CO_2 sequestration potential of Indian coalfields

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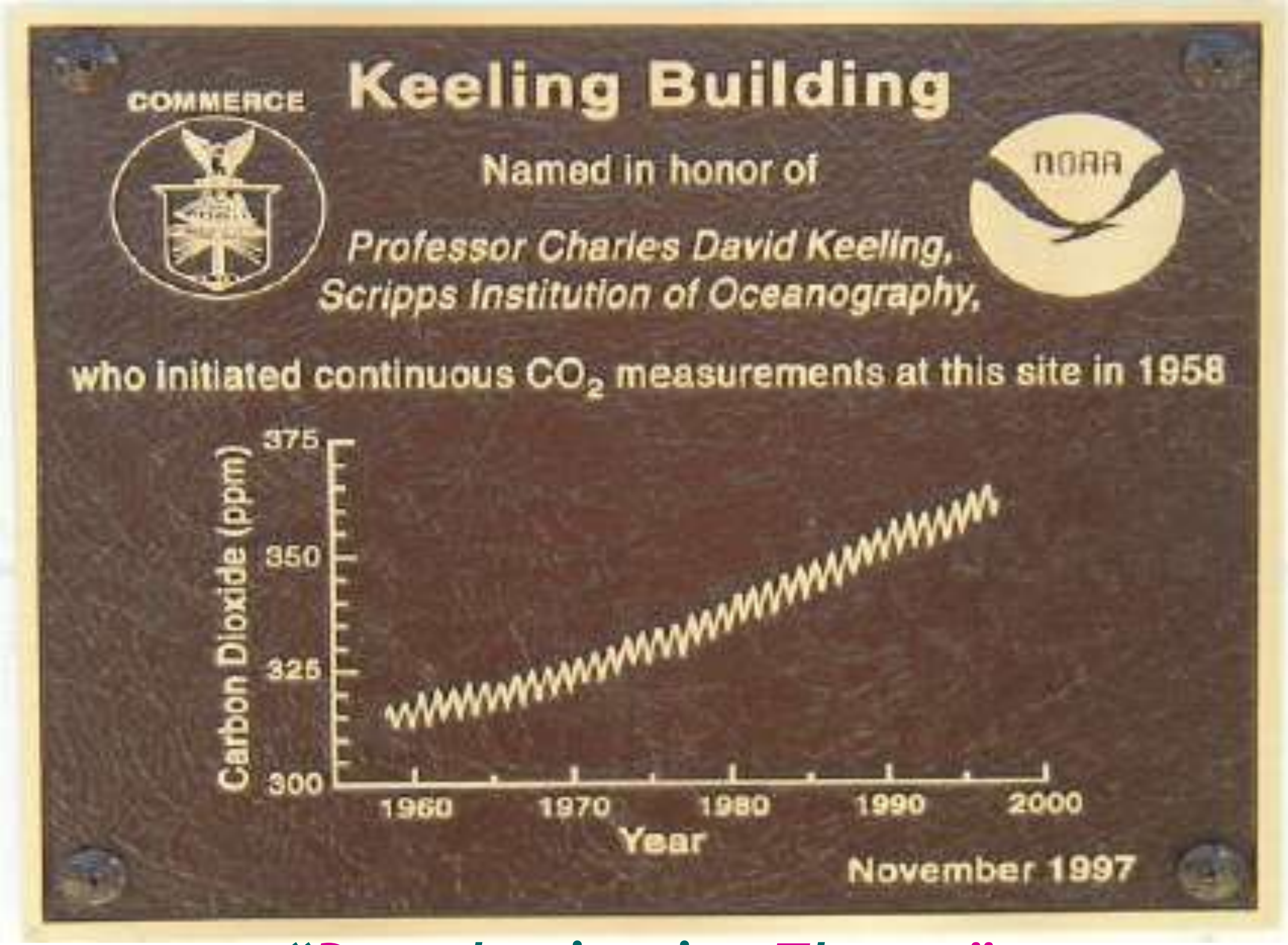
LECTURE OUTLINE

- CCS ~ CO_2 GEO-SEQUESTRATION
- COAL – COALIFICATION – COAL SEAM METHANE
- COAL AS A POROUS MEDIA
- RETENTION AND RELEASE MECHANISM
- WHY ECBM???
- DEPOSITIONAL SETTING OF COAL MEASURES
- DISTRIBUTION OF INDIAN COALFIELDS
- CO_2 STORAGE ESTIMATES



"Decarbonization Theory"

United Nations Framework Convention on Climate Change

"Low Carbon Economy"

CCS ~ CO_2 Geo-Sequestration

- What CCS is?
- Why Geo-sequestration: Is it Critical?
- Eligibility & Prospective Geologic Candidates
- Fundamental Concepts of Trapping
- Multi-component Sequestration System
- Site Selection Criteria

Carbon Capture & Storage (CCS)

Technological Innovations & efforts towards near-zero GHG emissions to the atmosphere

Major Concern: CO_2

Major Sources: Point Sources like Power Plants

3 Key Steps in CCS
- Capture
- Transportation
- Injection & Storage

Capture, Transport & Injection: Technology available with Upstream Oil & Gas Industry, Power Sectors etc.

Storage: Artificial storage of huge emission is impossible & GEOLOGIC SINKS are the *only* solutions

Identifying Geologic Sinks are CRITICAL & SITE SPECIFIC

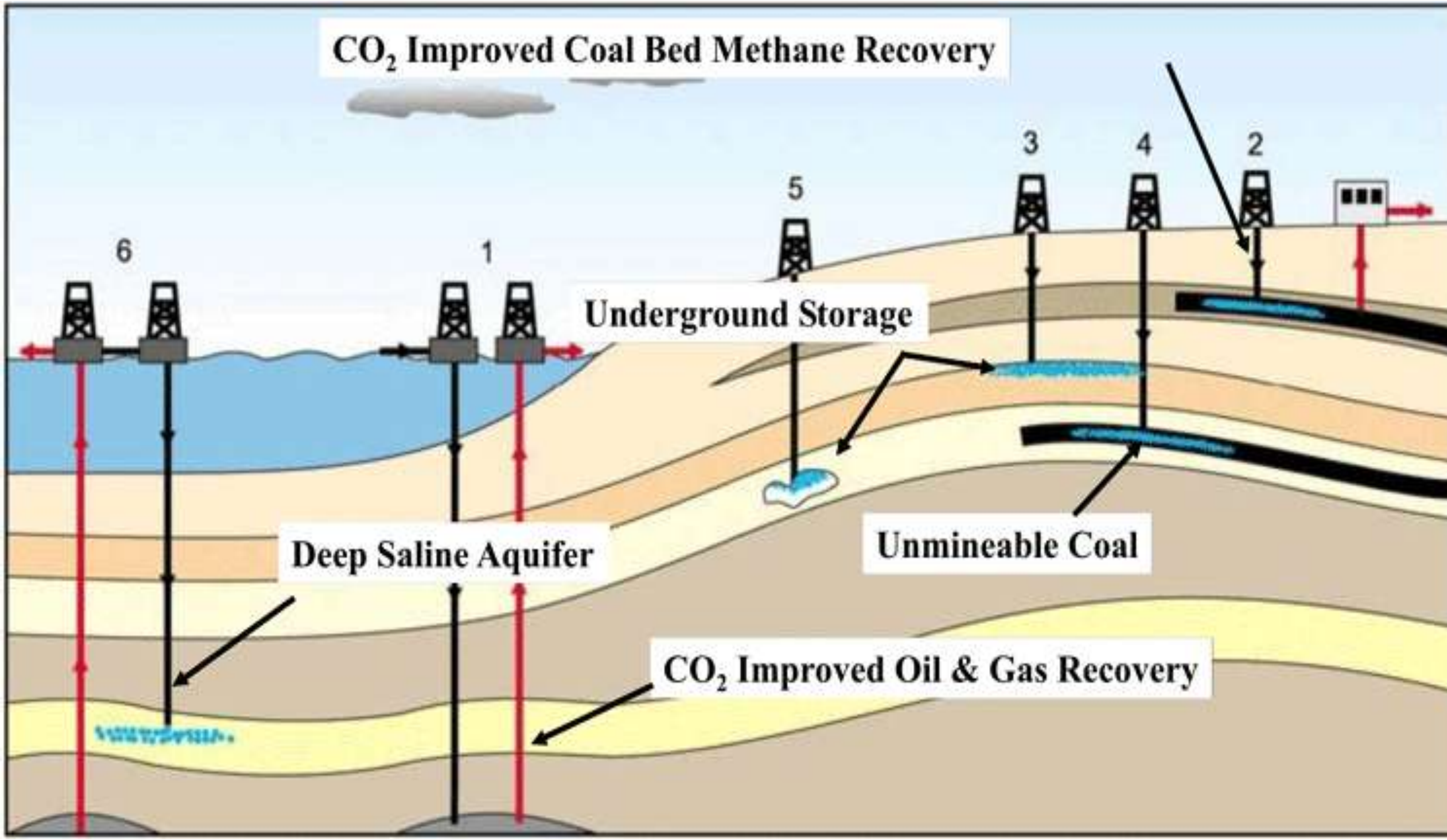
Eligibility

- Capacity to accommodate huge volume of CO_2 for geologically significant time span
- Leak Proof Storage (IPCC: leakage <1% over 1000 yrs)

