Prerequisites, general criteria and primary studies required in the Coalbed Methane prospecting and exploring: A review

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Notice

Part of the research team of the "Organic Petrology and Geochemistry Unit", Faculty of Sciences, University of Porto, has moved to a new entity entitled "Research Unit for Environment Systems Modelling and Analysis" at University Fernando Pessoa, Porto, Portugal. Researchers who moved to University Fernando Pessoa are those specialized in Coalbed Methane (CBM) and CO2 sequestration in coal seams.

Universidade Fernando Pessoa, Porto, Portugal

Centro de Modelação e Análise de Sistemas Ambientais - CEMAS

Research Unit for Environment Systems Modelling and Analysis

- **Main objectives**:
  - **To develop R & D projects related with Modelling and Analysis of Environment Systems (5 + 2 current R & D projects)**
  - **To assist Post-graduated teaching and student training**
- **Staff: 22 researchers of which**
  - **17 Ph D**
  - **2 M Sc**
  - **3 with Graduation**

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Research Team Practice in CBM studies

- Lorraine Basin (France) – Conoco, Dupont
- Waterberg Basin (South Africa) – Anglo Coal

- Spain
- Brazil
- Chile

Publications: 19 papers, abstracts and posters

Research Team main Publications

see:

www.ufp.pt

Bibliotecas

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Geosciences and Environment

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Contents:

Key-words:

Coal, Coalbed Methane (CBM), Natural gas, Exploration, Prospection, Sorption (adsorption, desorption) isotherms.

Abstract:

The main objectives of this paper are: (i) to review and summarize current concepts of Coalbed Methane (CBM) genesis and storage, (ii) to highlight and present the principal procedures and methodologies concerned with prospecting/exploring of CBM leading to a sequence of basic criteria to be followed at an early stage and, subsequently, during research and exploration, and (iii) to present a list of the most important analytical requirements during the investigations.

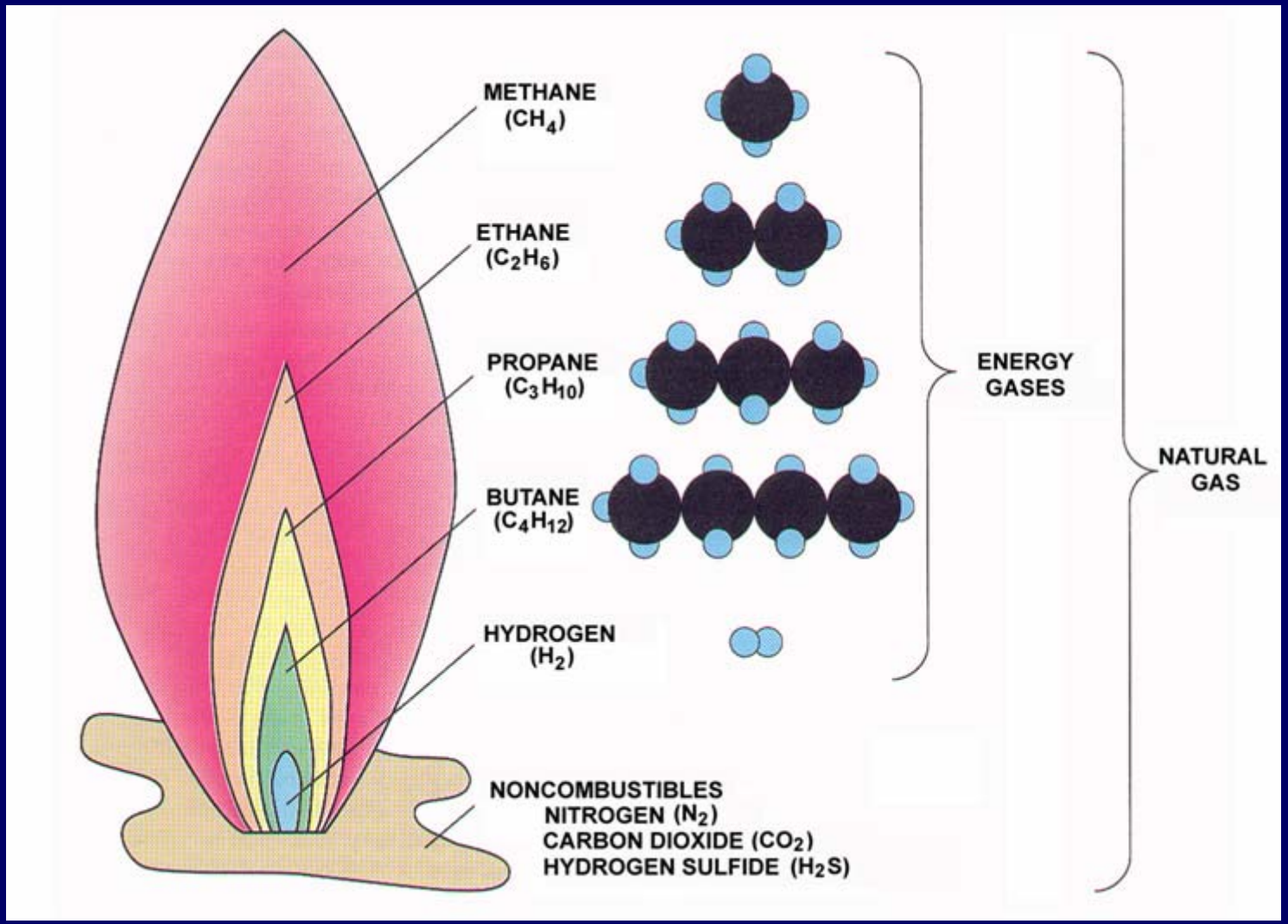
1. Definition

Definition

Coalbed Methane (CBM) is a natural gas, generated and/or stored in coal seams in situ and mainly composed of energy gases (combustible gases) of which methane is predominant.

(Rice et al 1993)

Natural gas composition



(after McCabe et al 1993)

CBM *versus* CSM and CMM

Seam gas		Firedamp gas			
In situ		Active coal mines		Abandoned coal mines	
Coalbed Methane CBM		Coalseam Methane CSM		Coalmine Methane CMM	
	Vol. %		Vol. %		Vol. %
CH_4	90 - 95	CH_4	25 - 60	CH_4	60 - 80
CO_2	2 - 4	CO_2	1 - 6	CO_2	8 - 15
CO	0	CO	0.1 - 0.4	CO	0
O_2	0	O_2	7 - 17	O_2	0
N_2	1 - 8	N_2	4 - 40	N_2	5 - 32
H_2O - residual		H_2O - residual		H_2O - residual	

2. Generation

Biogenic gas

Methane gas that was generated by microorganisms at the Earth's surface or at shallow depths within sedimentary basins (McCabe et al. 1993).

Generated in different stages

Specific sedimentary environment conditions

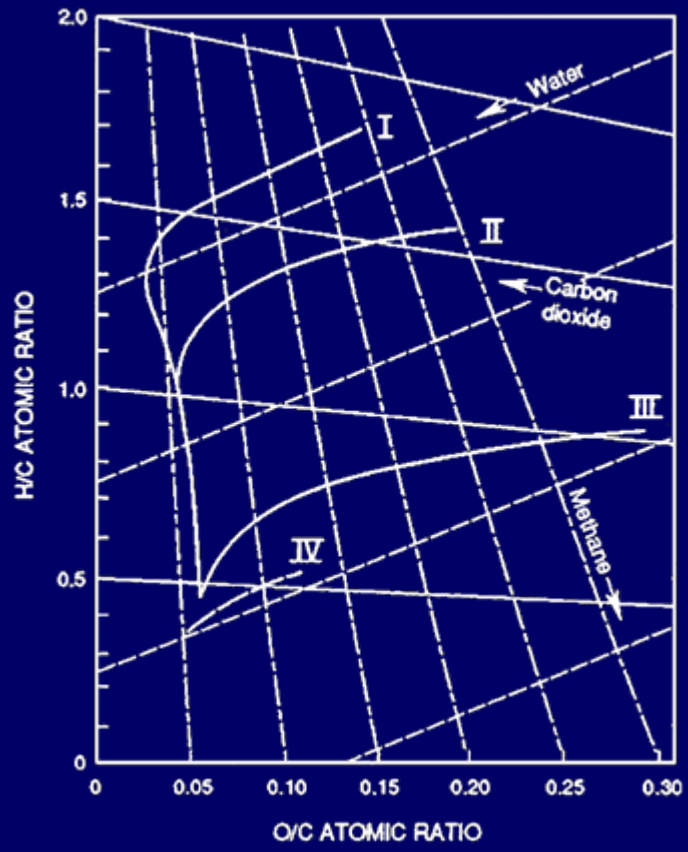
Thermogenic gas

Natural gas formed by the thermal decomposition of organic matter in rocks as they are buried (increasing pressure and temperature) in sedimentary basins (McCabe et al. 1993).

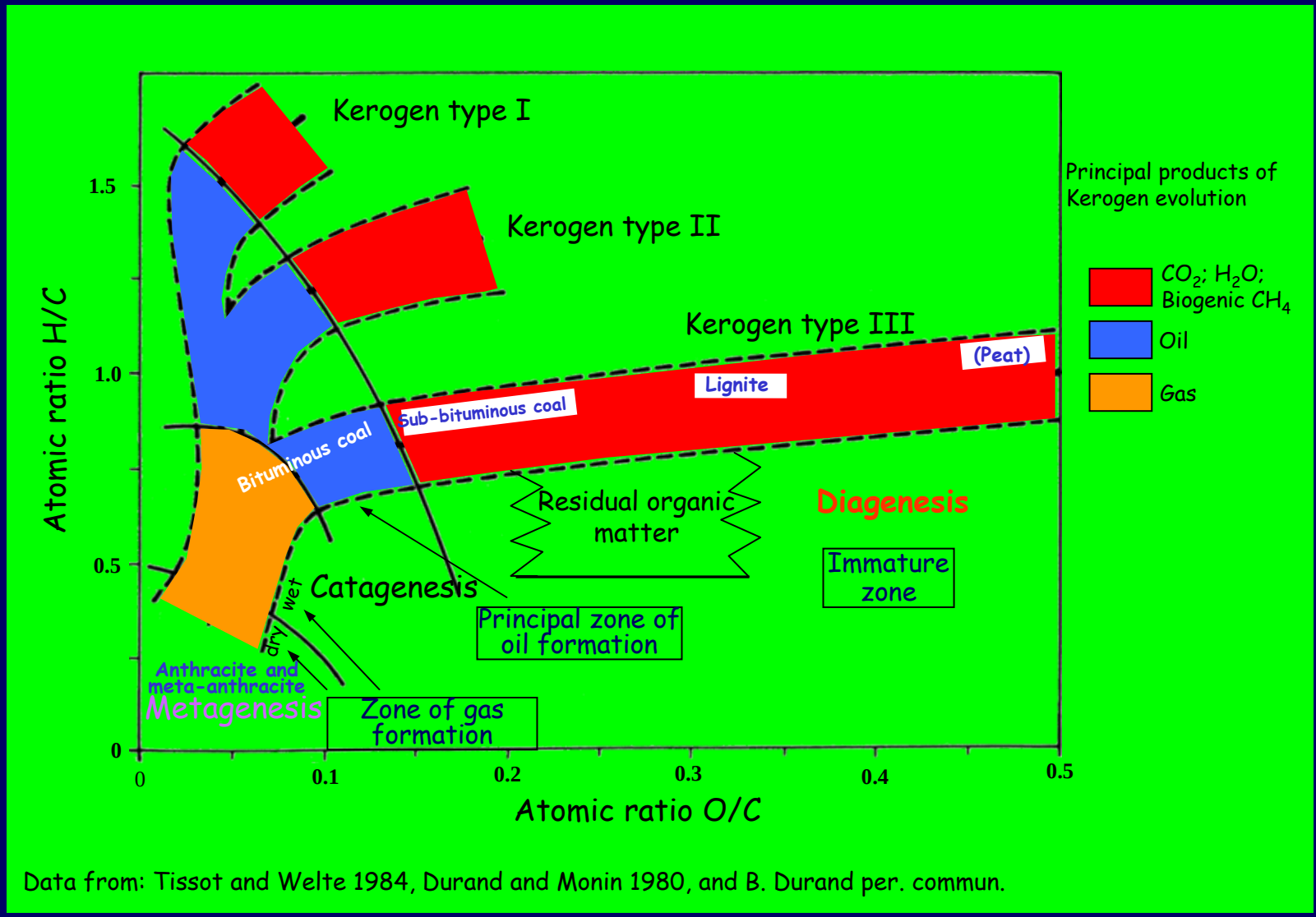
Devolatilisation products:

- methane
- carbon dioxide
- water

❖ The relative amount of these products can be estimated from the element composition (C, H, O) which varies with kerogen type (Rice et al. 1993).

