Introduction To Coal Mine Methane and Coalbed Methane : The Potential for Unconventional Gas Development In Colombia

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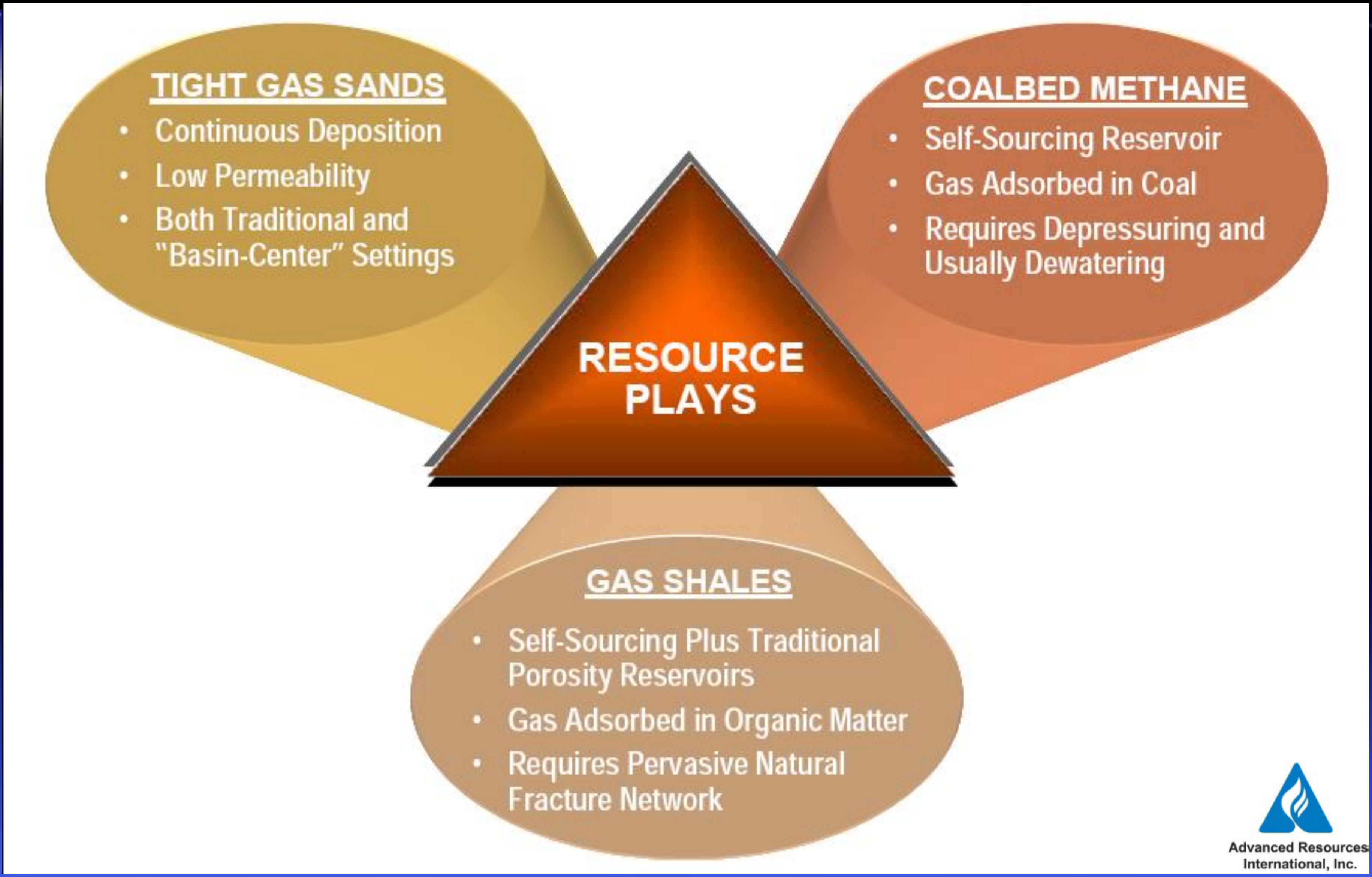
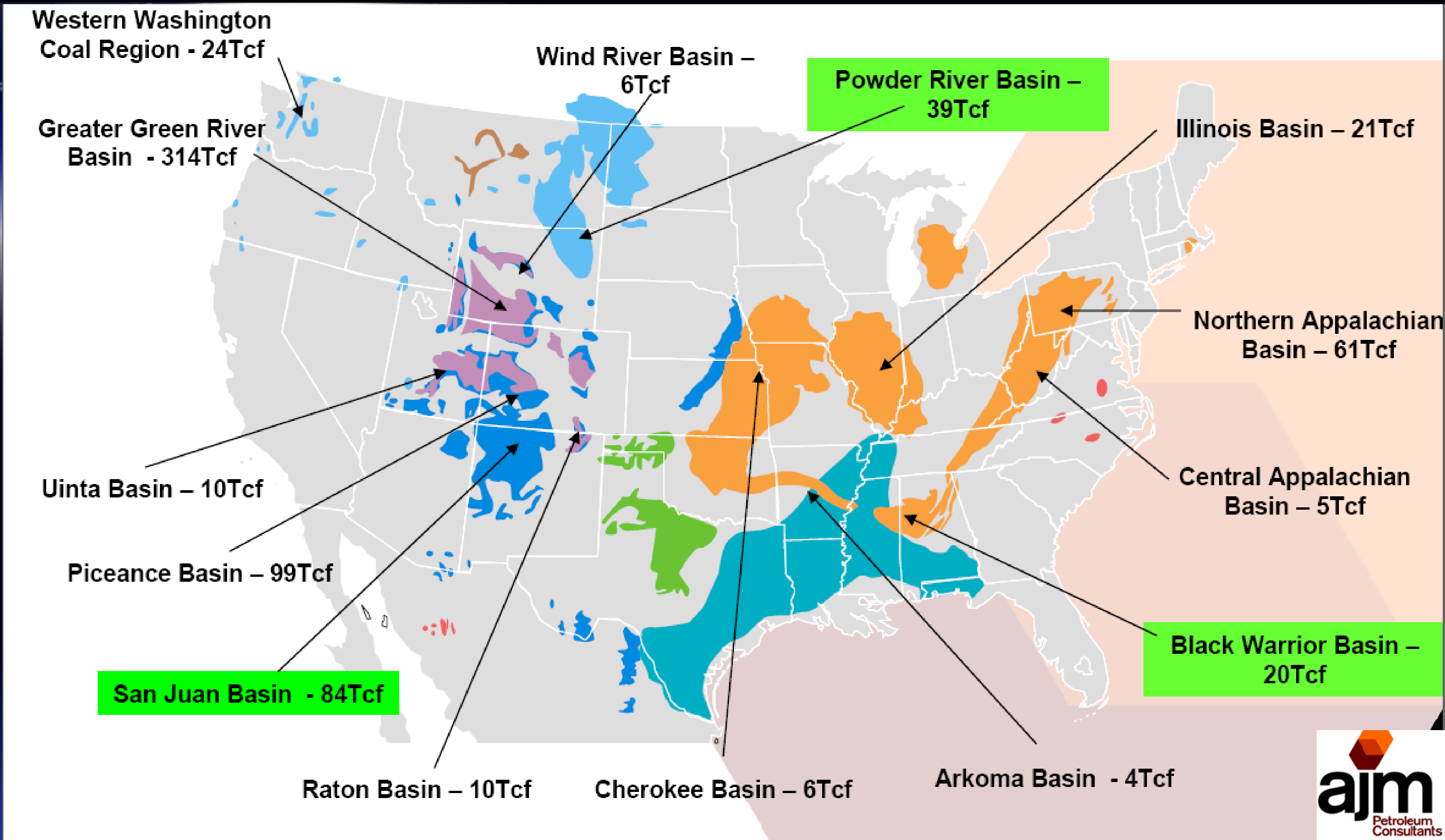
WELCOME AND INTRODUCTION

UNCONVENTIONAL GAS RESOURCE PLAYS



US COALBED GAS BASINS AND RESOURCES



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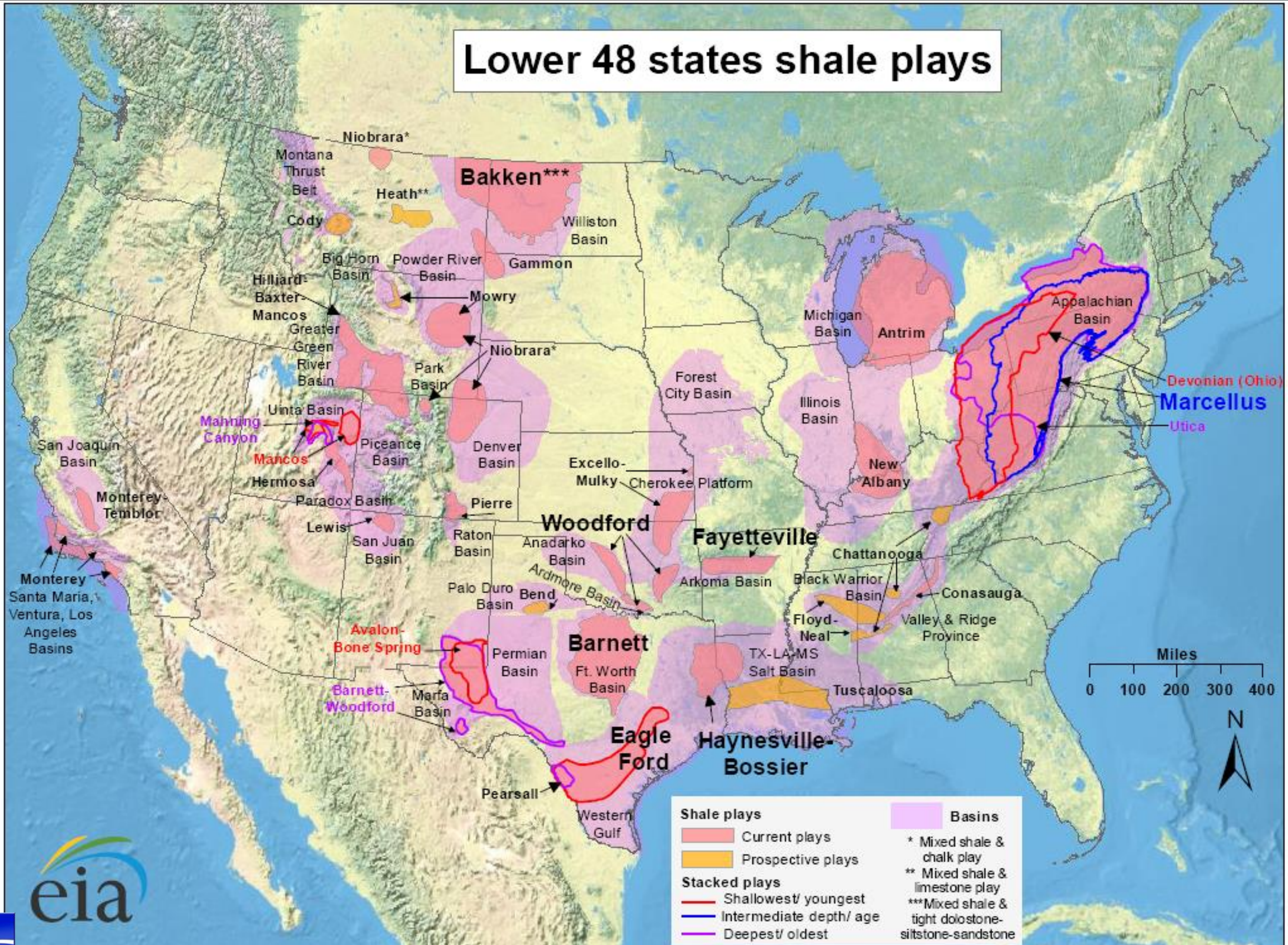
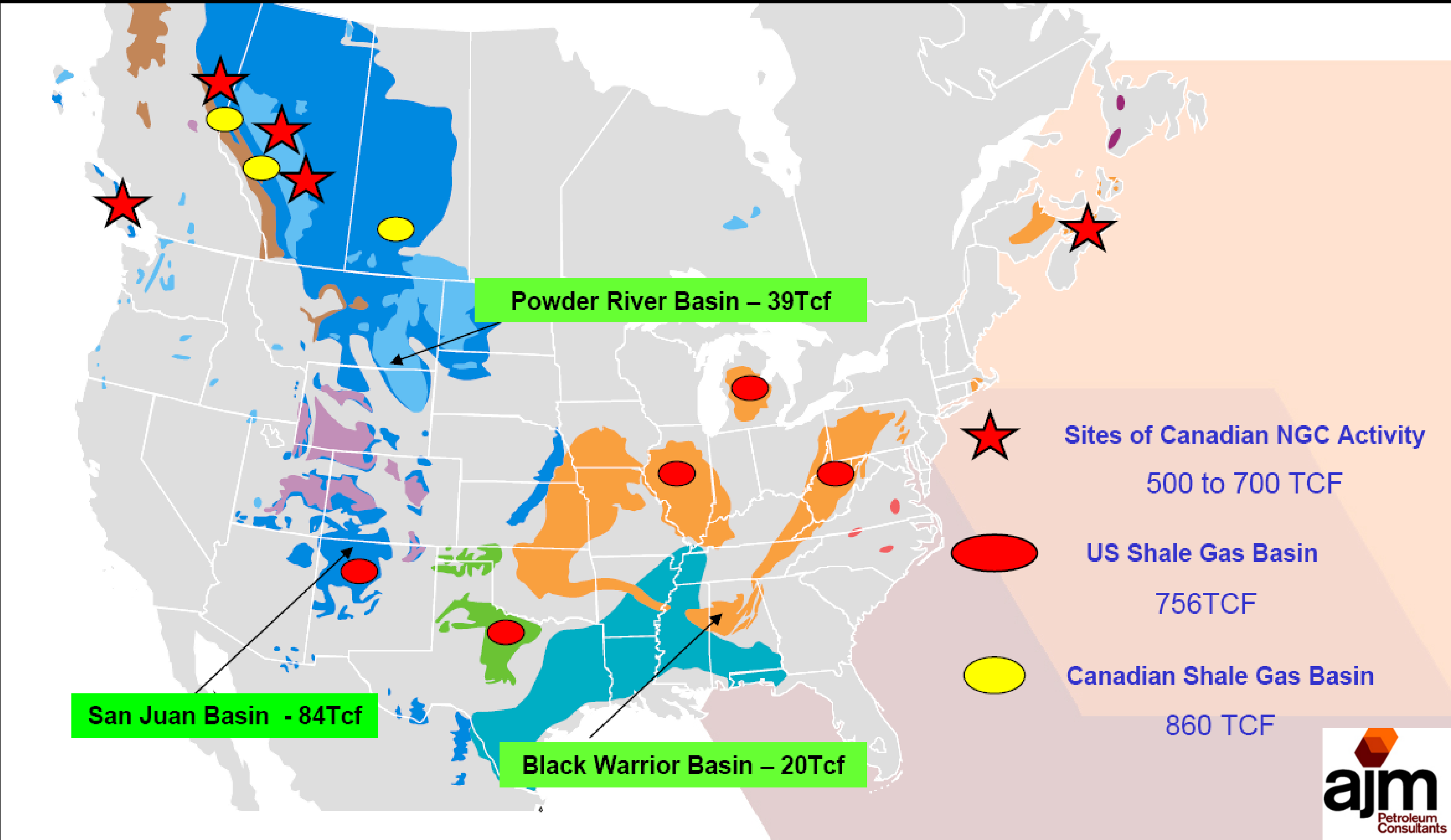
US SHALE GAS BASINS

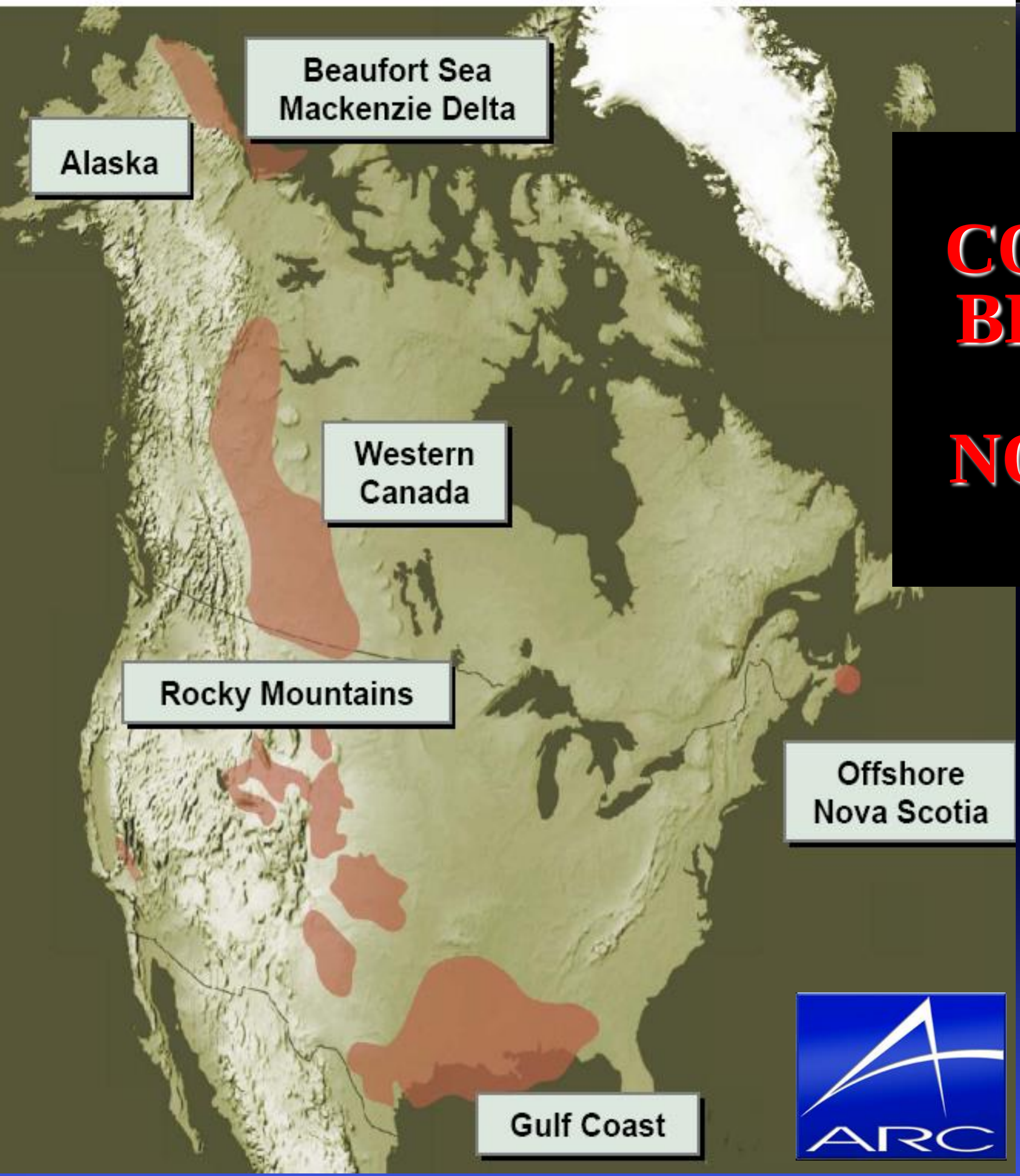


http://www.eia.gov/oil_gas/rpd/shale_gas.pdf

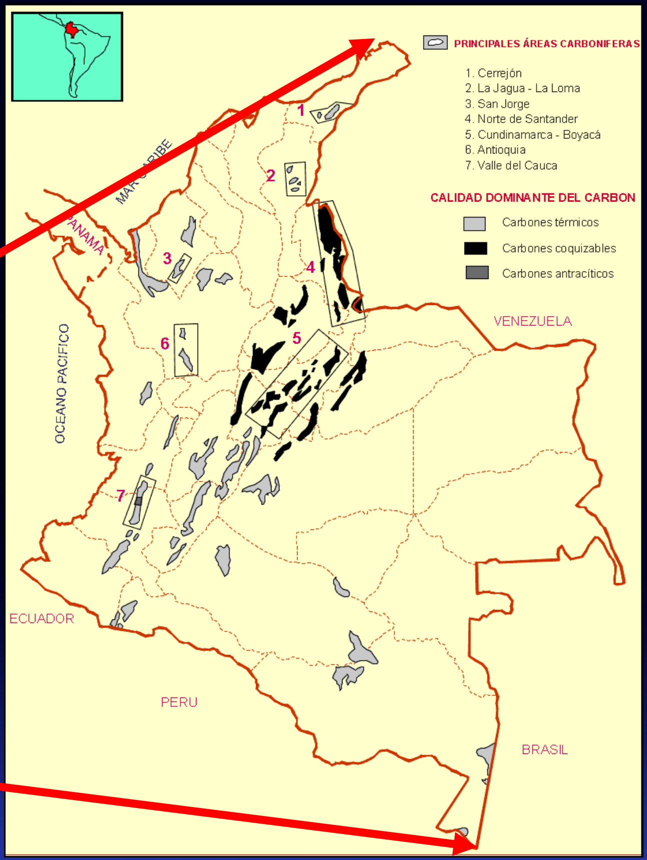
NORTH AMERICA NATURAL GAS PRODUCTION BASINS



COAL AND SHALE BEARING BASINS IN WESTERN NORTH AMERICA



SIMILAR DEPOSITIONAL SYSTEMS (COAL AND SHALE) AND SIMILAR TECTONIC HISTORY



Ingeominas, 2004

Coalbed Methane Resources

China	1,060 – 1,240 Tcf
Russia	600 – 4,000
United States	400 – 690
Canada	200 – 2,700
Australia	300 – 500
Germany	100
United Kingdom	60
Kazakhstan	40
Poland	100
India	30
Southern Africa (SA, Zim, Bot)	30
Ukraine	60
World Total	**2,980 – 9,260 Tcf**

(Ayers, 2002)

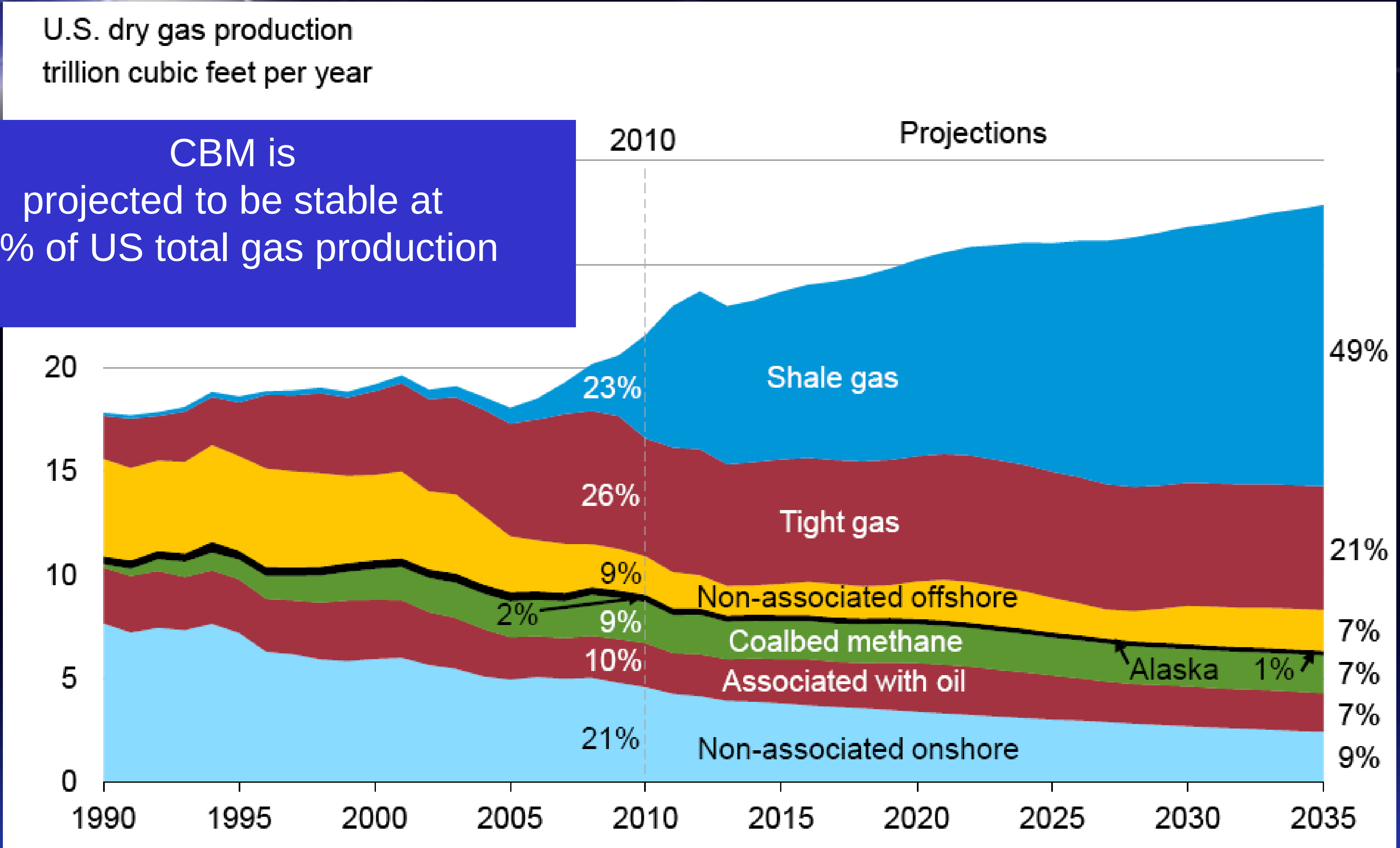
World –Wide Shale And CBM Resource Distribution

Region	Coal Gas (tcf)	Shale Gas (tcf)	Total Gas (tcf)
North America	3,017	3,840	6,857
Latin America	39	2,116	2,155
Western Europe	157	509	666
Central & Eastern Europe	118	39	157
Former Soviet Union	3,957	627	4,584
Middle East & North Africa	0	2,547	2,547
Sub-Saharan Africa	39	274	313
Centrally planned Asia & China	1,215	3,526	4,741
Pacific OECD	470	2,312	2,782
Other Pacific Asia	0	313	313
South Asia	39	0	39
World	**9,051**	**16,103**	**25,154**

From Holditch, 2005 (after Rogner, taken from Kawata et al.)