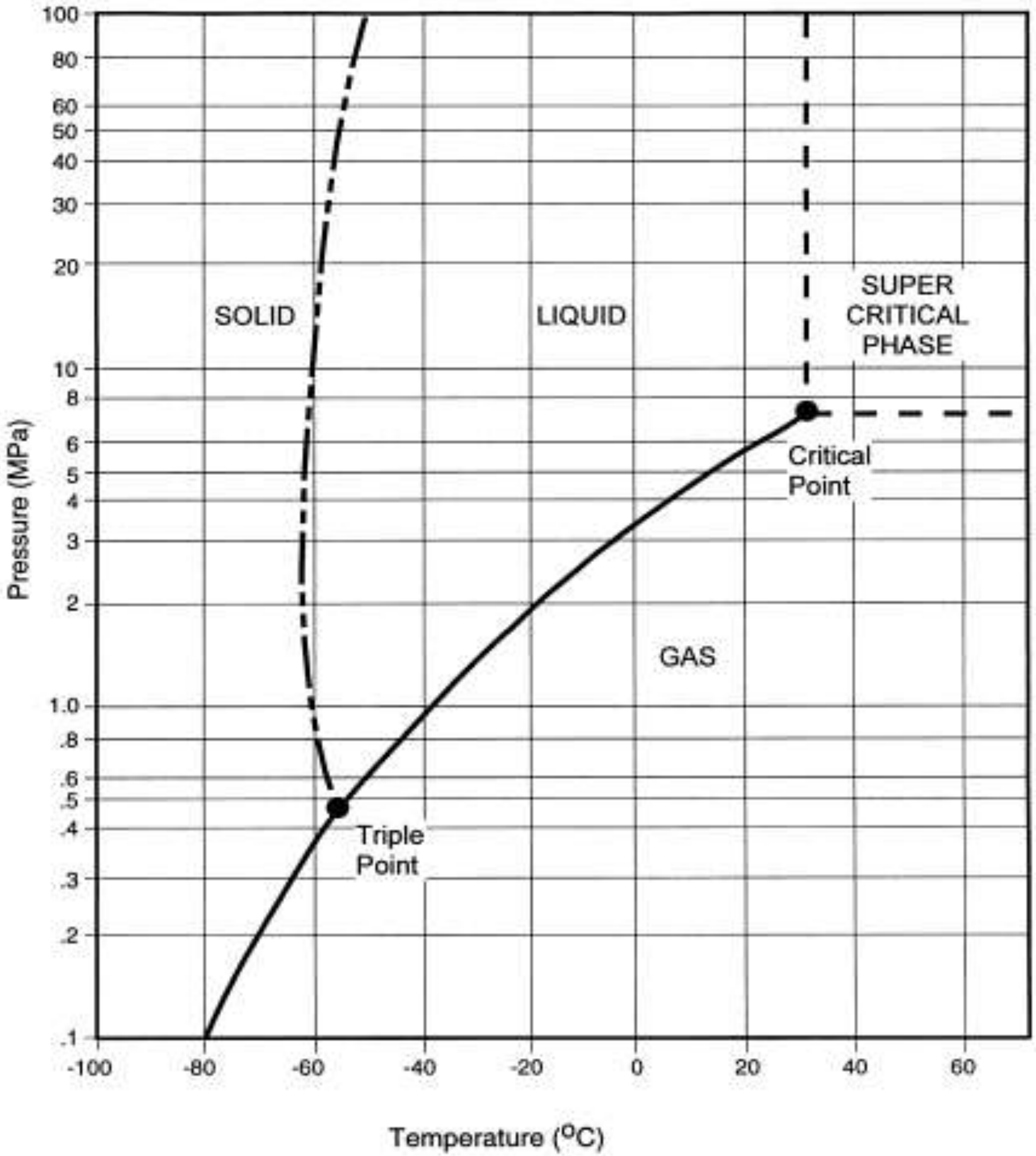
Prospective Geologic Candidates as CO_2 Storage Options

- Deep Unmineable Coal seams
- Depleted Oil & Gas Reservoirs
- Deep Saline Water Aquifers
- Mafic / Ultramafic Rocks

- Eligibility & Prospective Geologic Candidates



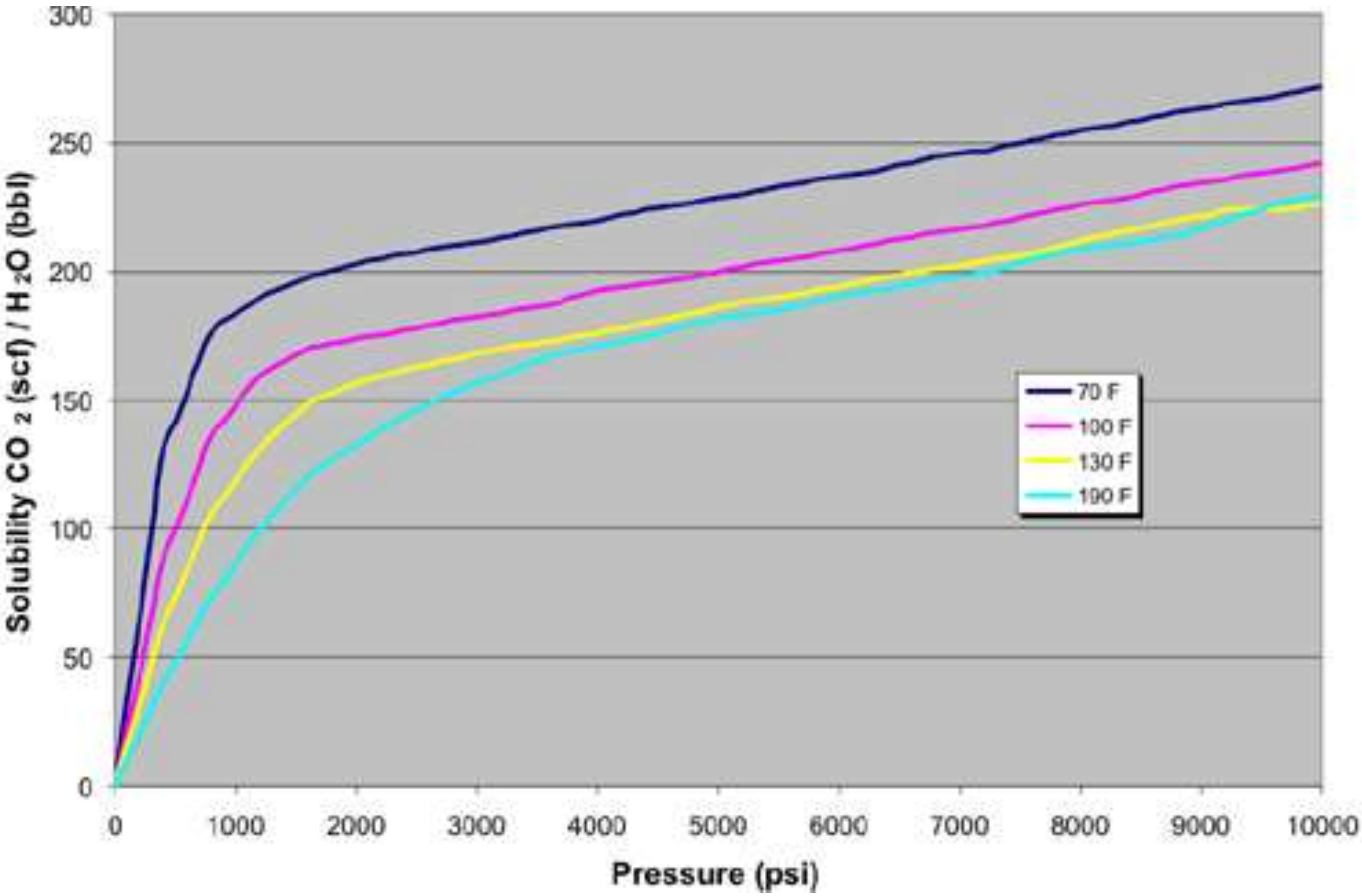
- Fundamental Concepts of Trapping



P=7.38 MPa,
T=31.1 C
(a storage reservoir depth~ 800m)