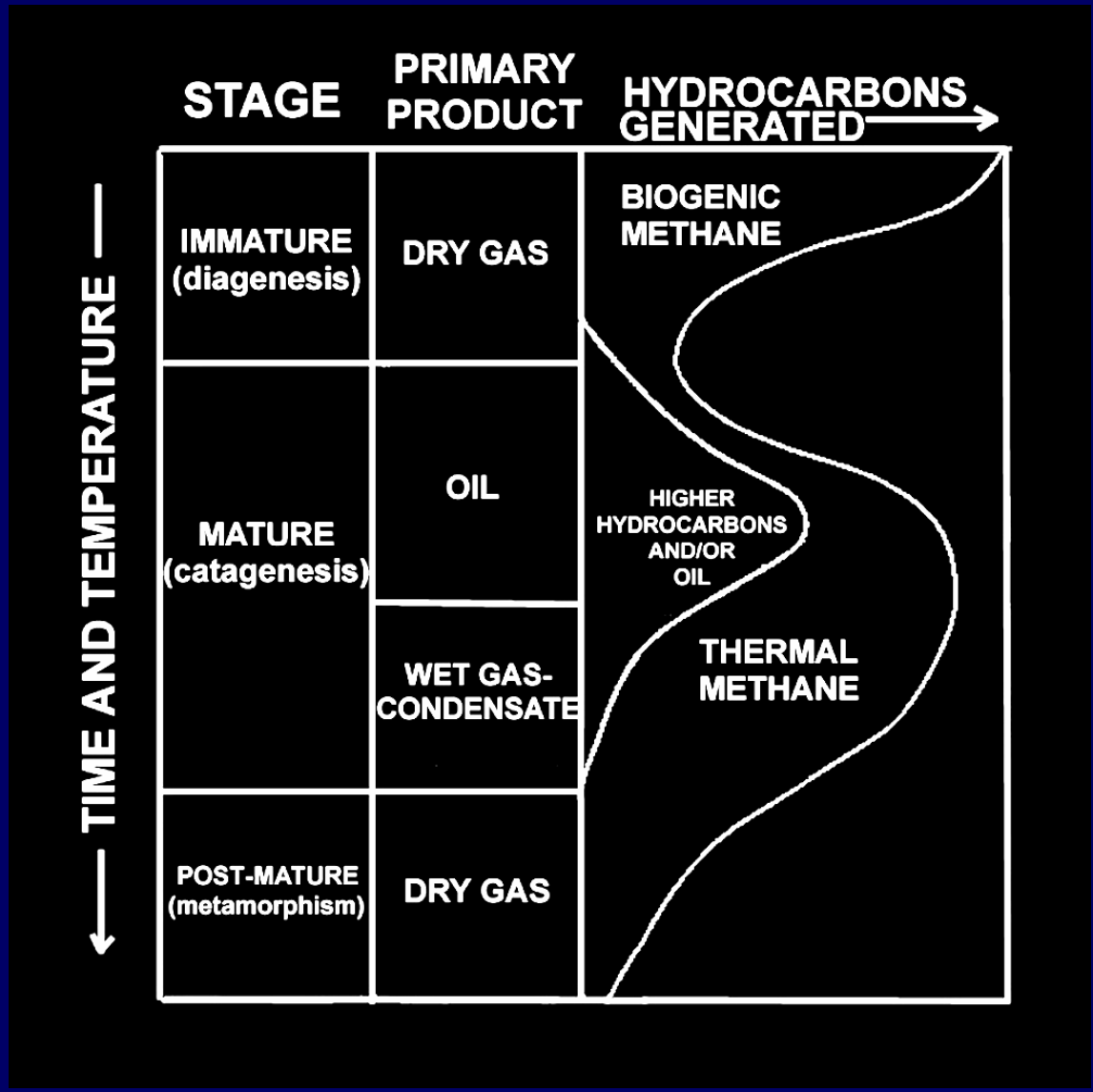


General scheme of kerogen evolution



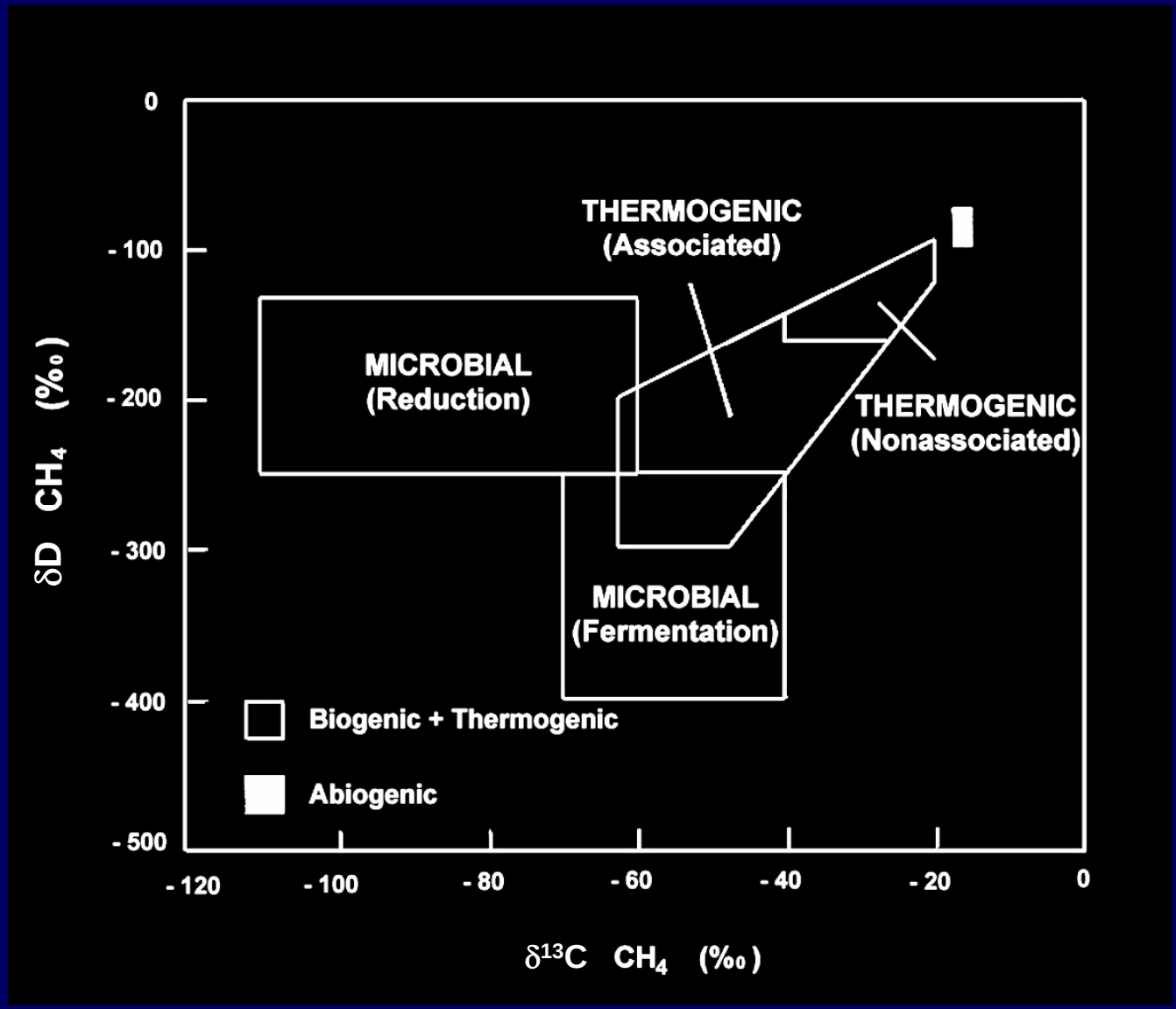
Data from: Tissot and Welte 1984, Durand and Monin 1980, and B. Durand per. commun.

Major stages of hydrocarbons generation

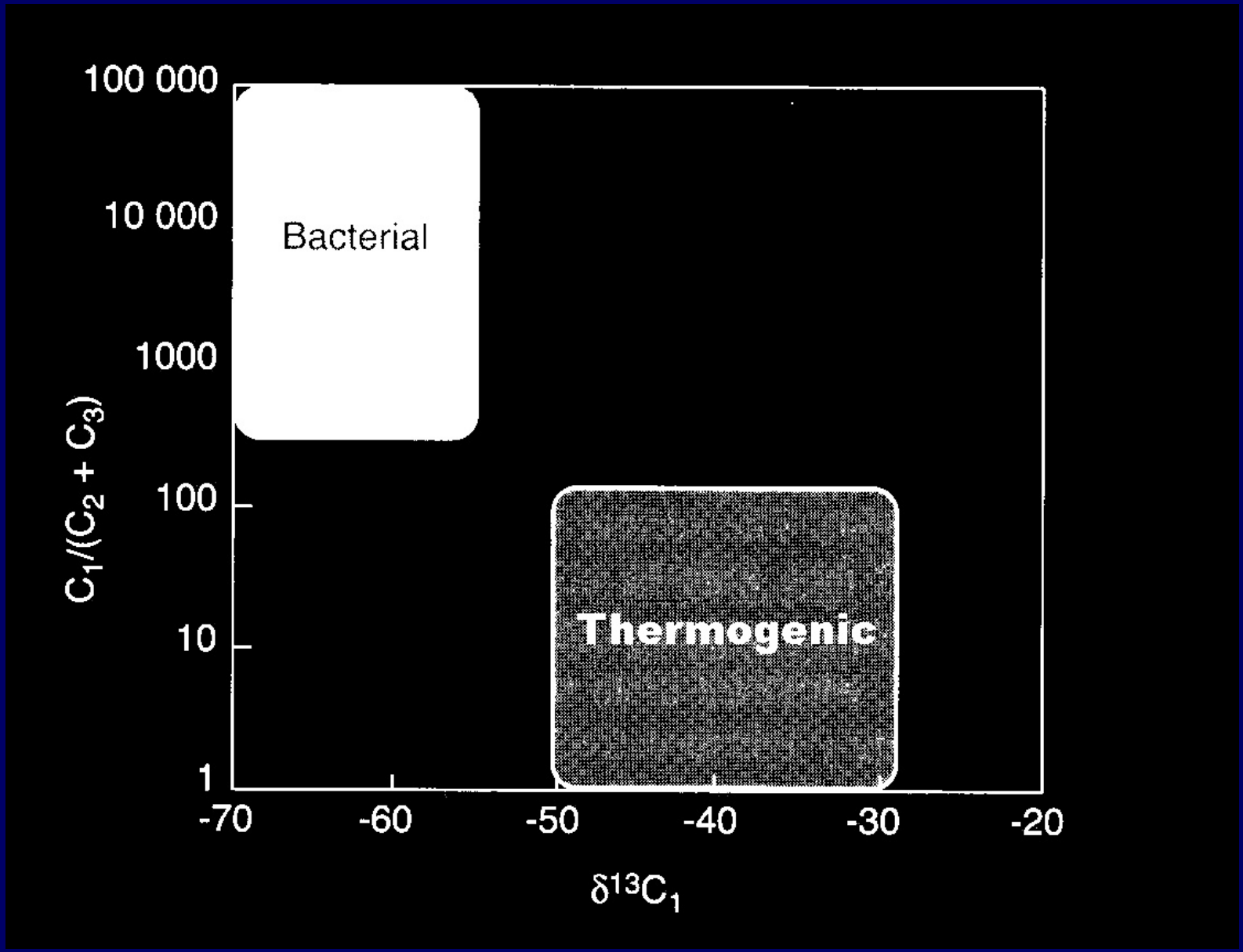


(after Rice 1993)

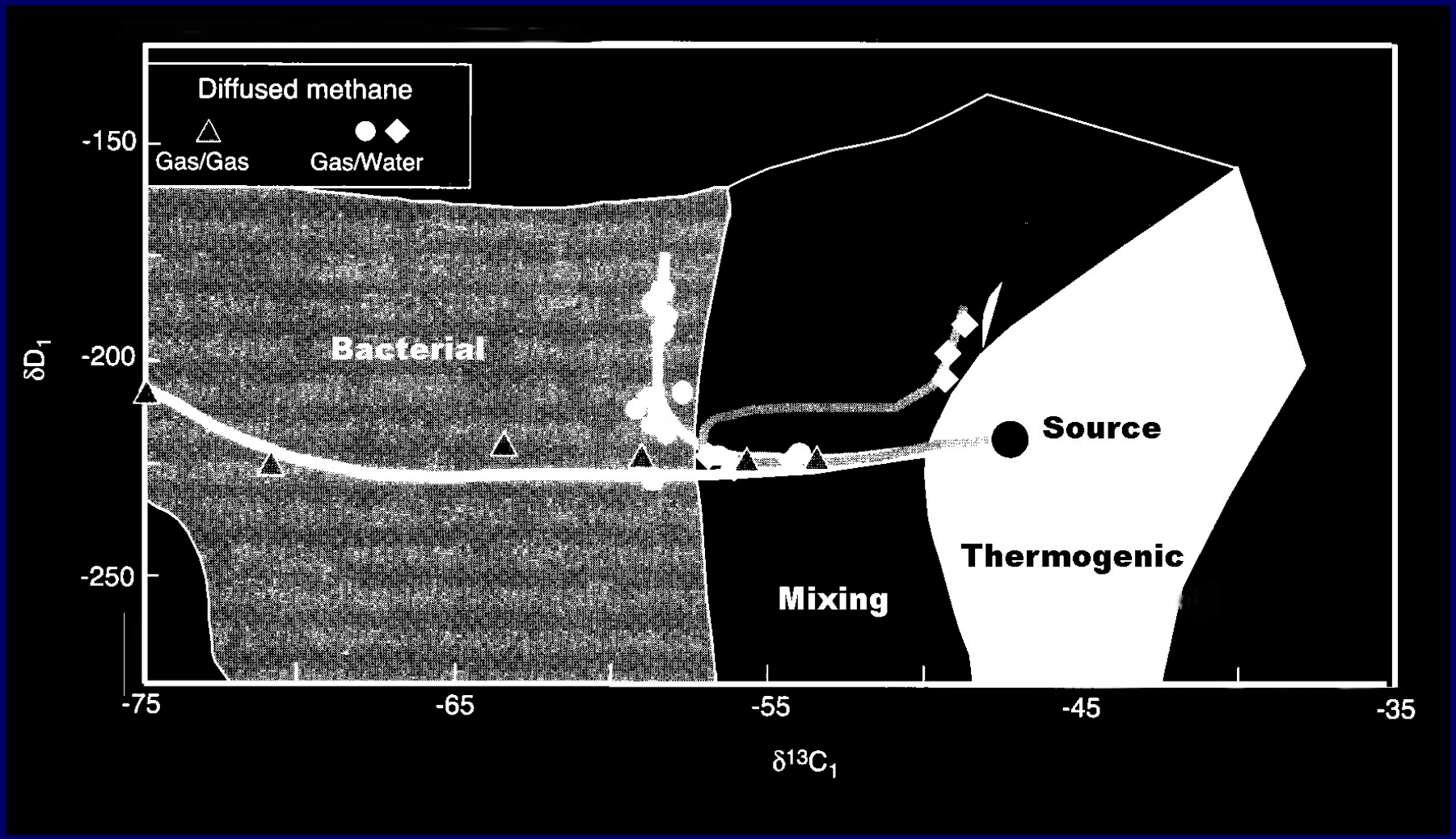
Isotope ratios of gases



(after Wiese and Kvenvolden 1993, modified)



(after Prinzhofer and Battani 2003)



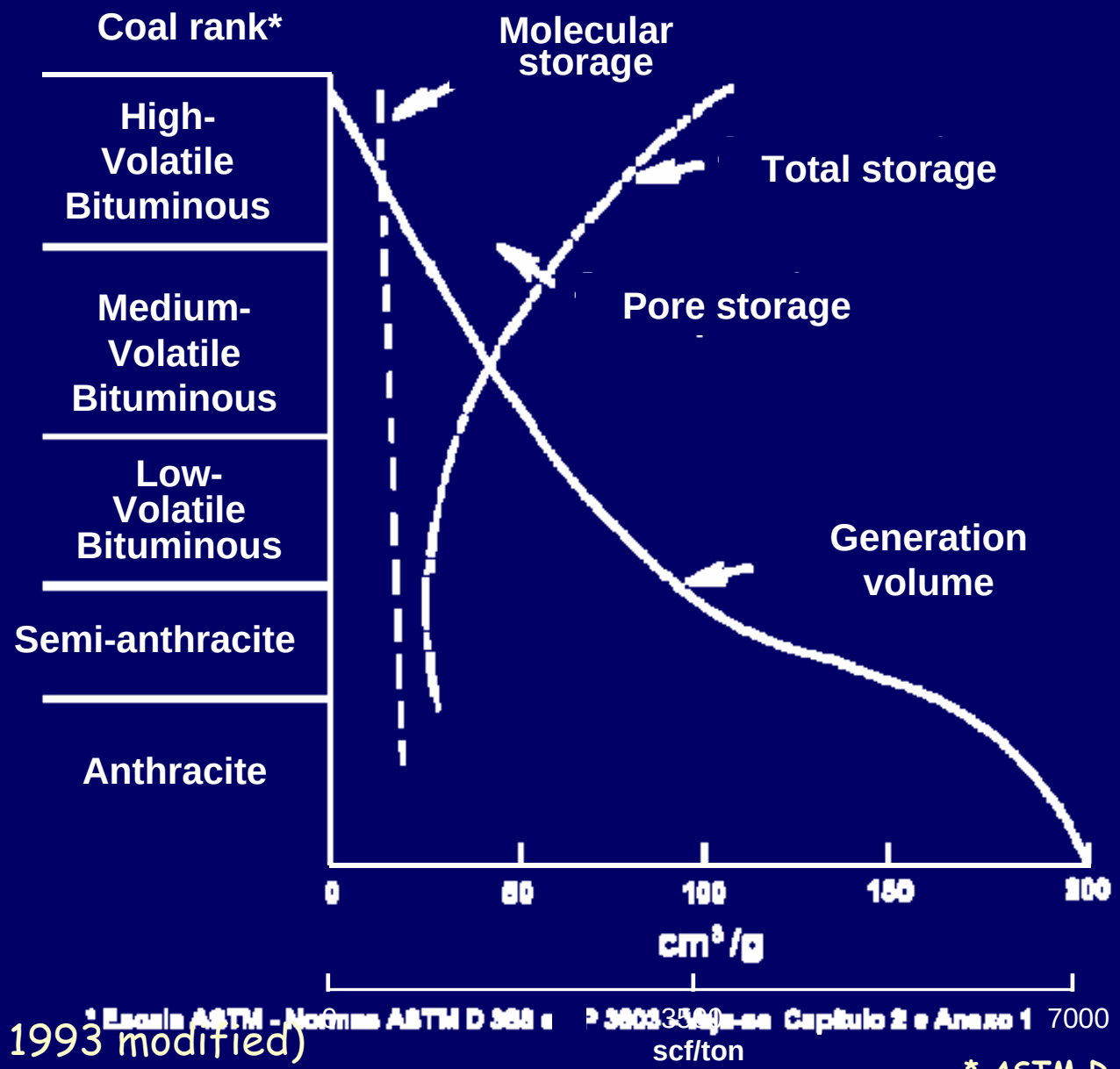
(after Prinzhofer and Battani 2003)

3. Storage *versus* release

Characteristics of coal as CBM reservoir

- ✓ Coal is simultaneously a source rock and a reservoir rock
- ✓ The mechanism of gas storage: condensed form very close to a liquid state
- ✓ Coal moisture:
  - Moisture Holding Capacity/Equilibrium moisture
  - Water of meteoric origin
  - Water from adjacent aquifers
- ✓ The fracture system of coal/"cleat system": relation with mechanical properties and permeability