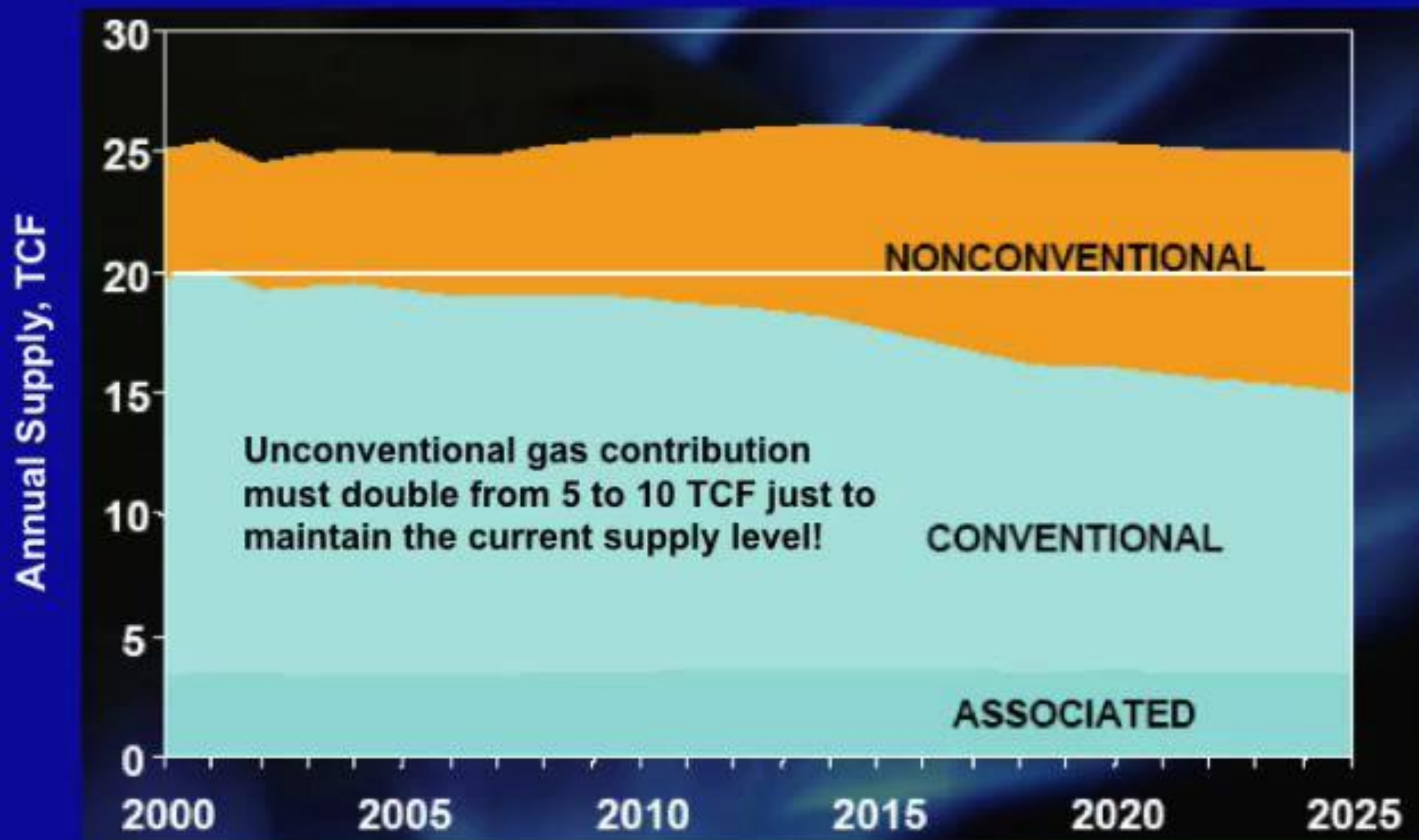
United States Dry Gas Production (EIA, 2012)

CBM is projected to be stable at 7% of US total gas production



Source: *EIA, Annual Energy Outlook 2012 Early Release*

Impact of Unconventional Gas in the U.S.



From National Petroleum Council, 2003

UNCONVENTIONAL GAS PRODUCTION

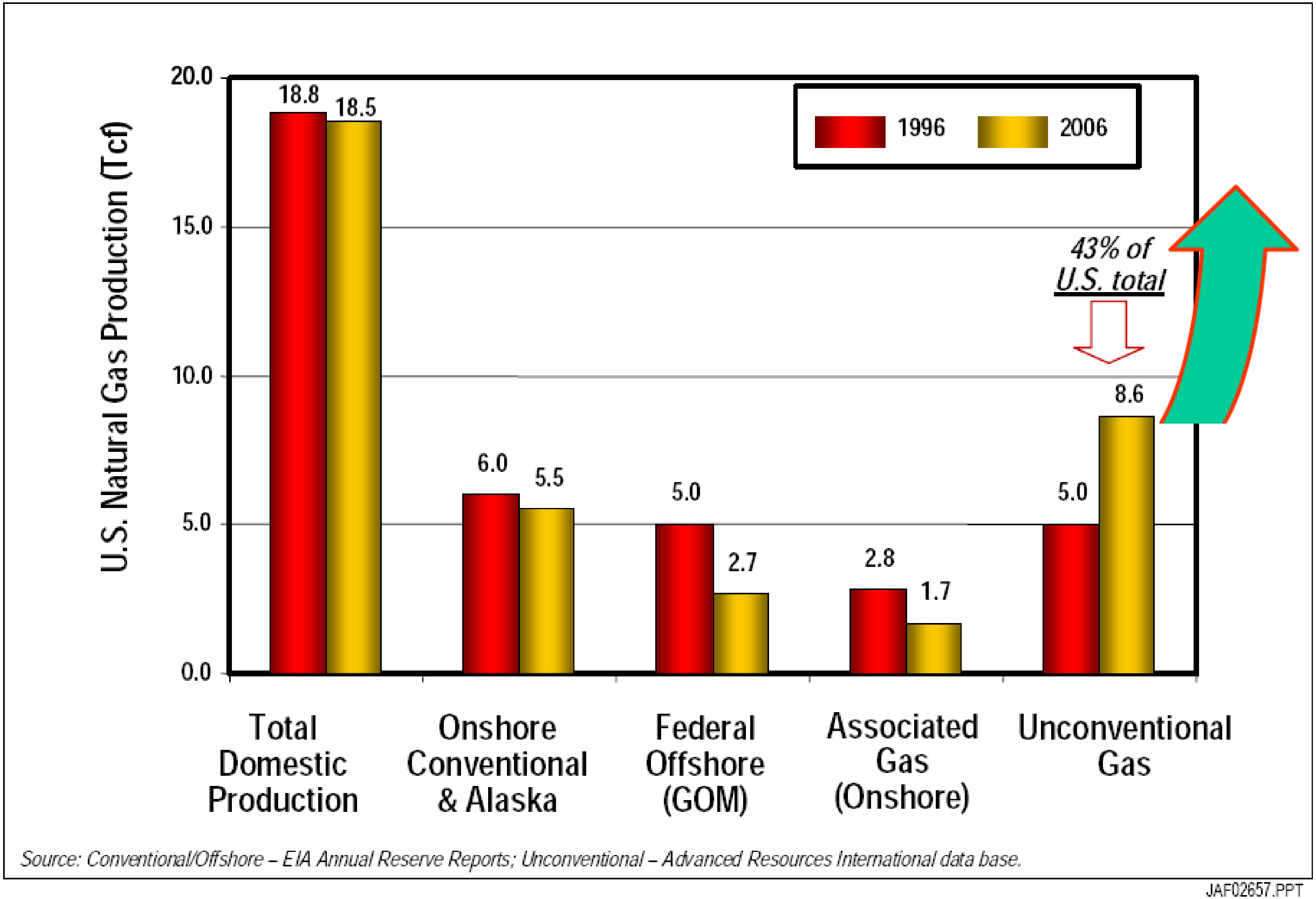
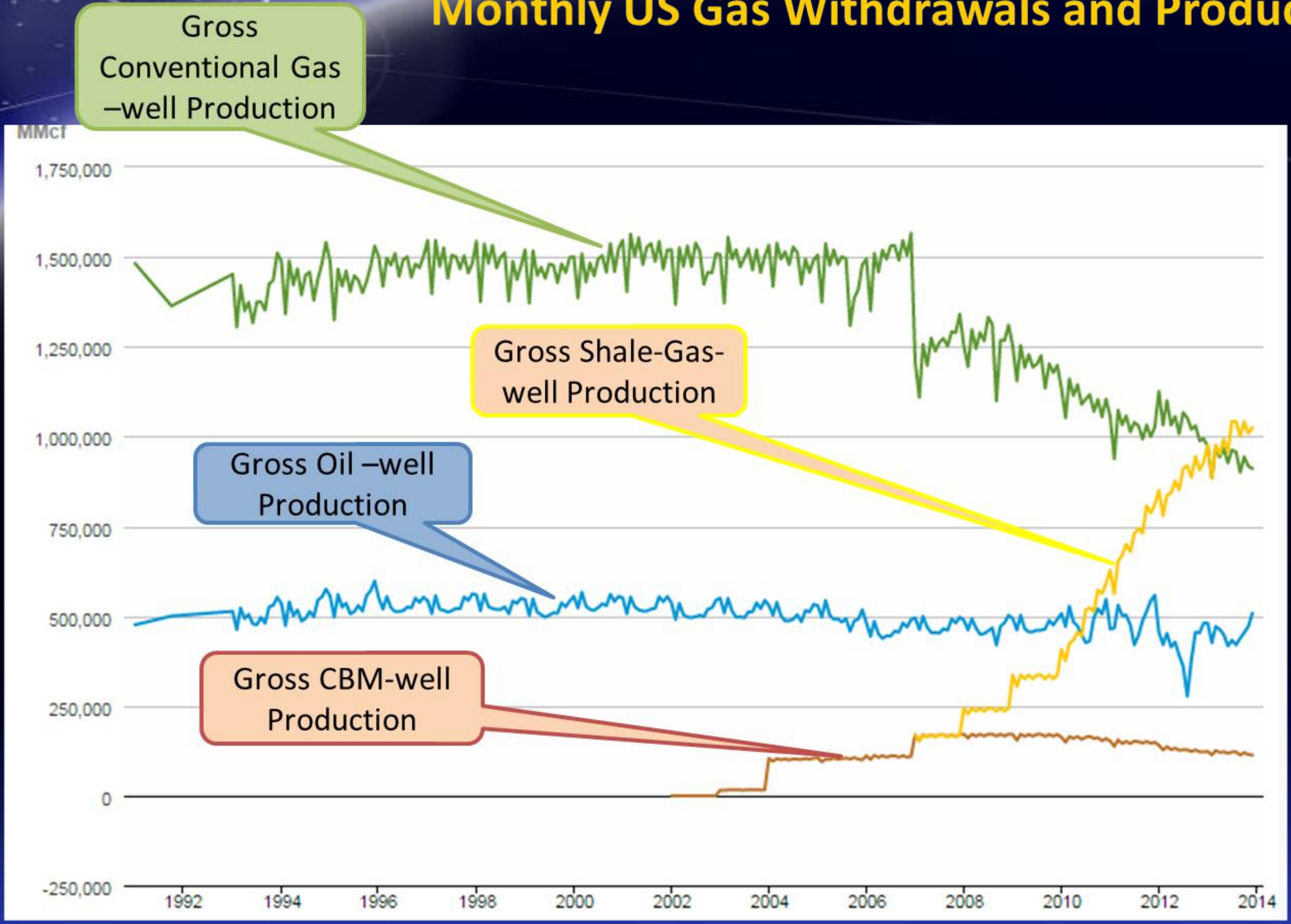


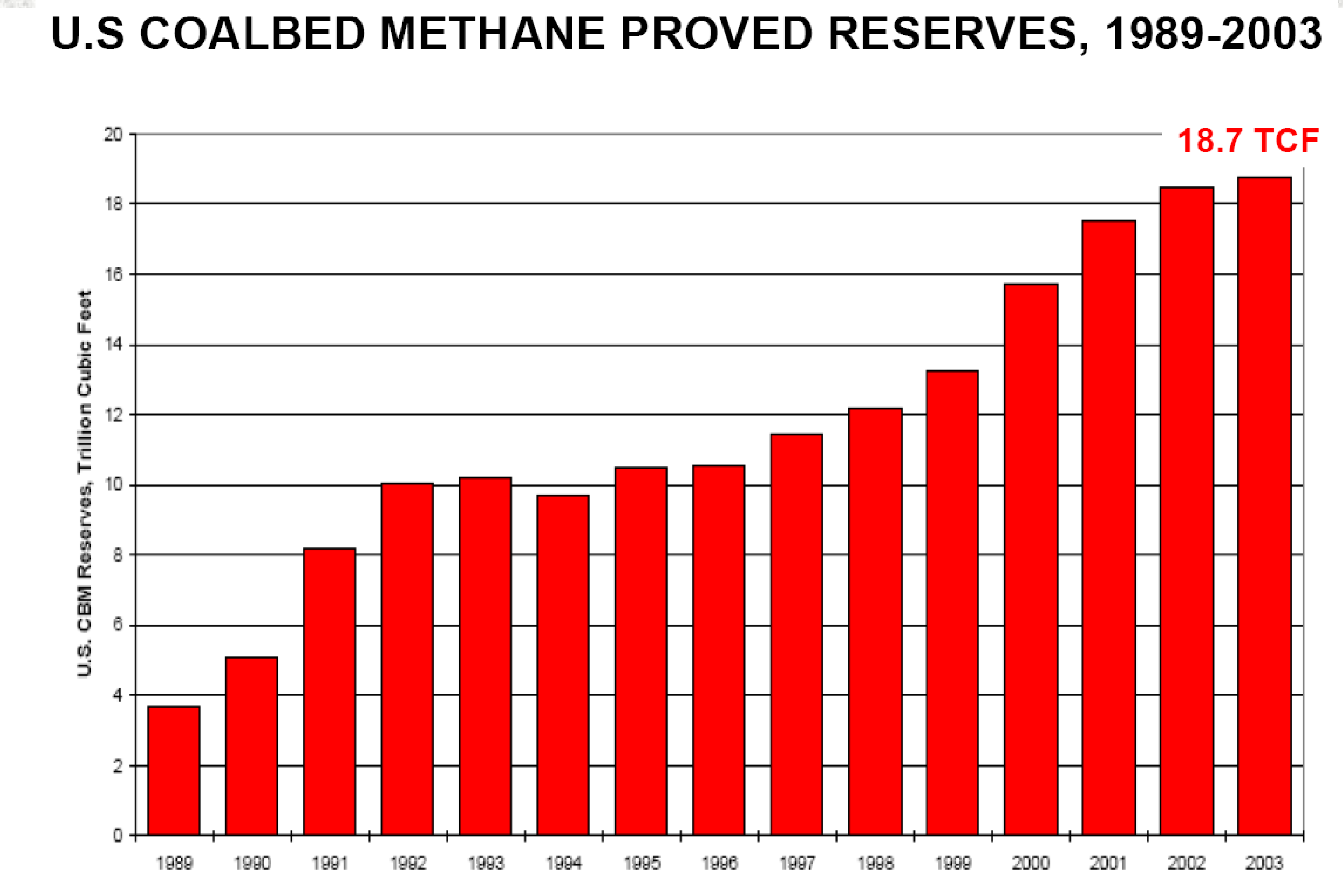
Figure 2. Unconventional Gas Now Accounts For 43% Of U.S. Natural Gas Production

Monthly US Gas Withdrawals and Production



Source: US Energy Information Administration, 2015

CBM ANNUAL GROWTH IN RESERVES



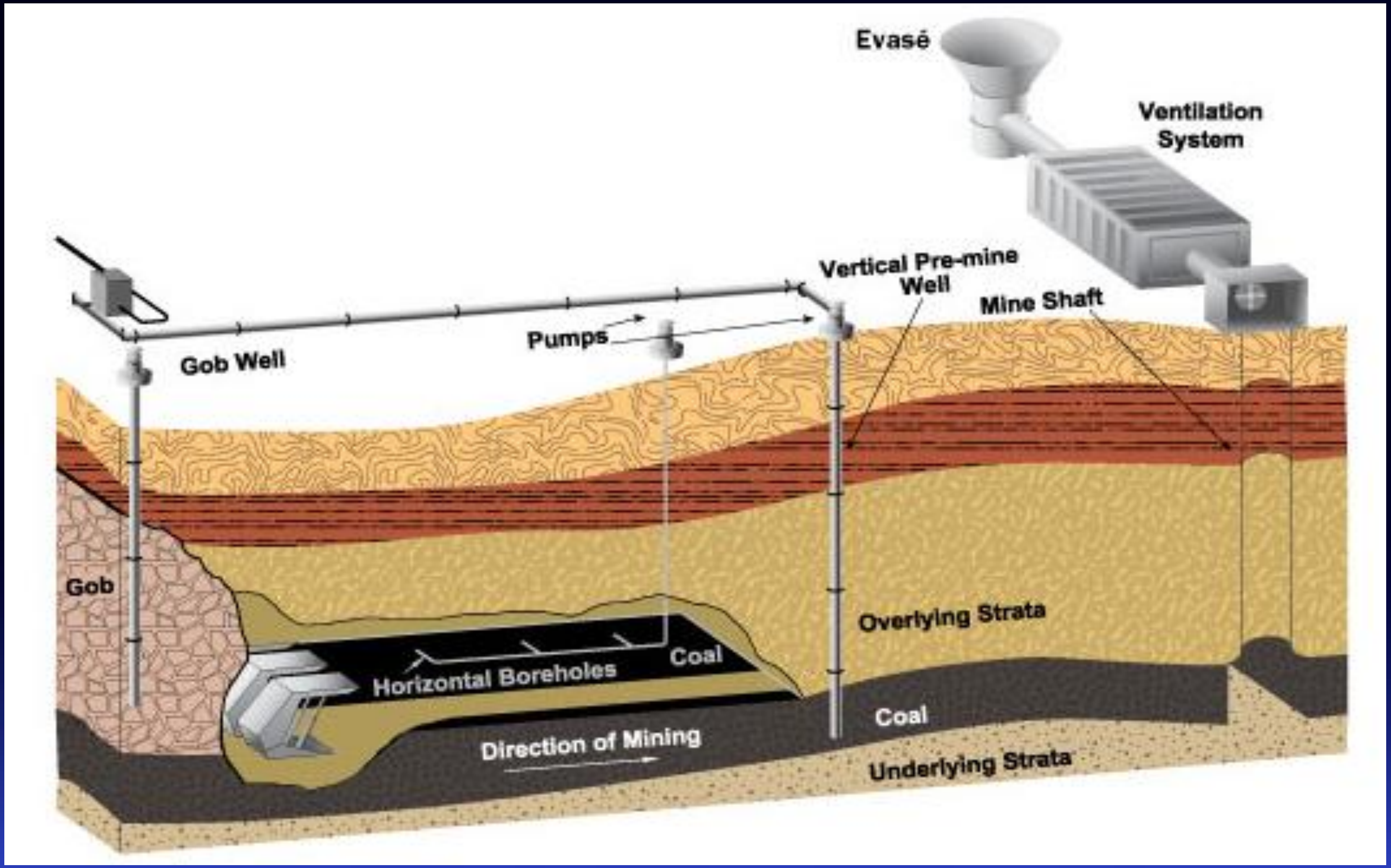
Source: U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 1989 through 2003 annual reports, DOE/EIA-0216.