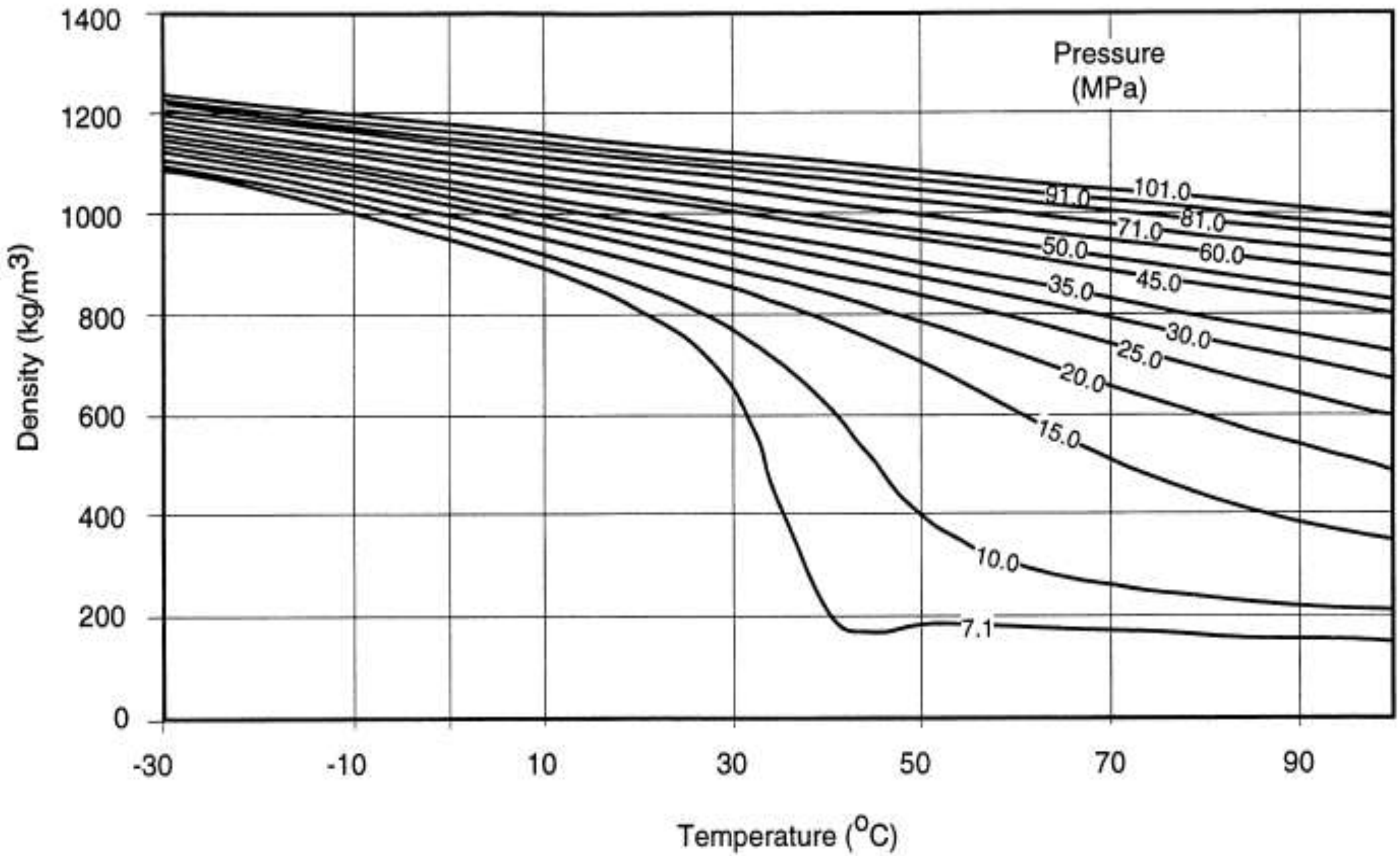
CO_2 Phase Diagram

- Fundamental Concepts of Trapping



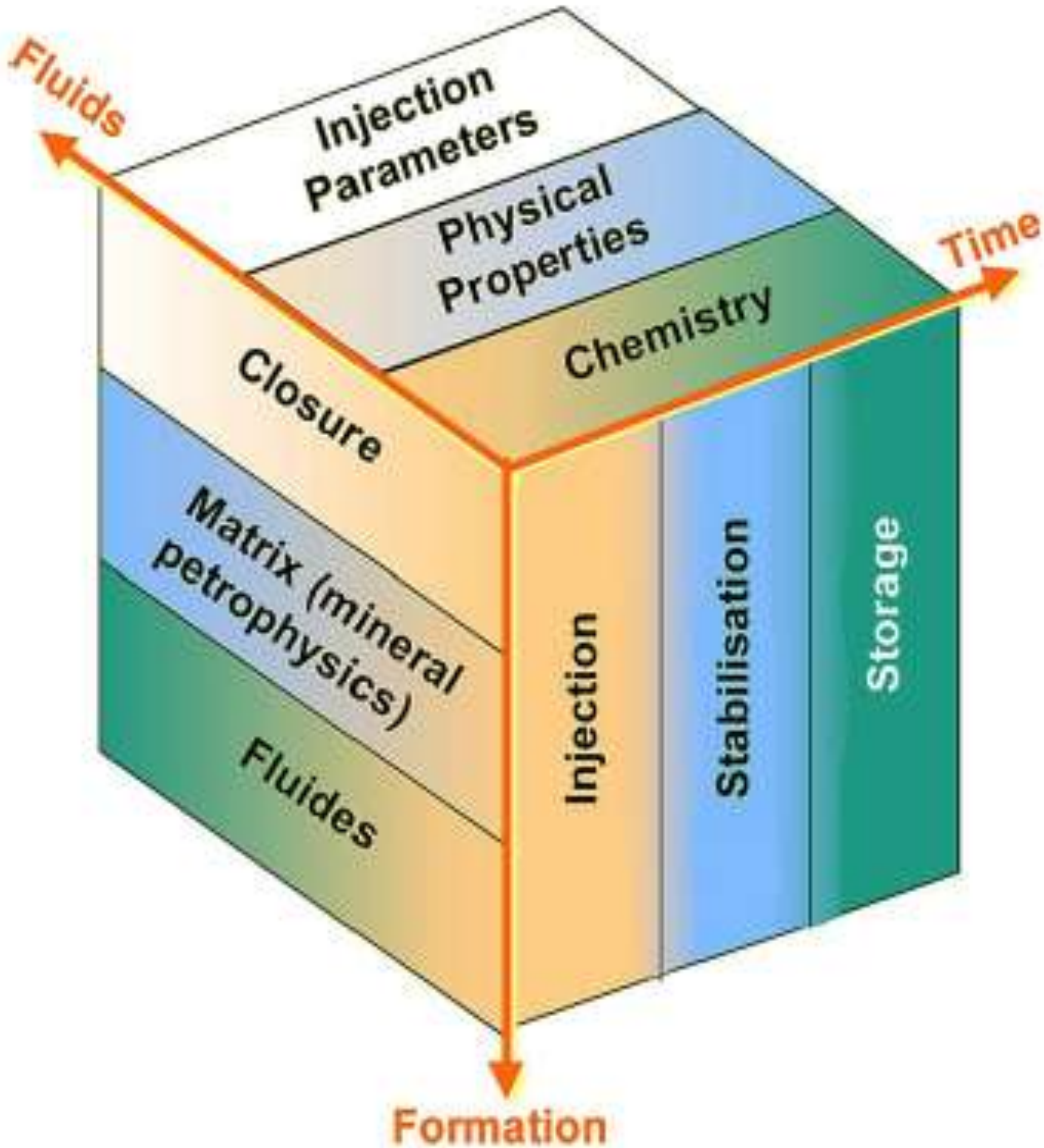
CO_2 solubility in water at different P-T condition

- Fundamental Concepts of Trapping

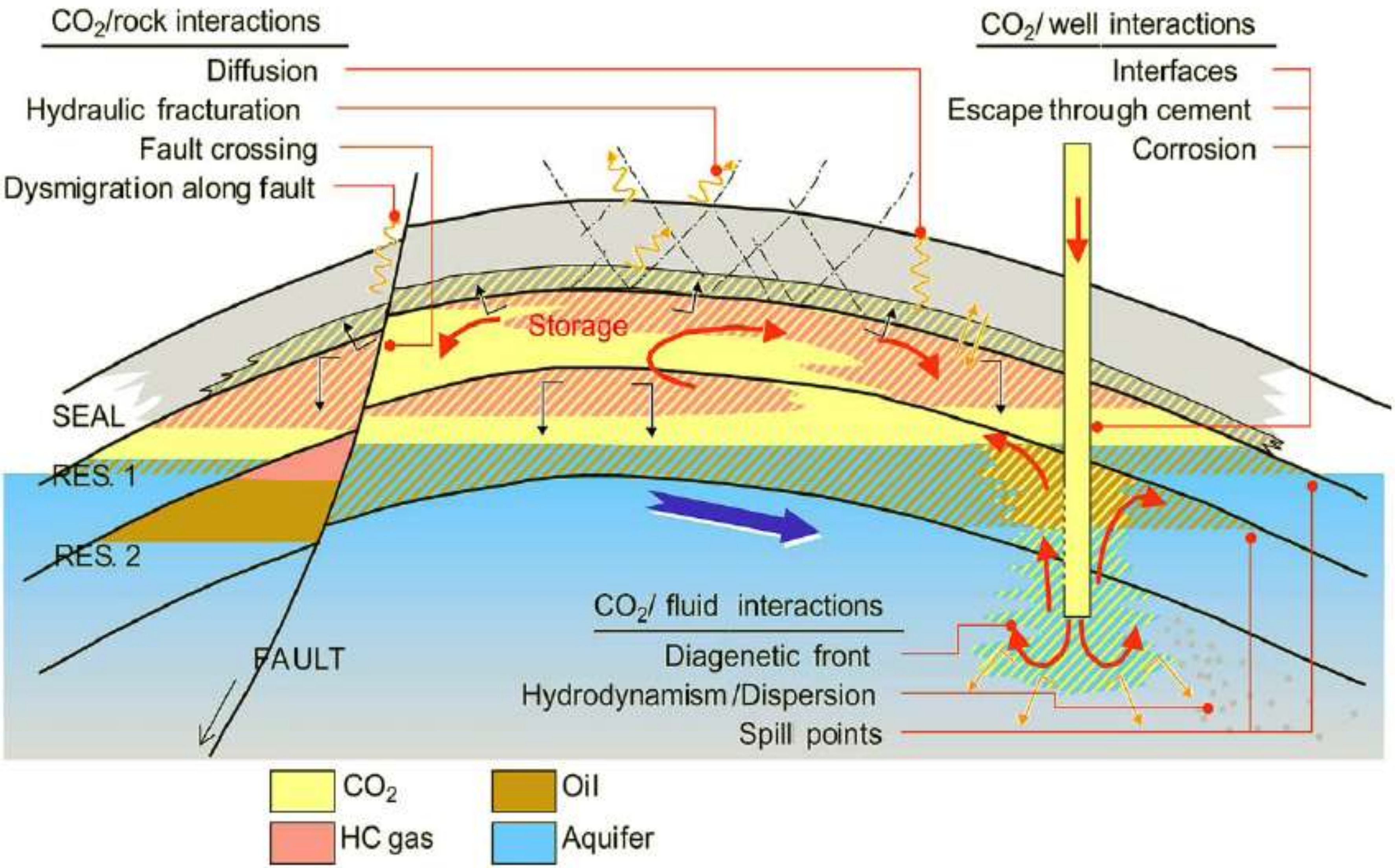


CO_2 density variation at different P-T condition

- **Multi-component Sequestration System**



- **Multi-component Sequestration System**



Mechanism of CO_2 Trapping

- **Hydrodynamic pressure**: CO_2 as Gas
- **Solubility Trapping**: CO_2 in solution
- **Mineral Trapping**: CO_2 as mineral, permanent sequestration