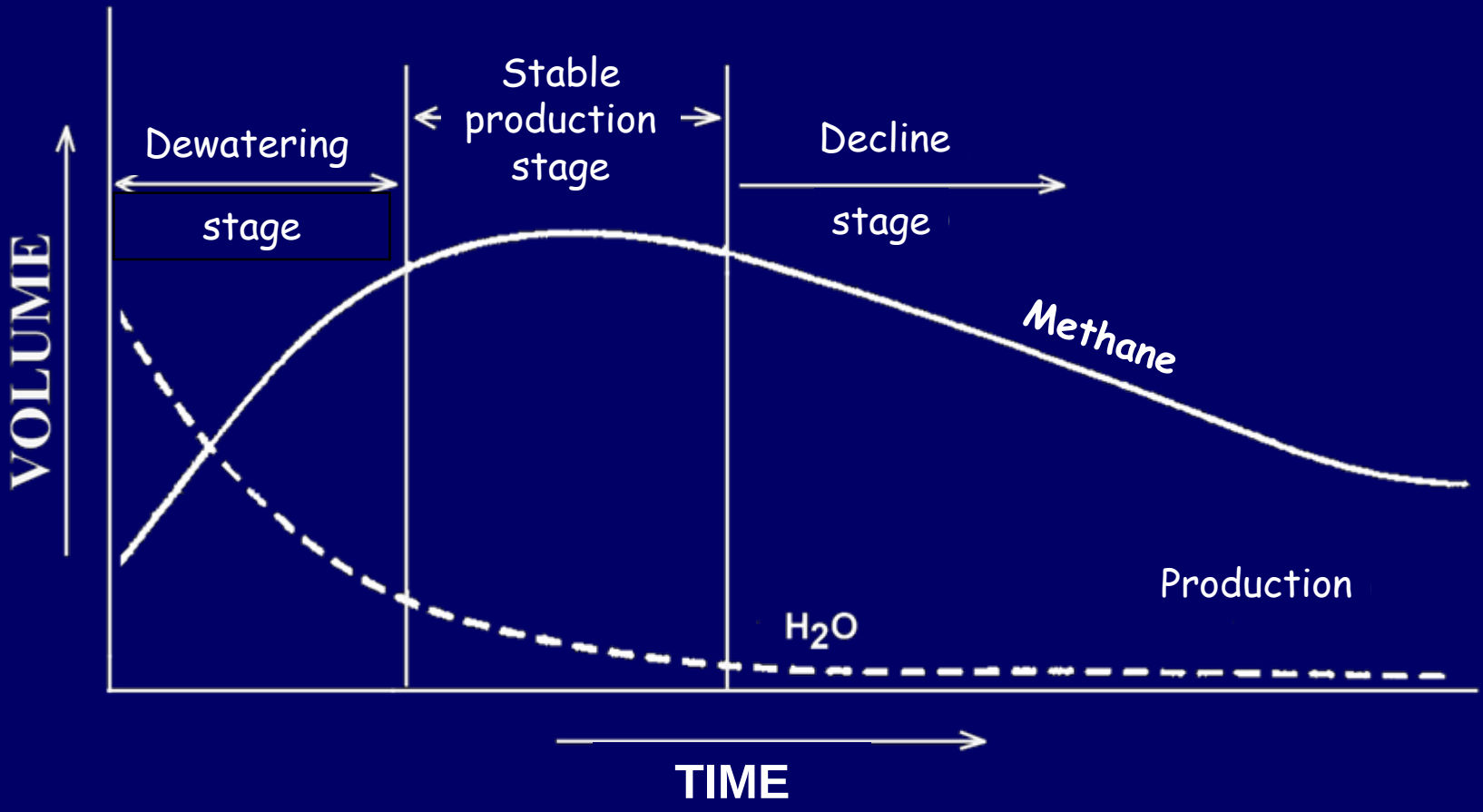
Volume (cm^3) of methane generated and stored per gram of coal with increasing rank



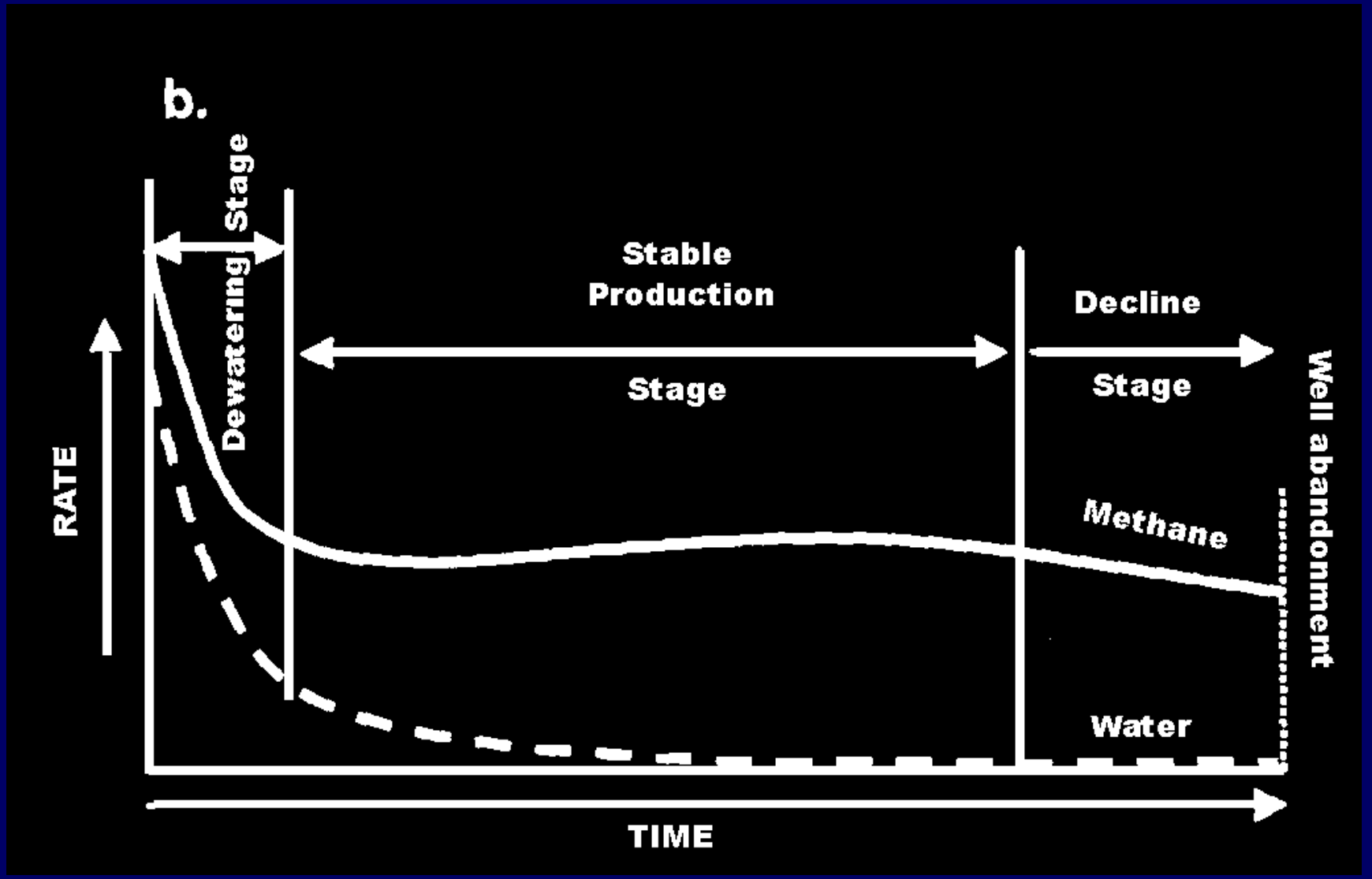
(after Rice 1993 modified)

* ASTM D-388 Standard

Generalised production history of a CBM well

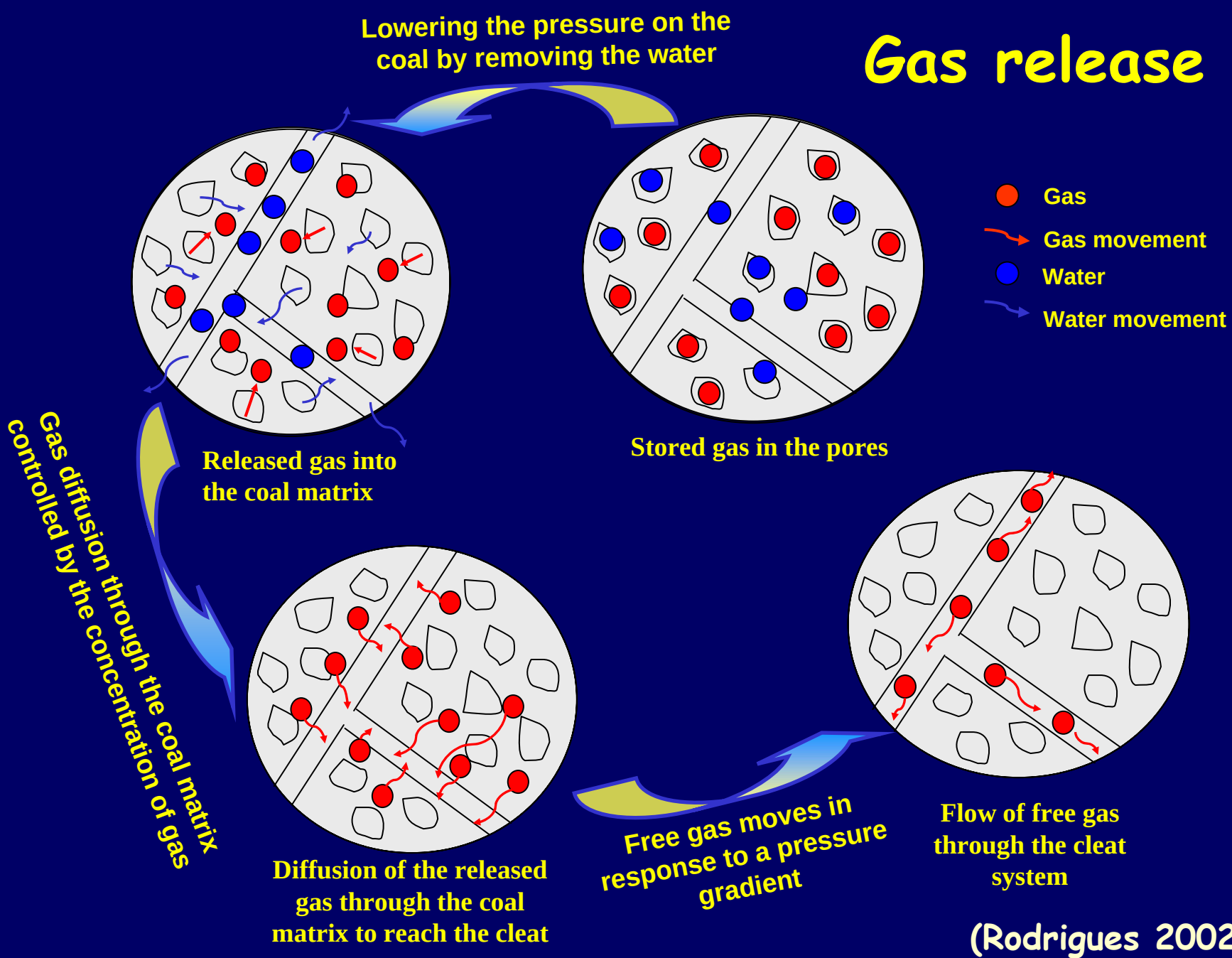


(after Kruuskraa and Brandenberg 1989 in. Rice et al. 1993)



(after Ayers Jr. 2003)

Gas release



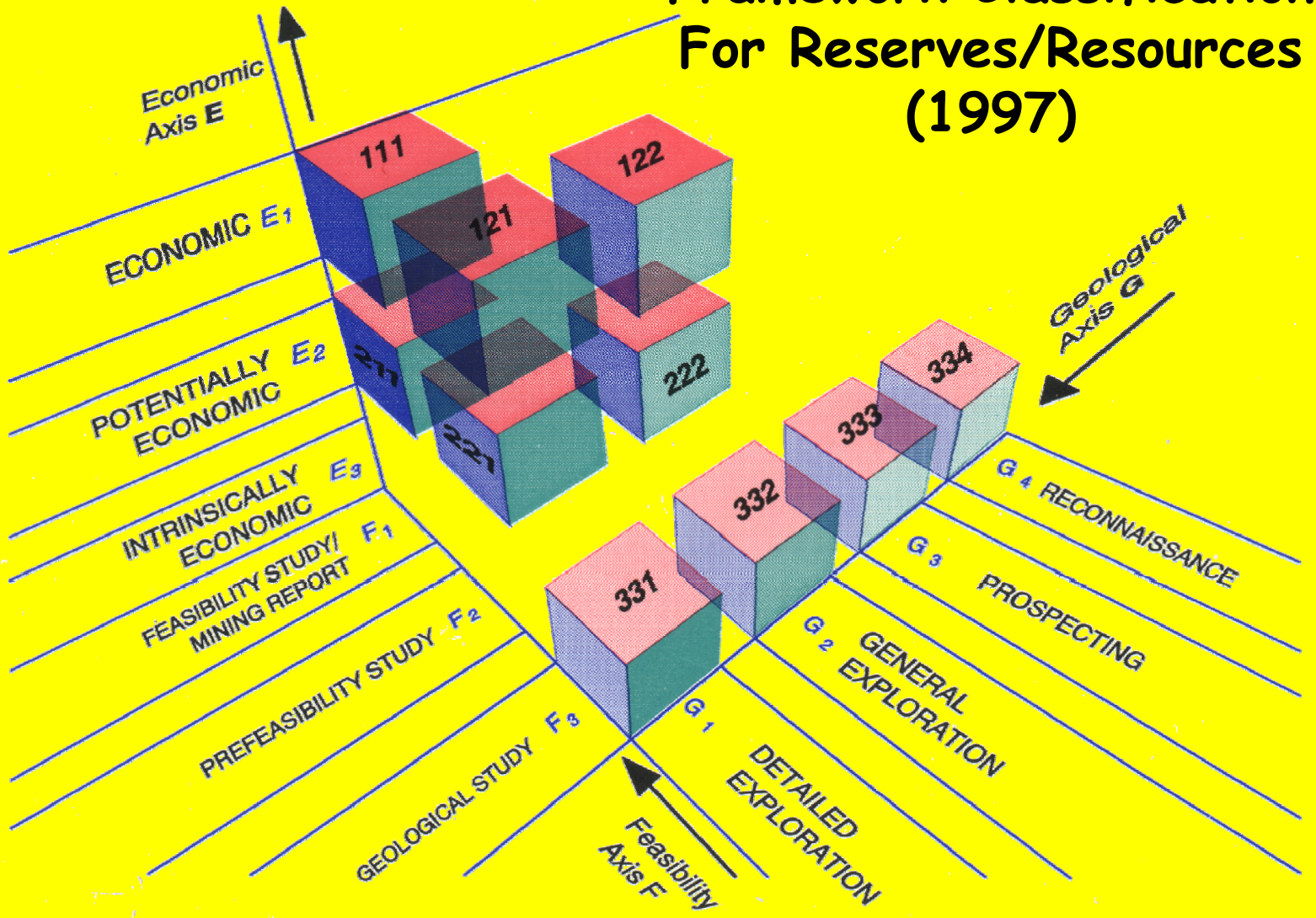
(Rodrigues 2002)

4. Criteria to be followed in prospecting/exploring for CBM

Criteria to be followed in prospecting/exploring for CBM

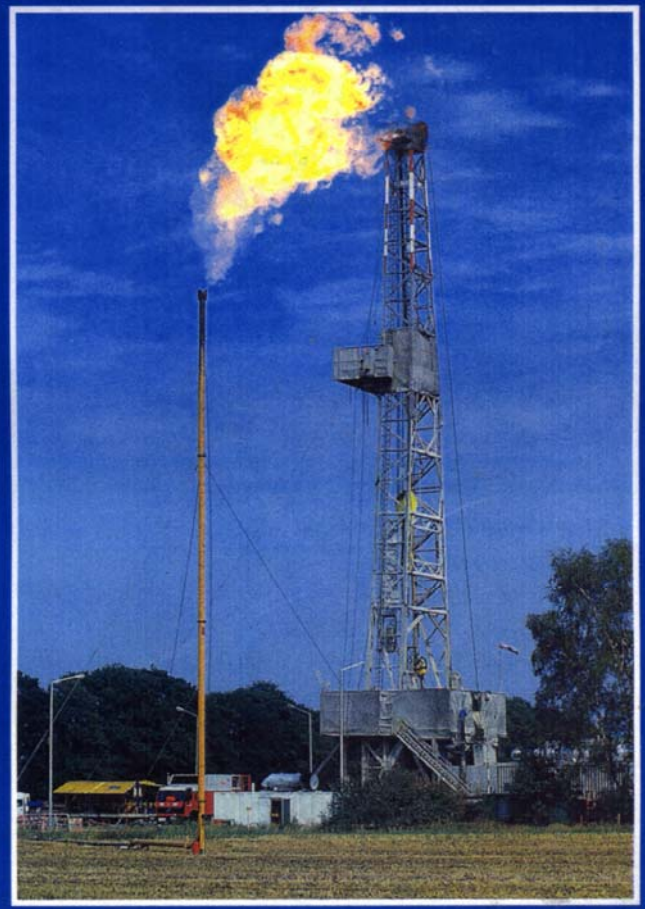
- Sufficient coal resources/reserves
- Required rank, petrographic composition and percentage of mineral matter
- Favourable geological and structural conditions
  - significant number of seams per unit, of reasonable thickness;
  - structural regime compatible with gas retention and release

UN International Framework Classification For Reserves/Resources (1997)



Glossary of Natural Gas Reserves

Exploration Exploitation Economics



BGR NLfB

Hannover 1996

5. Basic and fundamental studies in CBM prospecting/exploring

Basic and fundamental studies in CBM prospecting/exploring

General analyses:

- Total moisture and Moisture Holding Capacity analyses
- Density
- Proximate and Ultimate analyses
- Petrographic analyses (Reflectance, Macerals, Microlithotypes, Carbominerites and Minerite)
- Mineral Matter content by low-temperature ashing
- Chemical and mineralogical analyses of the mineral matter
- Isotopic composition of produced gas
- Palaeofacies of coal sedimentation

Specific analyses:

- ✓ **Gas content: Q1 (lost), Q2 (desorbed) and Q3 (residual)**
- ✓ **Molar composition of the produced gas**
- ✓ **Gas sorption (adsorption + desorption) isotherms**
- ✓ **Detailed study of the Cleat System**
- ✓ **Water produced with Coalbed Methane**

Oversimplifications can lead to faulty coalbed gas reservoir analysis

Jeffrey R. Levine (Oil & Gas Journal, Nov. 23, 1992)