Coal Mine Methane (CMM)

- Methane is formed during coalification
- Methane released during and associated with coal mining is Coal Mine Methane (CMM)
  - Coal Mine Methane
    - Is a greenhouse gas
    - Is explosive and must be removed for mine safety
    - Is a clean energy resource with many potential uses
- Methane can be removed from mines using vertical gob wells, or pre-mining by short horizontal drain and vertical wells

Coal Mine Methane (CMM) Recovery

- Pre-mine vertical wells
- Pre-mine short and long reach wells
- Gob wells in existing mines

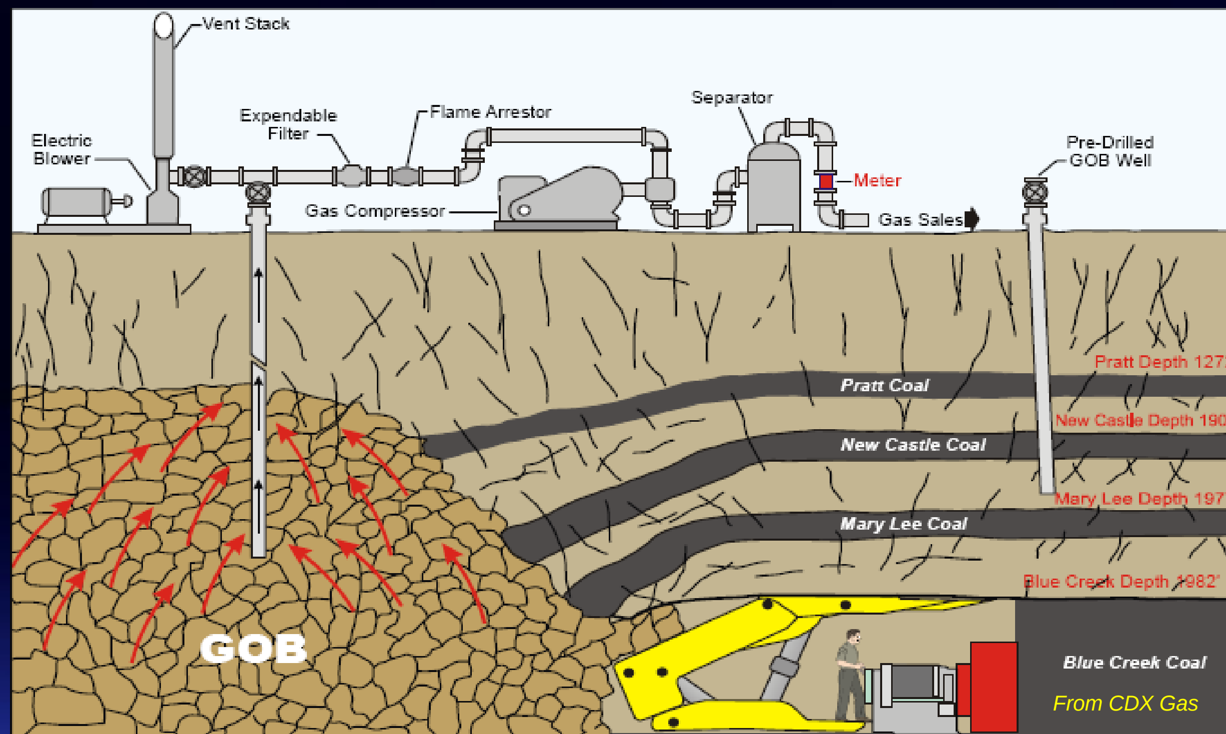


From EPA 2009

Coal Mine Methane (CMM)

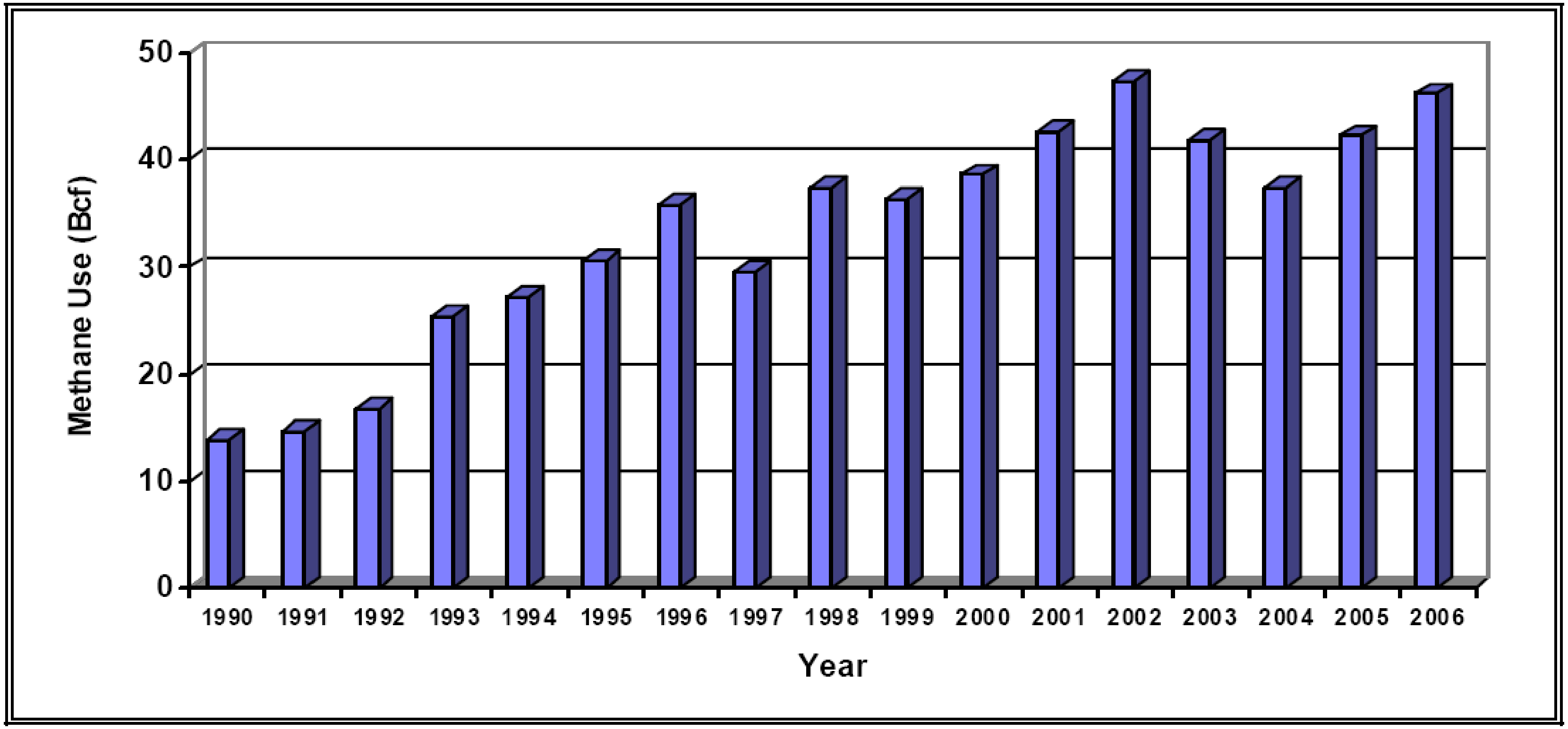
Global Usage

- 14 countries have CMM drainage projects in active mines
- 200 CMM projects world wide
- Of these, more than 100 are for power-generation projects
- Most capacity in China, Europe and Australia
- Estimated annual use from US coal mines is 40-50Bcf



Coal Mine Methane (CMM)

Figure 2-2: Estimated Annual Use of Methane Recovered From U.S. Coal Mines (based on publicly available information)



(FROM USEPA_GMI)

COAL MINE METHANE VS. COALBED METHANE - - DEPTH

Why Should Colombia Recover Methane (CMM/CBM)?

- There are a variety of profitable uses from CMM/CBM including: natural gas pipeline injection, co-firing of boilers, district heating, coal drying, use as a vehicle fuel and manufacturing/industrial uses such as feedstock, etc.

- For Colombia, the gas obtained from coalbed resource development could be used for:

  Local source of gas,
  Regional and local power generation, and
  Shortages of gas especially in remote areas.

FACTORS AFFECTING UNCONVENTIONAL TIGHT GAS, SHALE, COAL MINE METHANE, AND COALBED METHANE EVALUATIONS

- Geologic Factors
  - Thickness
  - Maturity
  - Gas content
  - Areal extent
  - Depth
  - Structural complexity
  - Lateral continuity
- Engineering Factors
  - Permeability
  - Pressure regimes
  - Gas and water rates
  - Gas composition
  - Gas saturation state
  - Regional hydrology
  - Available technologies and expertise
- Economic Factors
  - Gas price
  - Access to gas markets
  - Lease costs
  - Capital costs
  - Operating costs
  - Environmental costs
    - water disposal
  - Infrastructure costs
    - pipelines
  - Tax incentives
  - Land use constraints

Many projects are marginally economic—hence the need to appraise and develop them effectively!

(JENKINS et.al, PTTC WORKSHOP , 2008)

ARC GROUP ANALOG
COALBED METHANE RESOURCE EVALUATIONS

- **PRIMARY: SAN JUAN BASIN**

Most Prolific Producing CBM Basin In The World (GRI)

- **UNITED STATES COALBED METHANE BASINS:**

Eight Western United States Coal Basins Contain Approximately 82% of the Nations Total 690 TCF Resources (GRI)

- **ROCKY MOUNTAIN FORLAND COALBED METHANE BASINS:**

Four Intermontane Basins Within The Rocky Mountain Foreland Contain 522TCF Resources (Including San Juan , Powder River, Greater Green river , Piceance, And Raton) (GRI)

- **SOUTHERN AMERICA:**

WESTERN VENEZUELA (PDVSA) AND COLOMBIA (ECOPETROL, PETROBRAS, AND THE ARC GROUP)

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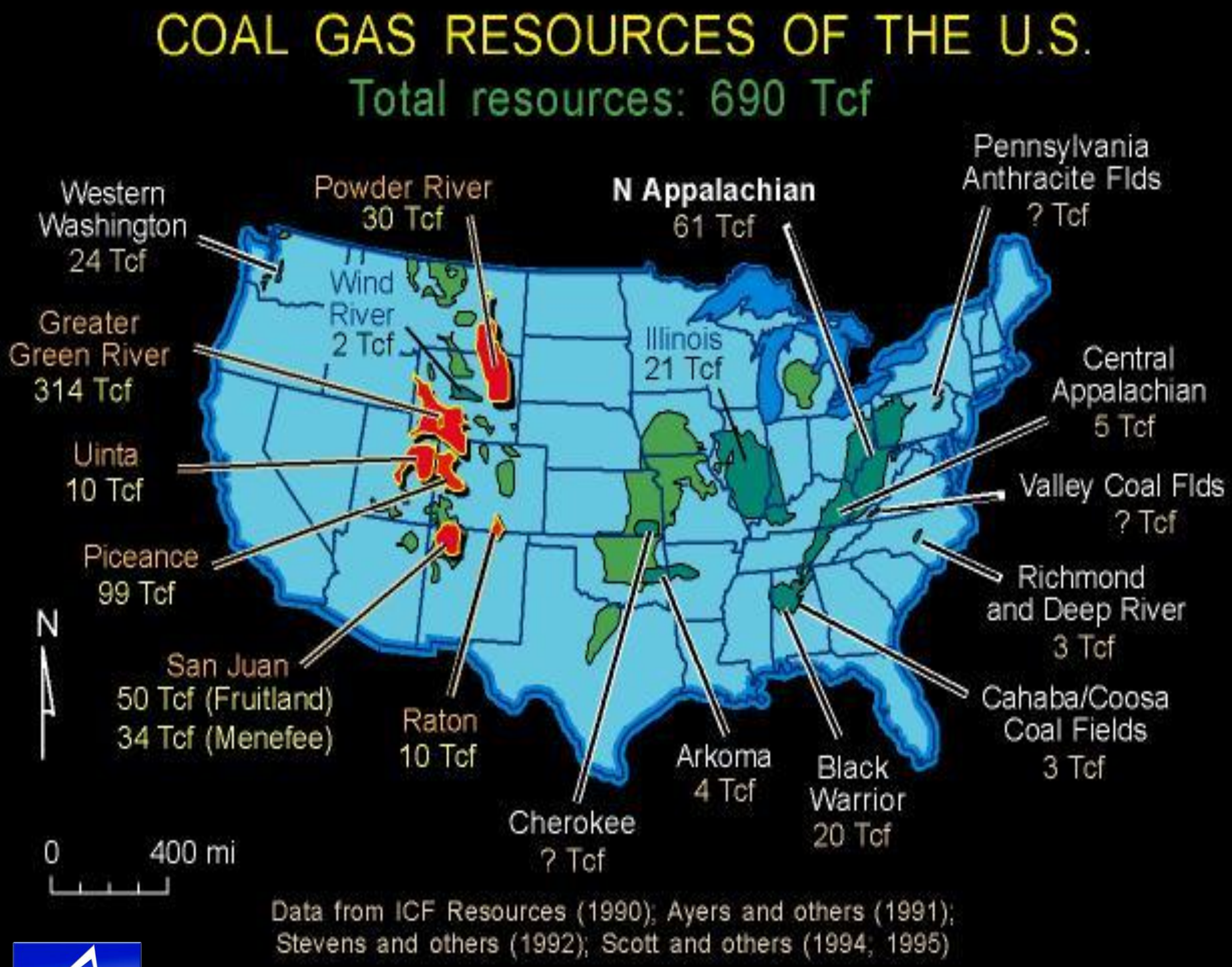
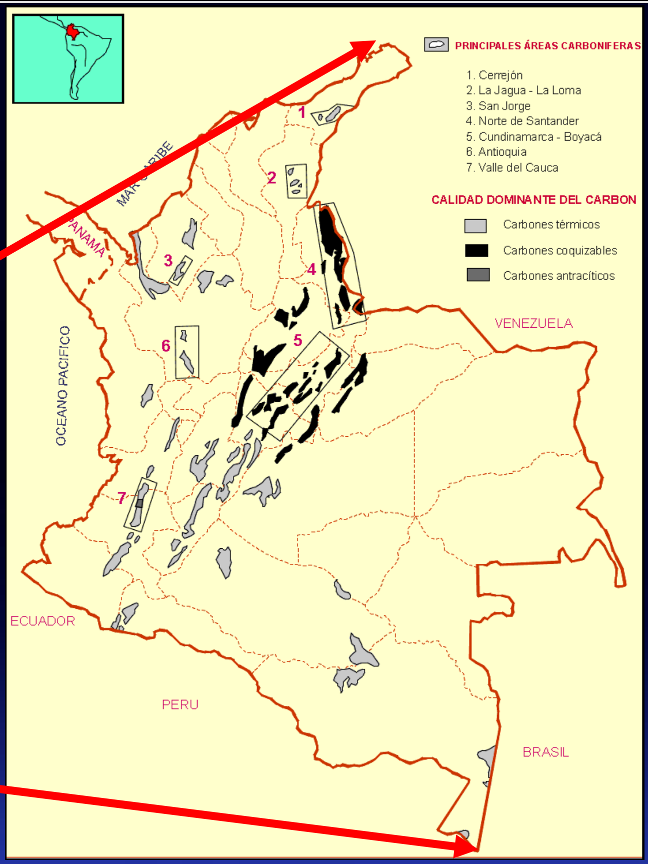
ANALOGOUS BASINS



Distribution of Coal and Tight Gas Sand Basins



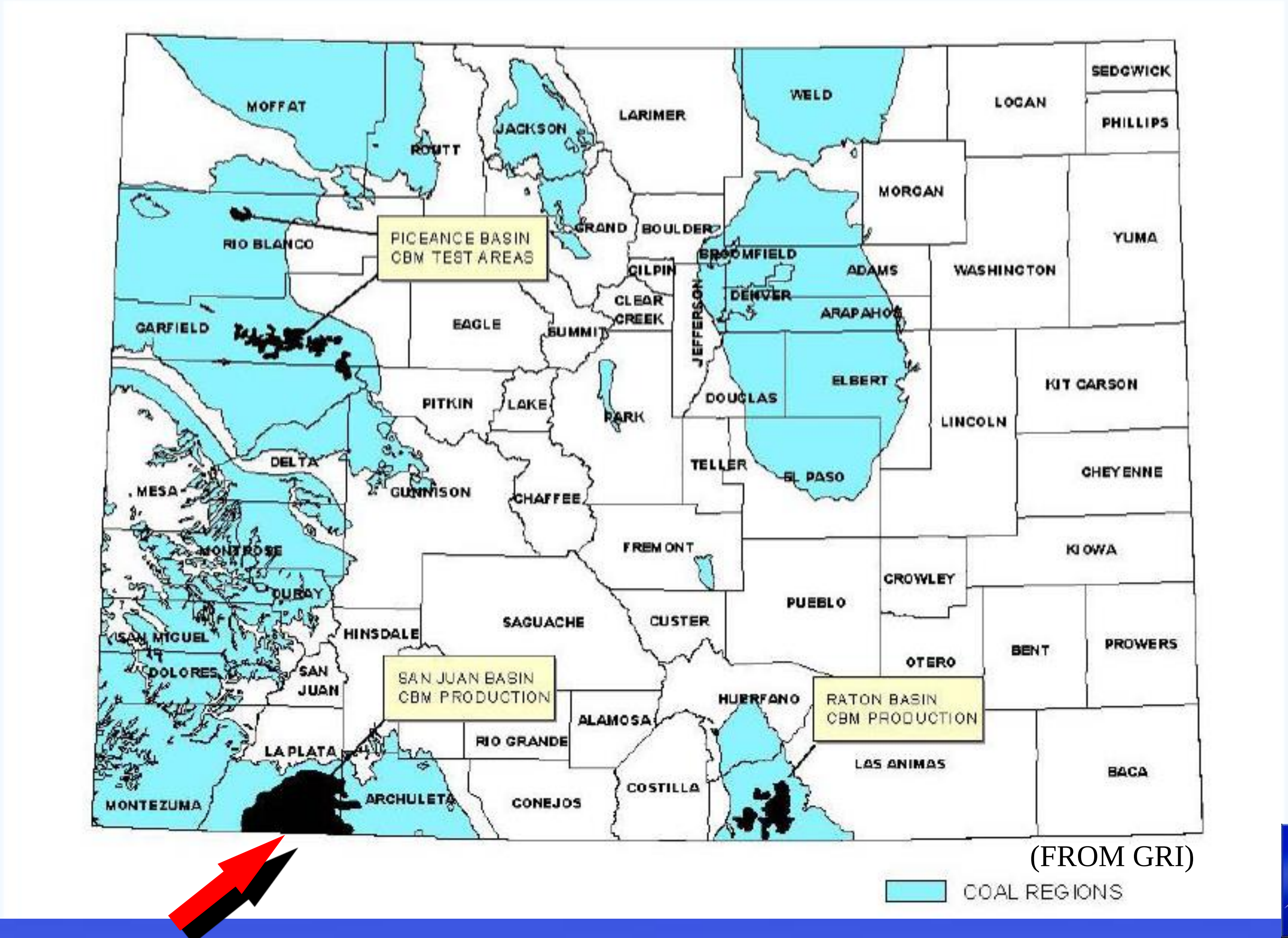
Ingeominas, 2004

3,855 COALBED METHANE (CBM) WELLS IN COLORADO

1,700 CBM WELLS IN LA PLATA COUNTY

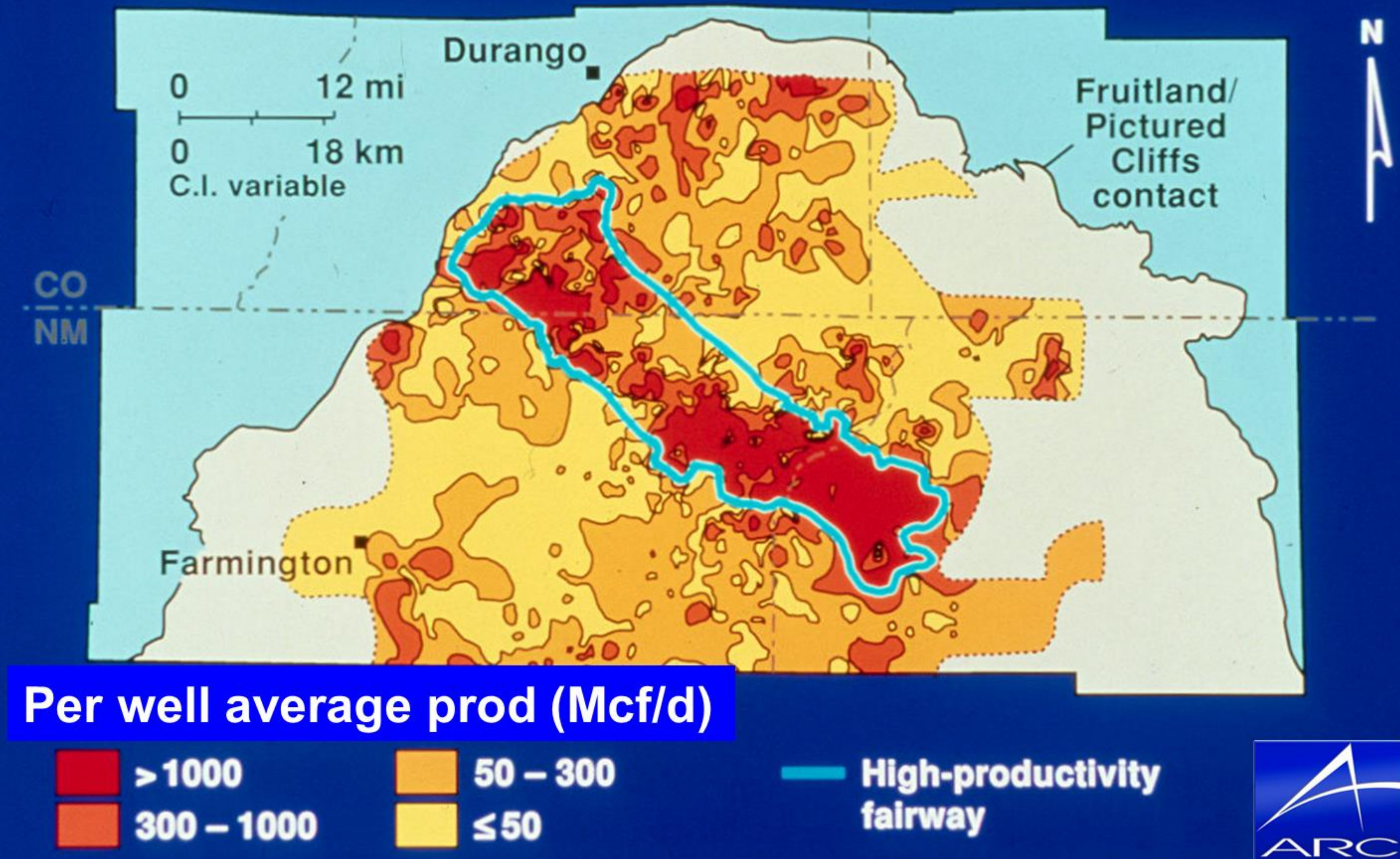
1,900 CBM WELLS IN LAS ANIMAS COUNTY

255 CBM WELLS IN PICEANCE BASIN



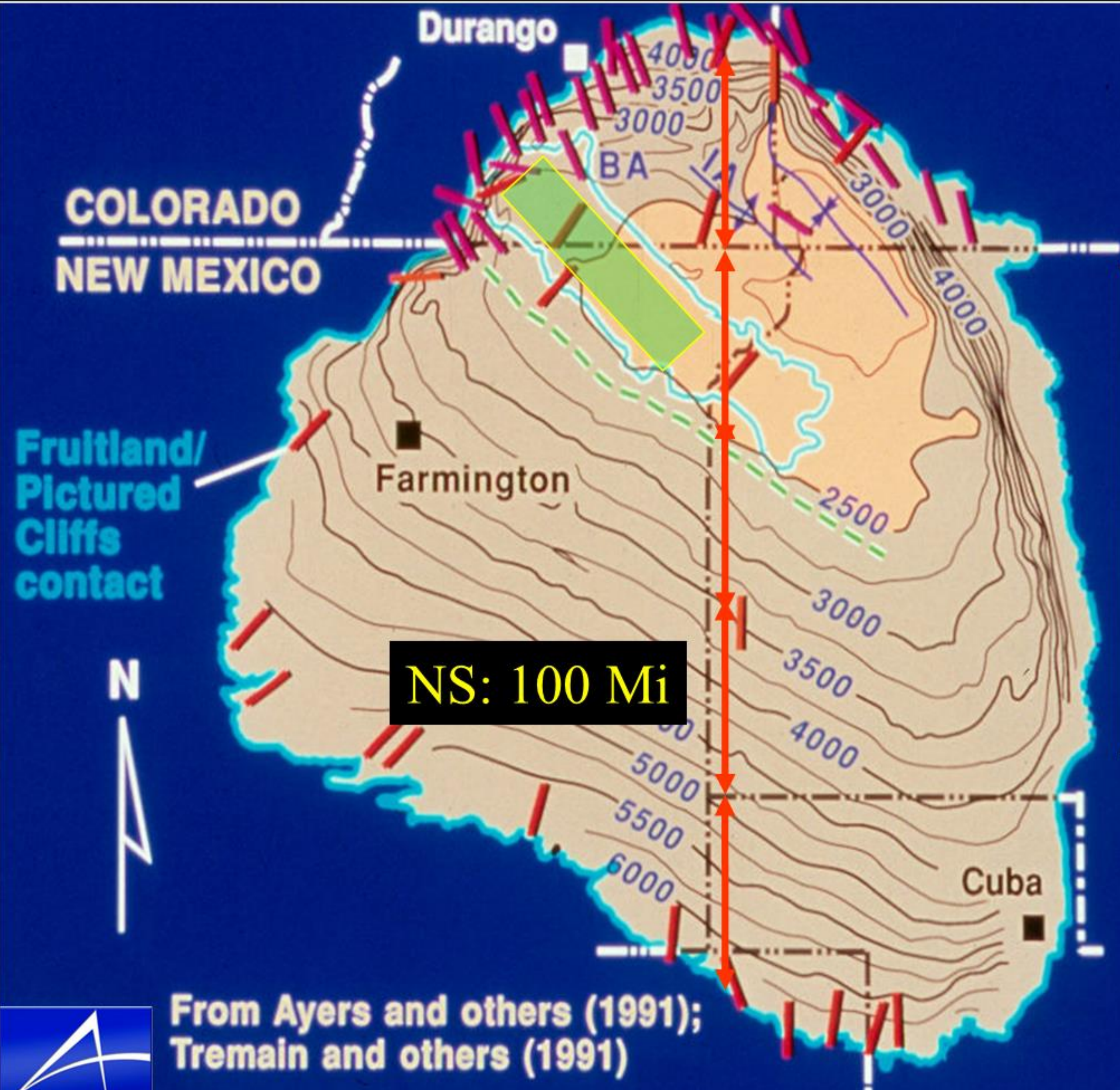
(FROM GRI)

FAIRWAY HETEROGENEITY



Individual wells in the high productivity fairway produce more than a Bcf of methane! Cum prod of fairway > 1 Tcf.

