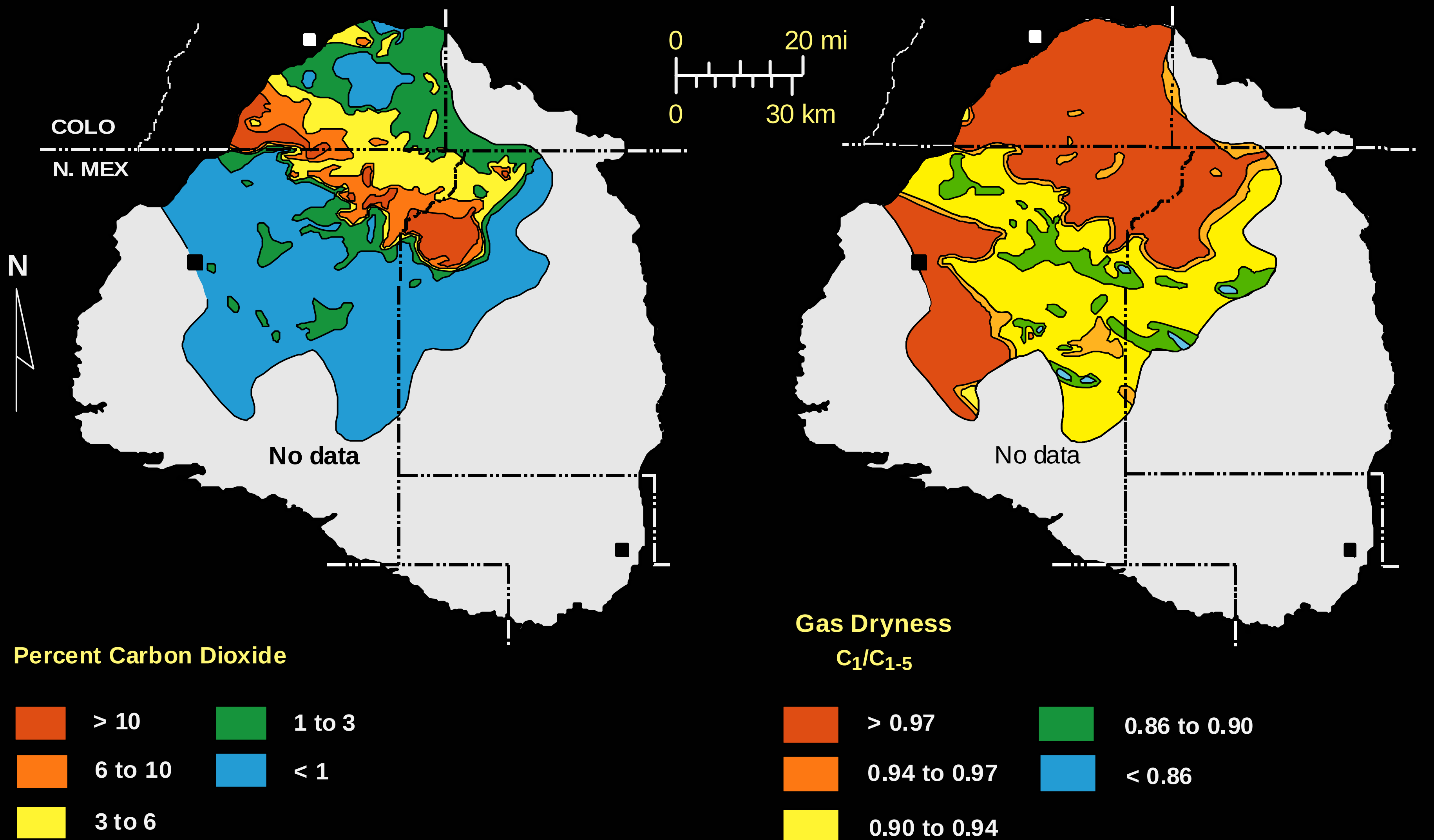
FRUITLAND COAL GAS CHEMISTRY



Scott and others (1994)

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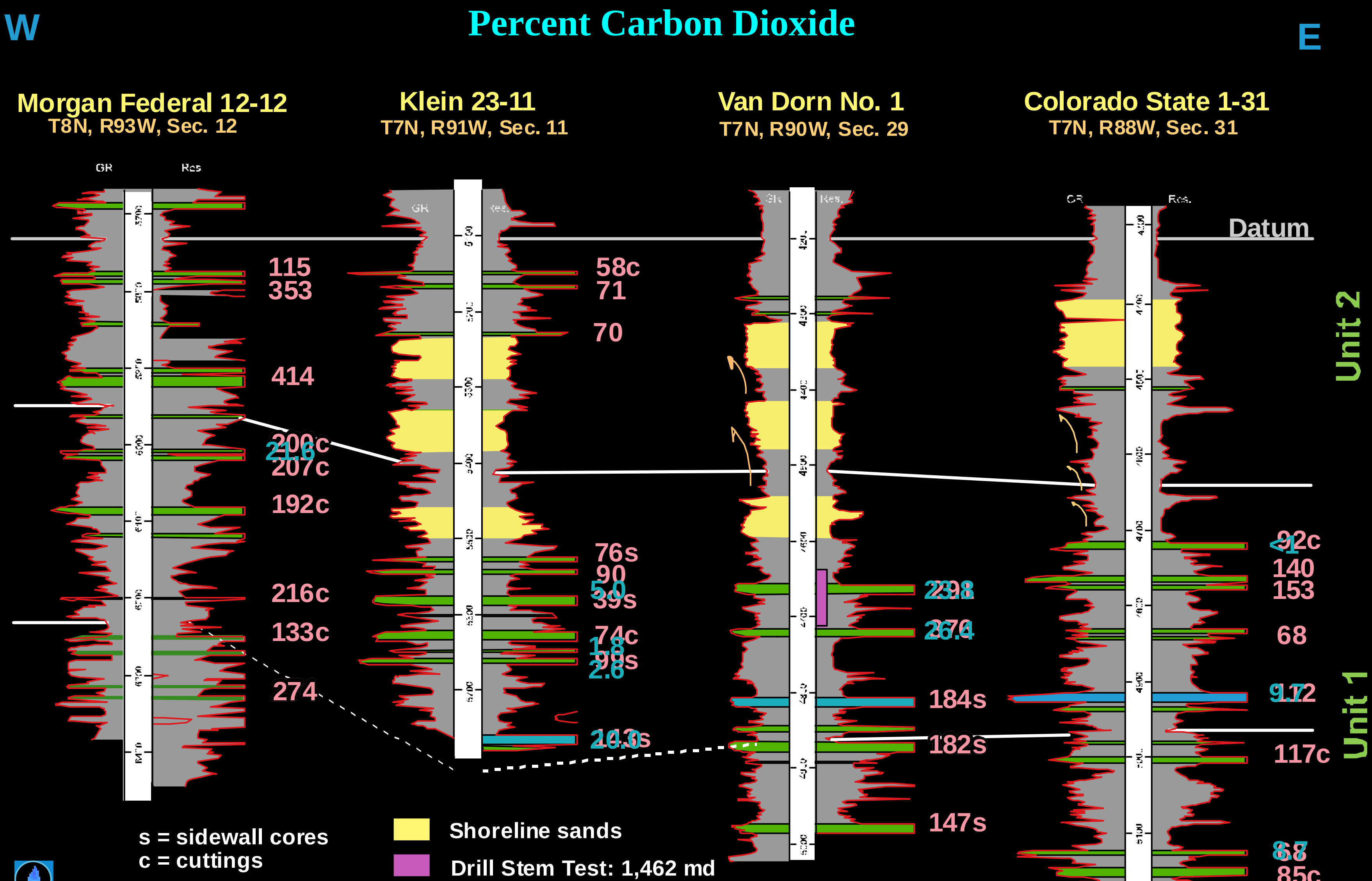
SAND WASH BASIN GAS CONTENT VARIABILITY