Basin Scale Criteria

- Geological
- Geothermal
- Hydrodynamic
- Hydrocarbon potential and basin maturity
- Economics
- Political and societal

Coal Seam Methane (CSM)

Methane formed during coalification trapped and stored in the coal seams

Occurrence

Absorbed

Adsorbed

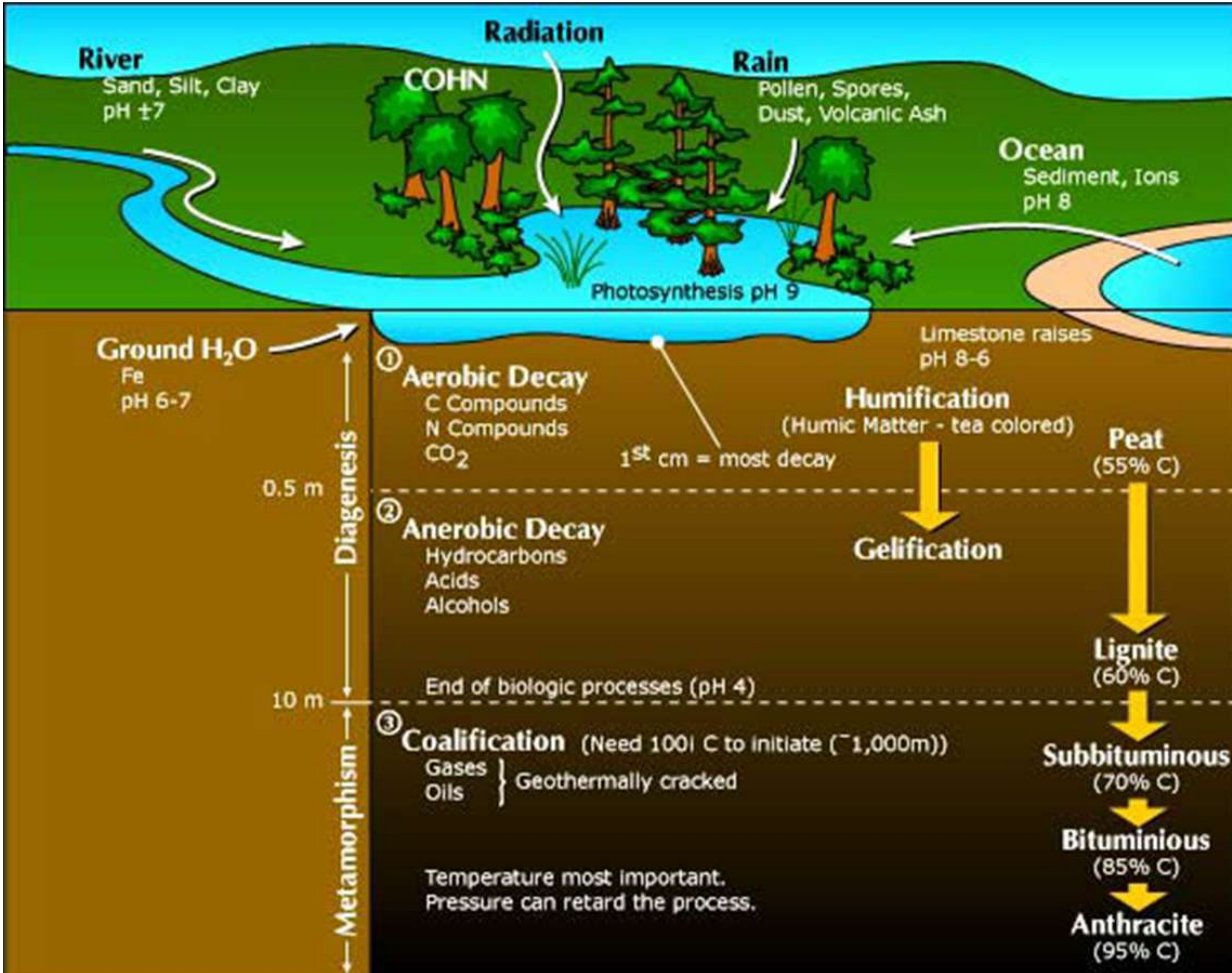
Free gas

Origin

Biogenic or

Thermogenic

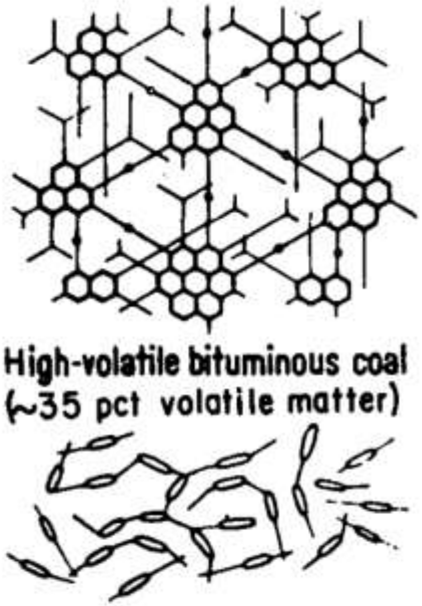
COAL – COALIFICATION – COAL SEAM METHANE

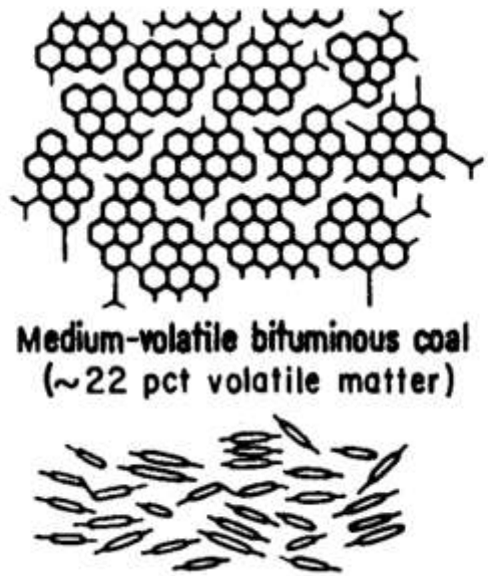


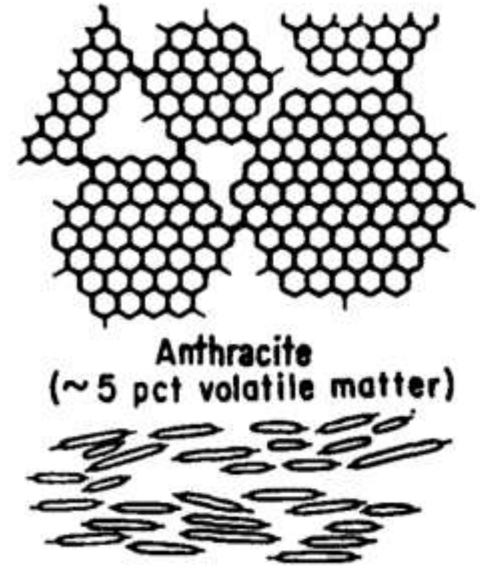
Elemental composition along with reflectance of Peat and coals of different rank

Rank	% C	% H	% O	Mean Ro%
Peat	55	6	30	< 0.28
Lignite	72.7	4.2	21.3	0.28–0.38
Sub Bitu	77.7	5.2	15.0	0.39–0.55
HV Bitu	80.3 – 84.5	5.5 – 5.6	11.1 – 7.0	0.50–1.15
M V Bitu	88.4	5.0	4.1	1.15–1.45
LV Bitu	91.4	4.6	2.1	1.45–1.90
Anthracite	93.7	2.4	2.4	>2.8