SAN JUAN BASIN STRUCTURE



San Juan Basin

80 miles wide (W/E) by
100 miles long (N/S)=
Total Area: 8,000 Square Miles
(Approximated)

San Juan Basin
Exploration Fairway

26 mi long by 10 mi wide
Total Area: 260 square miles
(Approximated)

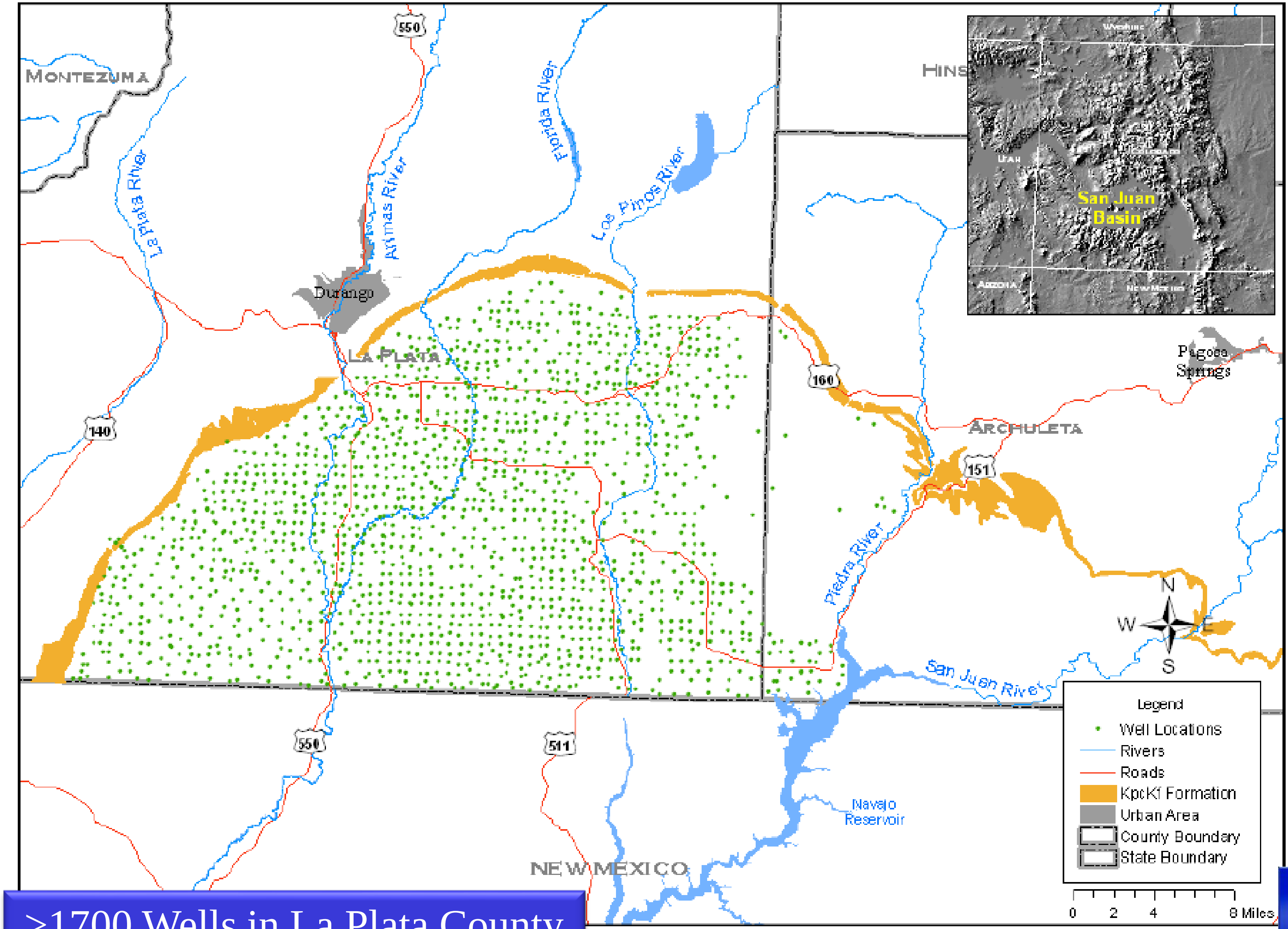
Structure on Huerfanito Bentonite

0 20 mi

0 30 km

C.I. 250 ft

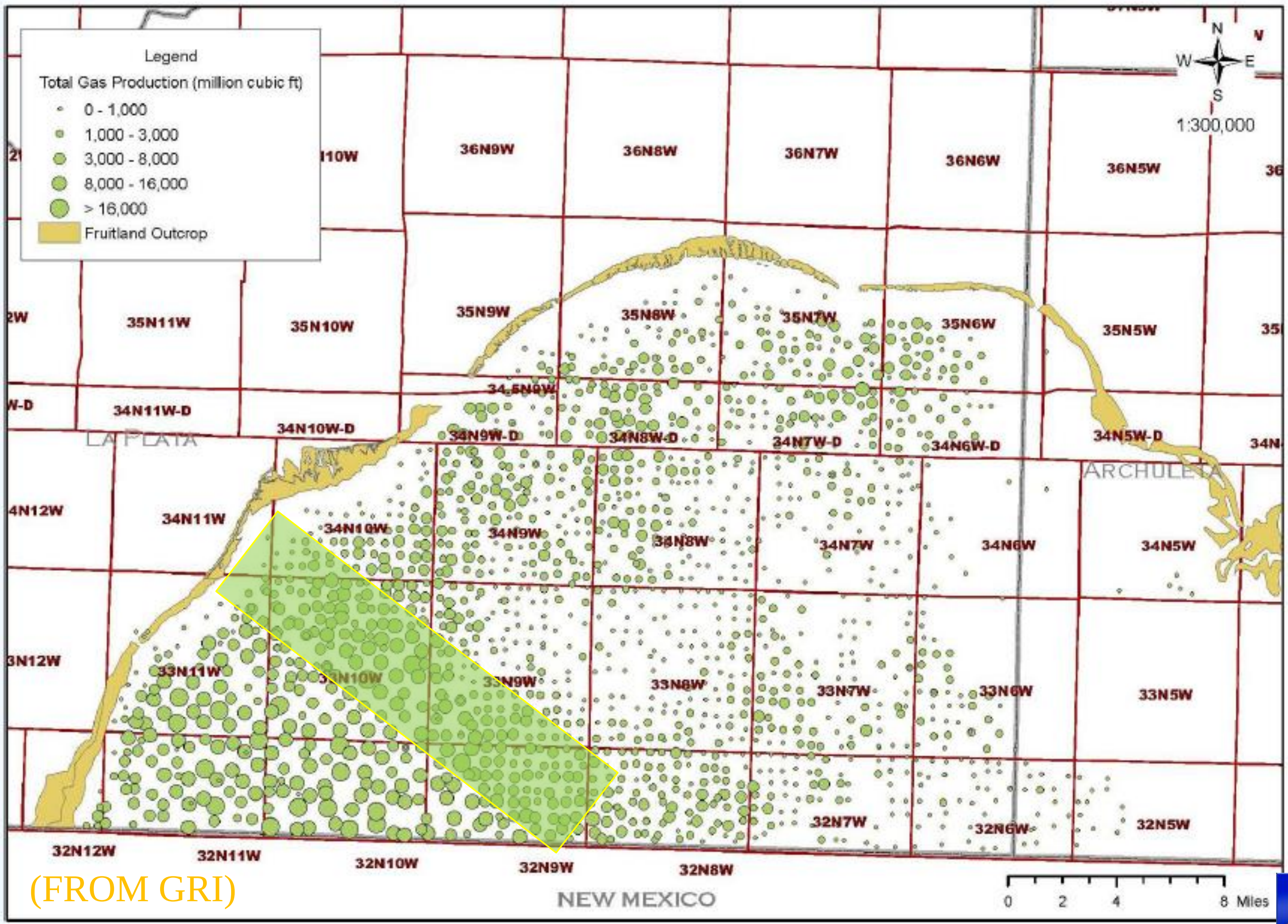
Wells in San Juan Basin, Colorado



>1700 Wells in La Plata County

(FROM GRI)

Cumulative Coalbed Methane Production (million cubic feet)

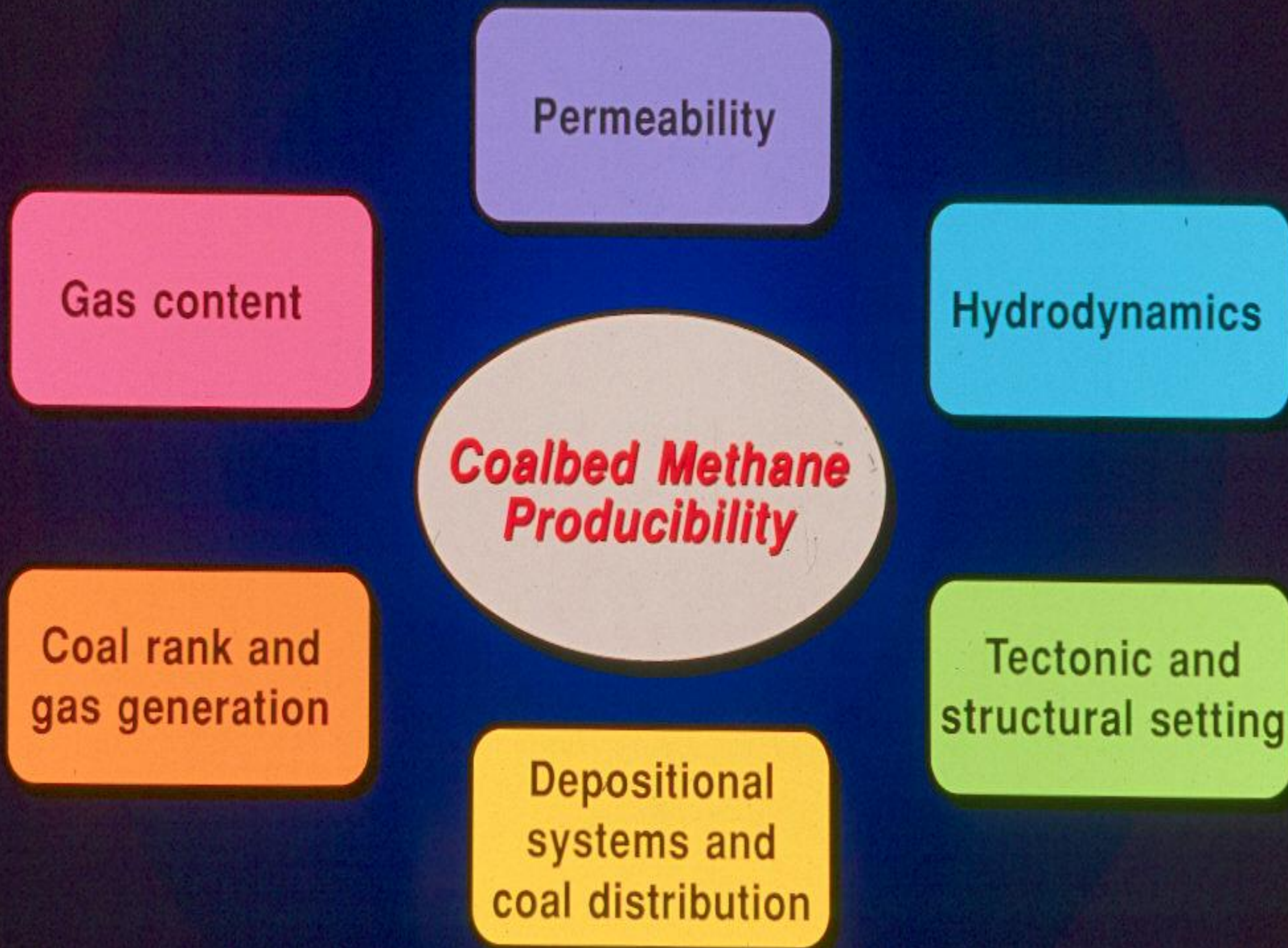



An Unconventional Resource?

KEY QUESTIONS IN GEOLOGIC AND HYDROLOGIC CHARACTERIZATION OF COALBED METHANE

- What are the depositional controls on coal distribution?
- What is the basinal hydrologic regime and how may it be enhancing or inhibiting accumulation and production of coalbed methane?
- Where are the thermally mature areas capable of generating coalbed methane?
- How does structural dip, cleat orientation, and faulting affect accumulation and production of coalbed methane?
- How do all factors of the coal's physical setting combine to influence overall coalbed methane producibility?

HYDROGEOLOGIC CONTROLS CRITICAL TO COALBED METHANE PRODUCIBILITY



UNITED STATES COALBED METHANE EXPERIENCE

- What has not been widely recognized is that while coalbed methane resources in some basins have been successfully exploited, other basins with seemingly similar attributes have proven to be disappointing coalbed methane producers.

- Understanding the reasons for these contrasts in producibility is vital to worldwide coalbed methane exploration and development.

➢ **Basin comparative evaluations provide a rationale for exploration and development strategies**

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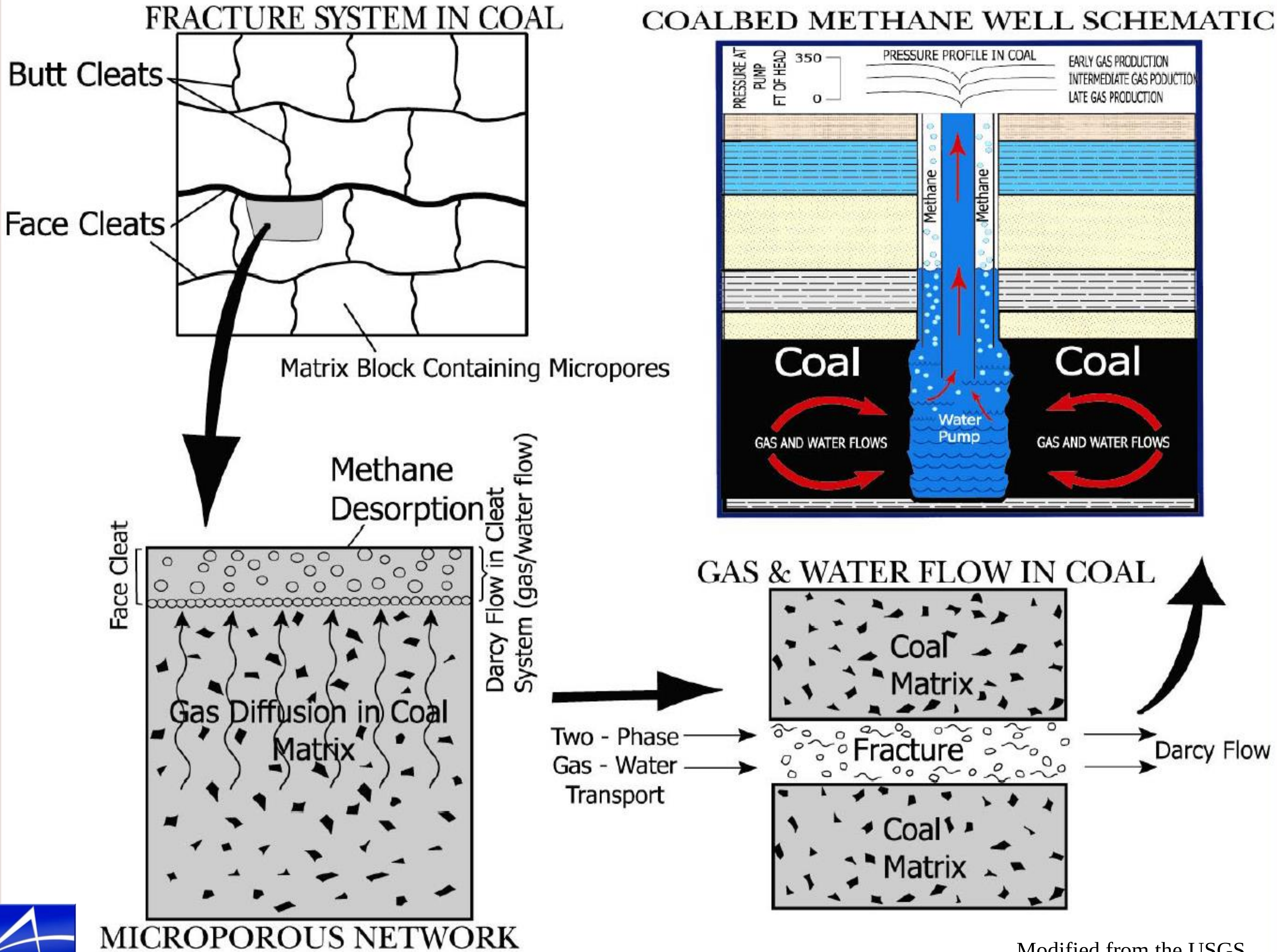
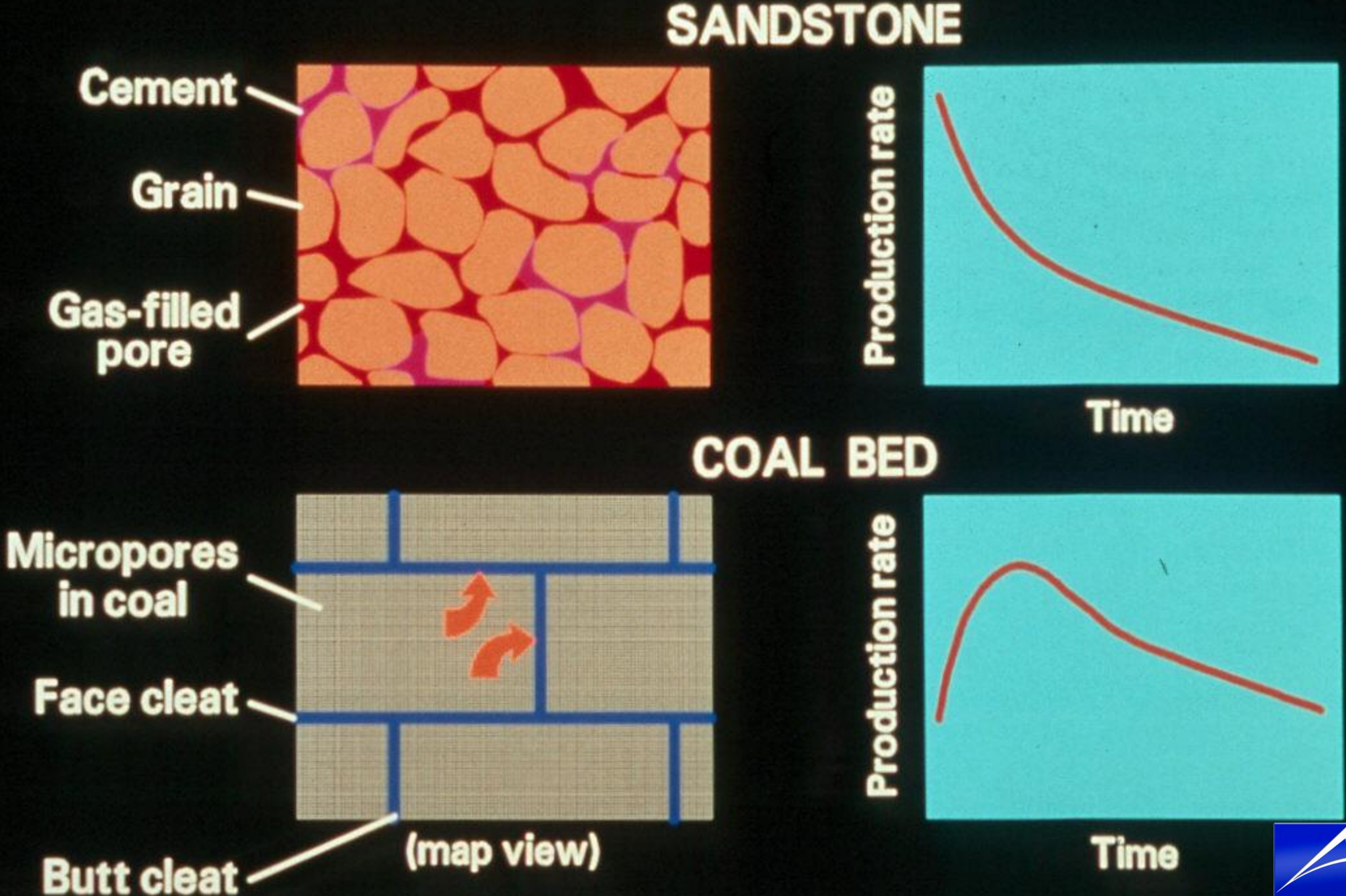
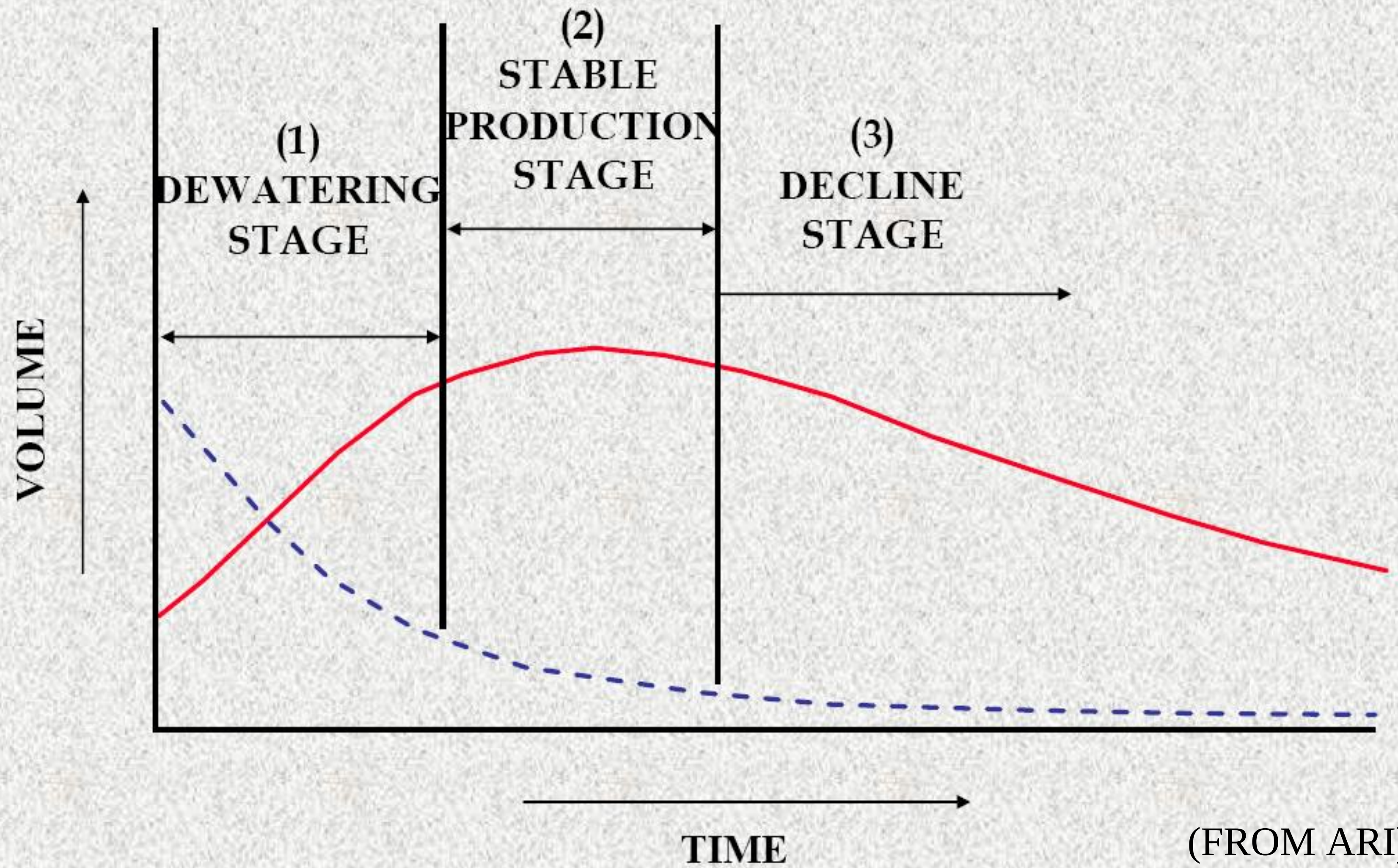