Percent Carbon Dioxide



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Gas content values are given on non-ash-free basis

Scott (1993)

BASIC TYPES OF COAL GASES

Thermogenic

- Coal gases are produced during thermal maturation of peat (organic-rich sources)
- Variable gas composition: high BTU wet gases or nearly 100% methane
- Brackish to saline formation water
- Low to very high gas contents (<1 to 25+ g/cc; <32 to 800+ scf/ton)

Secondary Biogenic

- Coal gases formed by bacteria transported basinward in permeable coal seams
- Occur at any coal rank after basin has been uplifted and coals exposed at outcrop
- Biogenic gases are nearly 100% methane; variable carbon dioxide
- Fresh to slightly brackish formation water.
- Low gas contents (1 to 3 g/cc; 32 to 90 scf/ton)

Migrated

- Migration of thermogenic or secondary biogenic
- Some coal gases not derived from coals – can be derived from shales

Indigenous

- Retained or adsorbed to the coal surface at time of generation.
- May be thermogenic or secondary biogenic

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THERMOGENIC GASES

Thermogenic gases in coal beds are derived from the thermal maturation of organic matter.

Early Thermogenic gases form at low coal ranks (subbituminous to high-volatile B bituminous; VR < 0.80%) from hydrogen-rich coals. Early thermogenic methane may form in coal beds at vitrinite reflectance values of 0.40 percent.

High BTU gases and some oil or paraffins are common in some areas and the peak of wet gas generation occurs between VR values of 0.60 and 0.80 percent. Gas contents are generally low, but 100 to 200 Mcf per day is possible from some low rank coals.

Main Stage Thermogenic gases are formed when the threshold of thermogenic methane generation is reached at vitrinite reflectance values between 0.80 to 1.00 percent (high-volatile A bituminous rank). Gas contents are variable, but can exceed 800 scf/ton in higher rank coals. Production rates of more than 5 MMscfd are reported.

COAL RANK AND THERMOGENIC GAS GENERATION

	Stach (1975)	ASTM (1983)	Scott (1995)	Coal Rank
lig				lignite
	0.38	0.38	0.38	
sub				subbituminous
	0.65	0.49	0.49	
hvCb				high-volatile C bituminous
	0.65	0.51	0.65	
hvBb				high-volatile B bituminous
	0.78	0.69	0.78	
hvAb				high-volatile A bituminous
	1.11	1.10	1.10	
mvb				medium-volatile bituminous
	1.49	1.60	1.50	
lvb				low-volatile bituminous
	1.91	2.04	1.91	
sa				semianthracite
	2.50	2.40	2.50	
a				anthracite
	5.00	5.00	5.00	
ma				meta-anthracite

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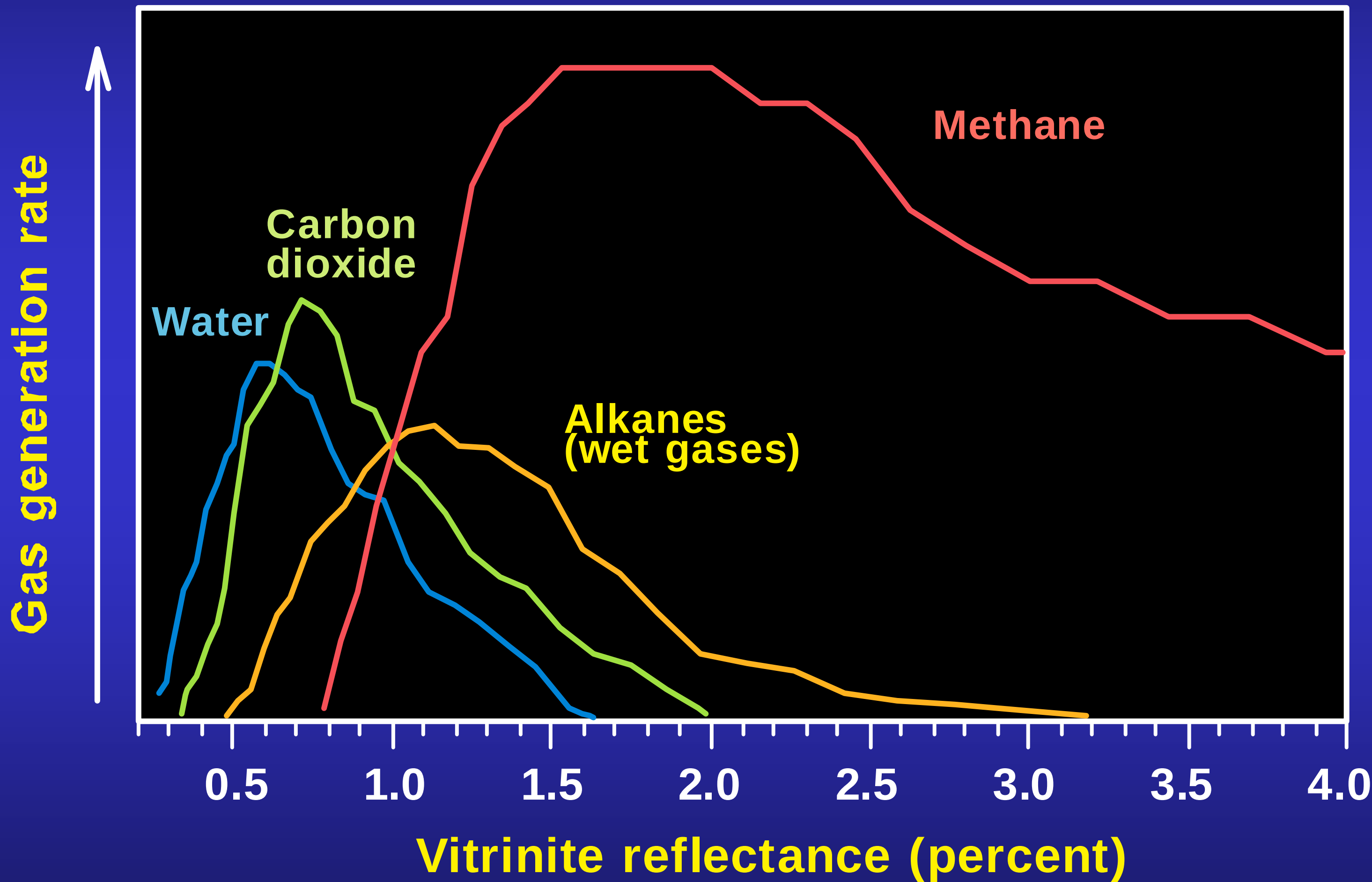
COAL RANK AND THERMOGENIC GAS GENERATION