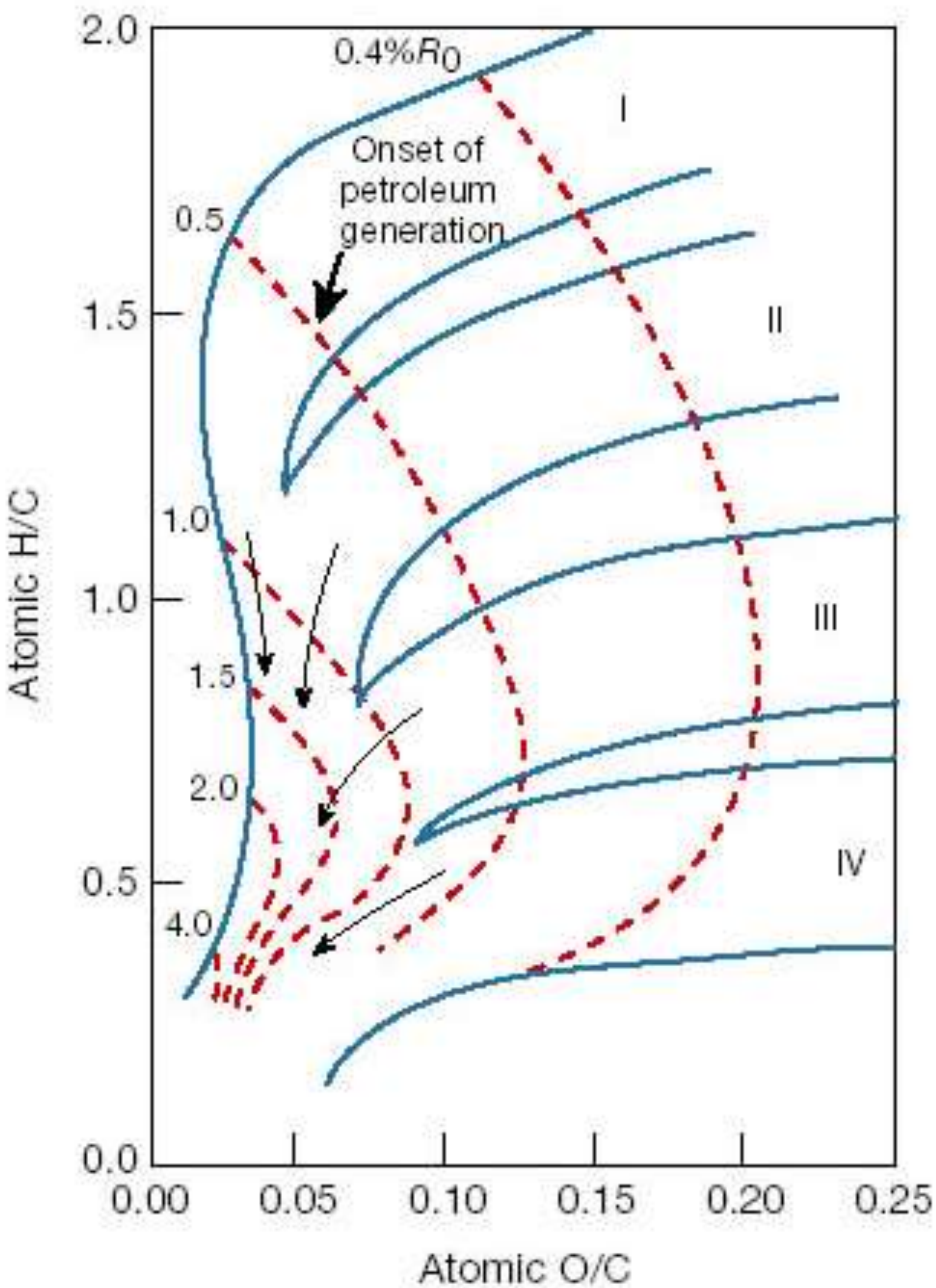
Coal as a Source Rock







Coal as a Source Rock



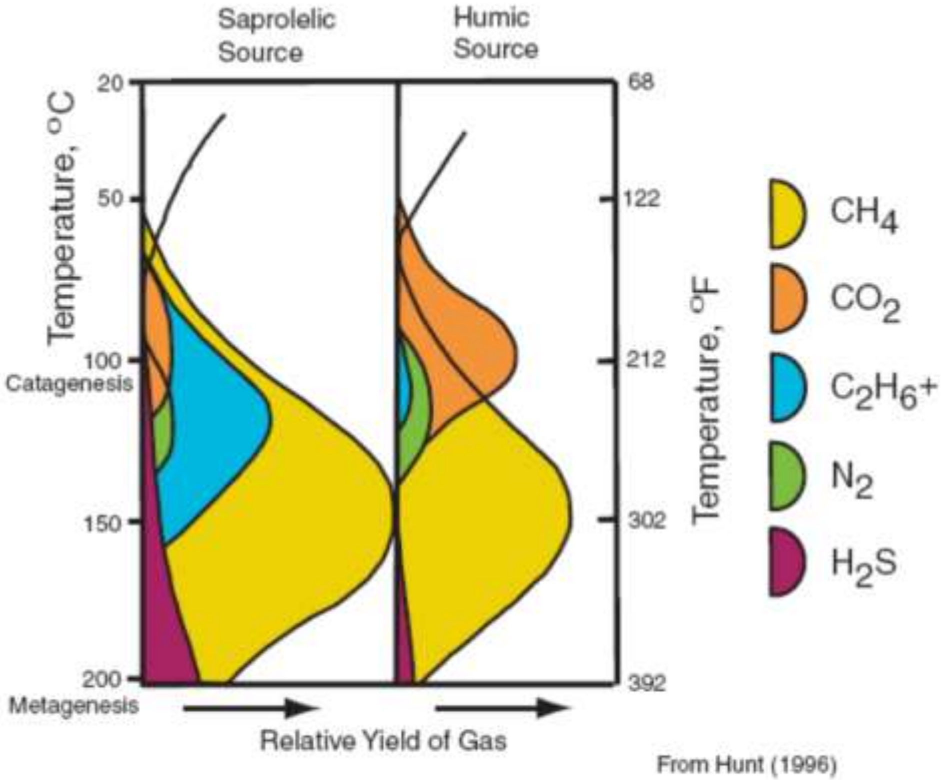


Table 1: Volume of gas generated during coalification (Scott 1993)

Methane	2,000 to 5,000+ scf/ton (63 to 157+ m^3/t)
Carbon dioxide	6,000)+ scf/ton (188+ m^3t) 177 scf/ton (6 m^3/t)
Wet gases	100 to 1,000+ scf/ton (3 to 31+ m^3/t)
Nitrogen	250 to 500 scf/ton (8 to 16 m^3t)

COAL AS A POROUS MEDIA

Gas-in-place ≤ Methane generated

Dependent on

- **Degree of confining pressure**
- **Seam permeation**

- **Porosity**
- **Permeability**

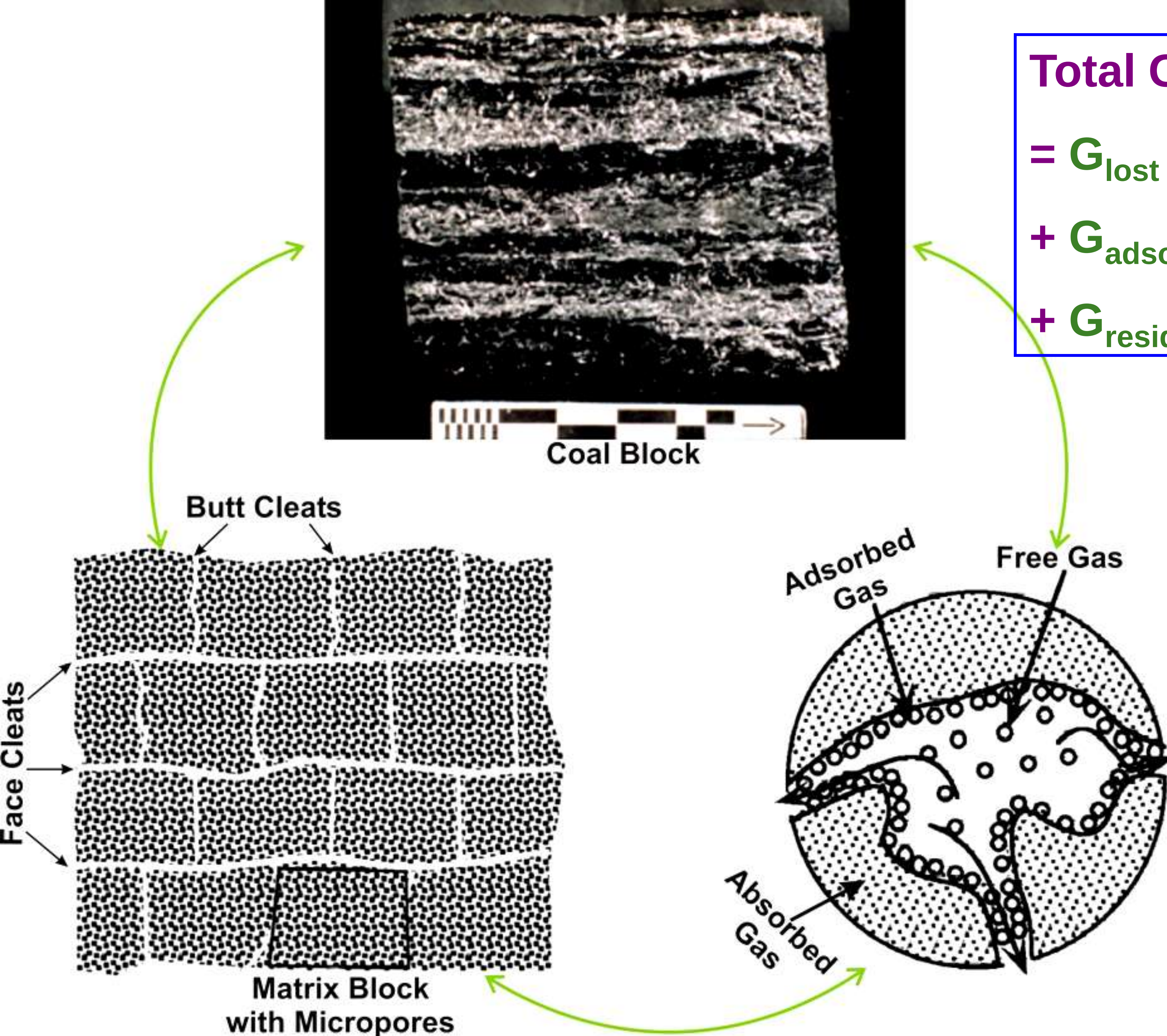
- **Surface area for sorption**
- **Facilitate flow of gas**