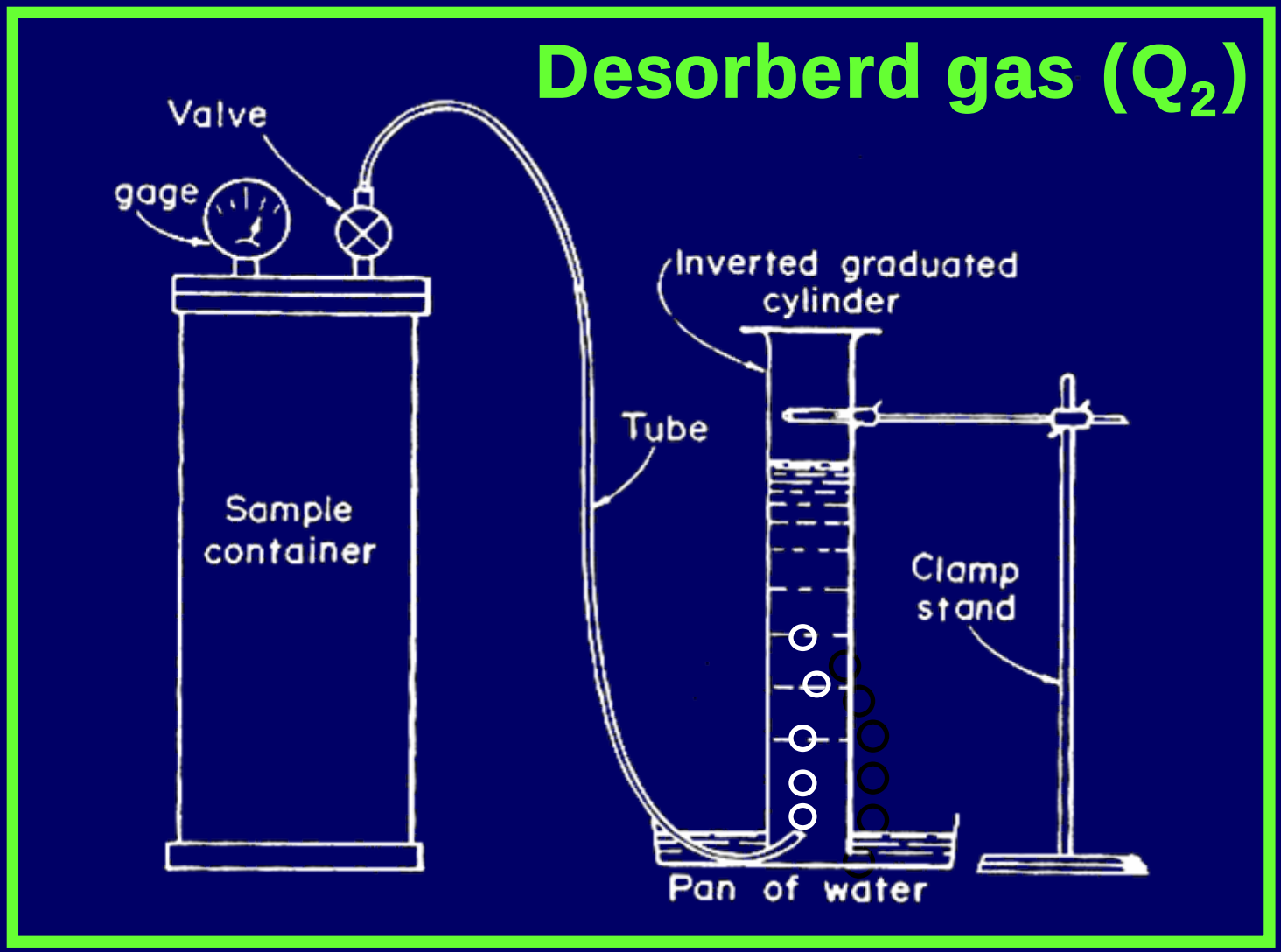
5.1. Gas content

Q_1 (lost)

Q_2 (desorbed)

Q_3 (residual)

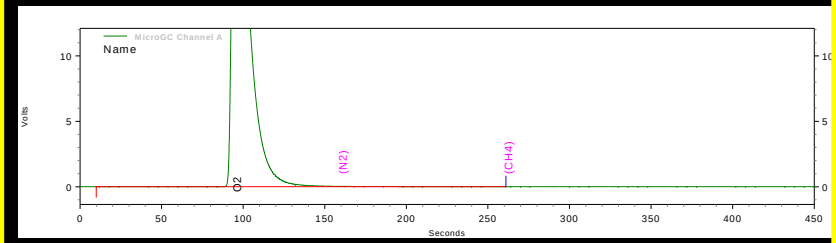
Gas content determinations (Q_2 and Q_3) - USBM direct method



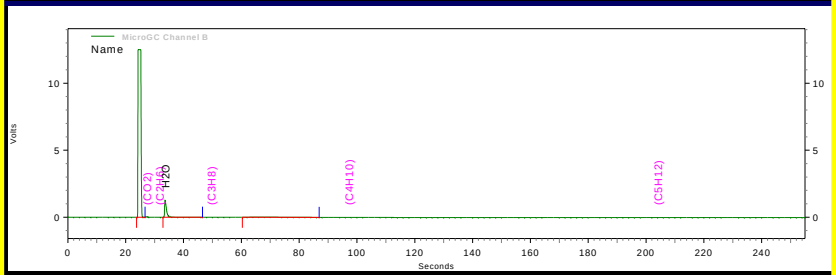
Residual gas (Q_3)

5.2. Molar composition of the produced gas

Chromatographic analyses of molar composition of gases



Totals			40676328	**103,790**



Totals			940439	**214,712**

5.3. Coal Sorption (adsorption + desorption) Isotherms

Gas Sorption (Adsorption + Desorption) Isotherms

The main objectives related to this experimental method are:

- to determine the maximum gas storage capacity of a coal *in situ*.
- to estimate the actual volume of gas *in situ*.
- to estimate the gas saturation degree of a coal by the difference between the maximum gas storage capacity and the actual volume of gas.
- to estimate the diffusion rate of gas flow.
- to estimate the gas stored composition.
- to estimate the volume of gas that will be released from the coal as reservoir pressure decreases.

Isotherm Models

- Gibbs
- Potential theory
- Langmuir

Langmuir Isotherms

- Provides a good description of sorption for microporous sorbents such as coal, where the gas molecule and sorbent pore size are of comparable size.

- This model describes the existing equilibrium between the stored gas and the free gas in microporous structures.

(Yee et al 1993)

Langmuir equation

$$V = (VL \times P)/(P+PL)$$

- V = adsorbed gas volume (scf/ton or cm^3/g)
- VL = Langmuir volume (scf/ton or cm^3/g)
- P = pressure (Psi or MPa)
- PL = Langmuir pressure (scf/ton or cm^3/g)

Prototype for the determination of gas adsorption isotherms by coal.

- 1. Reference cell; 2. Sample cell; 3. Helium valve; 4. Methane valve; 5. Supply valve; 6. Purge valve of the system; 7. Purge valve of the cells; 8. Termocouple (temperature T_2); 9. Thermocouple (temperature T_3); 10. Connection valve between cells; 11. Thermostatic head; 12. Thermometer (T_1); 13. Voltmeter; 14. Computer with software to performe the data acquisition.

Variables that influence a coal isotherm (in terms of gas storage)

Coal sample characteristics

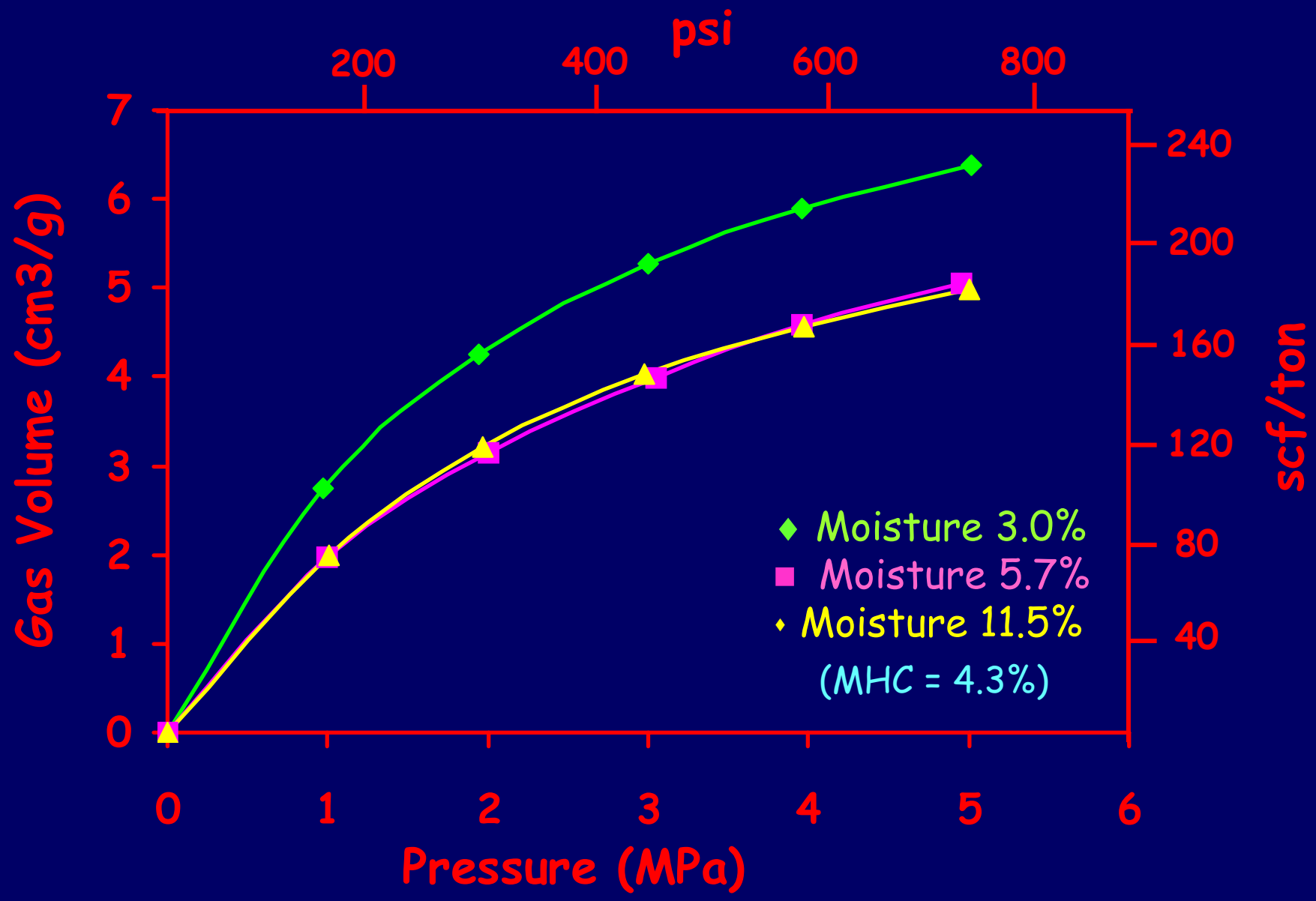
- Rank
- Petrographic composition
- Mineral matter content

Experimental

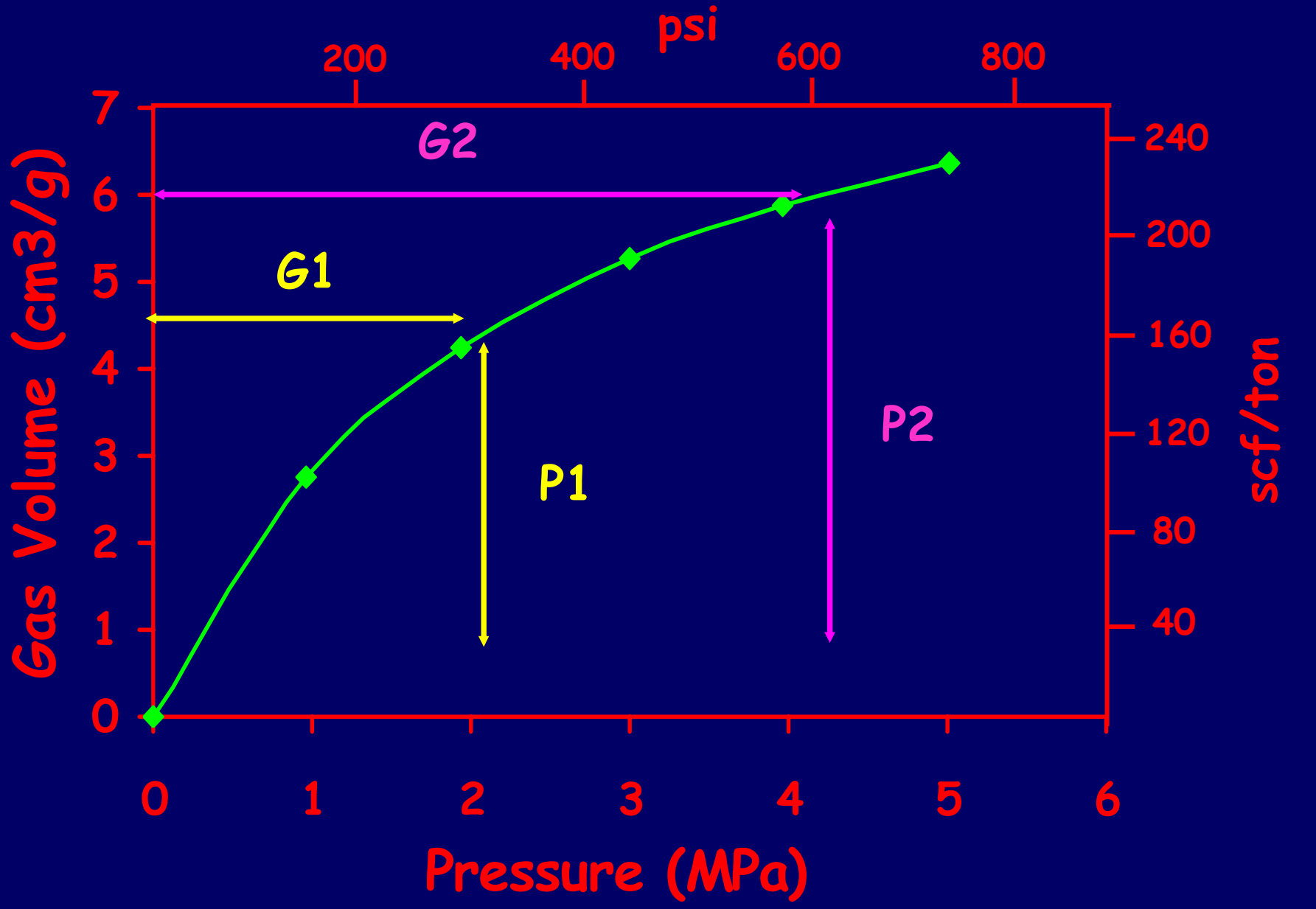
- Moisture
- Temperature
- Pressure
- Gas composition