Data from Burnham and Sweeney (1989);
Tang and others (1991); Killops and others (1994)

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BIOGENIC GAS ORIGINS

Biogenic gases in coal beds were originally believed to be preserved swamp gas. Previous explanations of gas origins evolved into exploration models and strategies that were erroneously based on the assumption that biogenic gases in coal beds were formed in peat swamps.

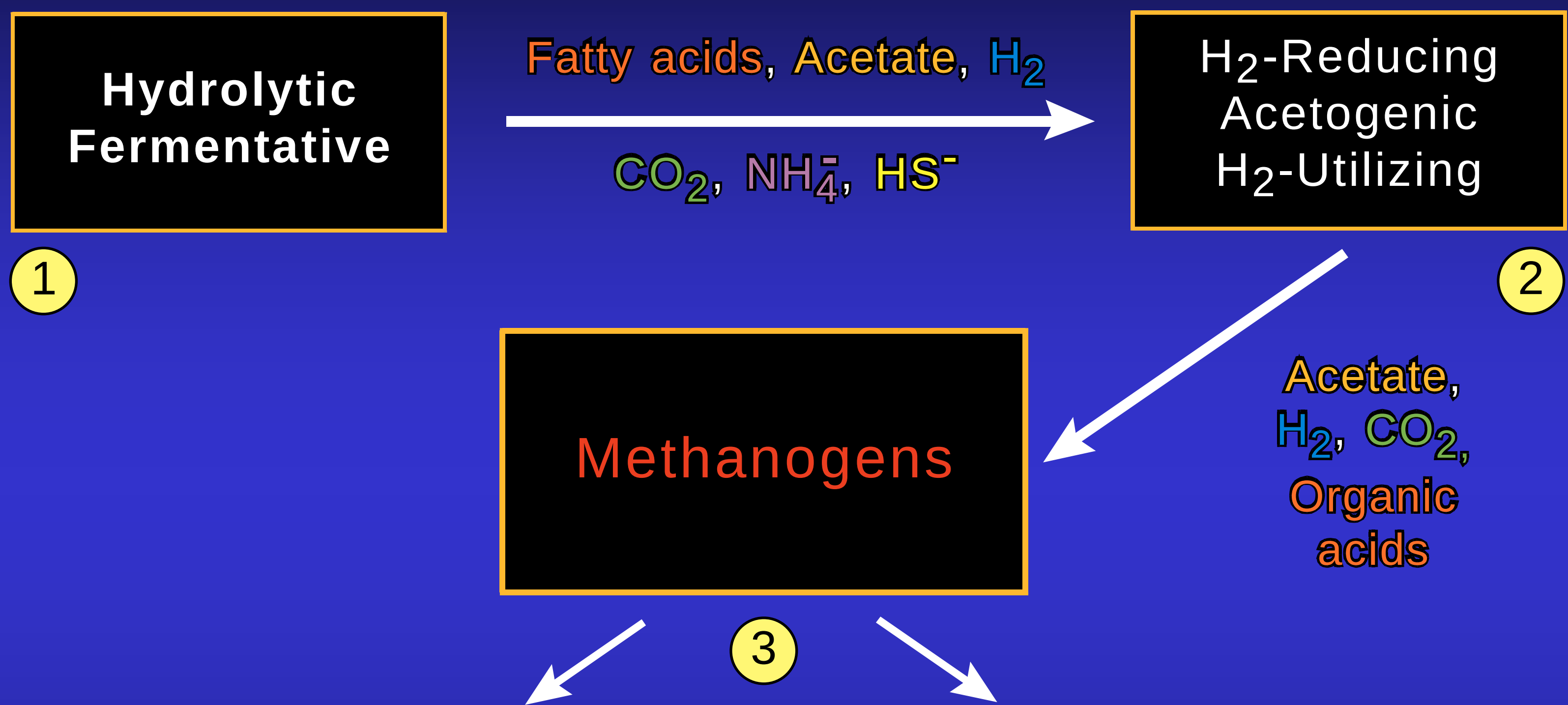
Primary biogenic gases formed in the peat swamp were probably not preserved because (1) there is little pressure at the surface to sorb gas molecules, (2) peat has a high moisture content indicating that many potential sorption sites are occupied by water molecules that are strongly sorbed to the peat surface, and (3) compaction would drive water and dissolved methane out of the peat.

It is possible some primary biogenic methane stored in larger cavities in the organic material could be preserved with burial.

Secondary biogenic gases formed after burial, coalification, uplift and erosion when bacteria and/or nutrients were introduced into the coal seam by meteoric fluids migrated basinward. Most biogenic gases were formed relatively late in the coal basin evolution. Production rates of more than 1 MMcfd have been reported.

SECONDARY BIOGENIC GAS GENERATION

BACTERIAL CONSORTIA



Acetate Fermentation

$CH_3COO^- + H^+ \longrightarrow CH_4 + CO_2$

Carbonate Reduction

$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$

Modified from Winfrey (1984)