Modified from the USGS

RESERVOIR CHARACTERISTICS

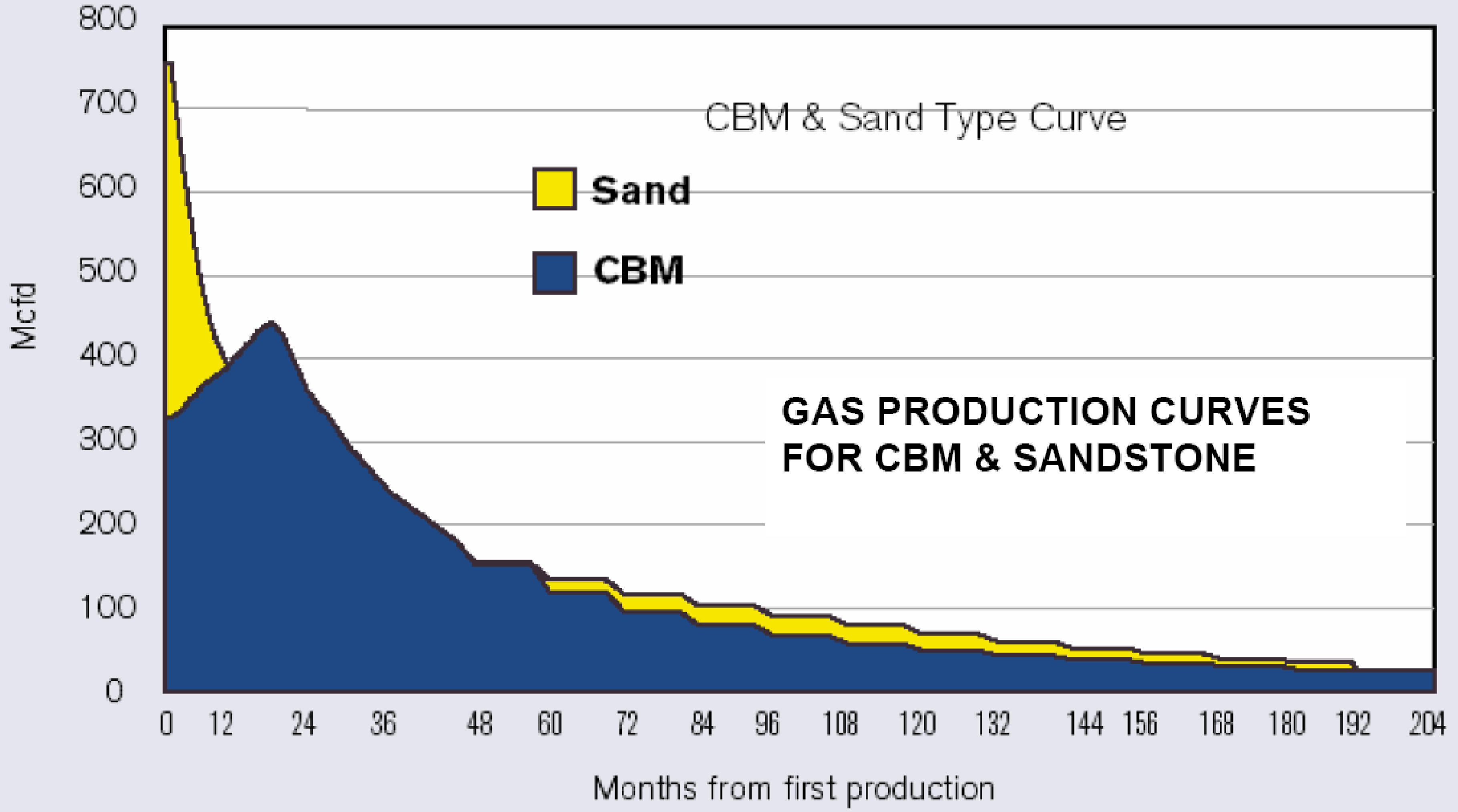


TYPICAL PRODUCTION STAGES OF A COALBED METHANE WELL



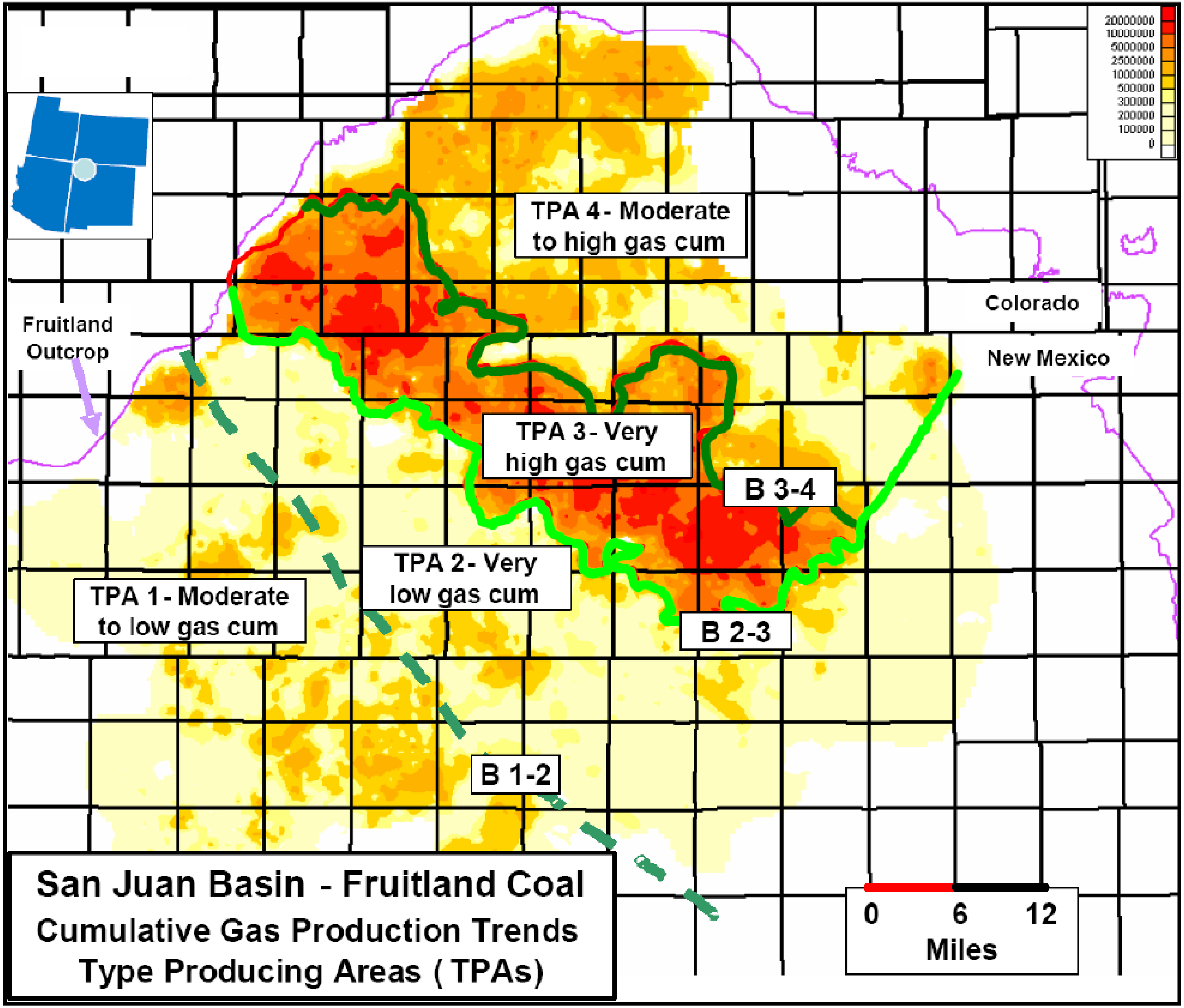
(FROM ARI)

Exh. # 9 **COMPARISON OF GAS PRODUCTION CURVES**



New technologies improve the time to first production of coalbed methane after the sands in a CBM well begin to play out.

Schwochow, Oil & Gas Investor Supplement Coalbed Methane, Dec. 2003, page CBM-11



gure 1. San Juan Basin - Fruitland Coal: Cumulative gas production trends--Type producing areas (TPA

(LEVINE, et. al, APPG, 2013)

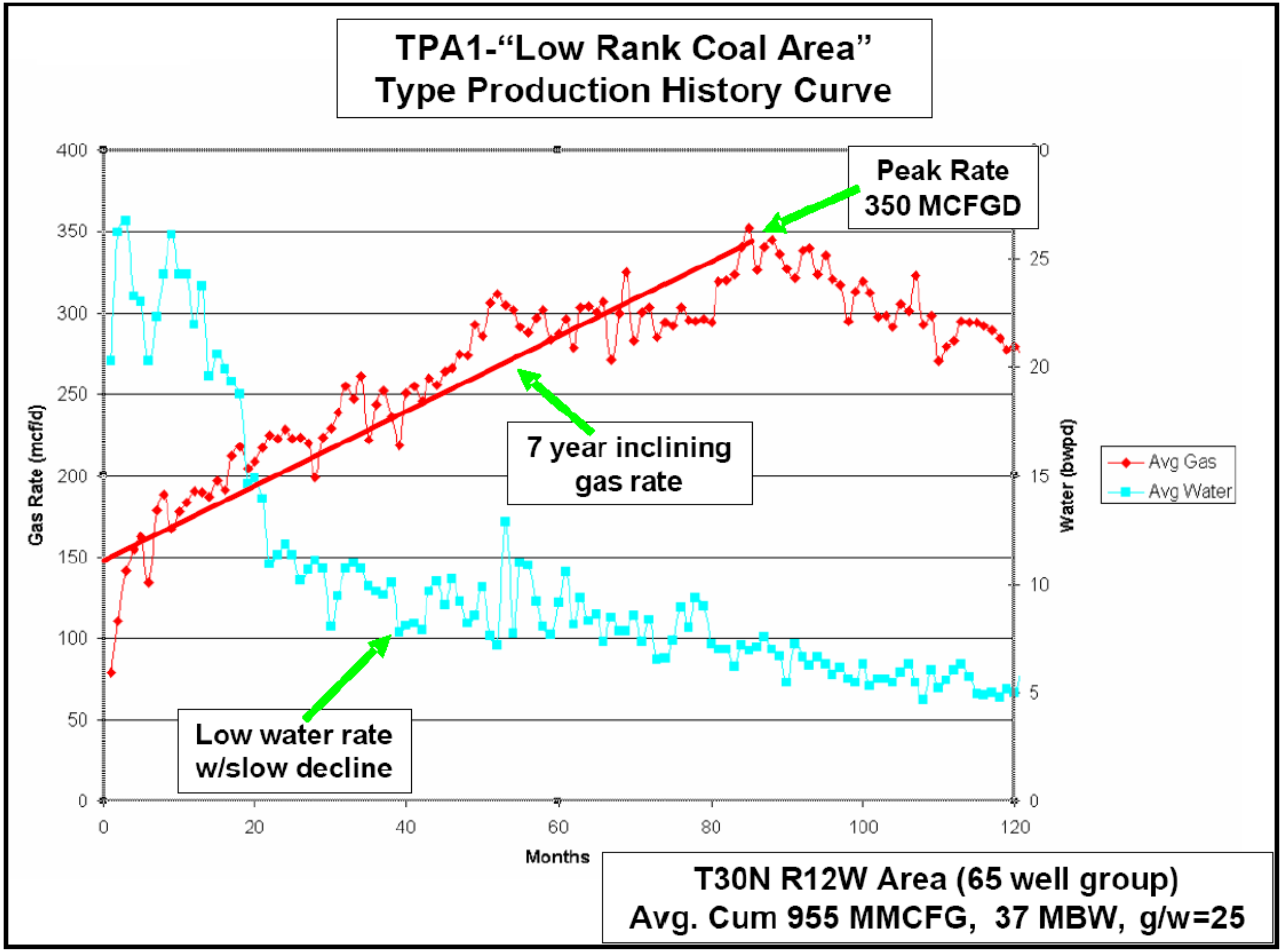


Figure 3. TPA1-"Low Rank Coal Area": Type production history curve.

(LEVINE, et. al, APPG, 2013)

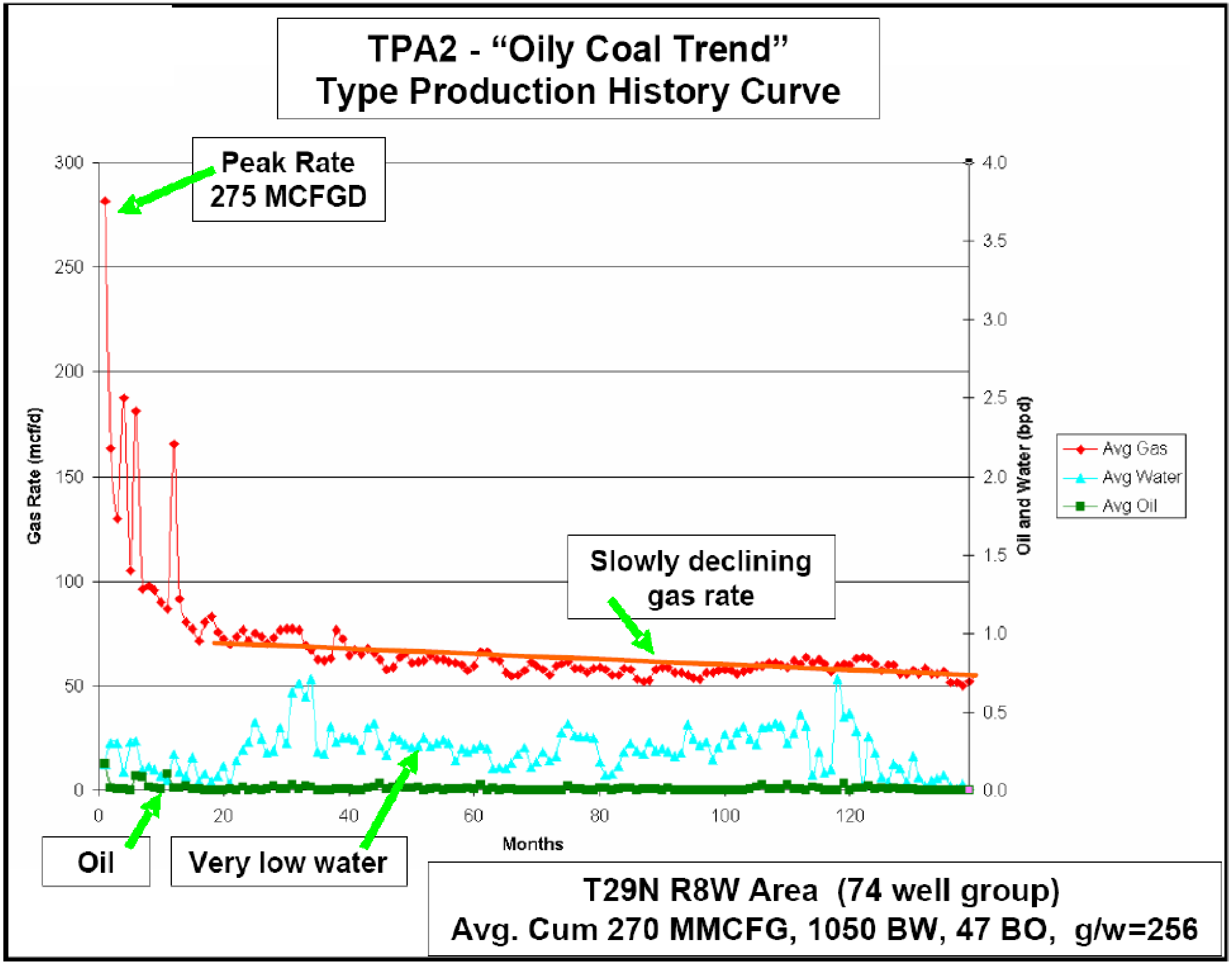


Figure 4. TPA2 - "Oily Coal Trend": Type production history curve.

(LEVINE, et. al, APPG, 2013)

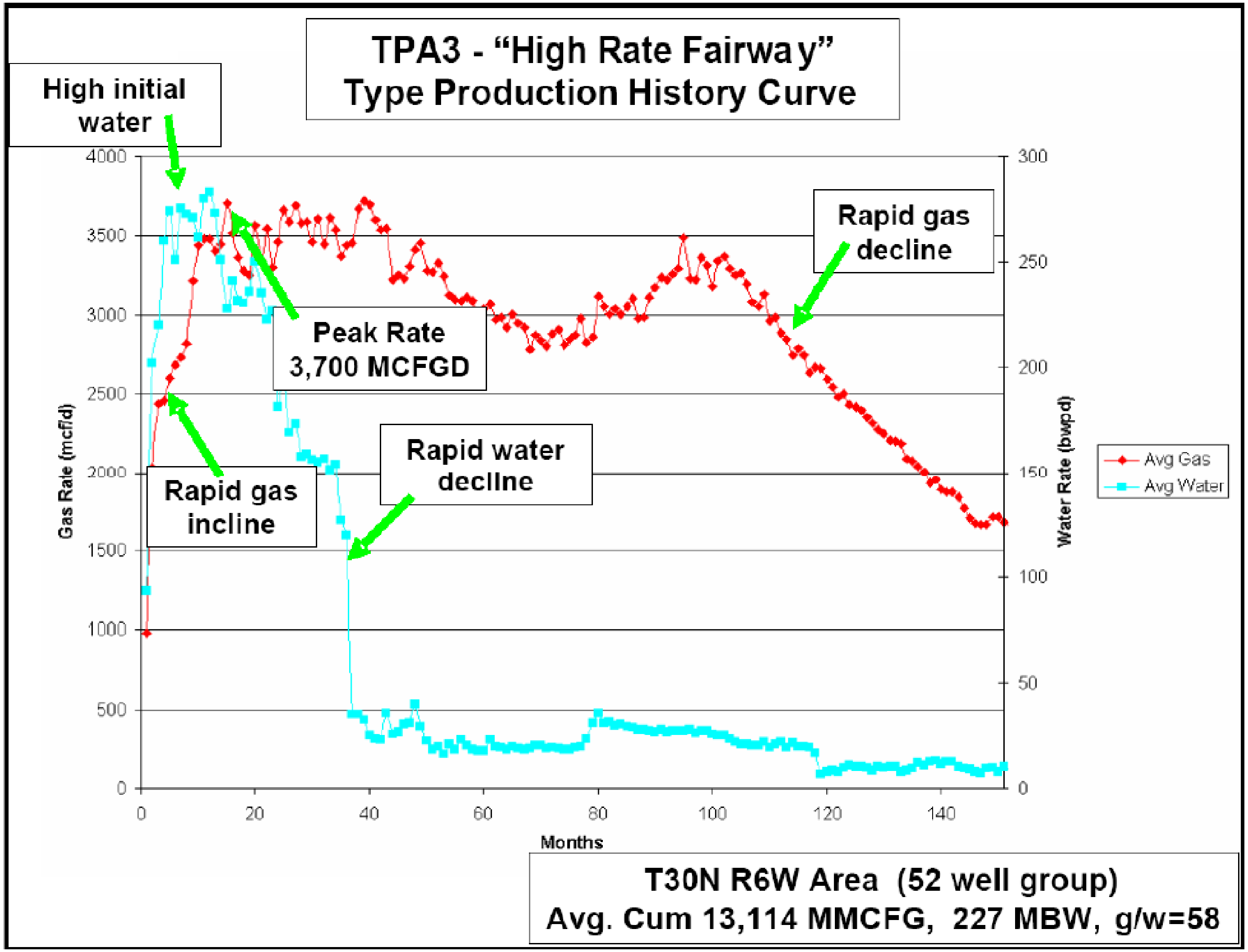


Figure 5. TPA3 - “High Rate Fairway”: Type production history curve.

(LEVINE, et. al, APPG, 2013)

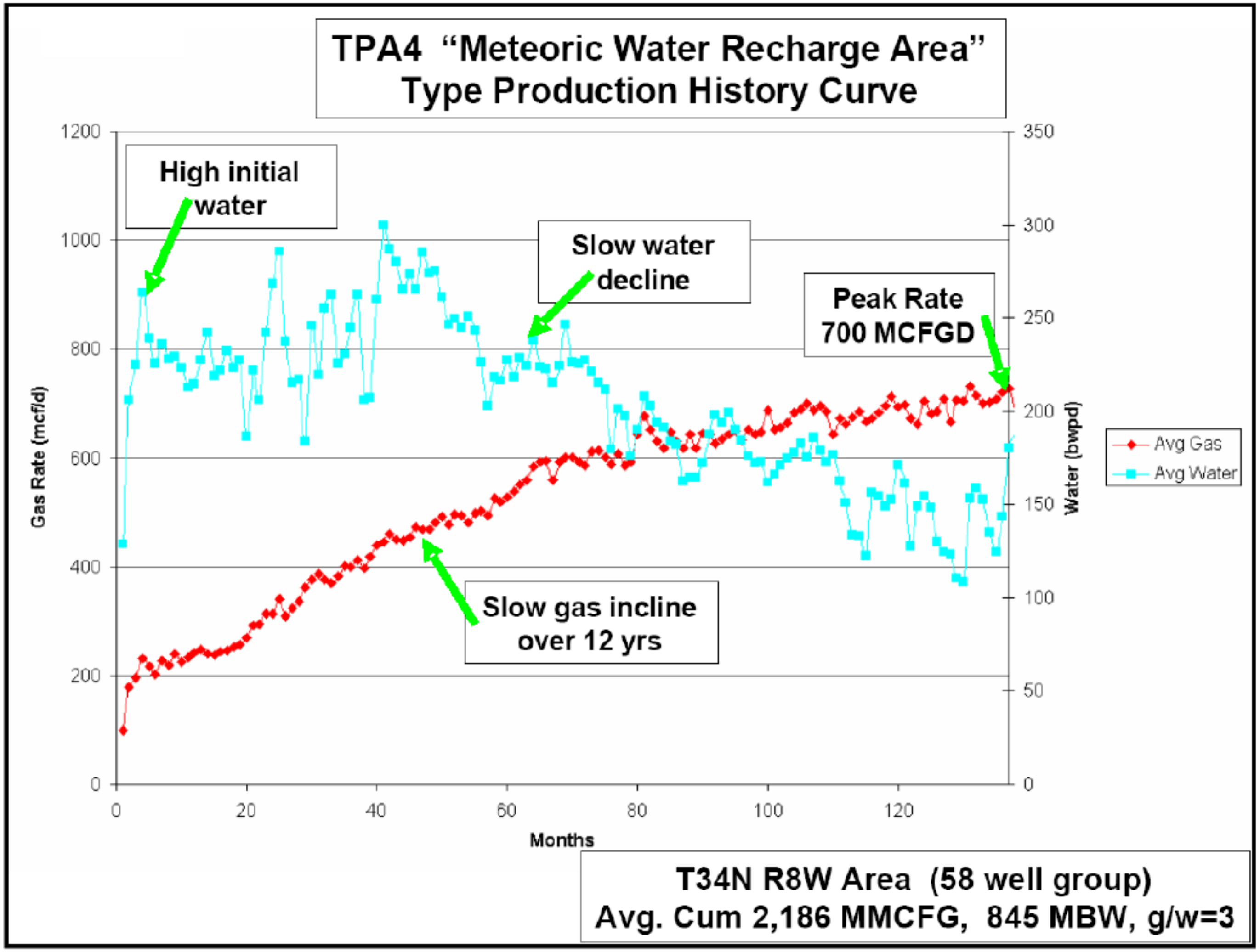


Figure 6. TPA4 "Meteoric Water Recharge Area": Type production history curve.

(LEVINE, et. al, APPG, 2013)

TRADITIONAL VIEW

- Coal gases are generated in situ during coalification and sorbed on the coal's large internal surface area. Sorption is pressure dependent and is promoted by increasing pressure.
- Gas production is achieved by reducing reservoir pressure through depressuring (dewatering) and thereby liberating the gases from the coal surface for diffusion to the cleat system for subsequent flow to the wellbore.
- The traditional view is oversimplified because it fails to recognize the need for additional sources of gas beyond that generated initially during coalification to achieve high gas content following basinal uplift and cooling.