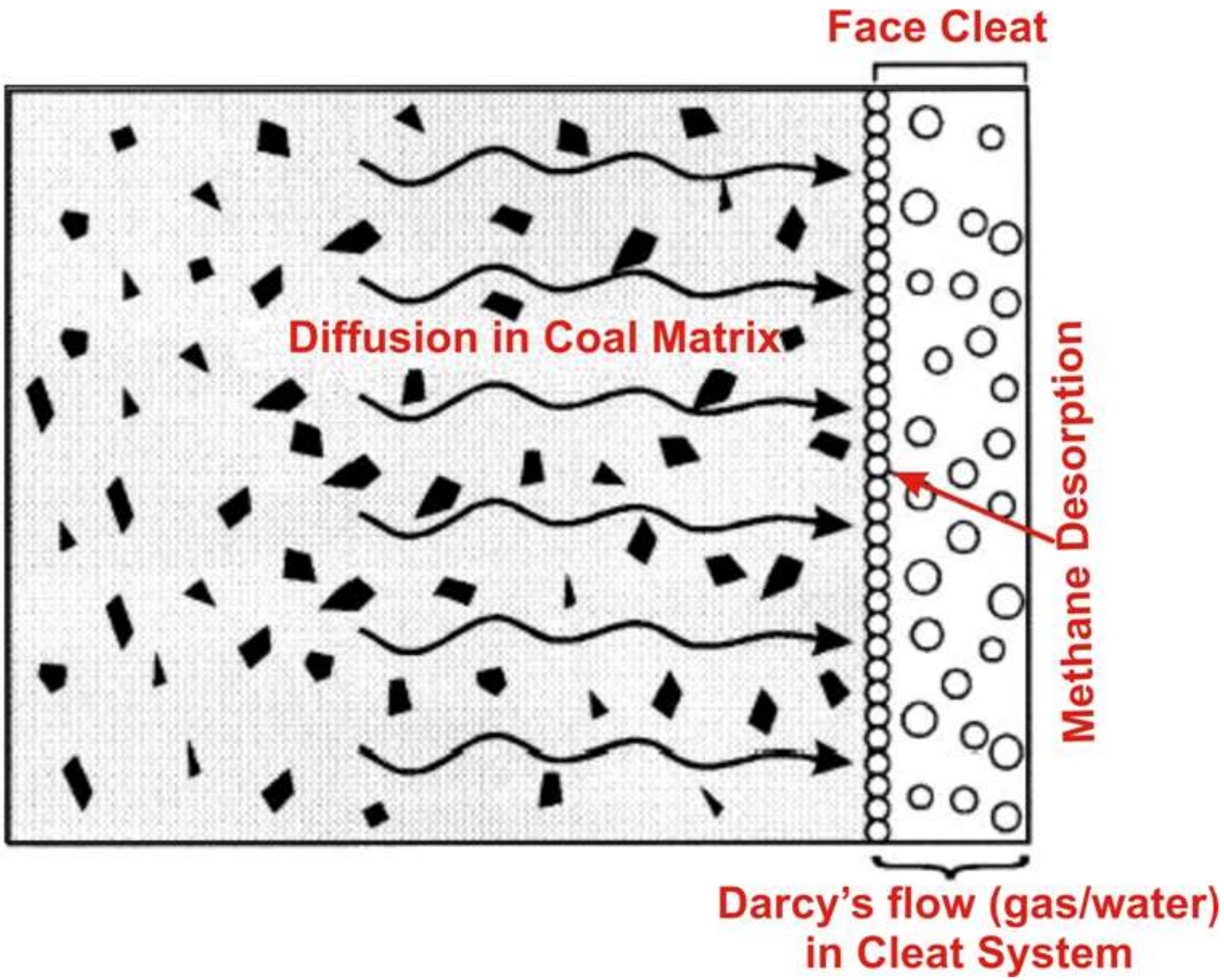
Total Gas, G_t

$= G_{lost}$

$+ G_{adsorbed}$

$+ G_{residual}$





FICK'S LAW

(Single Component, Unidirectional Flow)

CREATED IN-SITU GAS CONTENT FACILITY

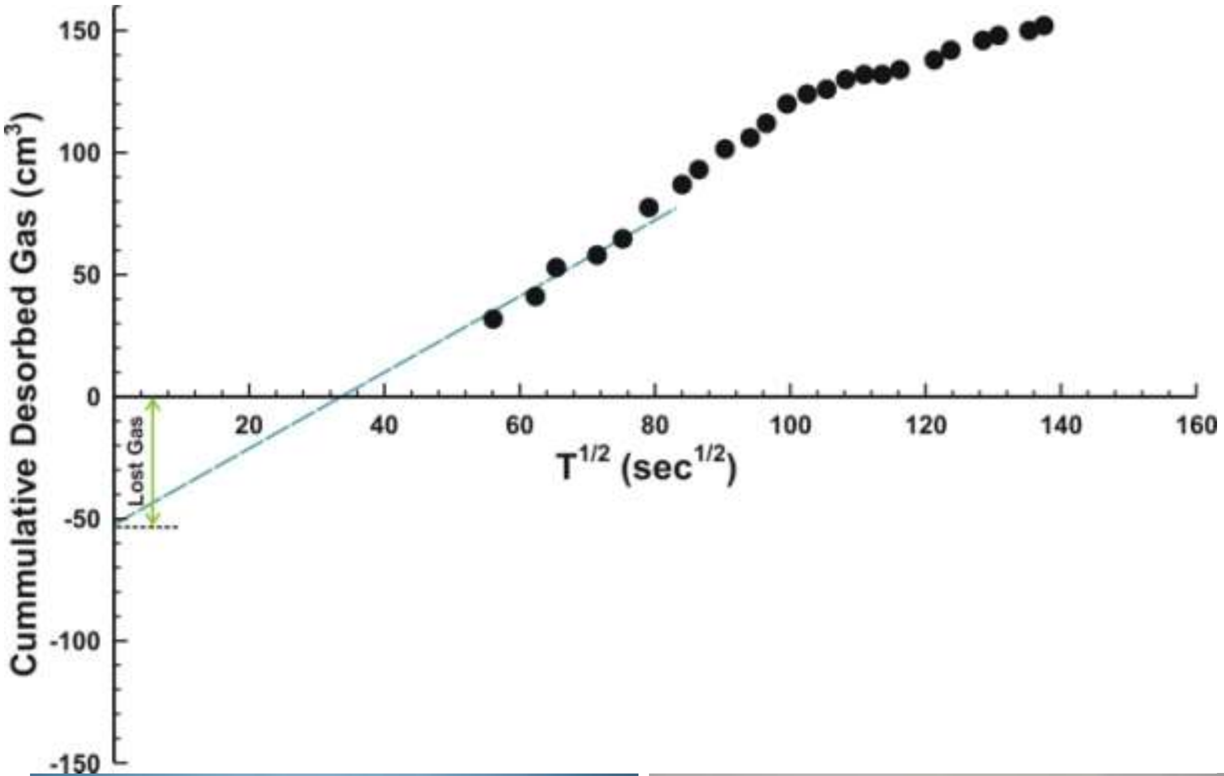


Table 4: Coalbed methane exploration model (Scott 1999)	
GAS CONTENT	
Coal rank and gas generation	Generally increases with coal rank and depth; updip migration diffusion coefficients
Depositional setting	Macerals affect gas sorption and desorption; shale seals; coal thickness and continuity
Tectonic setting	Conventional trapping of gases at faults and anticlines; burial history; diagenesis
Hydrodynamics	Secondary biogenic methane; high or low gas content at convergent flow; low gas content possible near recharge zone
Permeability	High permeability near recharge zone may allow flushing and low gas content

- ✓ **Matrix porosity:** inherent porosity (integral part of the petrographic entities)

  According to IUPAC

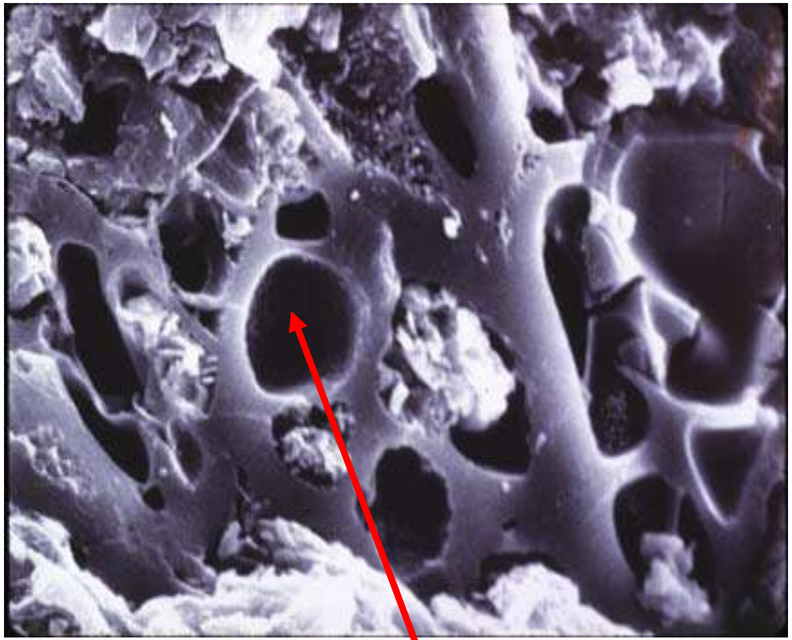
  Macropore: Pore of width $w \geq 50$ nm

  Mesopore: Pore of width 50 nm $\leq w \leq$ 2 nm

  Micropore: Pore of width $w \leq 2$ nm

- ✓ **Induced porosity:** (imparted by the fracture system Cleats: Master, Face, Butt cleats etc.)