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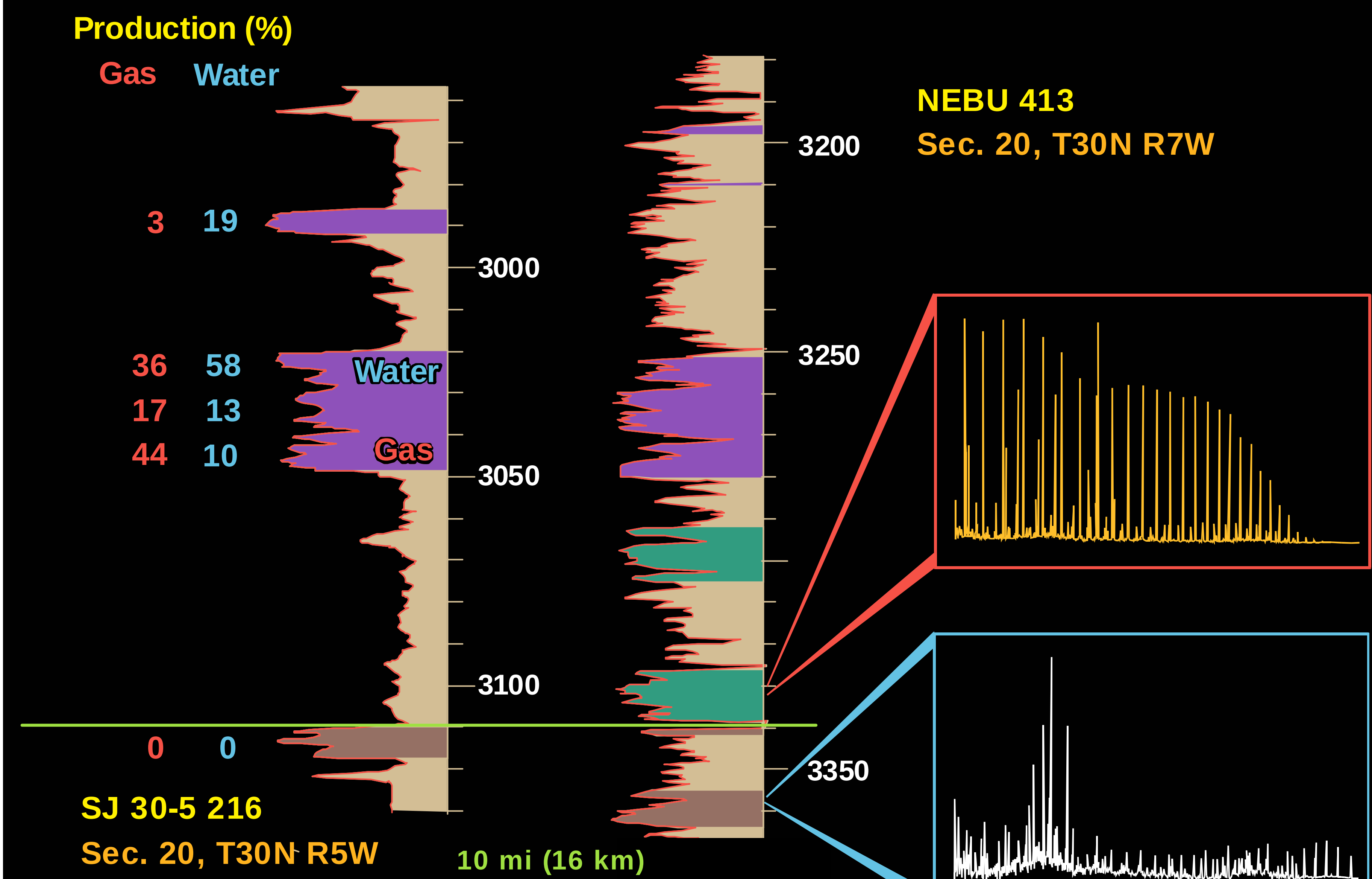
PRODUCTION HETEROGENEITY AND BIODEGRADATION

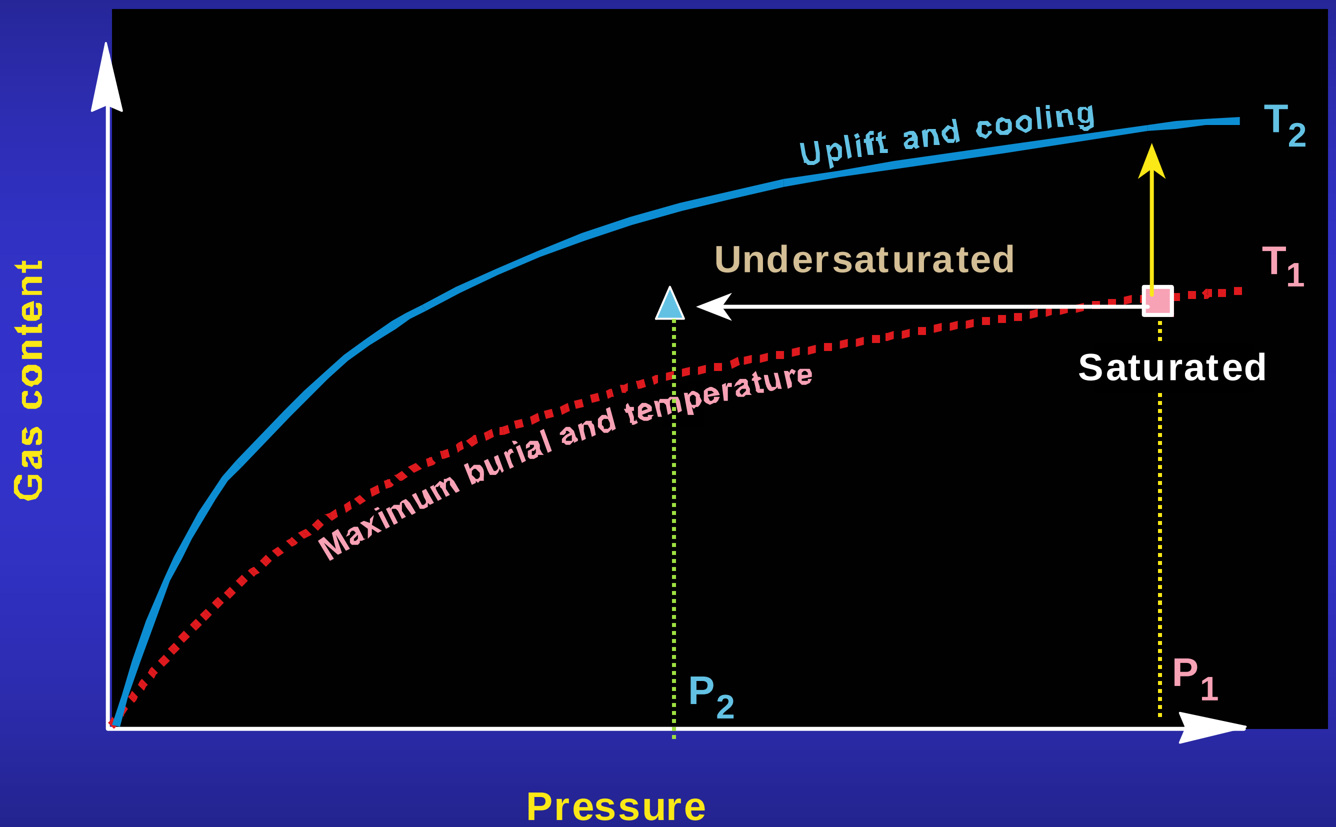


How to Determine Coal Gas Origins…….

…..and Develop Exploration Strategies.