} Gas compressibility factor

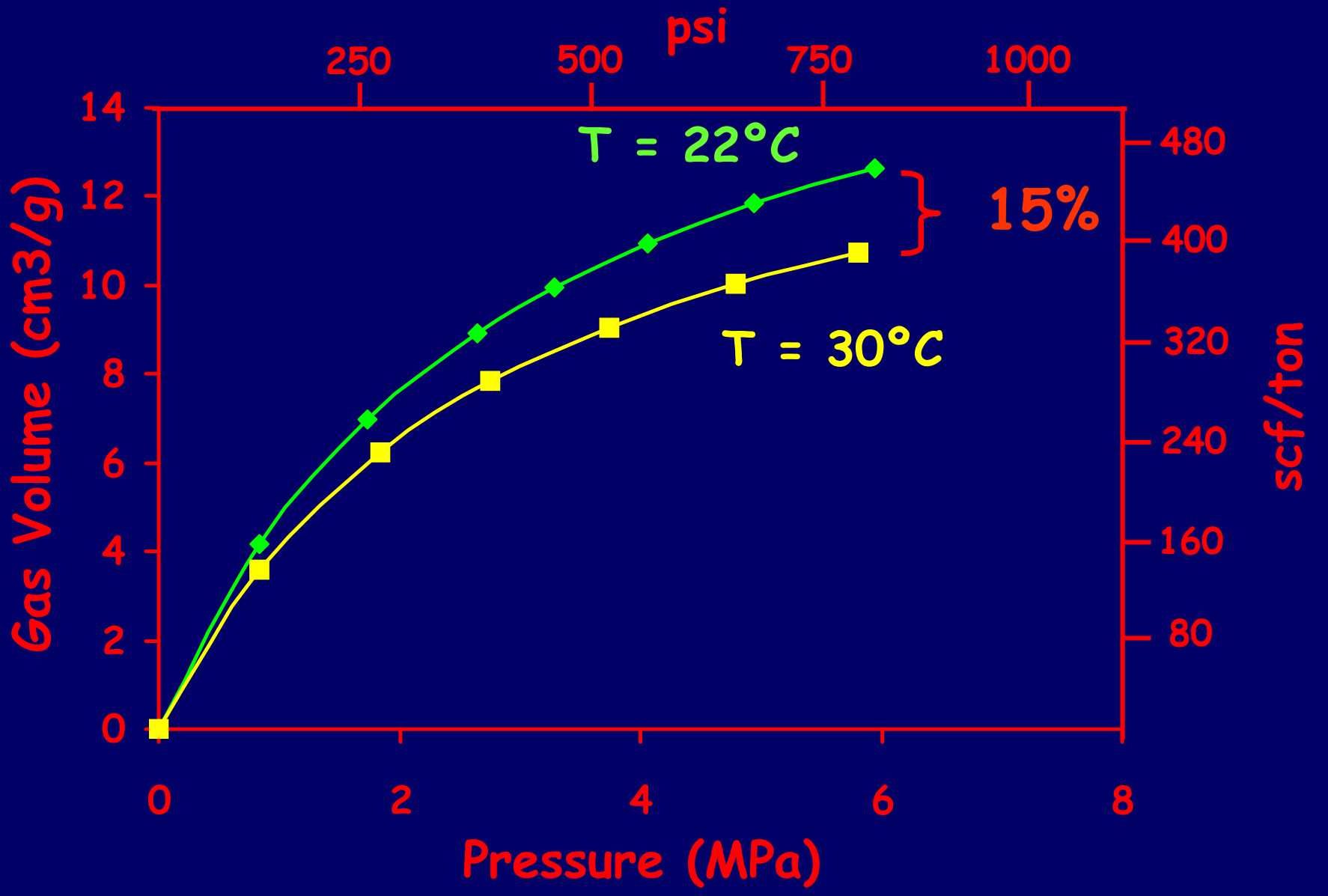
Moisture effect



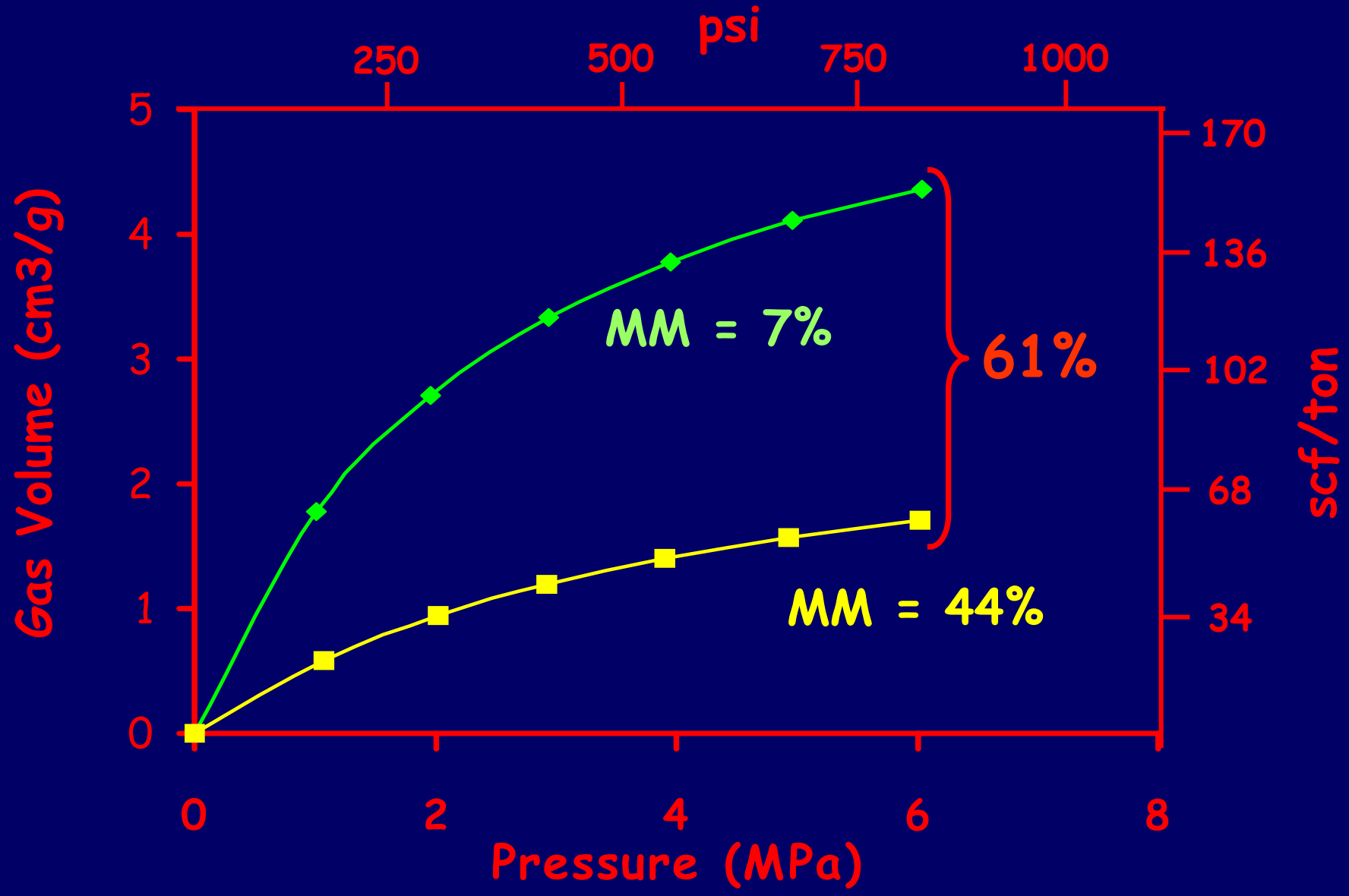
Pressure effect



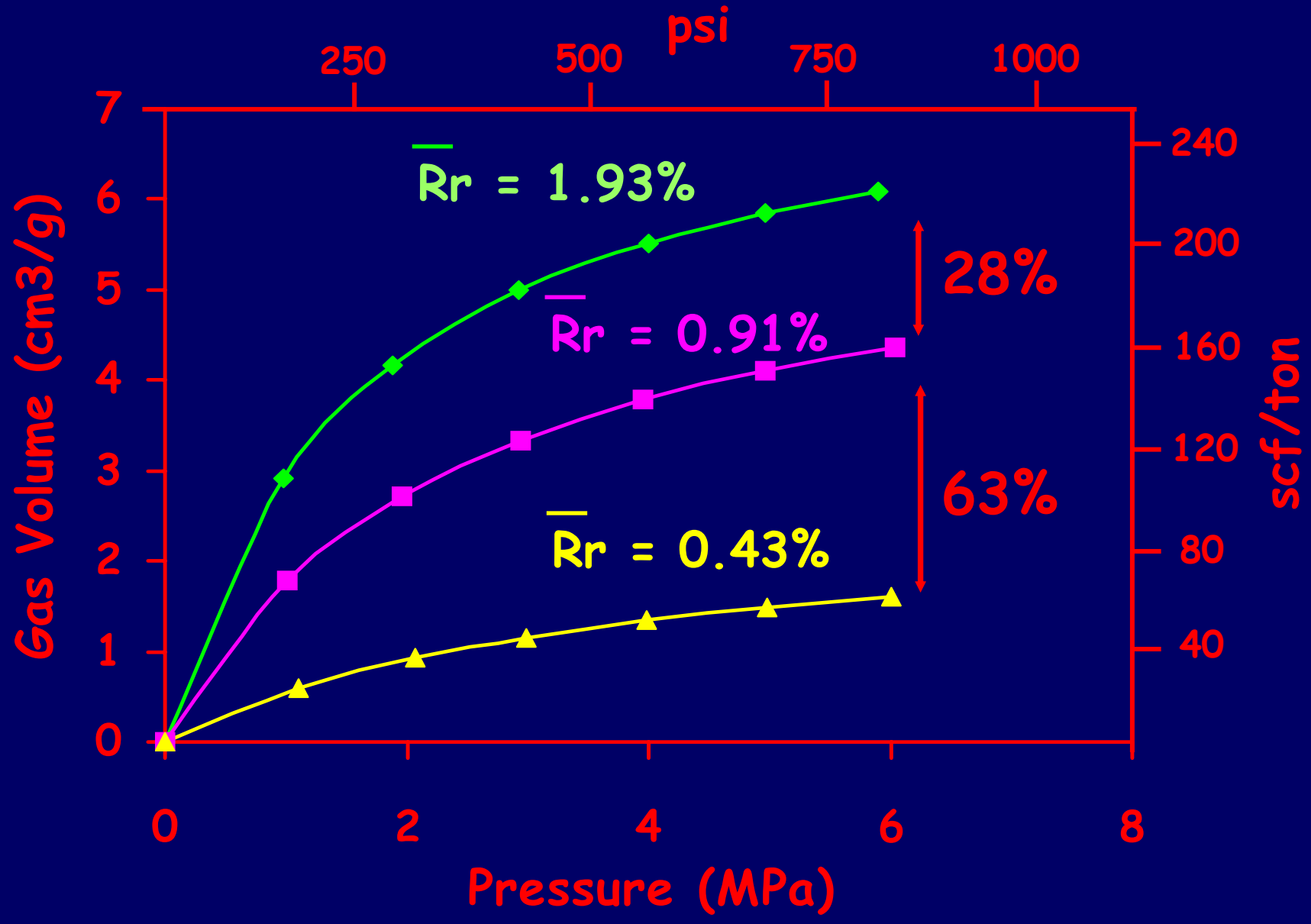
Temperature effect



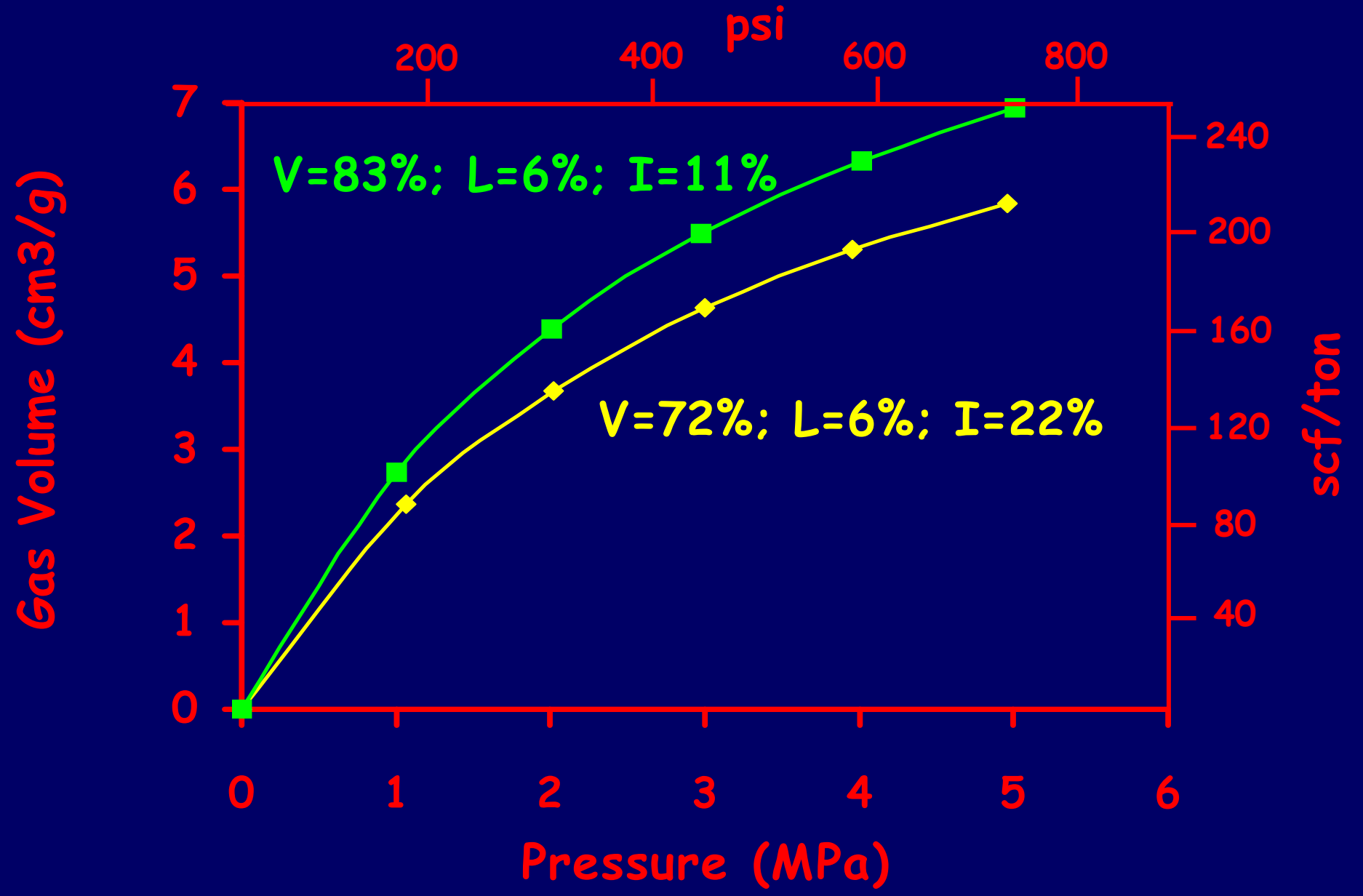
Mineral matter effect



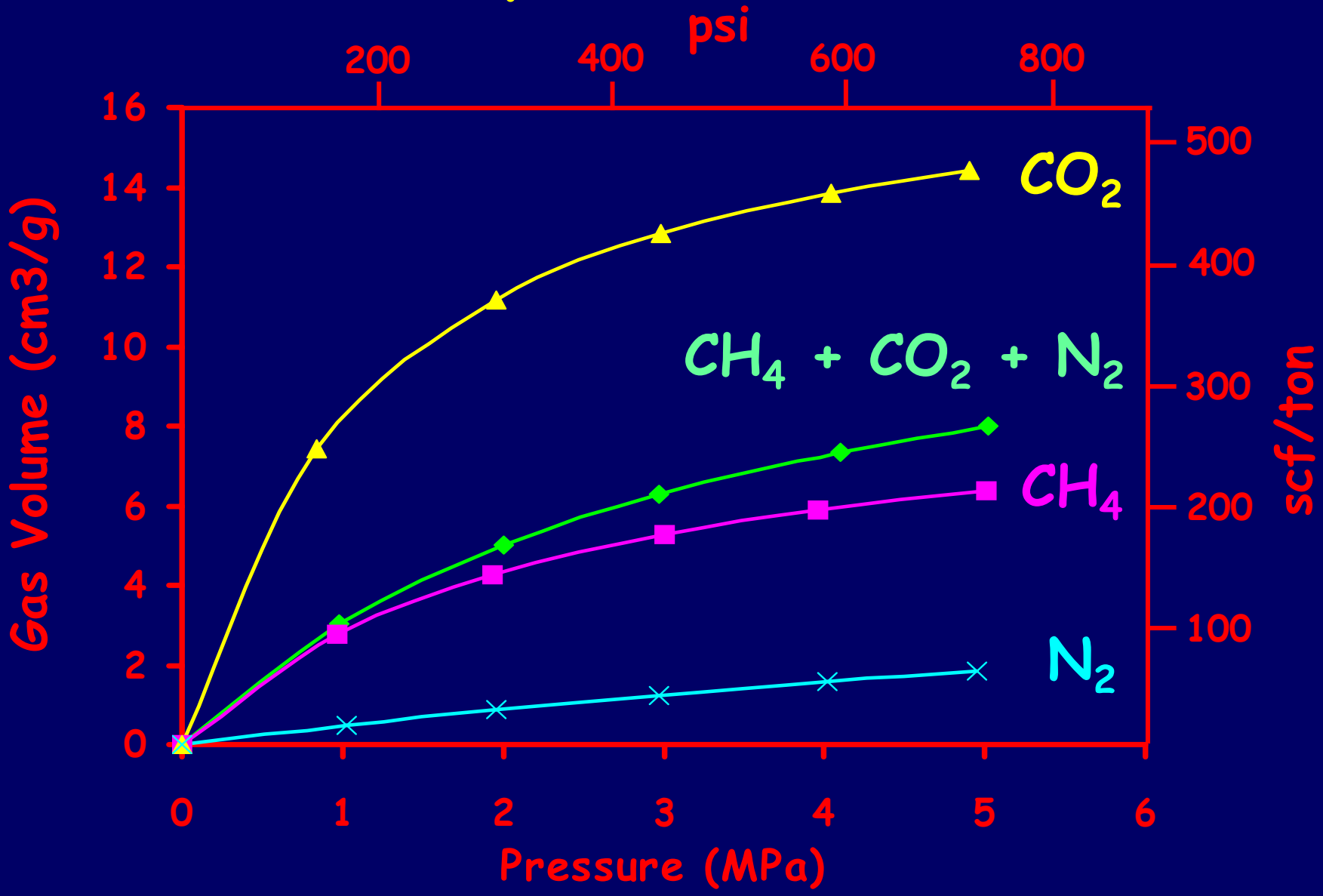
Rank effect


psi
250
500
750
1000
7
6
5
4
3
2
1
0
240
200
160
120
80
40
Gas Volume (cm3/g)
scf/ton
Rr = 1.93%
Rr = 0.91%
Rr = 0.43%
28%
63%
0
2
4
6
8
Pressure (MPa)