HYDROGEOLOGIC CONTROLS CRITICAL TO COALBED METHANE PRODUCIBILITY

Permeability

Gas content

Hydrodynamics

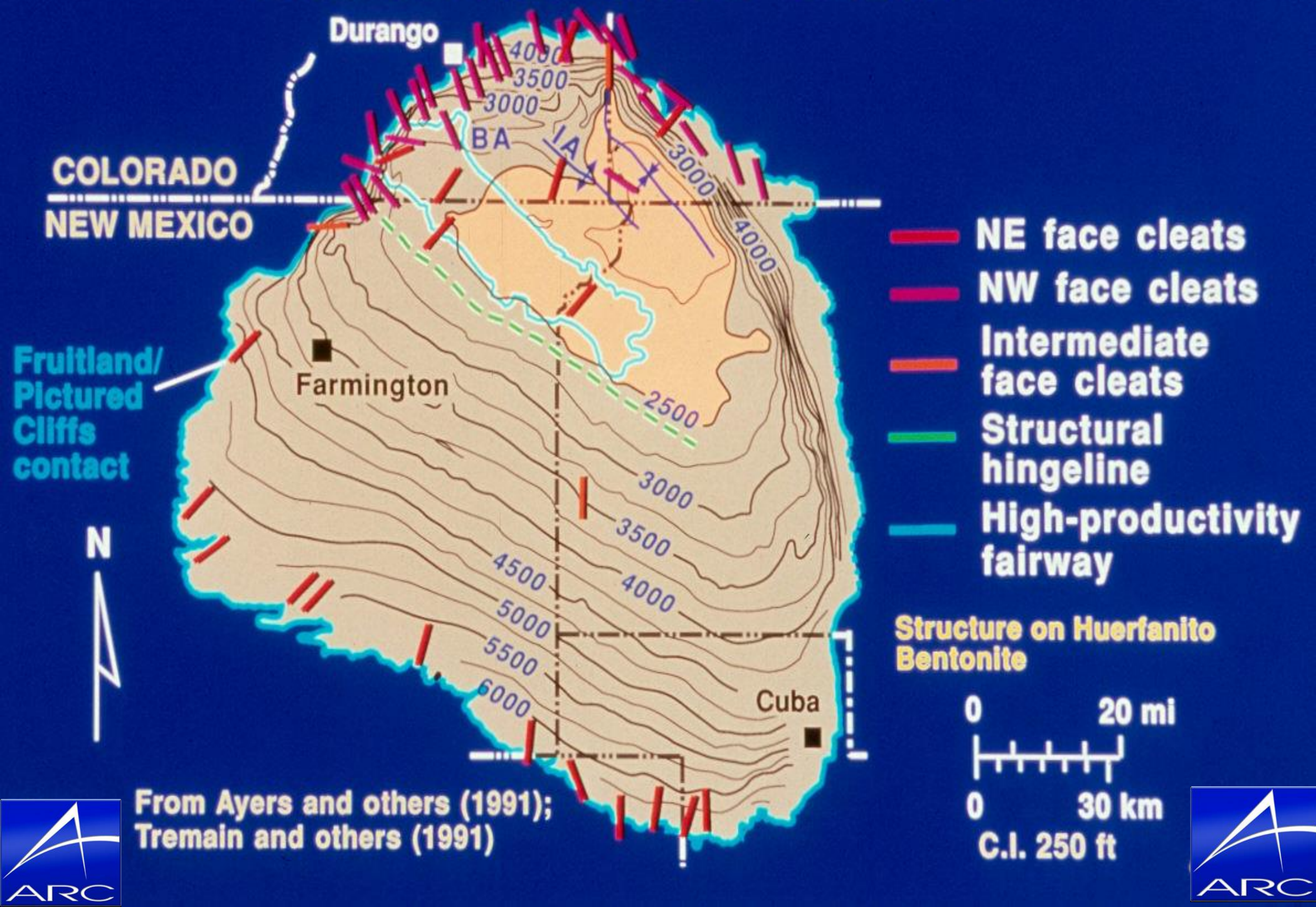
Coalbed Methane Producibility

Coal rank and gas generation

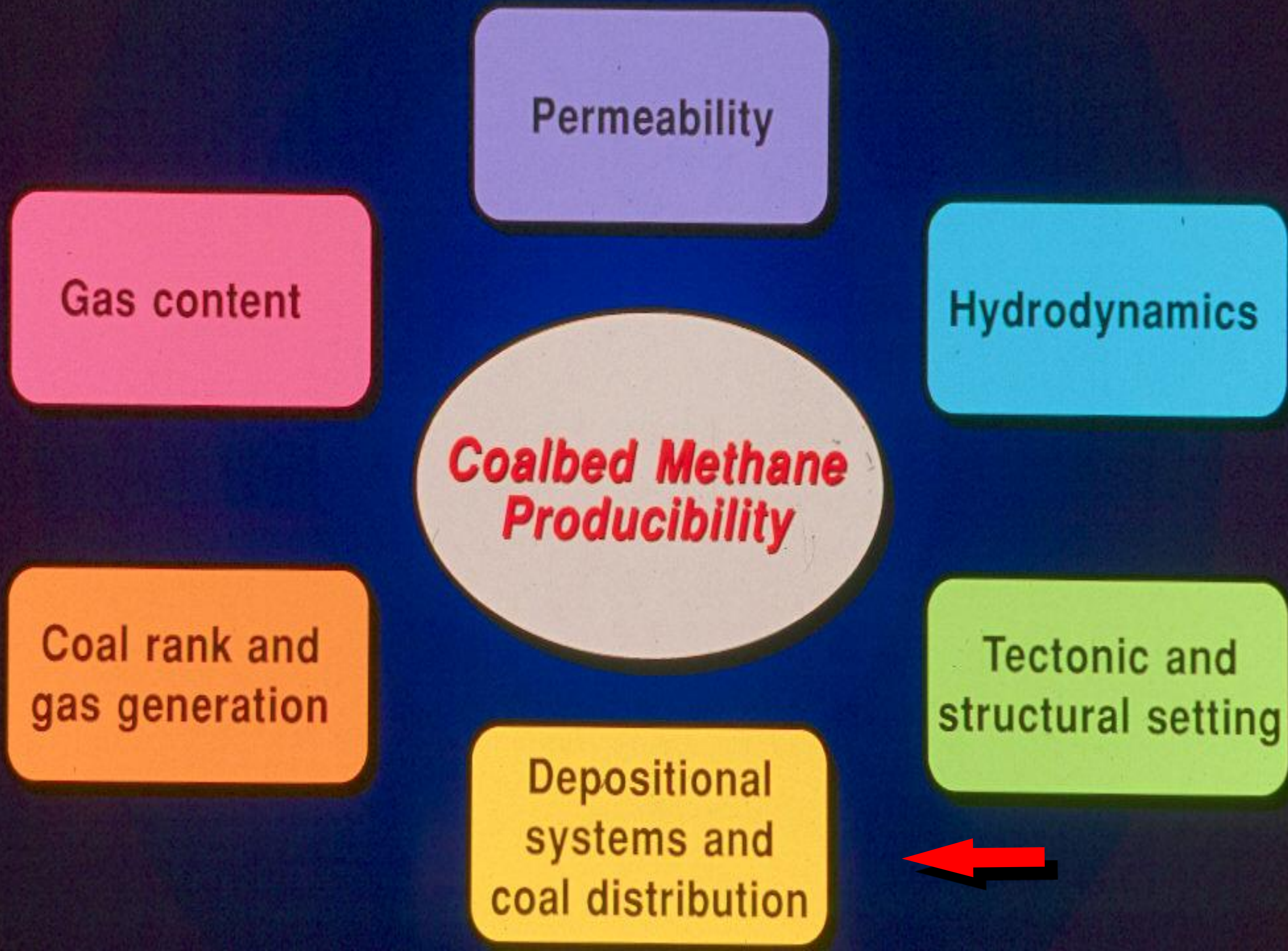
Tectonic and structural setting

Depositional systems and coal distribution

FRUITLAND FACE CLEATS



HYDROGEOLOGIC CONTROLS CRITICAL TO COALBED METHANE PRODUCIBILITY



FRUITLAND NET COAL

Ayers and others (1991)

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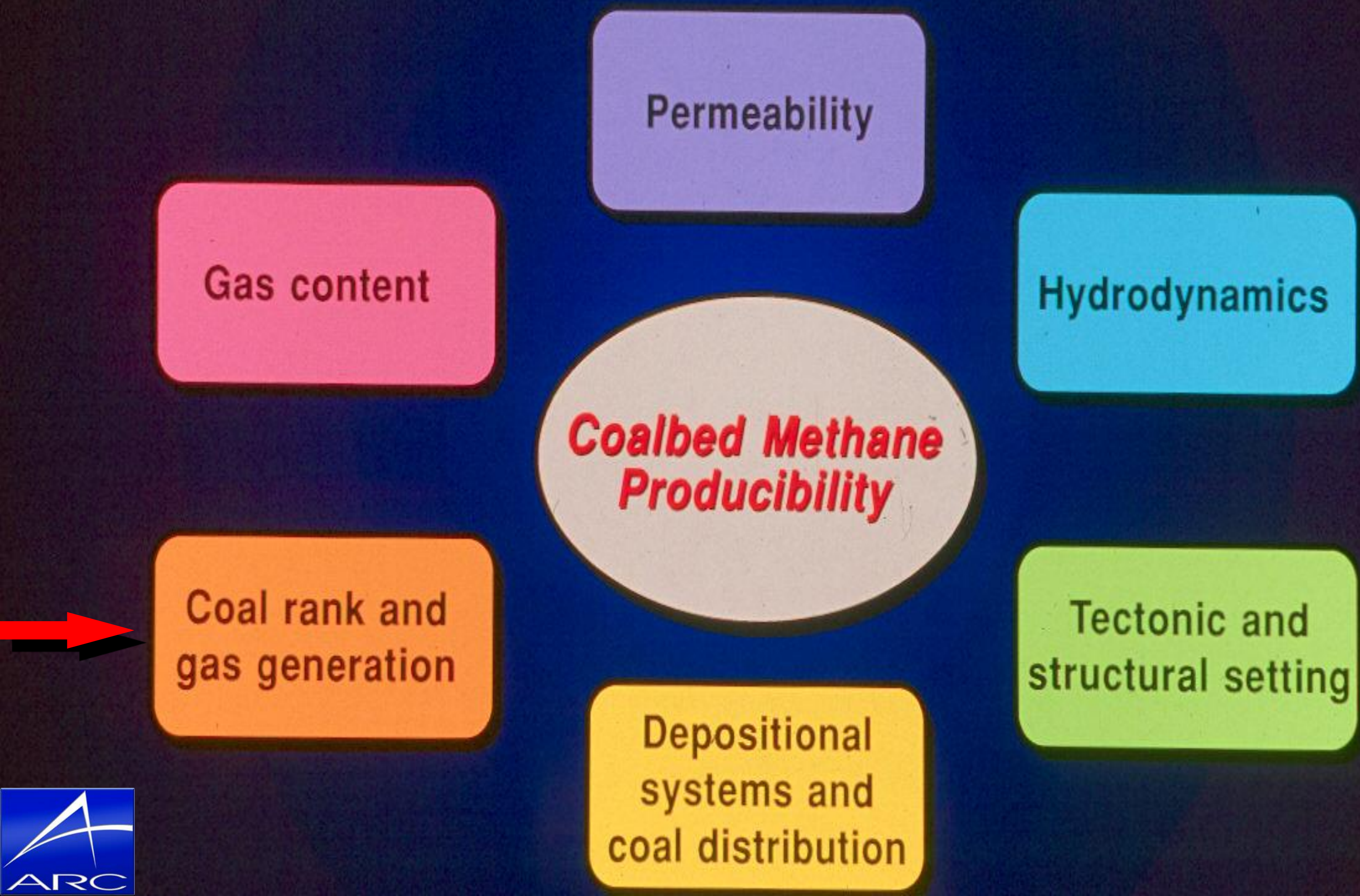
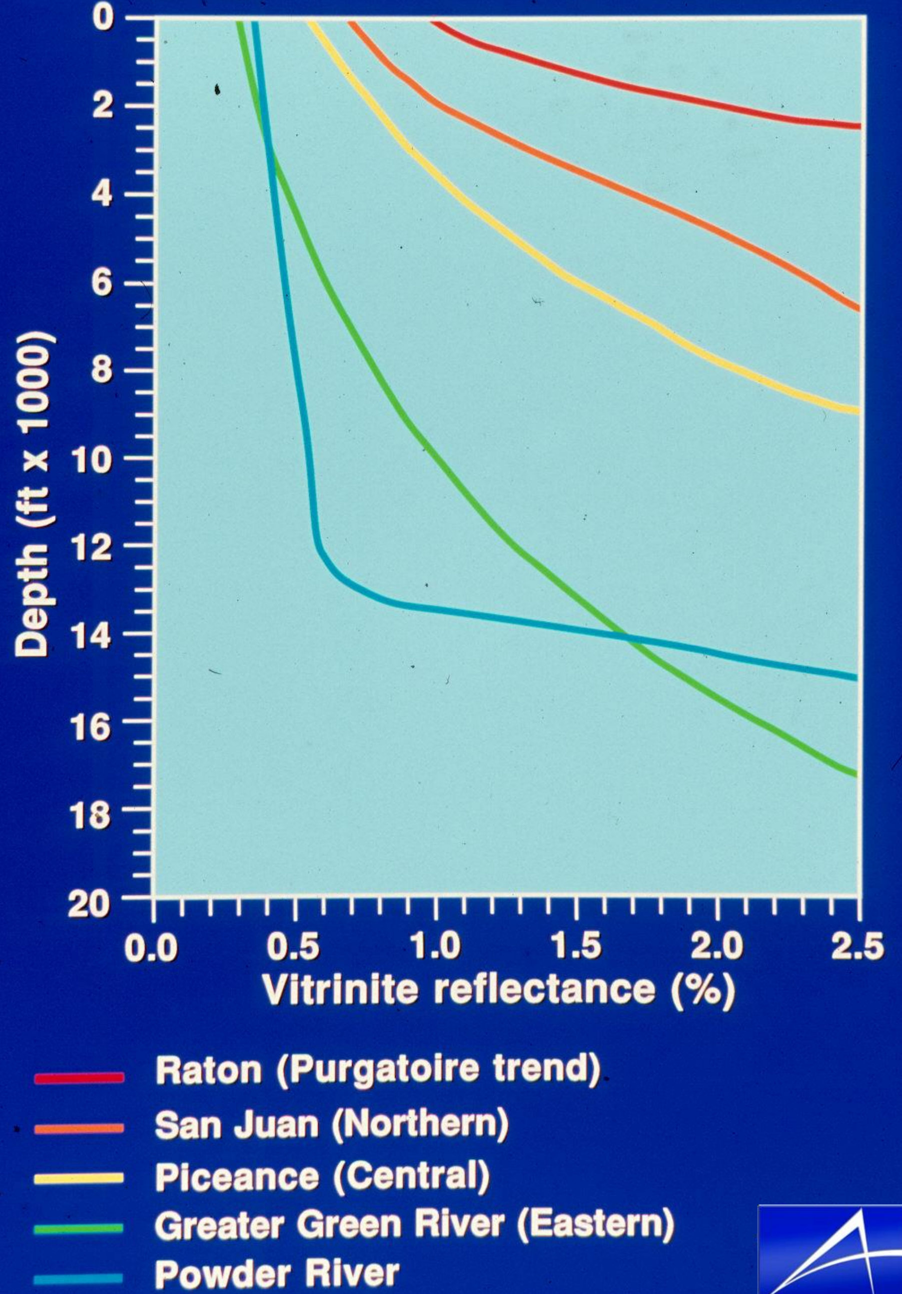
HYDROGEOLOGIC CONTROLS CRITICAL TO COALBED METHANE PRODUCIBILITY