Sorption Isotherm Saturation
Isotopic Data

ISOTHERM TEMPERATURE SHIFT



Scott and others (1994)

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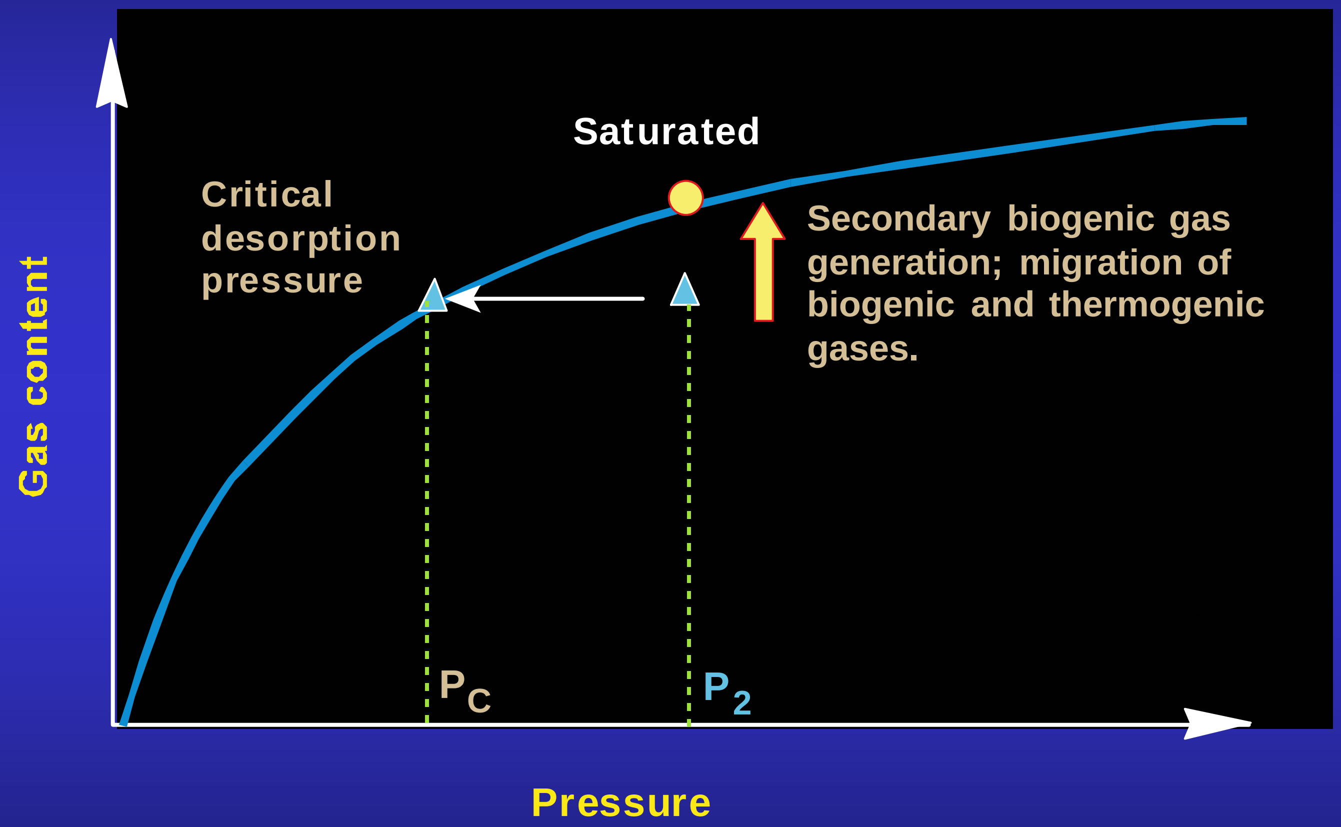
RESATURATION OF ISOTHERMS



Scott and others (1994)