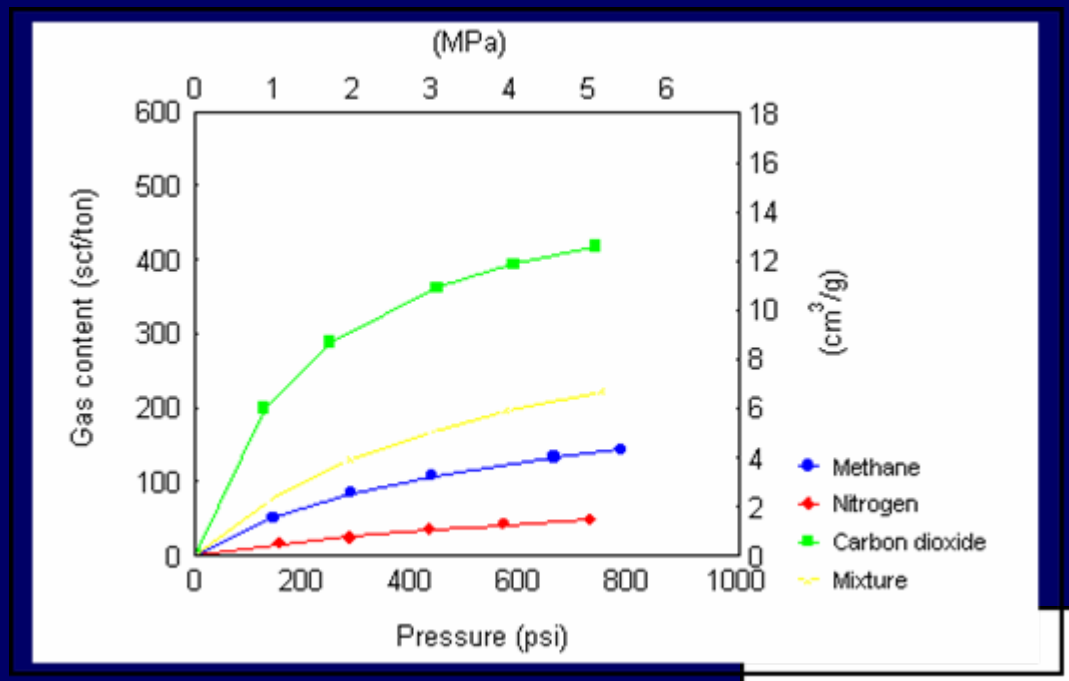
Petrographic composition effect

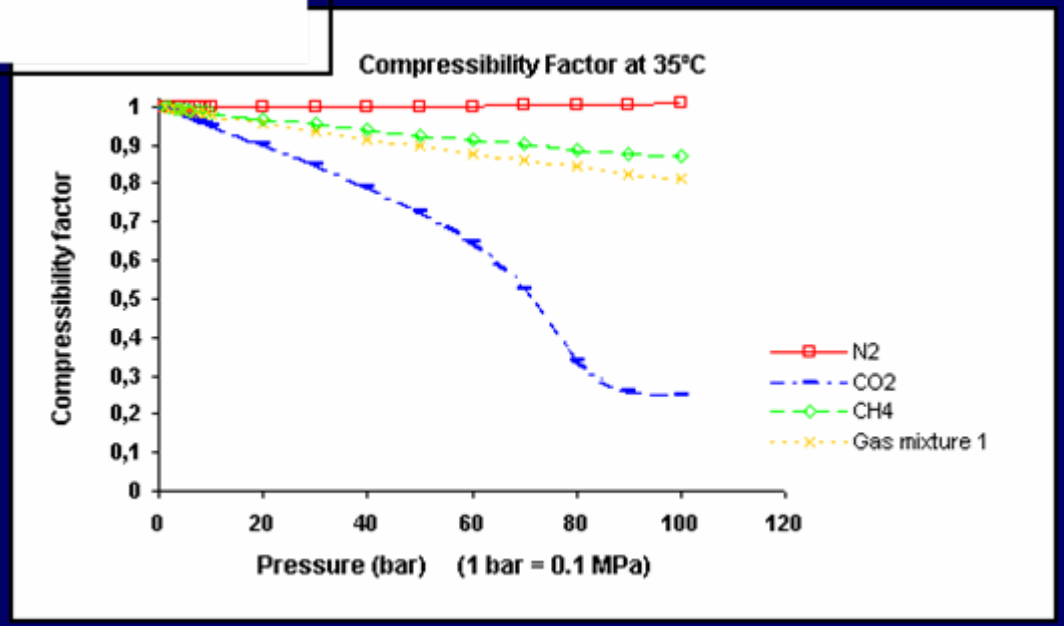


Gas composition effect

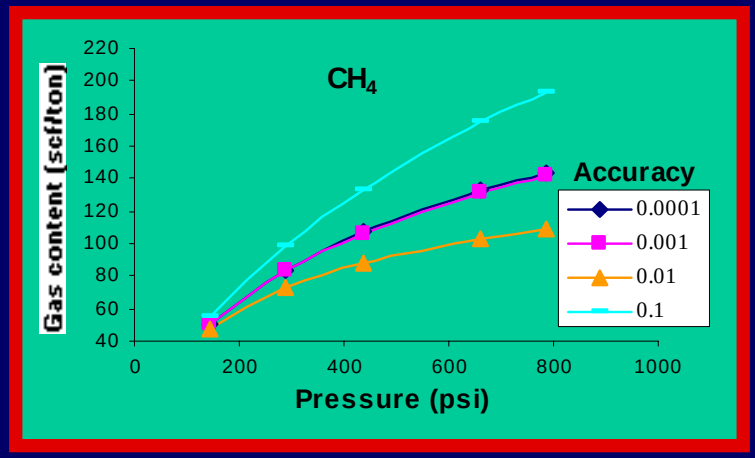


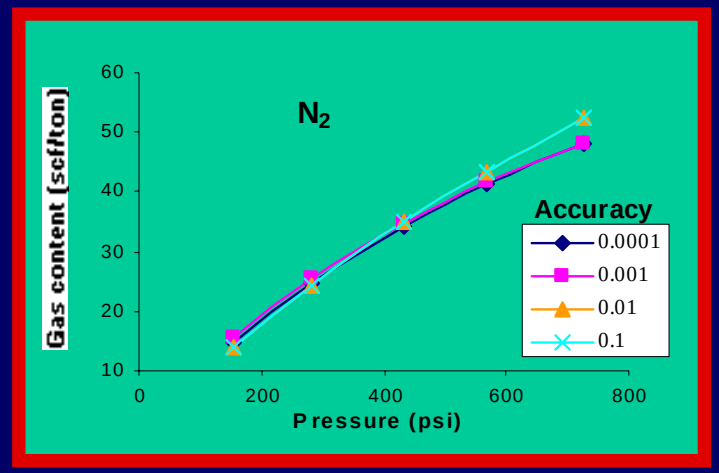
Compressibility factor

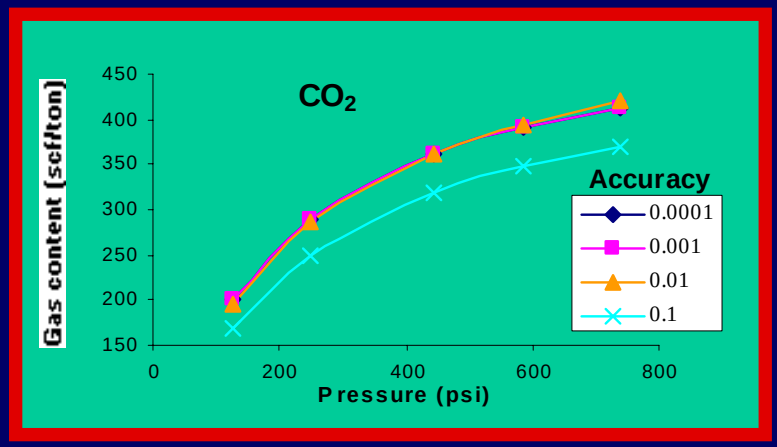


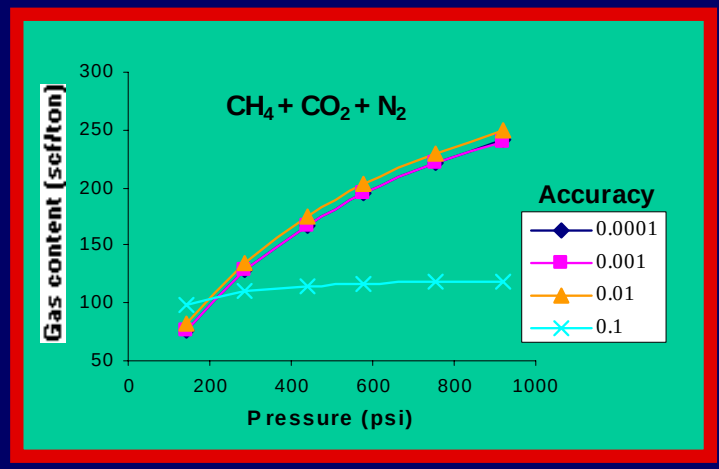


Accuracy values for the compressibility factor









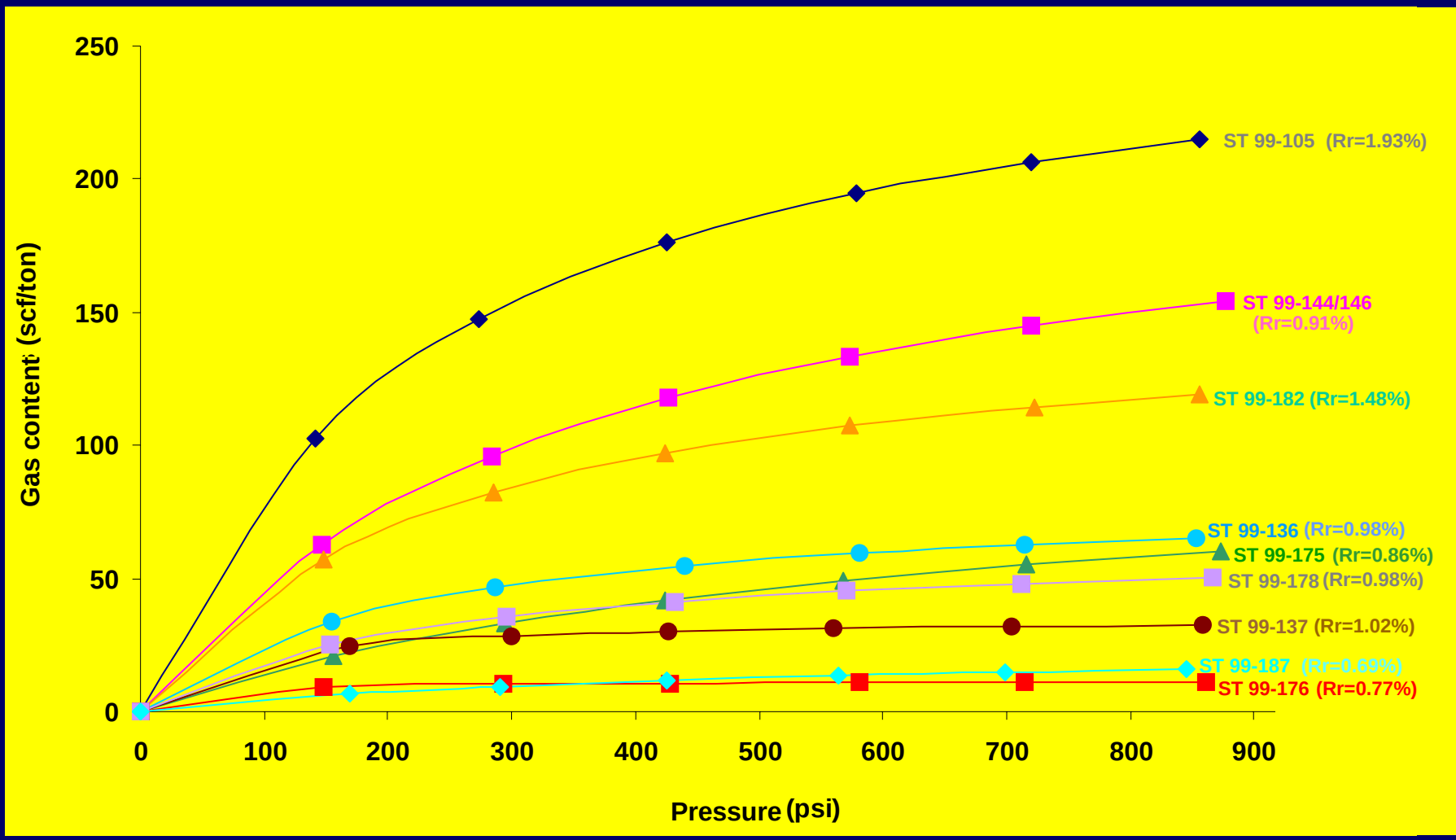
Cristina Fernanda Alves Rodrigues

The application of isotherm studies to evaluate the Coalbed Methane potential of the Waterberg Basin, South Africa

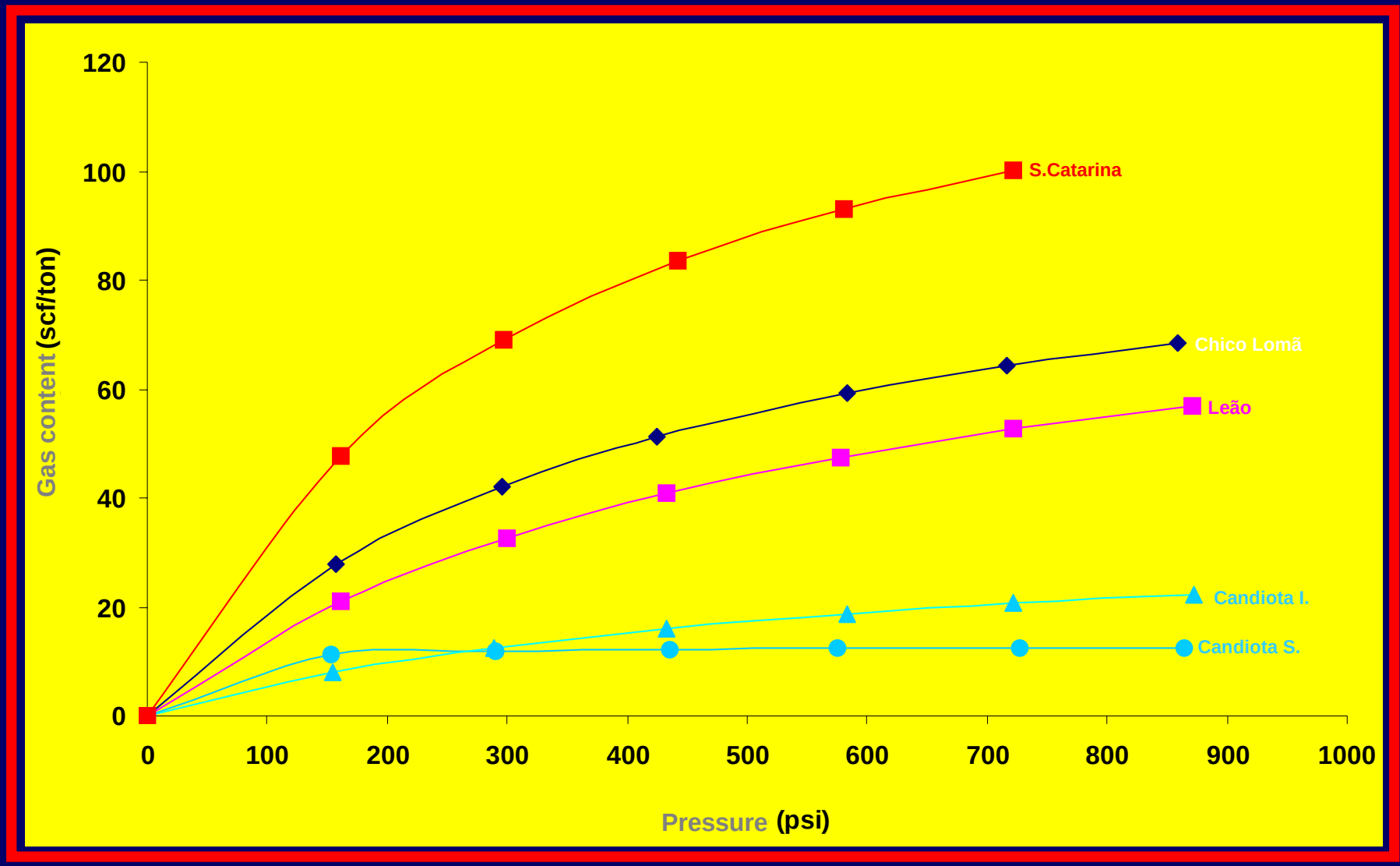
Universidade do Porto, Faculdade de Ciências
Departamento de Geologia