Dual Porosity of Coal



Microscopic view of the Micropores structure of coal

Fracture system, cleats in coal

Coal as a Porous Media

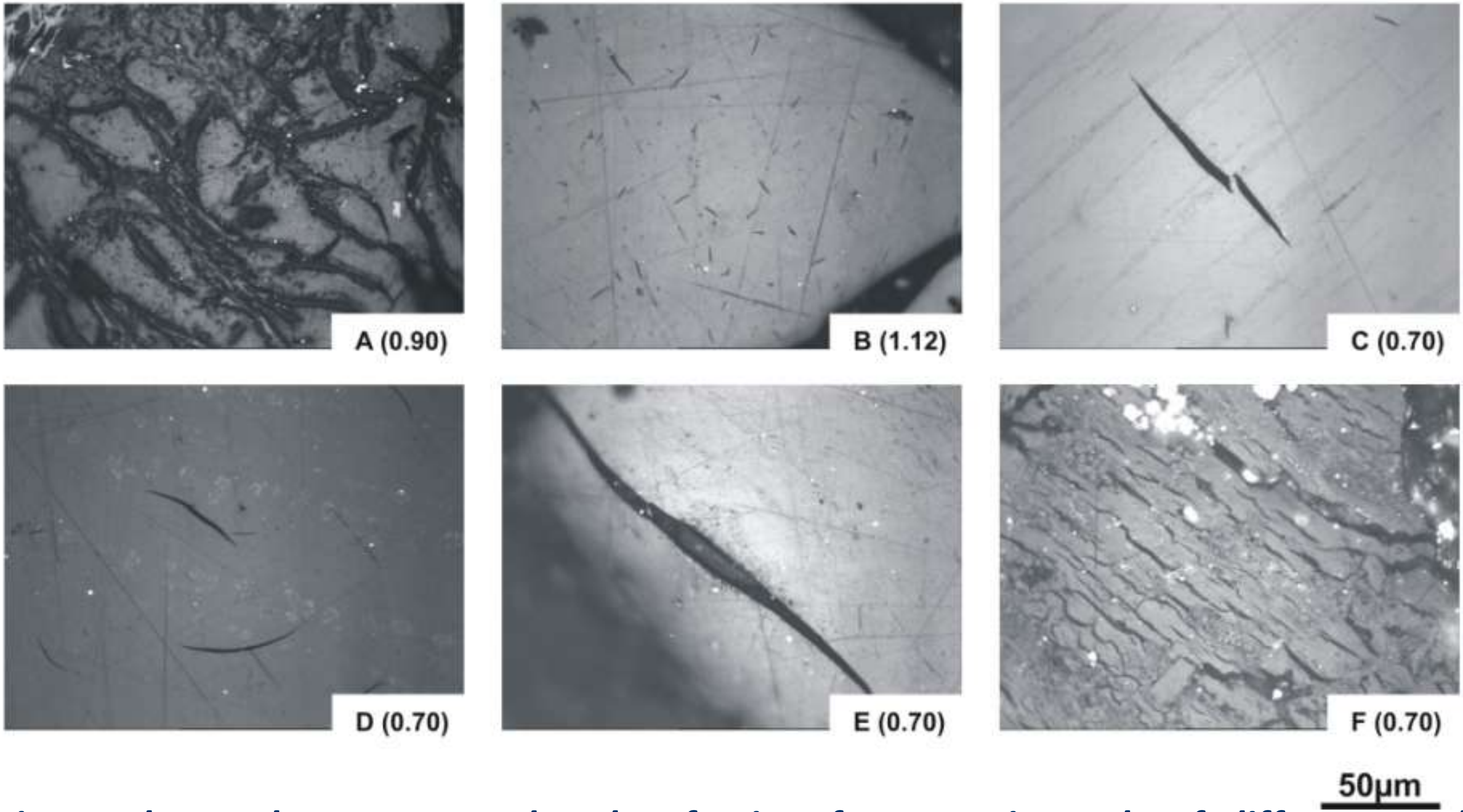


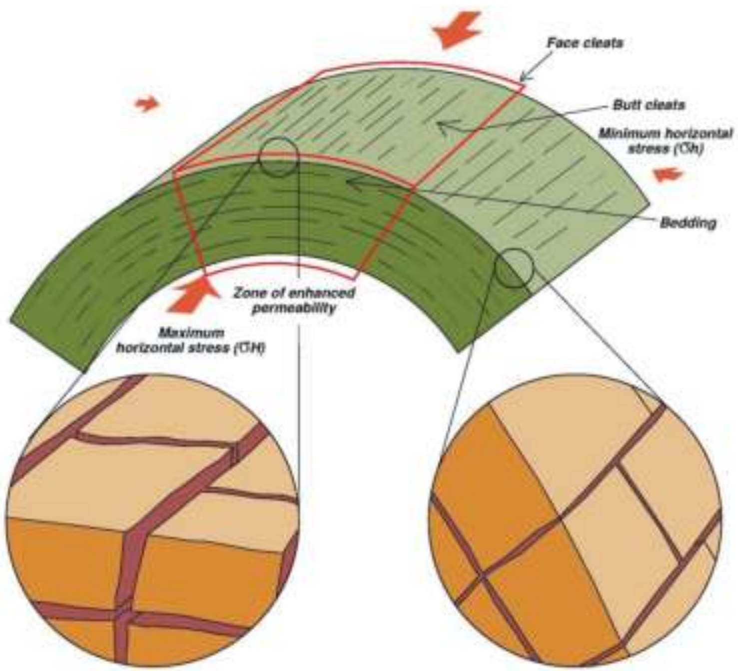
Figure shows the nature and style of micro-fractures in coals of different rank (values in the parenthesis indicate the mean R_0%) a) reticulated network of cleats; b) clusters of slits with almost uniform size; c) development of cleats almost perpendicular to the liptinitic layer; d) development of micrinites along the layers of liptinite; e) mineral infillings in cleats; f) cleats developed in low rank coals.

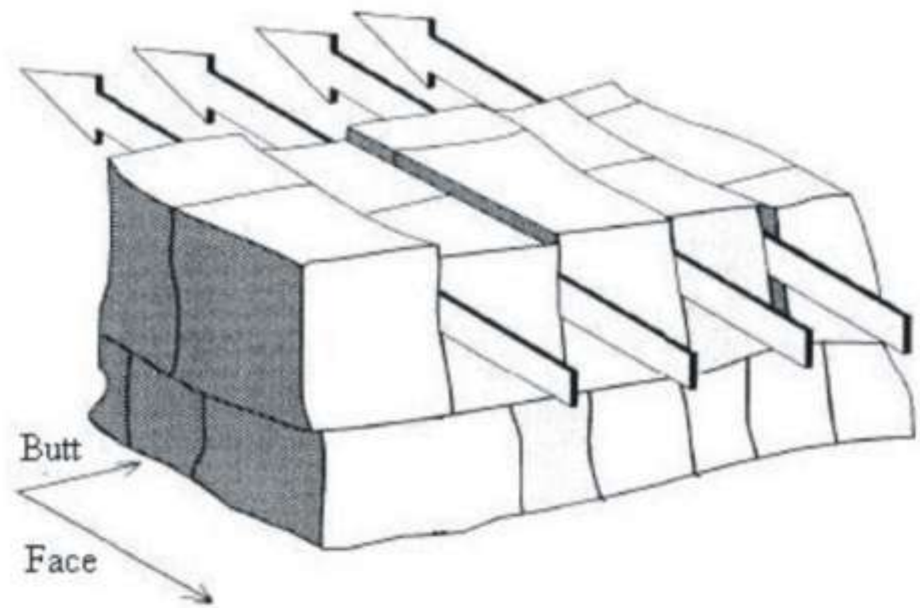
Coal as a Porous Media

CHARACTERISTICS OF CLEATS

- Cleats form an **interconnected** network in the coal, normal to bedding
- Angle between face cleats and butt cleats is **around 90°**
- Spacing between cleats is normally less than **25 mm** and the aperture is **0.1 – 2 mm**
- Butt cleats (shorter) **terminate** at a face cleat
- Cleats are formed due to **intrinsic tensile force (shrinkage), fluid pressure and tectonic stress**
- Tectonic stress controls the geometric pattern of the cleats (face cleats parallel to SH)
- Permeability ratio face cleats : butt cleats may range from 1:1 to 17:1

Coal as a Porous Media





Enhanced permeability of coal seams as a result of stress relaxation over an anticline crest and the maximum horizontal stress component being orientated parallel to the strike of face cleats

GWP of GHGs

- CO_2 – 1
- Methane – 21
- Nitrous Oxide – 310
- HFC 23 – 11700
- PFCs – 6500 to 9200
- Nitrogen Trifluoride - 17200
- Sulphur Hexafluoride – 23900

DIFFERENT CATEGORIES OF CBM

- VCBM
- CMM
- AMM
- VAM

CBM RESOURCES OF INDIA & WORLD

Sl. No.	COUNTRY	COAL RESOURCES (BILLION TONNES)	CBM RESOURCES TCM
1	CANADA	7000	6.5 – 76.4
2.	RUSSIA	6500	13.3 – 73.6
3.	CHINA	4000	16.4 – 34.0
4.	USA	3970	12.7 – 25.5
5.	AUSTRALIA	1700	8.8 – 14.2
6.	INDIA	550 (264 + 286)	3.0 – 4.0
7.	GERMANY	320	1.7 – 2.5
8.	U.K	190	1.1 – 1.7
9.	POLAND	160	1.4 – 2.0
10.	SOUTH AFRICA	150	1.4 – 2.0
11.	INDONESIA	17	0.1 – 0.2
12.	ZIMBABWE	8	0.04 – 0.05