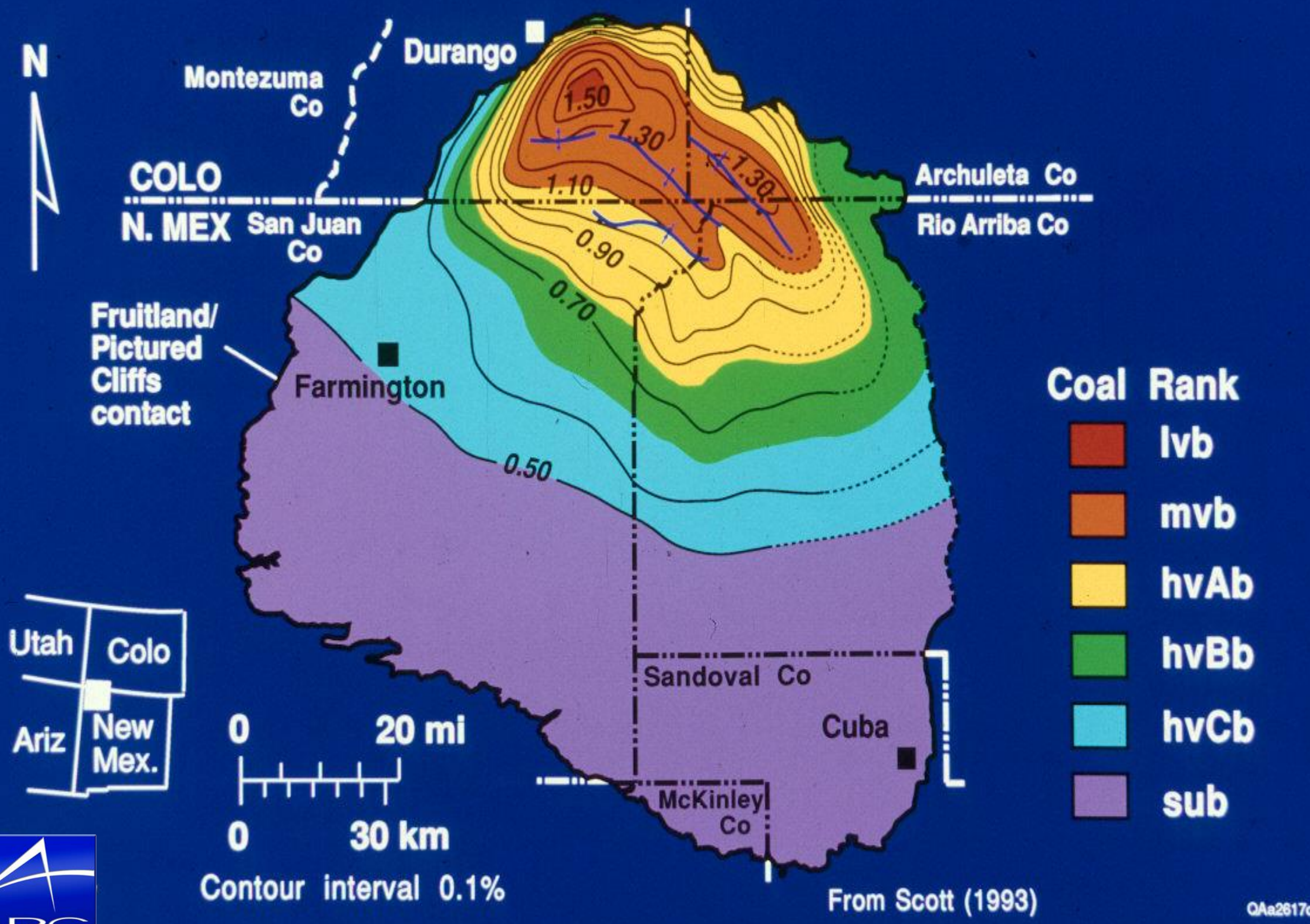
WESTERN BASINS R_o PROFILES



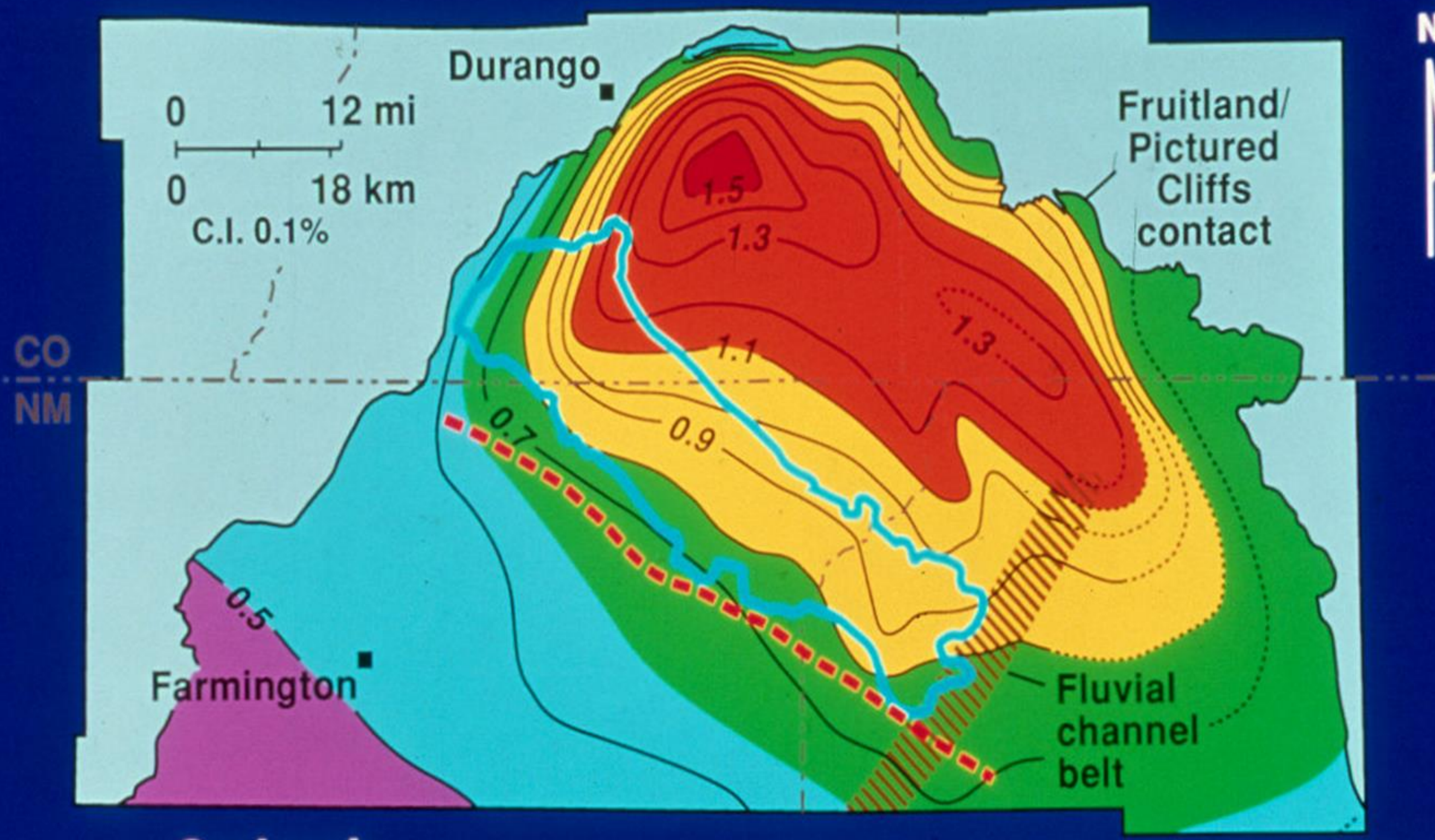
COAL RANK AND VITRINITE REFLECTANCE

	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	
ma				meta-anthracite

FRUITLAND COAL RANK



FRUITLAND COAL RANK



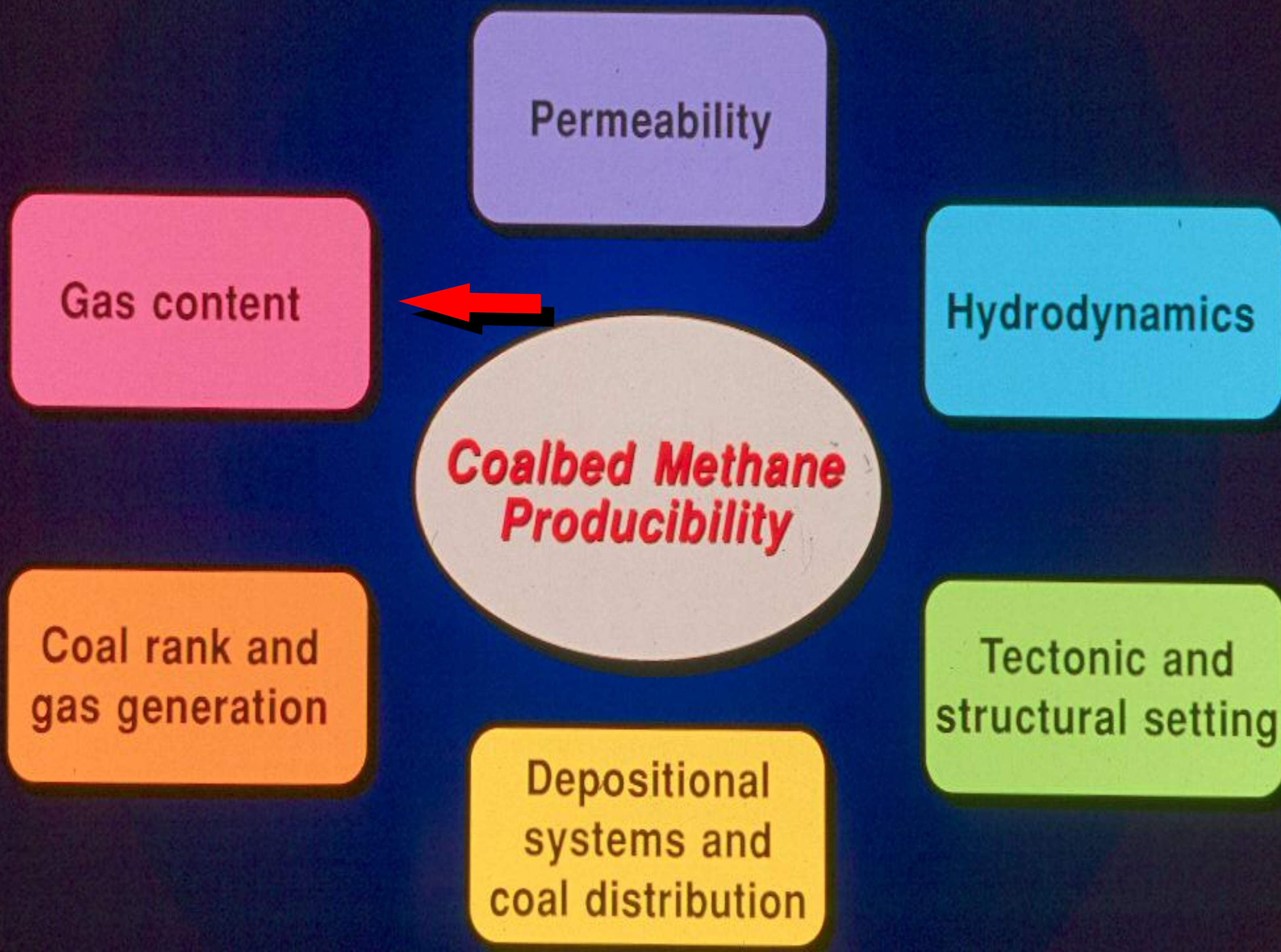
Coal rank

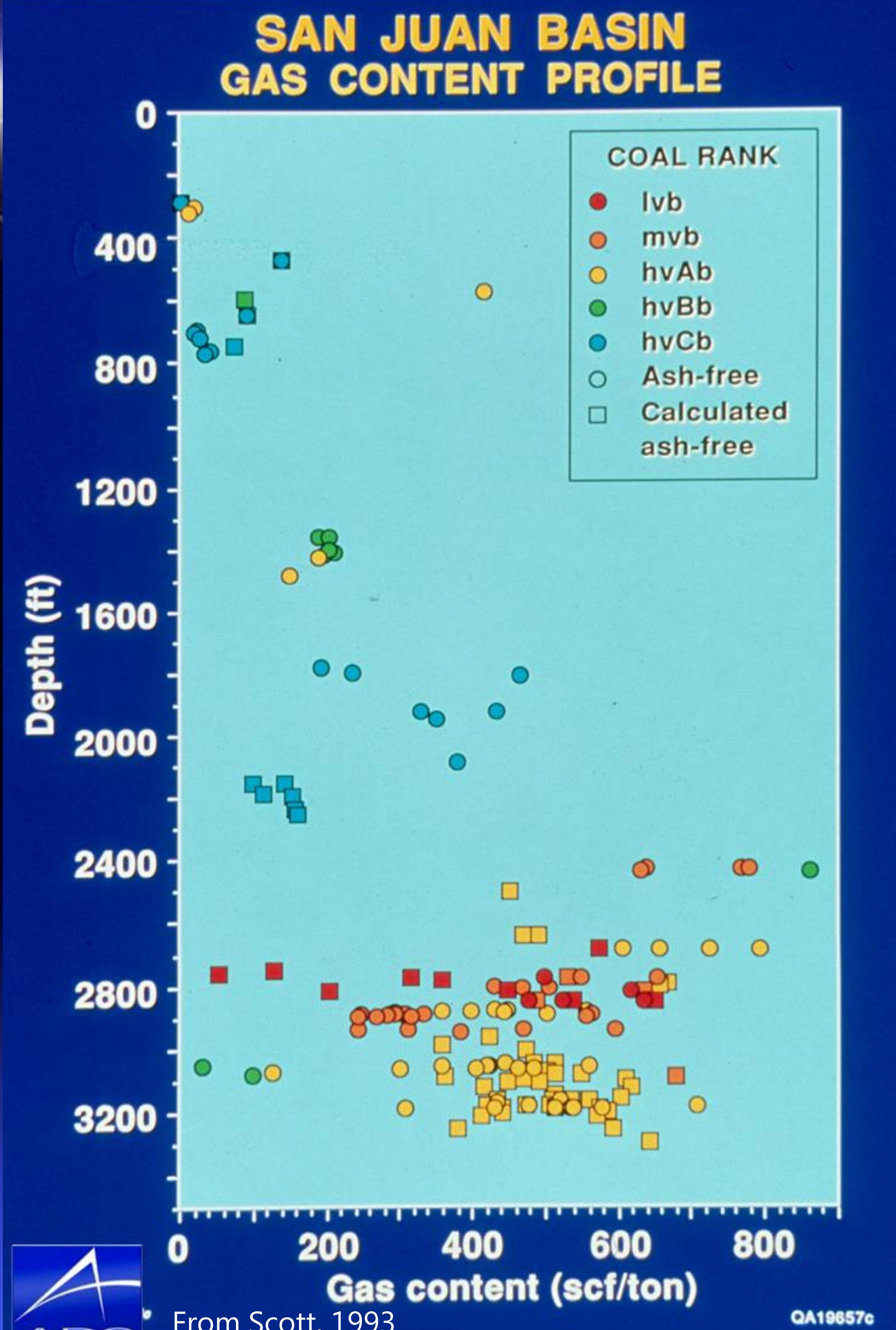
lvb
mvb
hvAb
hvBb
hvCb
sub

Structural hingeline
High-productivity fairway
– 1.1 – Vitrinite reflectance

Modified from Scott (1993)

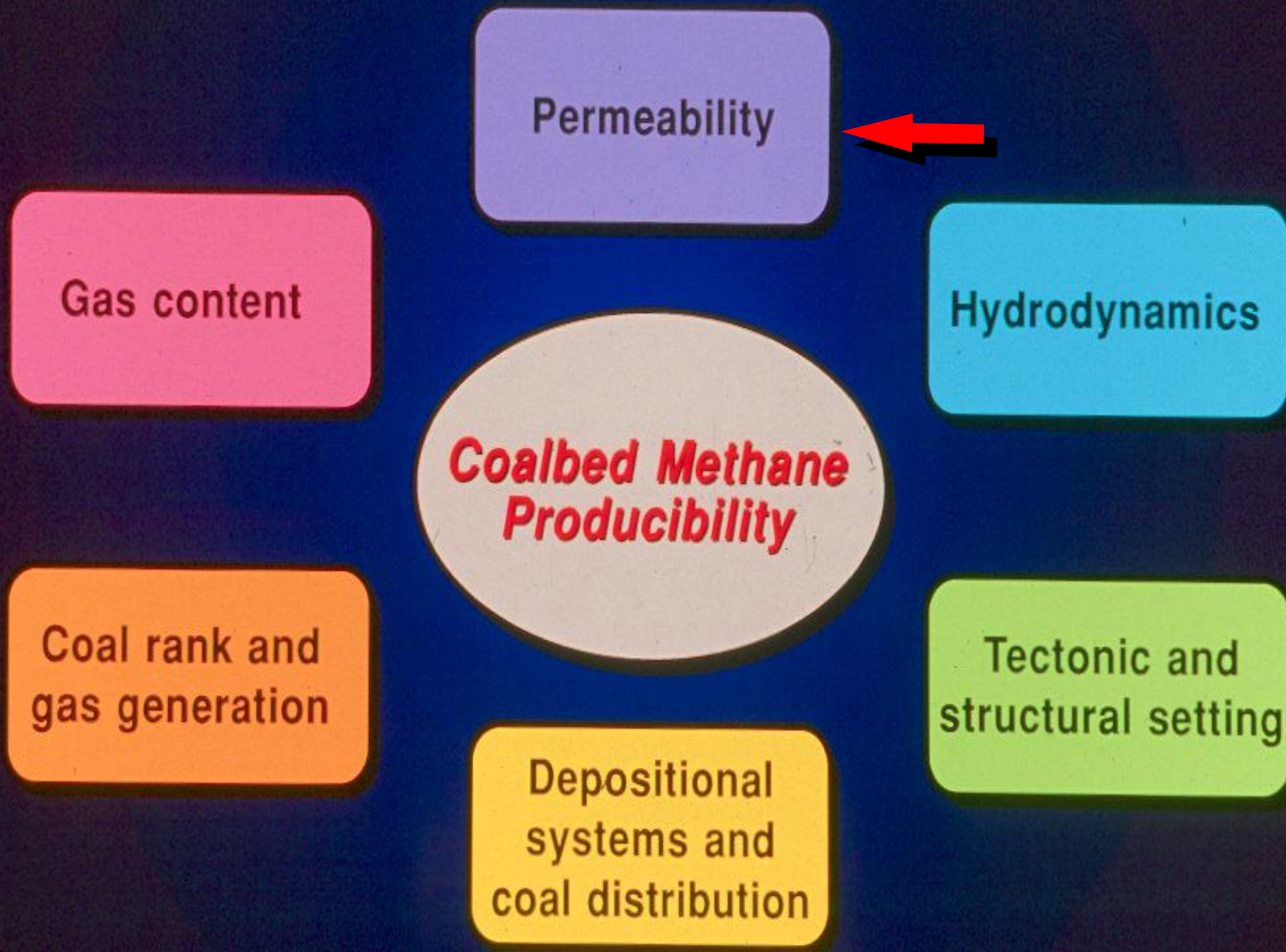
HYDROGEOLOGIC CONTROLS CRITICAL TO COALBED METHANE PRODUCIBILITY





From Scott, 1993

HYDROGEOLOGIC CONTROLS CRITICAL TO COALBED METHANE PRODUCIBILITY



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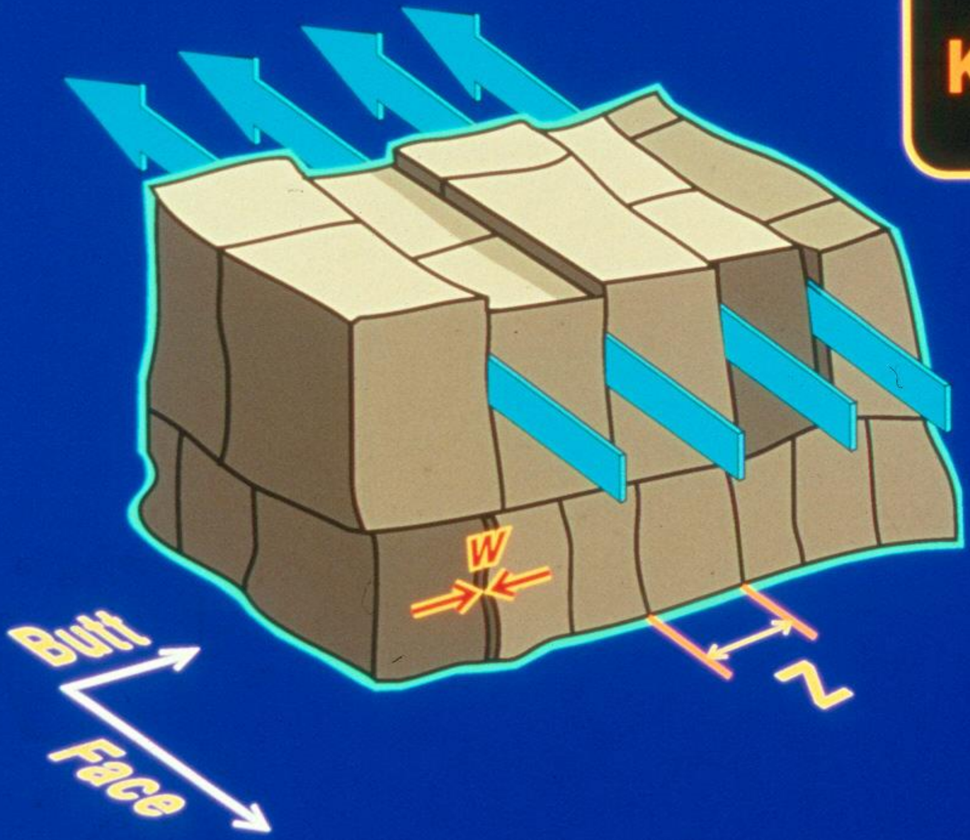
FRACTURE FLOW IN COAL BEDS

$$K_s = \frac{w^3}{Z}(84.4 \times 10^5)^*$$



Z = cleat spacing (cm)

w = cleat aperture (cm)

K_s = permeability (darcy)

* Lucia (1983)

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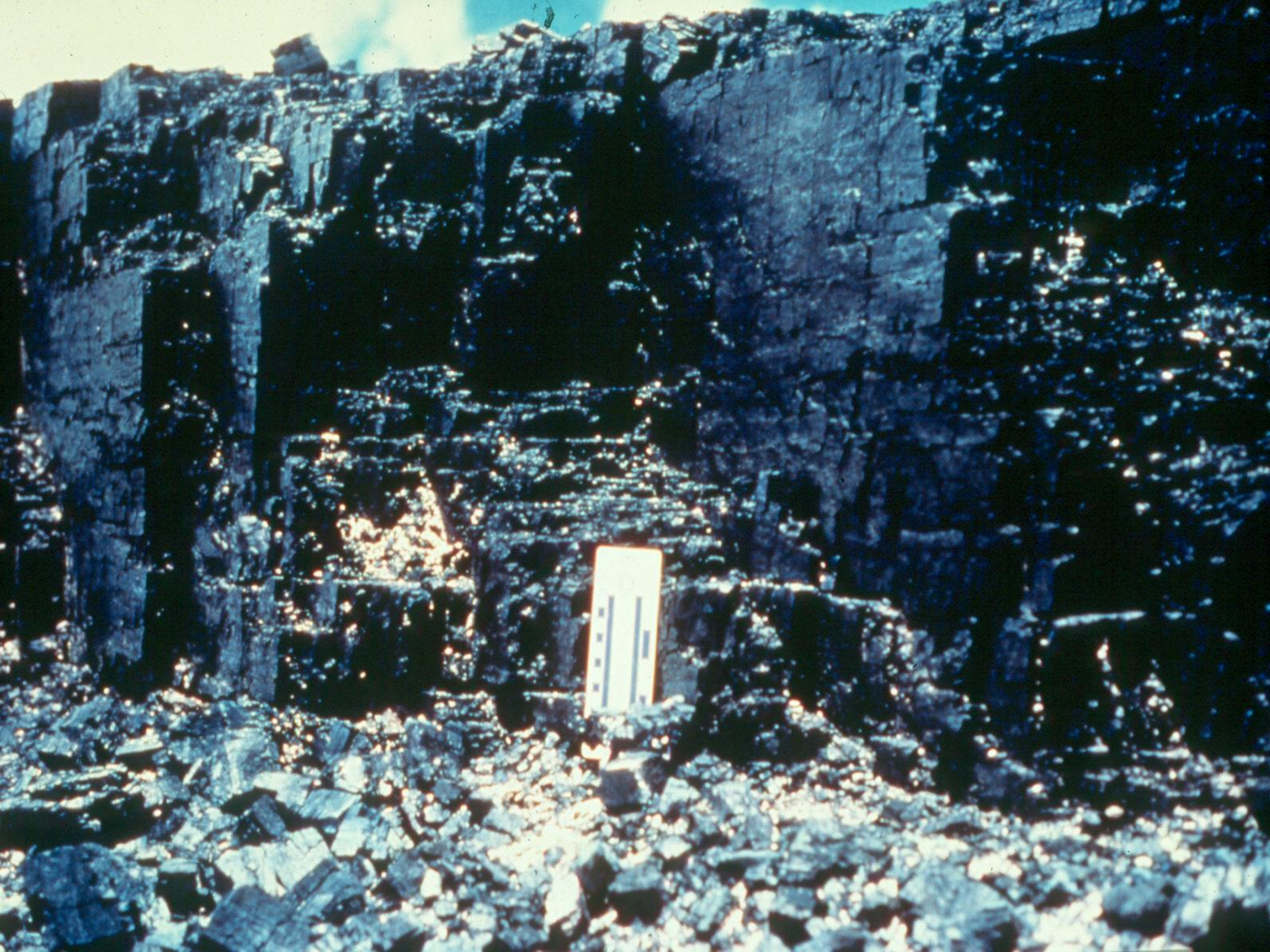
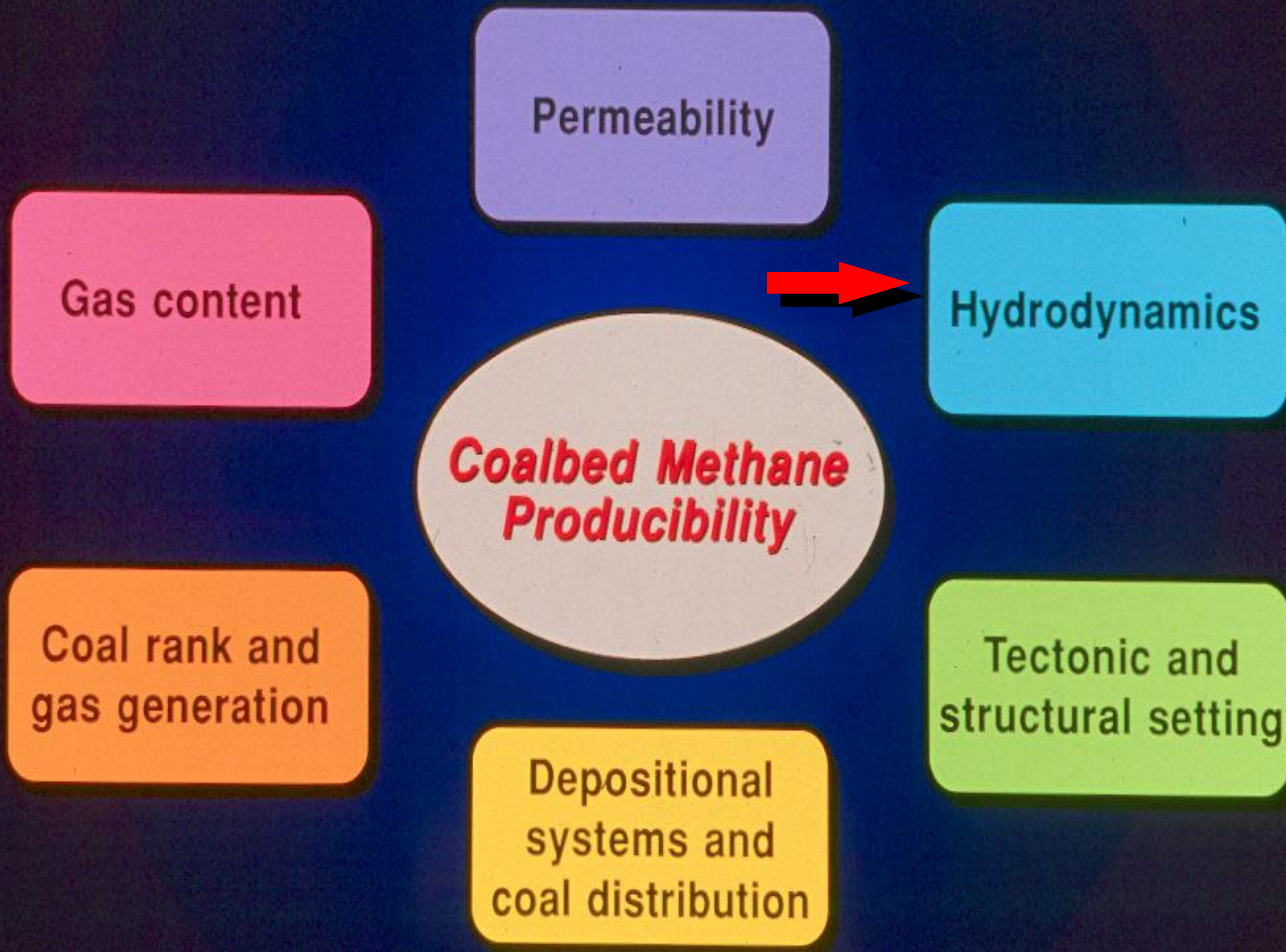
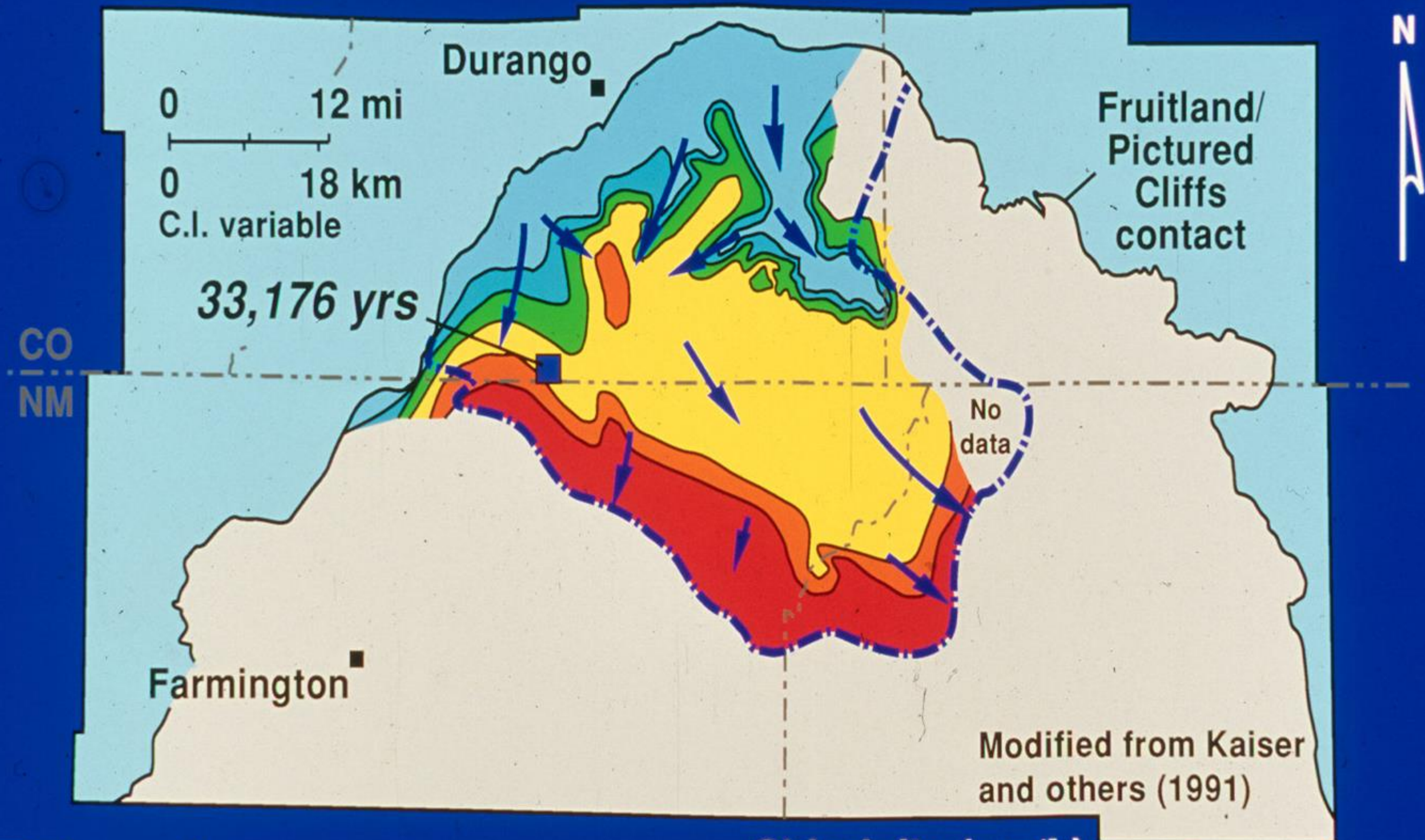