Dezembro 2002

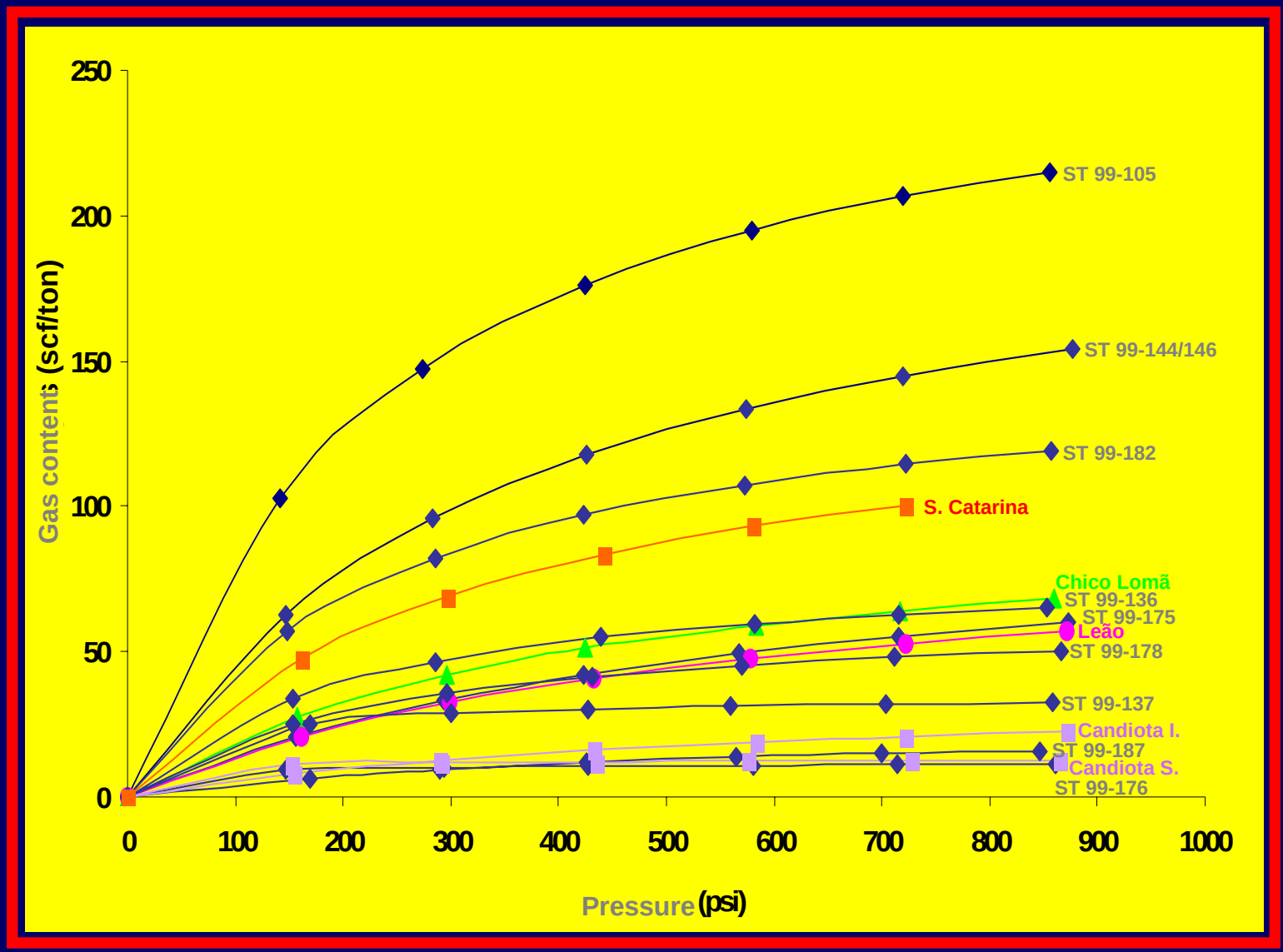
Santa Terezinha Basin (Brazil) Isotherms



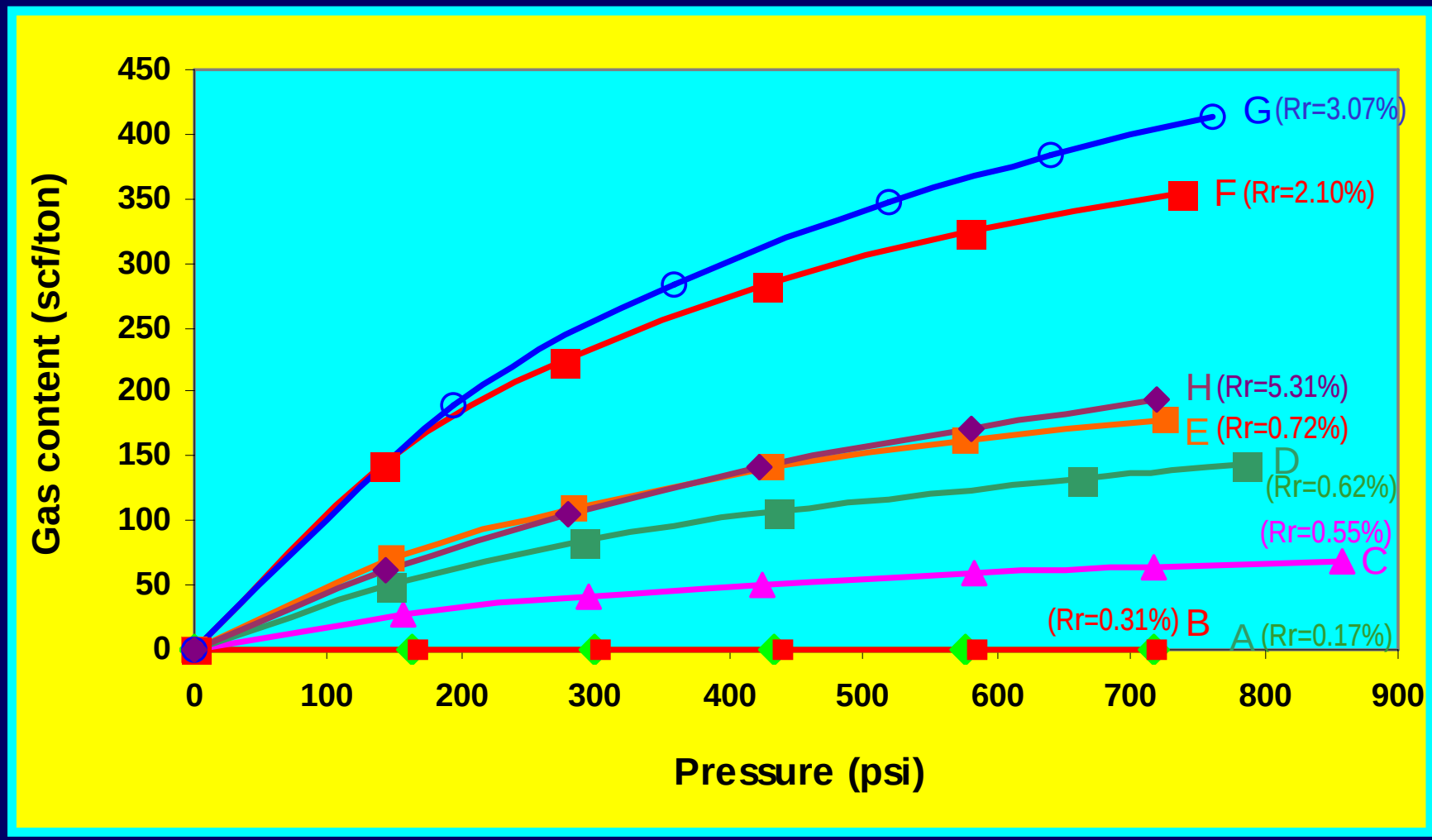
Brazil - Santa Catarina, Leão, Candiota and Chico Lomã basins Isotherms



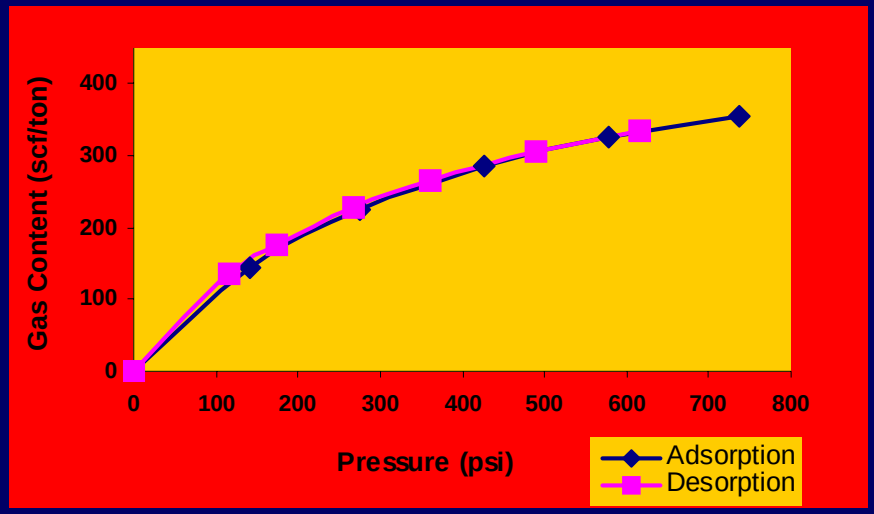
Brazilian Coal Basin Isotherms



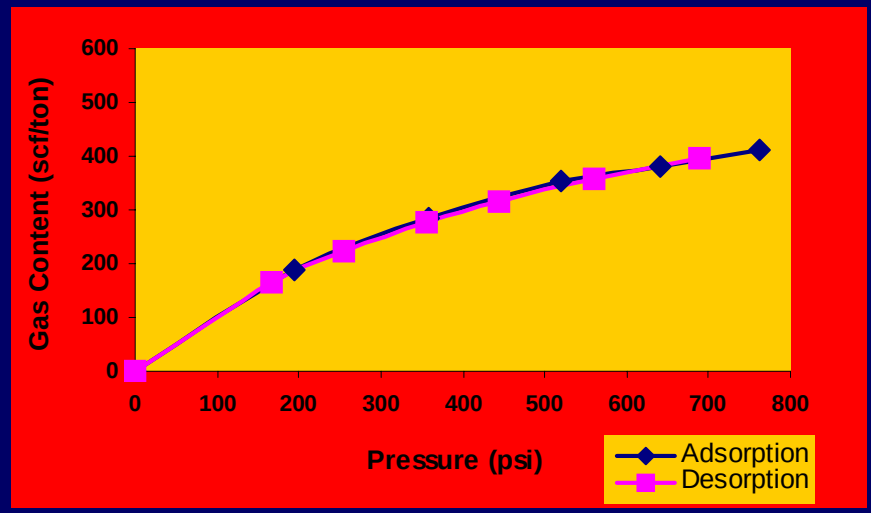
Gas sorption isotherms from lignite to anthracite



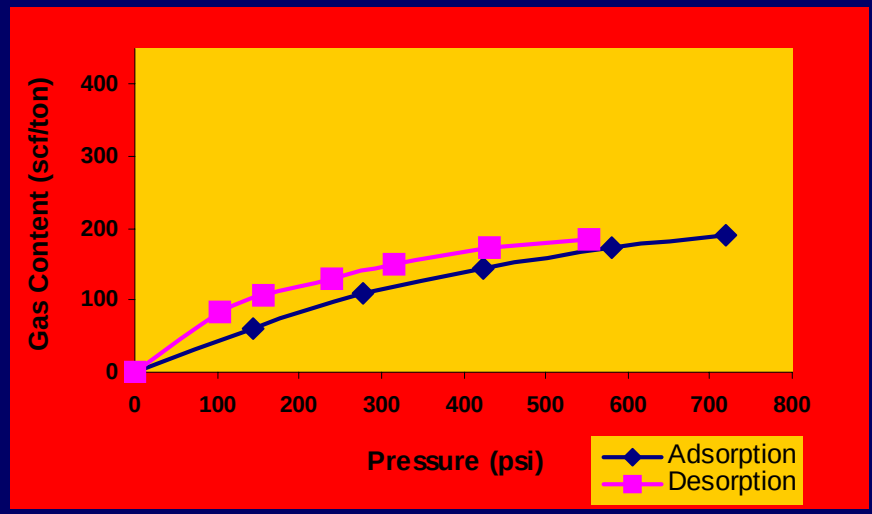
Adsorption/desorption curves of anthracites



Sample F (Rr=2.10%)



Sample G (Rr=3.07%)

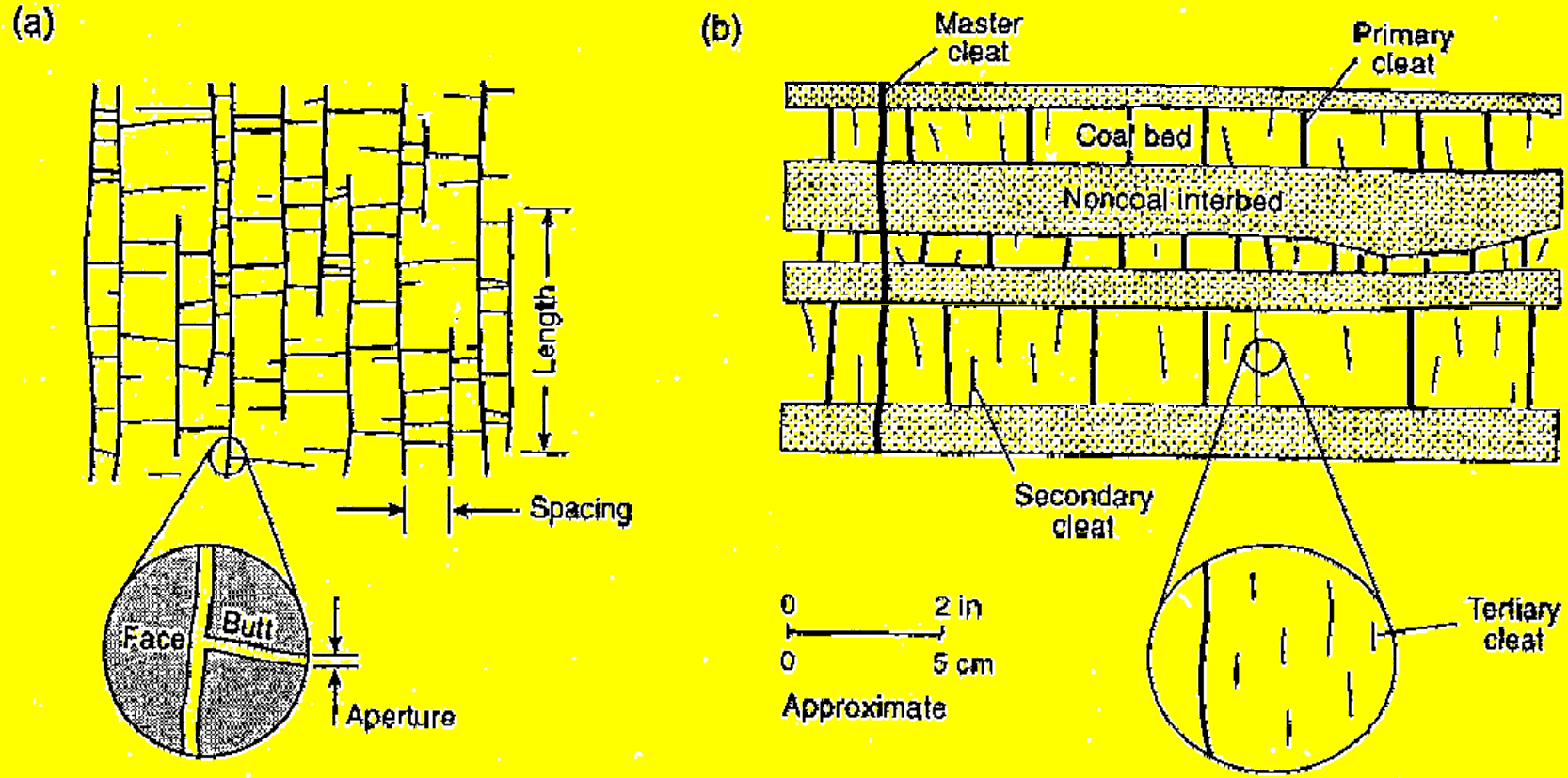


Sample H (Rr=5.31%)

5.4. Detailed study of the Cleat System

Schematic illustration of coal cleat

(a) cleat characteristics in plan view;
(b) cleat hierarchies in cross- section view



Laubach et al 1998

Coal cleat characteristics

- Cleat directions relative to a reference;
- Cleat frequency;
- Cleat height;
- Cleat length;
- Cleat spacing;
- Number of cleat connectivity/intersections;
- Cleat aperture;
- Number of cleats filled by minerals.

"Coal-core tectonics" (CCT) Method

Semi-automated computerized: GIS combined with a set of different softwares, such as "Georient", "Rockworks")

Save time

"time is money!"