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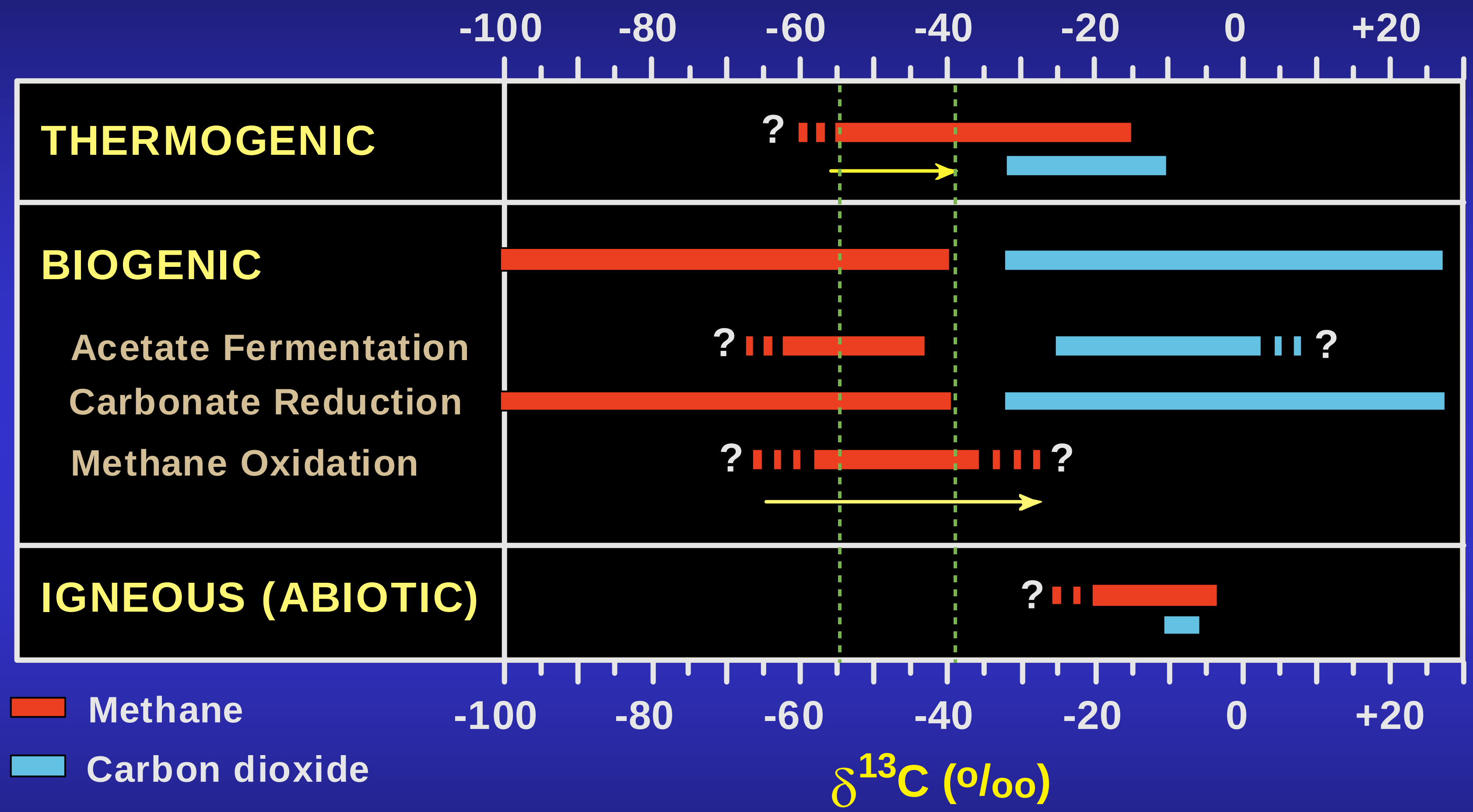
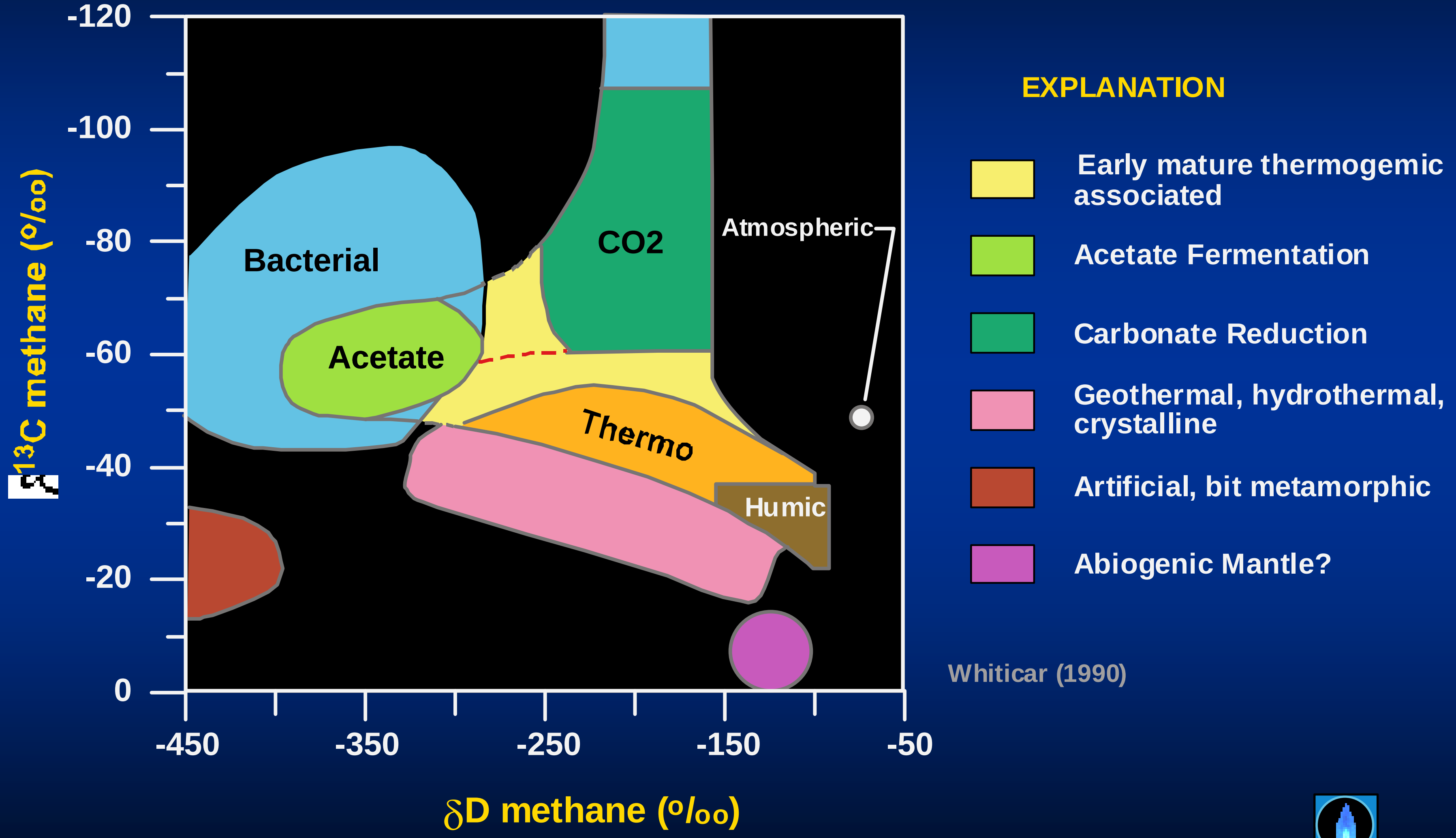
ISOTOPIC RANGES



Scott and others (1994)

COAL GAS ORIGINS CLASSIFICATION



Whiticar (1990)

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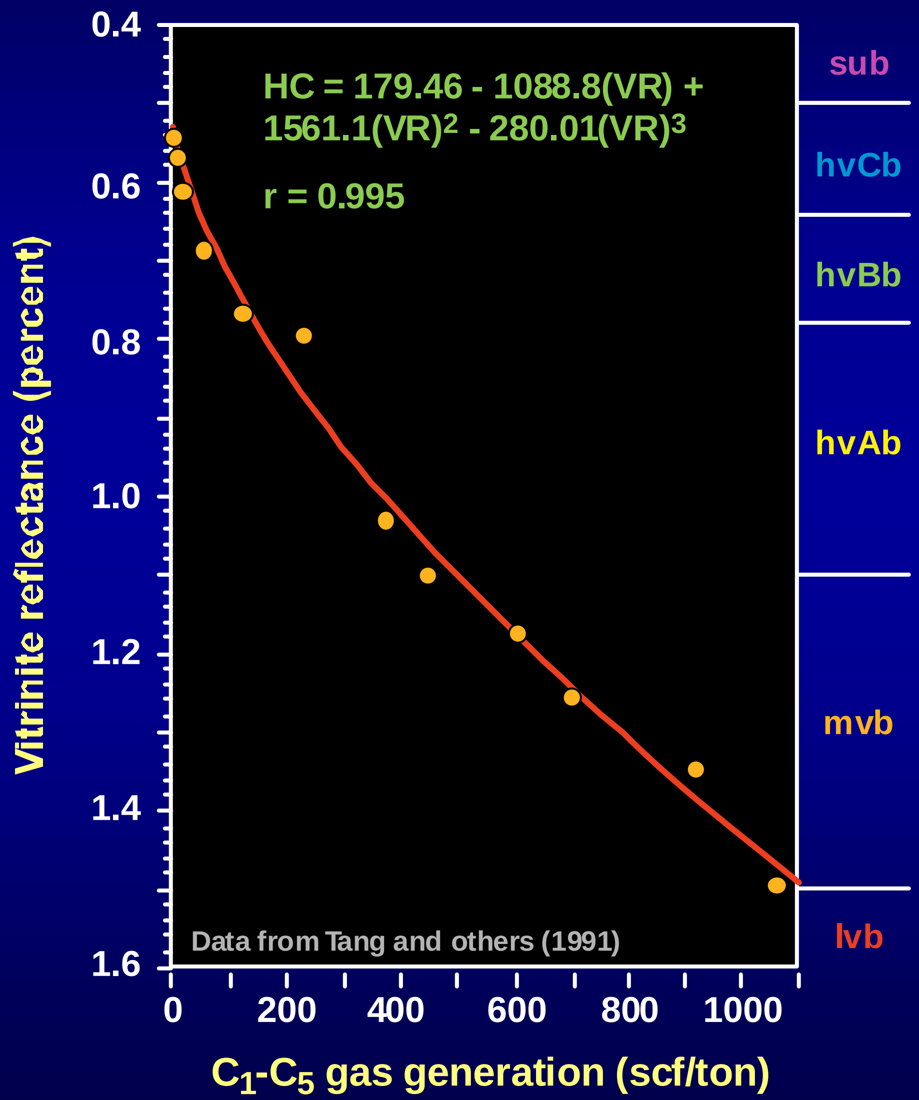
GAS CONTENT AND GAS ORIGINS SUMMARY