HYDROGEOLOGIC CONTROLS CRITICAL TO COALBED METHANE PRODUCIBILITY



FRUITLAND CHLORINITY MAP



Flow path

Overpressure boundary (0.44 psi/ft)

Chlorinity (mg/L)

>1600

800 – 1600

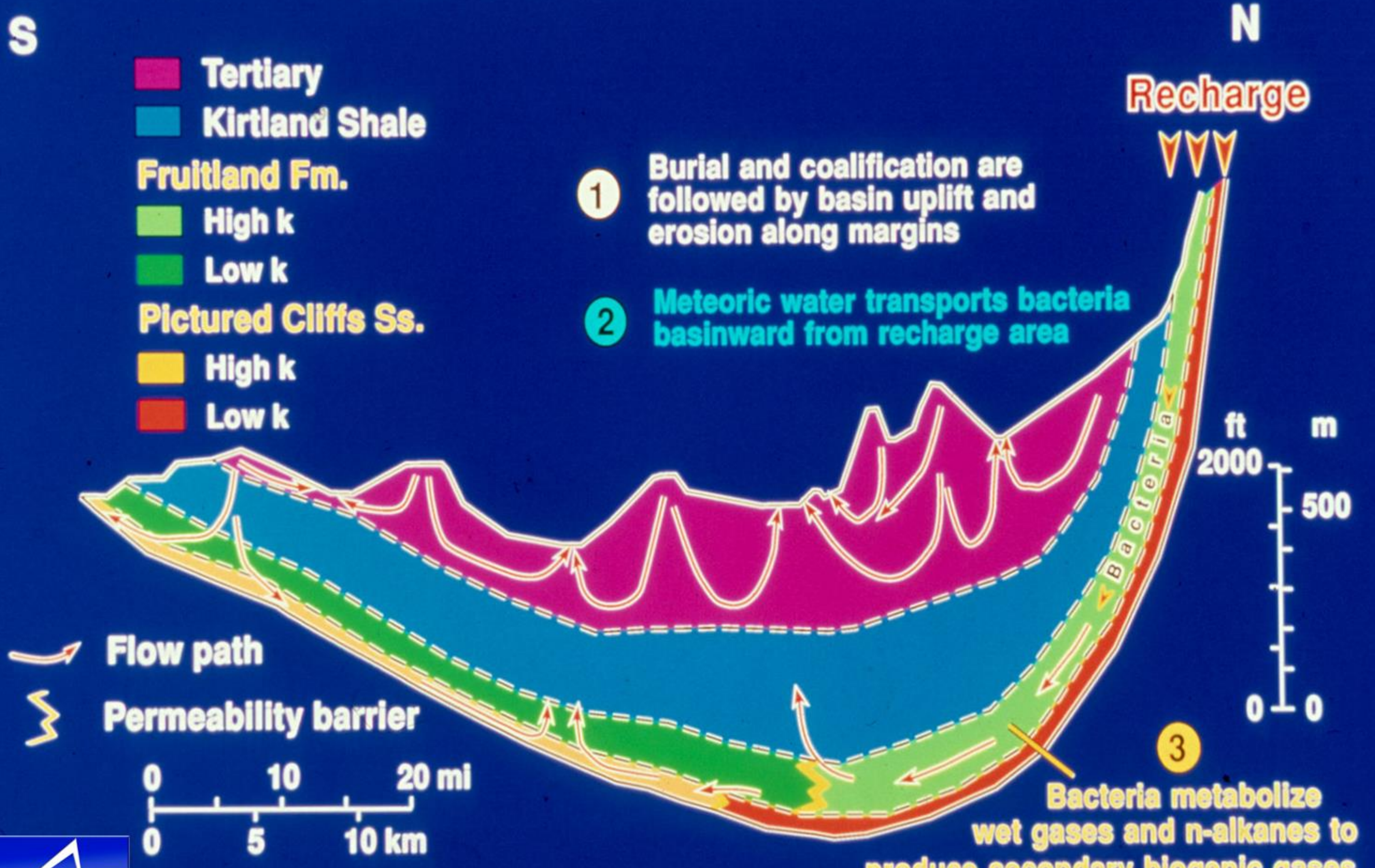
400 – 800

200 – 400

100 – 200

≤100

FRUITLAND HYDRODYNAMICS



Scott (1993) after Kaiser and others (1991)

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COALBED METHANE PRODUCIBILITY MODEL
NEW INSIGHTS

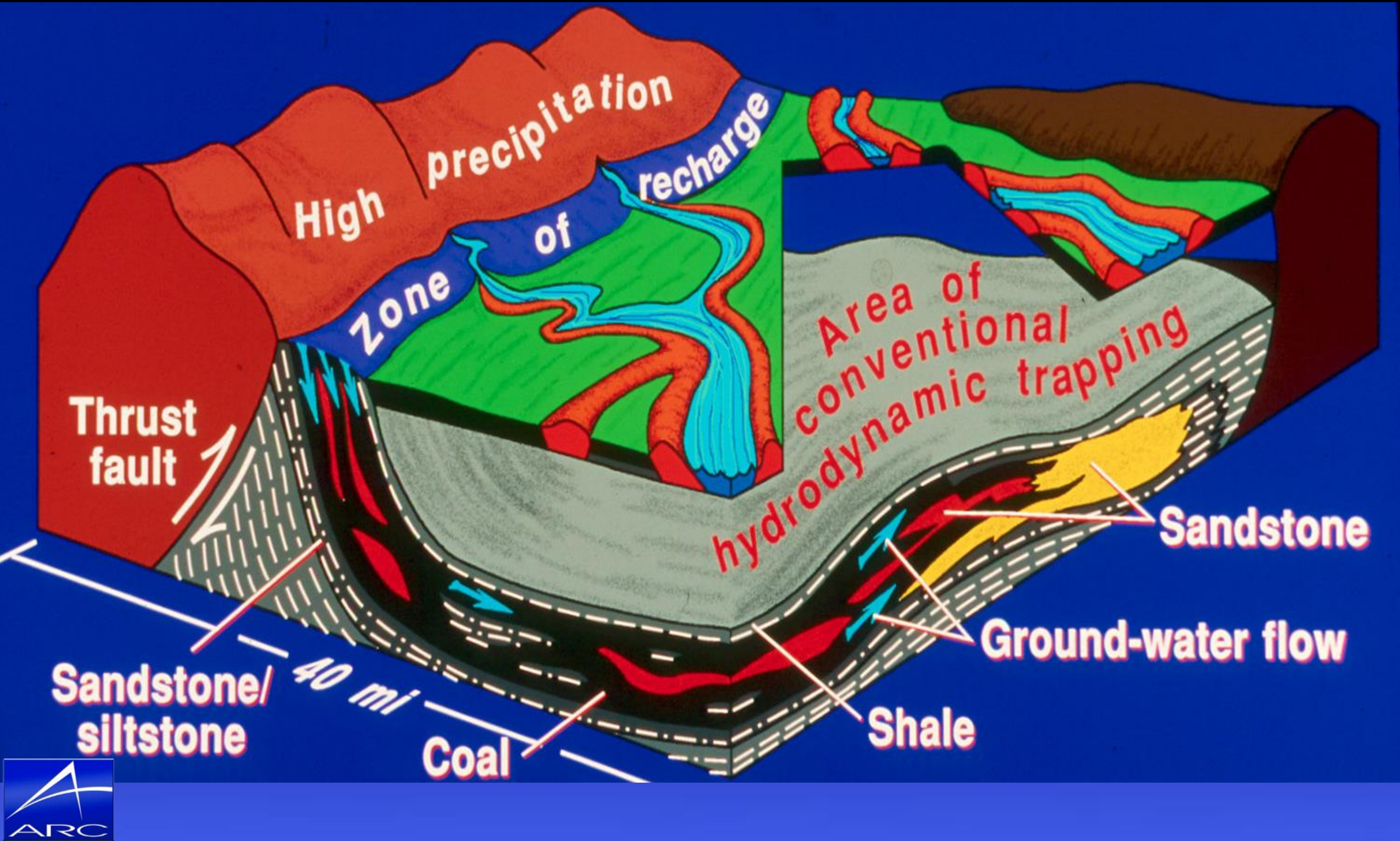
- Migrated conventionally and hydrodynamically trapped gases, in-situ generated secondary biogenic gases, and solution gases are required to achieve high gas contents or fully gas-saturated coals for consequent high productivity.

- To delineate the presence and origin of these additional sources of gas requires an understanding of the interplay among tectonic and structural setting, depositional systems and coal distribution, coal rank, gas content, permeability and hydrodynamics.

- Understanding the reasons for these contrasts in producibility is applicable and vital to worldwide coalbed methane exploration and development.

ARC

Conceptual Model for Coalbed Methane Reservoir Exploration:

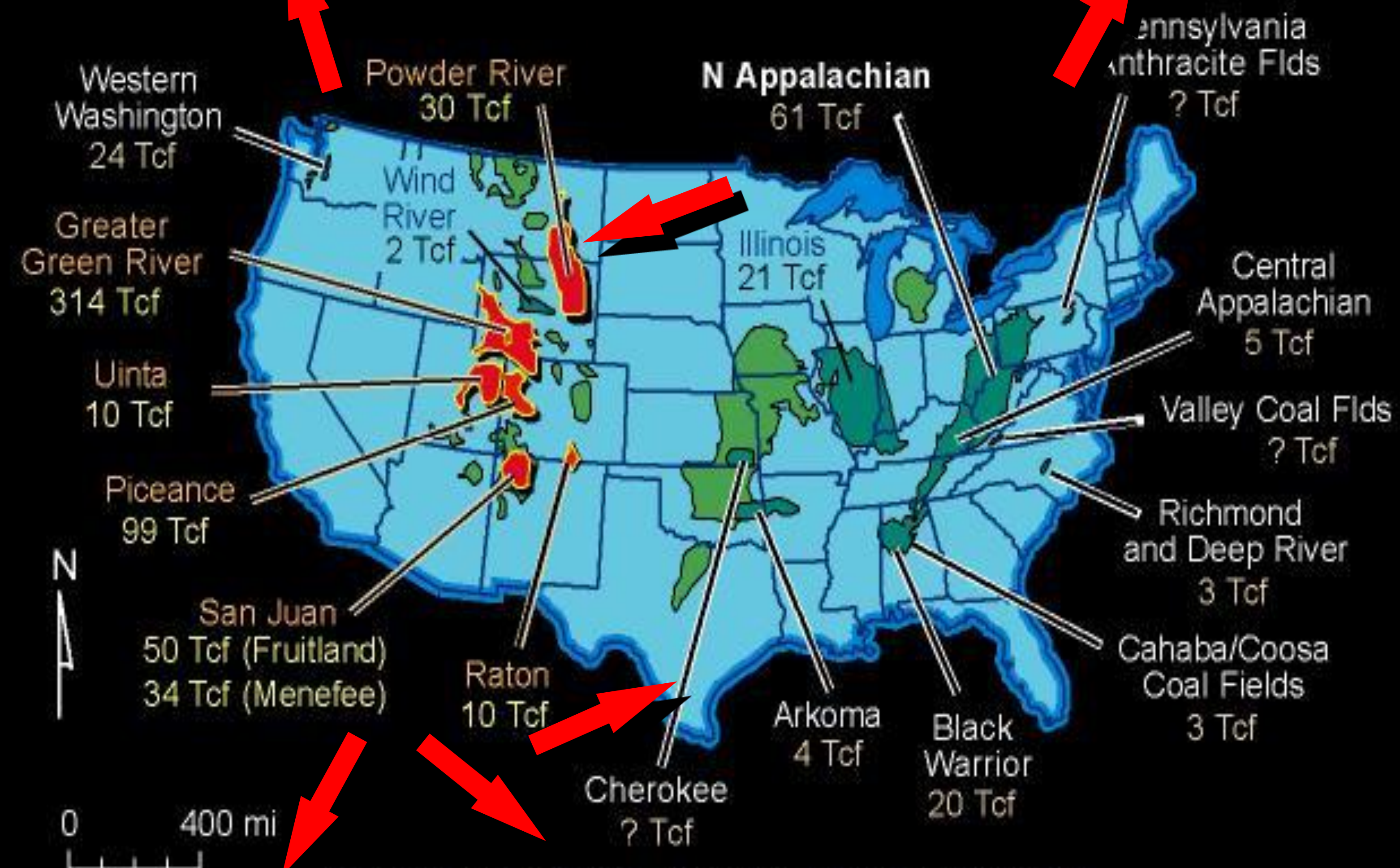


KEY ELEMENTS OF THE PRODUCIBILITY MODEL

- Coals of high thermal maturity
- Ground-water flow basinward through coals of high rank and high gas content orthogonally toward no-flow boundaries
- Conventional trapping of migrated gas along those boundaries

COAL GAS RESOURCES OF THE U.S.

Total resources: 690 Tcf



Data from ICF Resources (1990); Ayers and others (1991); Stevens and others (1992); Scott and others (1994; 1995)

COLOMBIA CMM AND CBM RESOURCE ESTIMATES

- Estimates of Colombia's CBM (?) resources range between 3 - 17 Tcf (Gonzales, 2010)
- Estimates of Colombia's CBM (?) resources range between 11 – 35 TCF (Guzman, Little and ANH, 2011)
- In the Cesar/Rancherias regions, numerous, thick (>10ft) seams are present with measured gas contents of up of 400 Scf/ton at depths of less than 2,000 feet.

(AFTER GARCIA GONZALES, 2010 AND ARI, INC.)

CBM Resources in Colombia

Cuenca	*Edad*	*Rango Carbon*	CBM
			Tcf
Cerrejon	*Paleoceno*	*Bituminous*	2.8
La Jagua	*Paleoceno*	*Bituminous*	2.1
Altiplano Cunl	*Maaestrichtian*	*Sub-Bituminous to Bitum.*	6.0
Valle Cauc	*Oligoceno*	*Sub-Bituminous to Bitum.*	1.9
Magdalena Me	*Maaestrichtian*	*Bituminous*	0.1
Catatumbo	*Paleo.-Oligo.*	*Sub-Bituminous to Bitum.*	0.2
San Jorge	*Oligo.-Mioceno*	*Lignite to Sub-Bitum.*	4.3
Antioquia	*Oligo.-Mioceno*	*Sub-Bituminous to Bitum.*	0.1
		TOTAL resources	17.5

(AFTER GARCIA GONZALES, 2010)

Colombia has significant coal reserves that have a coal rank suitable for CBM exploitation

Colombian Basins

Region	Mineable Coal in Place (Gmt)	Potential Total Gas in Place (TCF)	Coal Rank									
			Anthracite	Low Volatile Bitum	Medium Volatile Bitum	High volatile A Bitum	High volatile B Bitum	High volatile C Bitum	Sub Bitum A	Sub Bitum B	Sub Bitum C	Lignite
Cesar	6.6	2.3 – 6.3										
Guajira	4.5	2.5 - 10										
Boyacá	1.7	2.1 - 5										
Cundinamarca	1.5	2 - 5										
Valle del Cauca	0.2	0.1 – 6.2										
Norte De Santander	0.8	0.9 – 1.2										
Cordoba	0.7	0.4 – 0.5										
Antioquia	0.5	0.3 – 0.4										
Santander	0.8	0.5 - 0.7										
Total Minieable Coal potential	17.3	11.1 – 35.3										

ANH

Mineable coal in place no deeper than 300 m

(Guzman, Little and ANH, 2011)

CONCLUSIONS

The Coalbed methane resources in Colombia can reach 17.5 TCF. This figure is conservative because in some basins deep coal seam at depth greater than 300 m were not taken into account.

The main coal-bearing areas with the largest CBM potential are Maestrichtian-Paleocene in age and are located in the Cesar, Rancheria, and Bogotá basins.

(AFTER GARCIA GONZALES, 2010)

- **Higher resource estimates are likely more accurate as many areas have not been well defined and deeper wells have not been taken into consideration.**

ARC Group Resource Equations

$$\text{Ton} = (h \times A) \times \text{Density (Bulk)}$$

$$\text{GIP} = (h \times A) \times \text{Density (Ash Free)} \times \text{G.C.}$$

Ton = Coal Tonnage (Short tons)
GIP = Gas in Place (Scf)
G.C. = Ash Free Gas Content (Scf/ton)
Density (Bulk) = Bulk Density (tons/acre foot)
Density (Ash Free) = Ash Free Density (tons/acre foot)
h= Coal Thickness (Ft) and A = Area (Acres)

Assume for Bituminous Coals: 1800 tons per acre foot = 1.32 g/cm^3 or
for Semi-Anthracite/Anthracite: 2000 tons per acre foot = 1.47 g/cm^3

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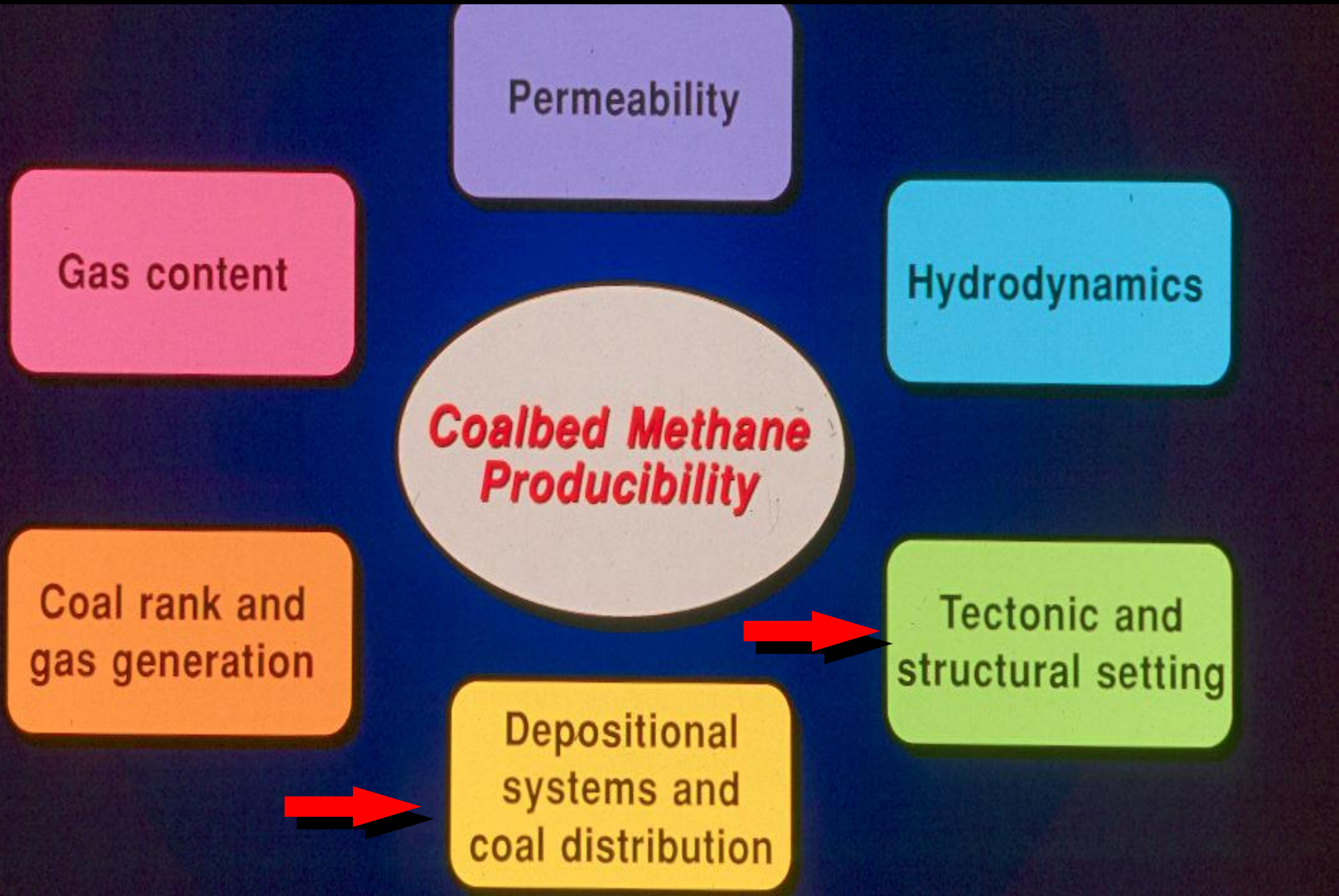
Application of the Conceptual Model for CBM Reservoir Exploration in Colombia:

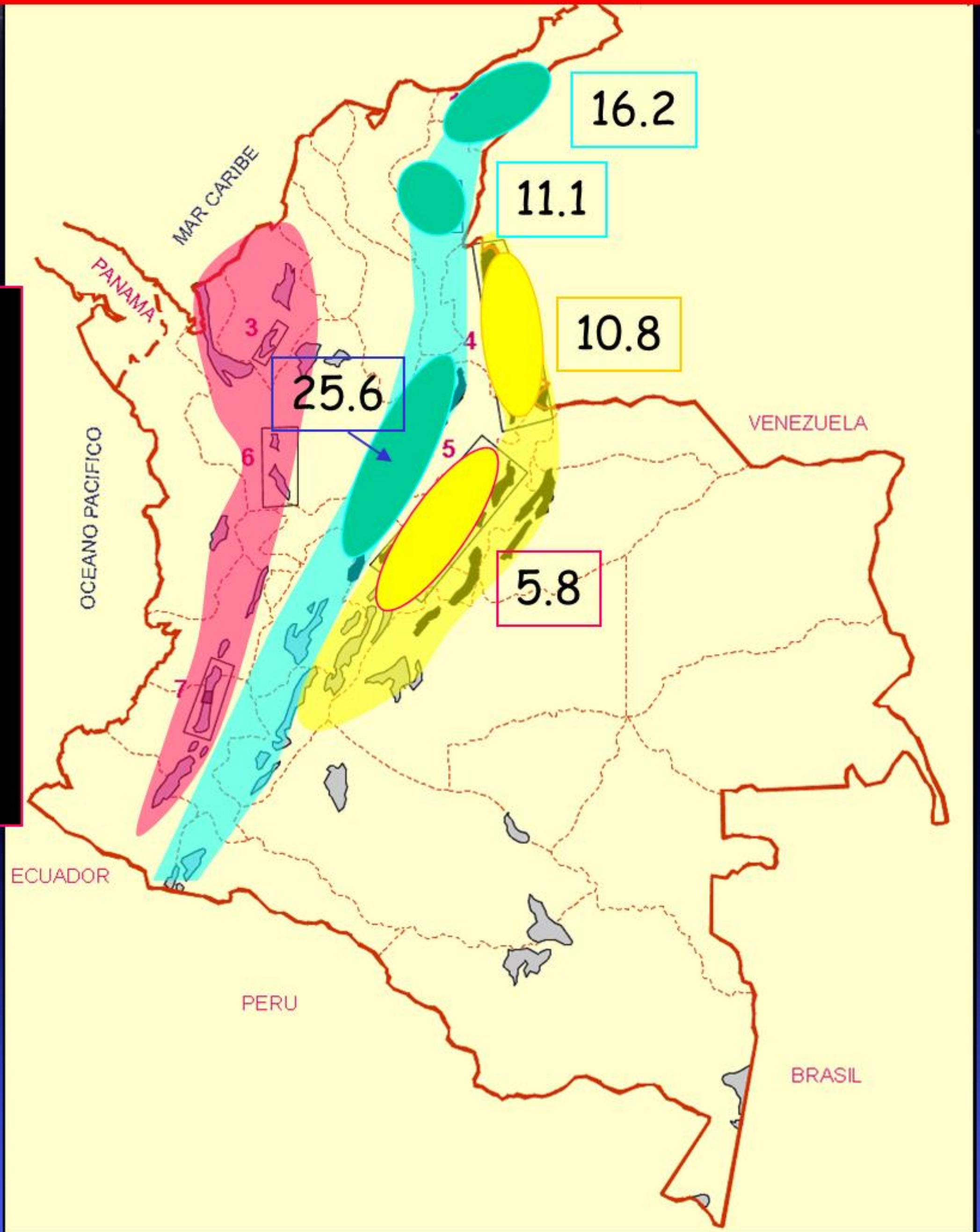


ARC GROUP – Initial Coalbed Methane Resources Estimates

Conservative est.

- 70 TCF
- Only 1 TCF in western fairway

(Certainly underestimated because of lack of data)



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