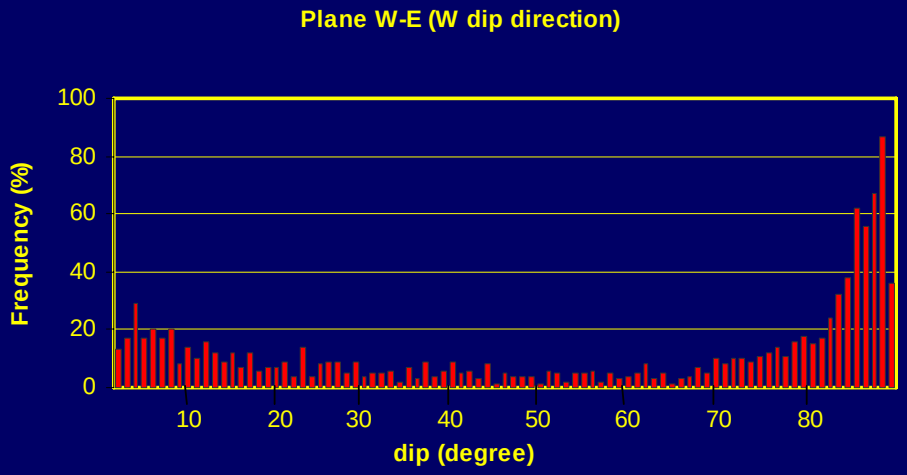
Save money

Direct link between field and computerized data

High accuracy

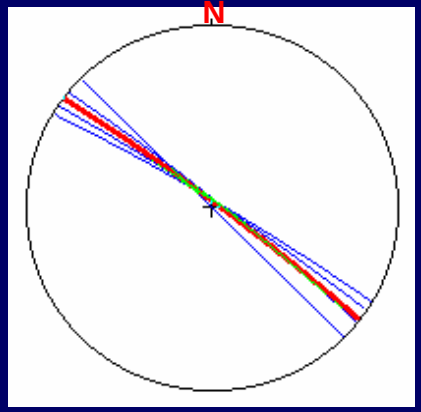
Representative statistical data

Statistical analyses from georeferentiated data



Cleat frequency (decrease order)	Cleat lines measured in N-S plane (N dip direction)	Cleat lines measured in W-E plane (E dip direction)
1	88º → 0º	88º → 90º
2	89º → 0º	87º → 90º
3	87º → 0º	85º → 90º
4	85º → 0º	86º →90º
5	86º → 0º	84º → 90º
6	80º → 0º	89º → 90º
7	3º → 0º; 83º → 0º and 84º → 0º	83º → 90º
8	2º → 0º	3º → 90º
9	5º → 0º	82º → 90º
10	82º → 0º	7º → 90º and 5º → 90º

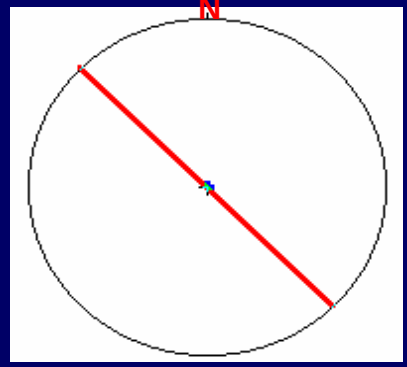
Dip direction interval 120º - 150º



Mean Orientation = 87/037
Mean Resultant dir'n = 87-037
Mean Resultant length = 1,00
(Variance = 0,00)
Calculated. girdle: 8/145
Calculated beta axis: 82-325

Mean Plane: N 127º, 87ºE

Cleat frequency 1

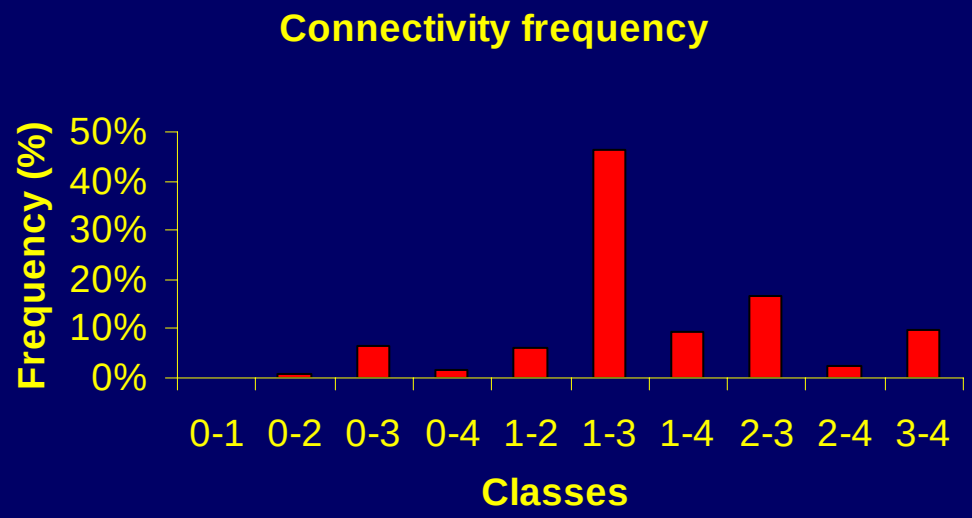


Mean Direction = 89-045
Mean Resultant dir'n = 89/045
Mean Resultant length = 1,00
(Variance = 0,00)
Calculated. girdle: 89/045

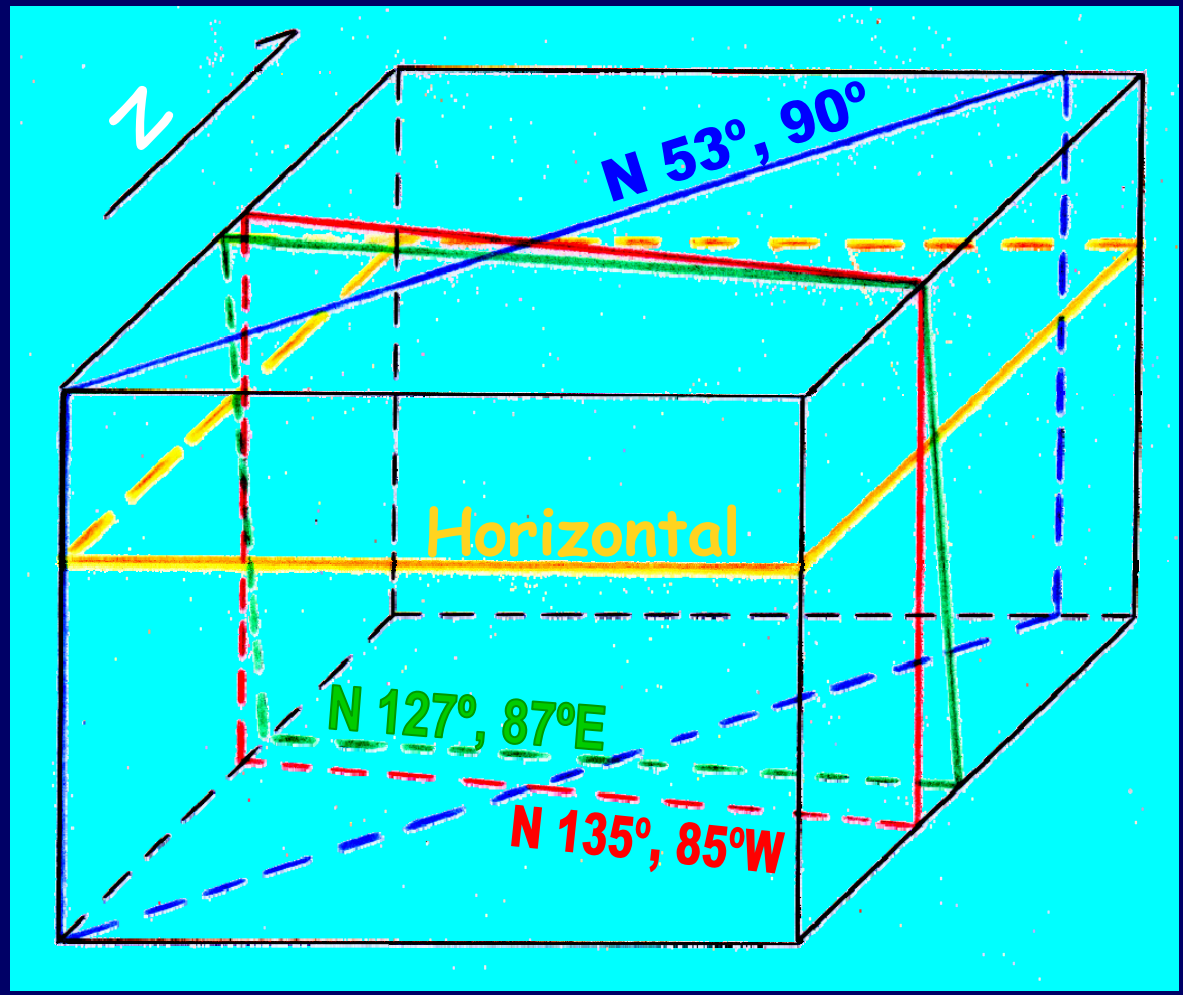
Plane: N 135º, 89ºE

Connectivity frequency

Class designation	Dip interval
Class 0	0º
Class 1	> 0º and ≤ 30º
Class 2	> 30º and ≤ 60º
Class 3	> 60º and ≤ 90º
Class 4	90



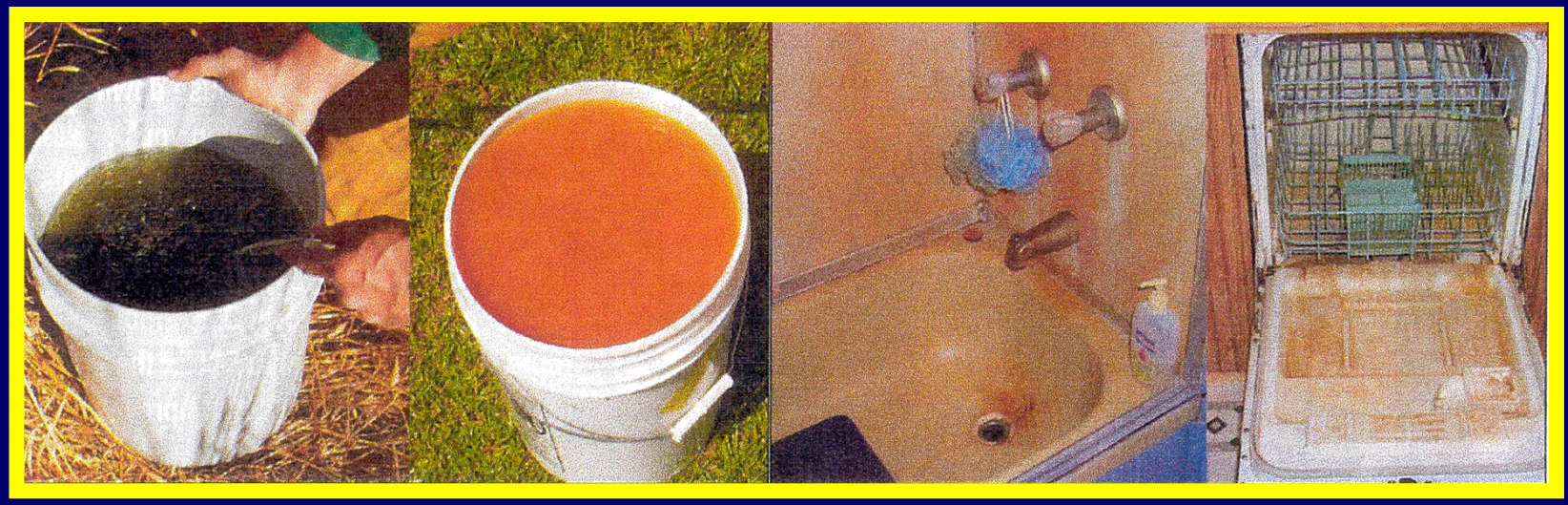
Schematic representation of the preferential planes



5.5. Water produced with Coalbed Methane

Methane Water: Friend or Foe?

Coalbed Methane: Gas Boom, Environmental Bust



A B C D

A – "Black water" (San Juan Basin) – Reduced iron and manganese, and sulphide smell.

B – "Red water" (Black Warrior Basin) – Oxidized iron.

C,D – Stained appliances in households in the Black Warrior Basin – Precipitated insoluble iron oxides.

(Gorody, 2001)

Water production in some USA major coal-bed-methane-producing basins

Basin	State	No. of wells	Avg. Water production		Ratio H_2O/gas	Primary disposal method
			(Bbl/day/well)	(m^3/day/well)		
San Juan	Colo./New Mexico	3089	25	2981	0.031	Injection
Black Warrior	Alab.	2917	58	6916	0.55	Surface disch.
Powder River	Wyo./Mont.	2737	400	47696	2.75	Ibid.
Uinta	Utah	393	215	25637	0.42	Injection
Raton	Colo.	459	266	31718	1.34	Ibid.

(USGS, 2000)

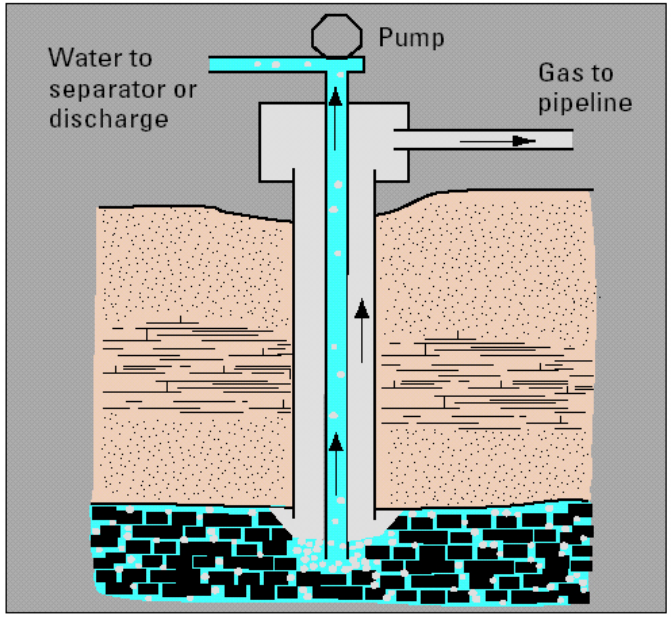
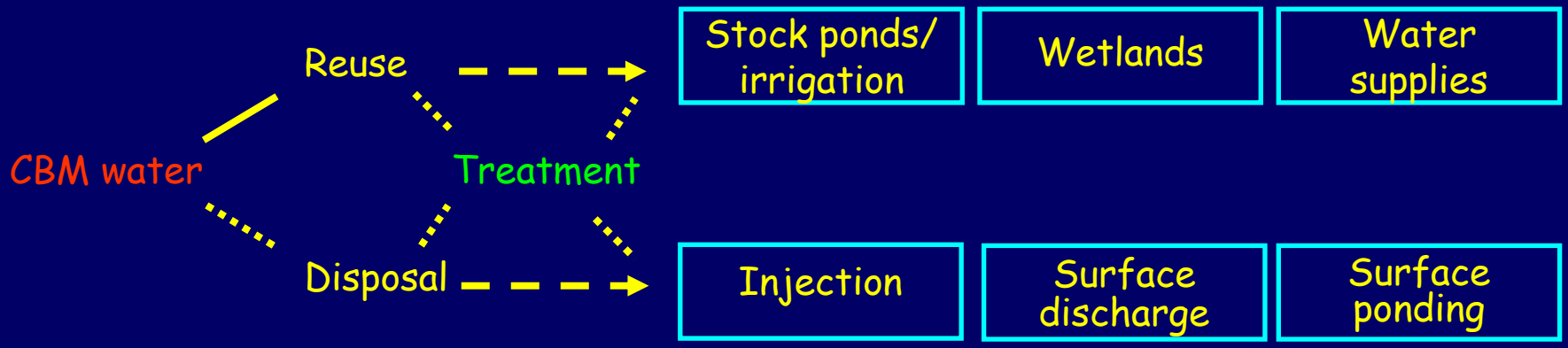


Figure 1. Simplified illustration of a coal-bed methane production well.

Figure 2. USGS chemist prepares to sample water from the wellhead of a coal-bed methane well. Wellhead sampling and on-site sample preservation and analysis are critical to obtaining good quality compositional and isotopic data. Many parameters, such as pH, alkalinity, and trace-metal content, change rapidly once the water is removed from the well.

(USGS, 2000)

Fate of CBM Water



(USGS, 2000)

6. Conclusions

In Conclusion

- Continuous re-evaluation and refinement of the criteria and parameters required for CBM prospecting/exploration is the only way in which **over-** or **underestimations** can be avoided or entirely eliminated.

- Additionally, **oversimplifications** are clearly detrimental to the competent assessment of a resource/reserve, especially with regards to its **economic value**.

- The systematic application of the mentioned criteria should be regarded as **decisive steps** that will allow for subsequent improved decisions to be made **concerning exploitation**.

- The **cost** apparently associated with very specialized investigations (sorption isotherms, cleat system, etc) are fully justified and should be considered as an **investment**, since their contribution **seriously reduces the risk** associated with **later decisions**, such as whether or not to conduct further drilling and more advanced tests (e.g. 3 or 5-spot tests).

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