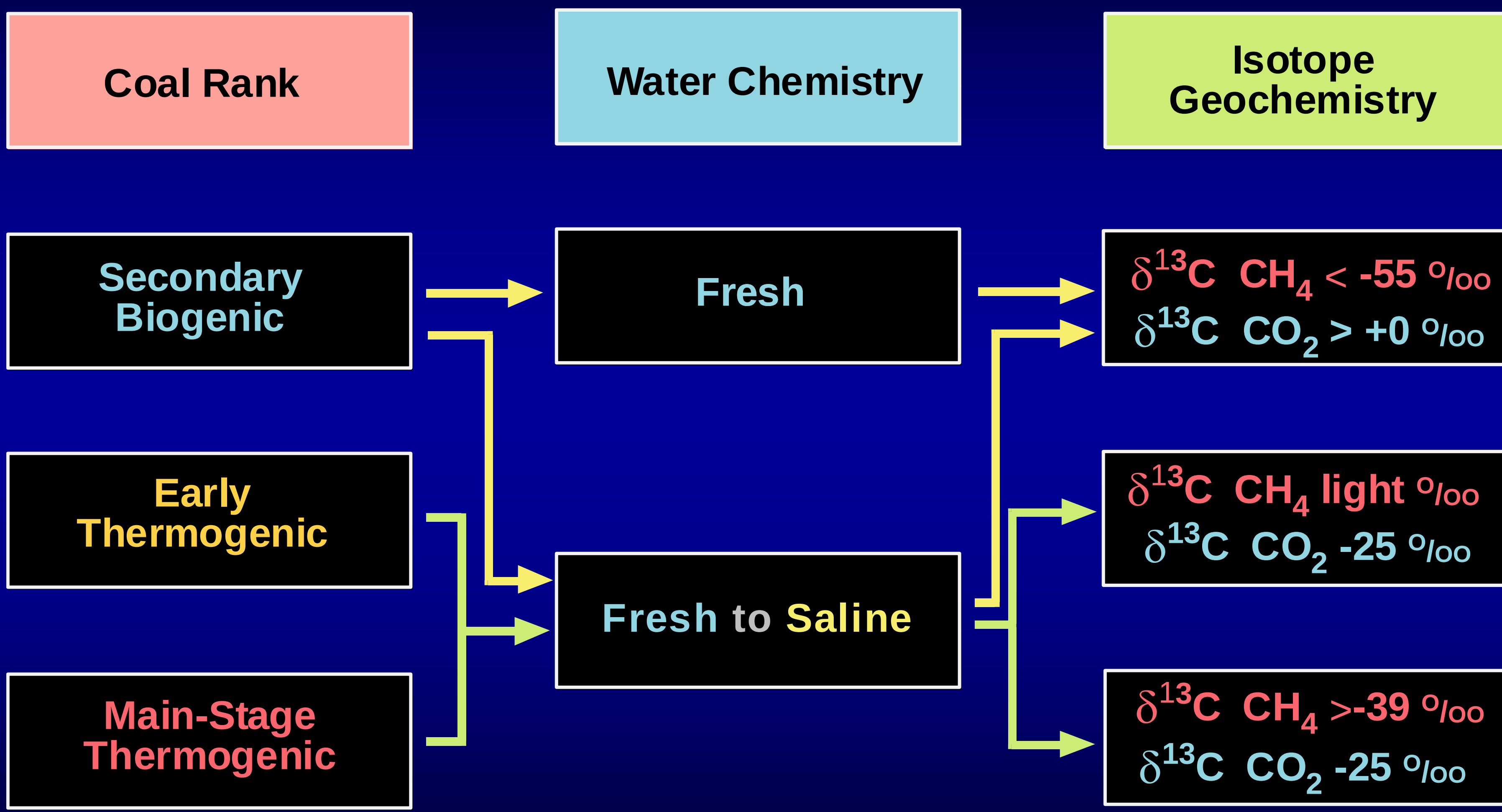


Gas content is not fixed, but changes when equilibrium conditions in the reservoir change.

The presence of unusually high gas contents in low rank coal beds

The presence of saturated or nearly saturated conditions

DEVELOPMENT OF EXPLORATION STRATEGIES



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- Low to very high gas contents (<1 to 25+ g/cc; <32 to 800+ scf/ton)

Secondary Biogenic (downdip migration or indigenous)

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- Occur at any coal rank after basin has been uplifted and coals exposed at outcrop
- Biogenic gases are nearly 100% methane; variable carbon dioxide
- Fresh to slightly brackish formation water.
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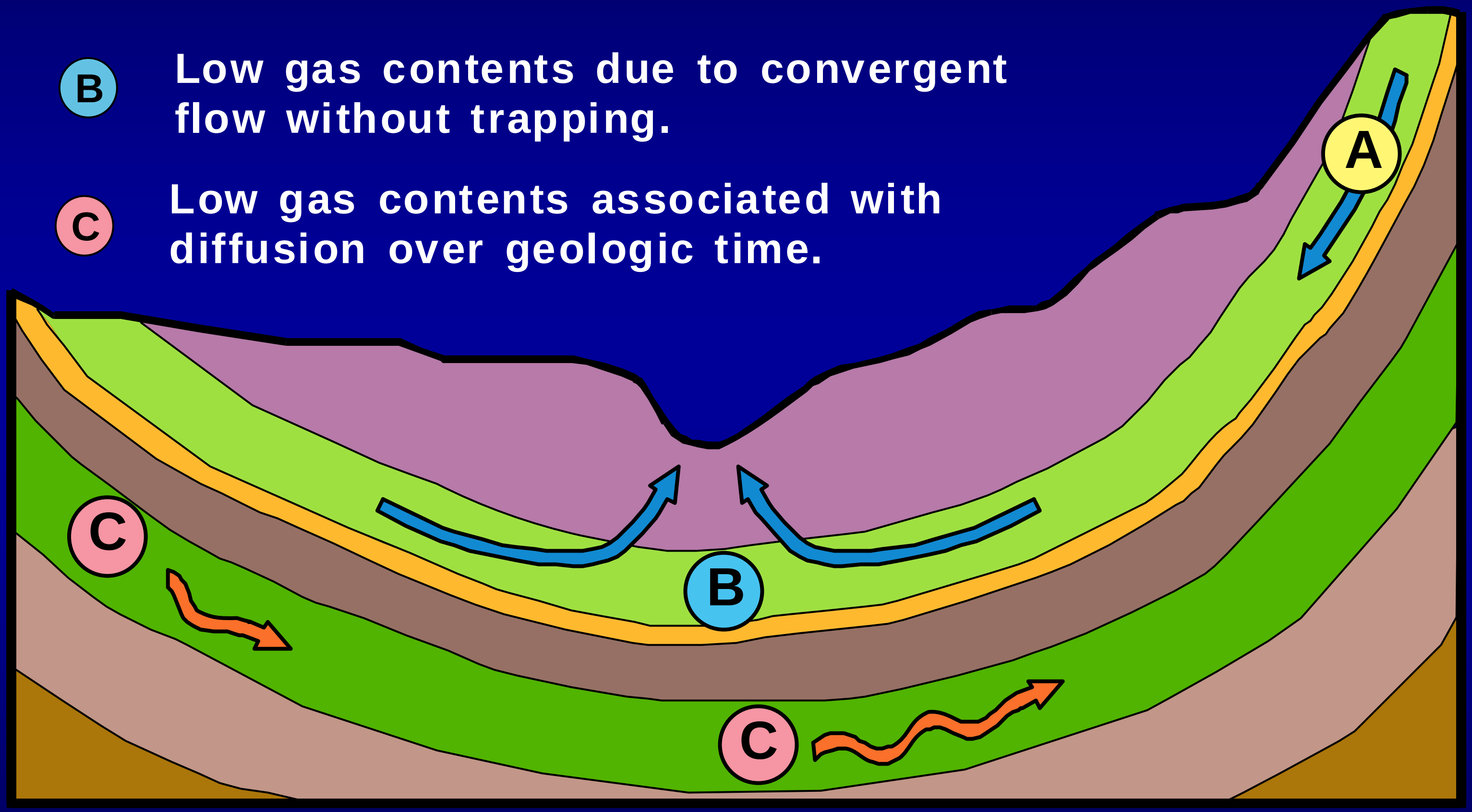
UNUSUALLY LOW GAS CONTENTS

A — Low gas contents due to meteoric recharge flushing.

B — Low gas contents due to convergent flow without trapping.

C — Low gas contents associated with diffusion over geologic time.



Modified from Scott (1999)

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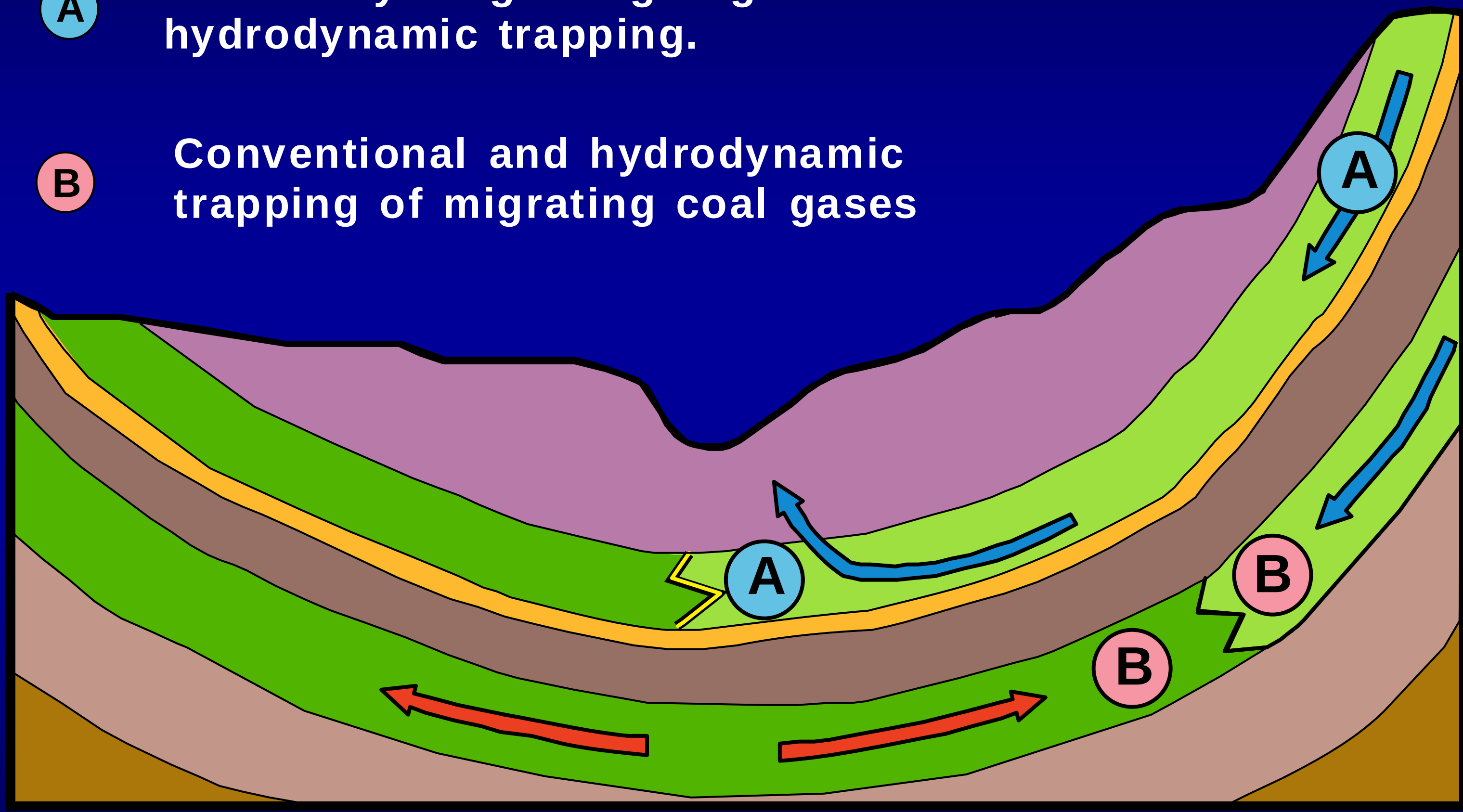
UNUSUALLY HIGH GAS CONTENTS

(A) Secondary biogenic gas generation and hydrodynamic trapping.

(B) Conventional and hydrodynamic trapping of migrating coal gases



Modified from Scott (1999)

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COALBED METHANE EXPLORATION MODEL