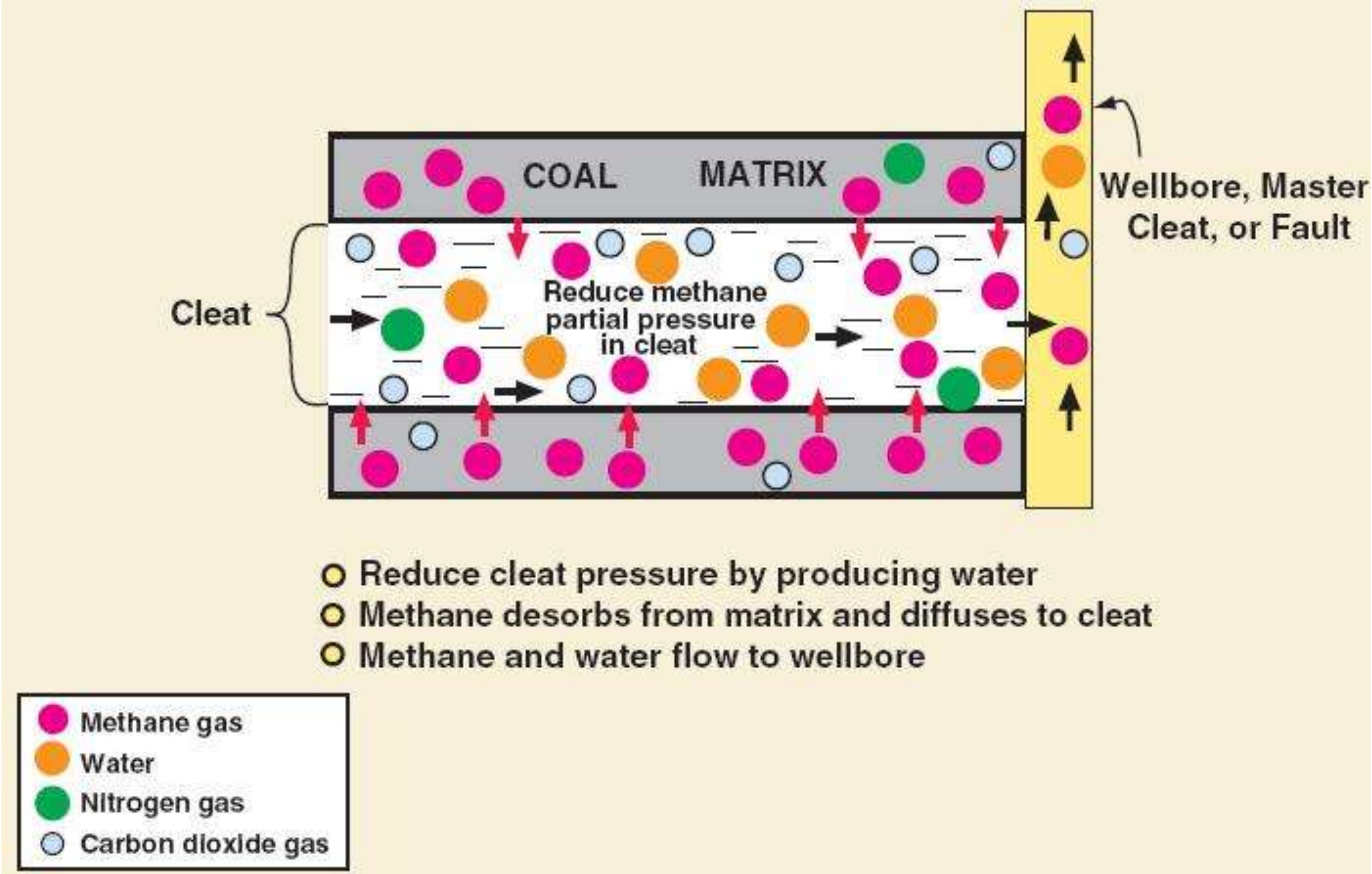
Global CMM Emission

Country	2000 Methane Released (M m^3)	2000 CO2 Equivalent (MMT)	2010 Methane Released (M m^3)	2010 CO2 Equivalent (MMT)
China	10,000	142.7	15,753	224.7
US	5,461	77.0	5,748	82.0
Russia	2,236	31.9	2,138	30.5
Australia	1,381	19.7	2,004	28.6
Ukraine	1,970	28.1	1,689	24.1
India	683	9.7	1,319	18.8
Poland	1,037	14.8	939	13.4
Germany	1,030	14.7	764	10.9
South Africa	496	7.1	506	7.2
Kazakhstan	488	7.0	447	6.4
UK	365	5.2	343	4.9
Czech Republic	351	5.0	266	3.8
Turkey	123	1.8	184	2.6
Japan	133	1.9	147	2.1
Canada	98	1.4	91	1.3

Why ECBM???

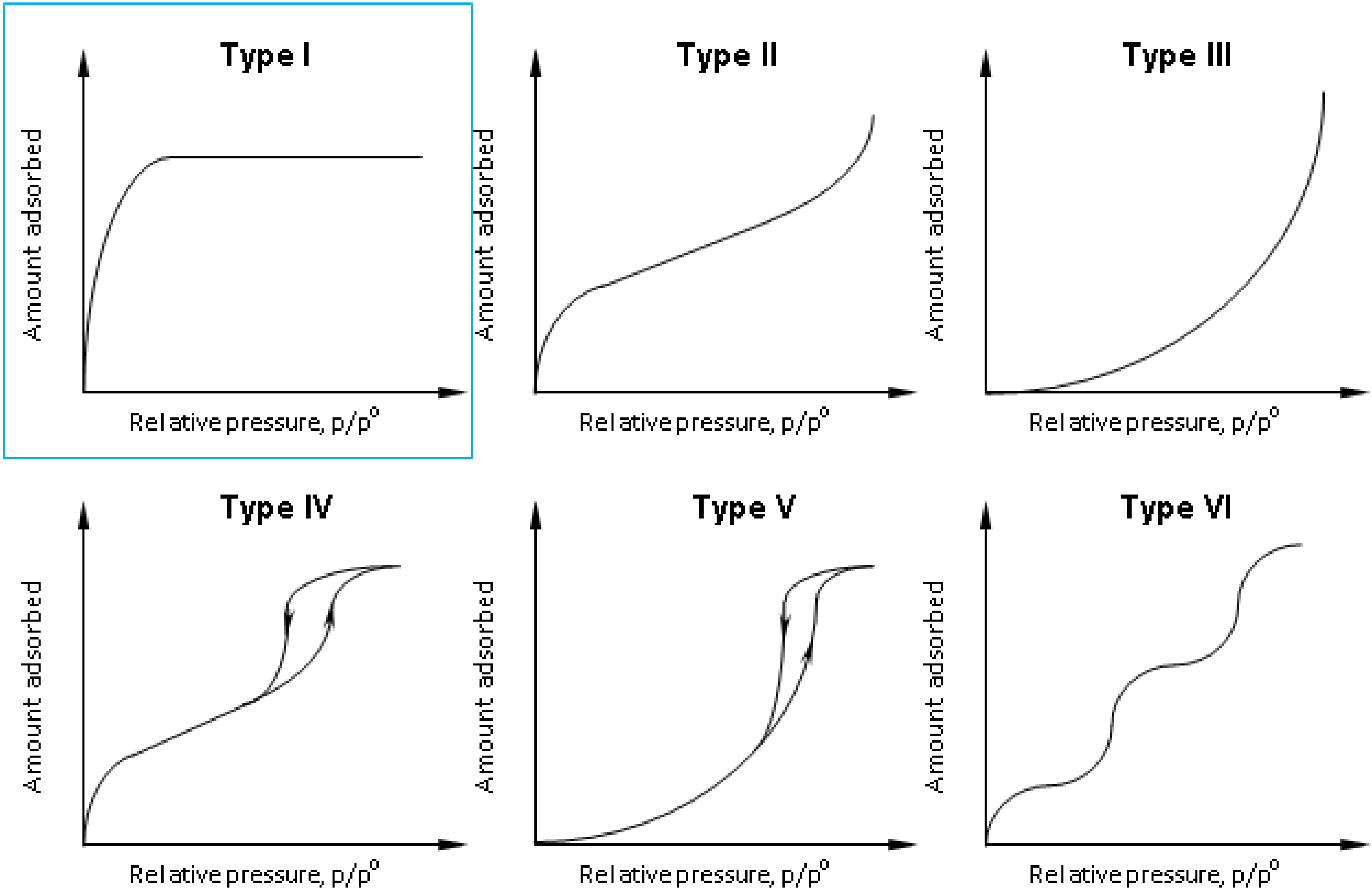
- **Studies conducted so far supports stronger affinity of CO_2 to the coal molecule.**
- **2 to 3 molecules of CO_2 may displace one molecule of methane**
- **It means carbon dioxide is preferentially adsorbed onto the coal structure over methane (2:1 ratio).**
- **Methane sorption capacity for Indian coals has been investigated by CIMFR.**
- **Understanding controls on CO_2 and CH_4 adsorption in coals is important for the modeling of both CO_2 sequestration and CBM production.**

VALUE ADDITION THROUGH CO_2 SEQUESTRATION

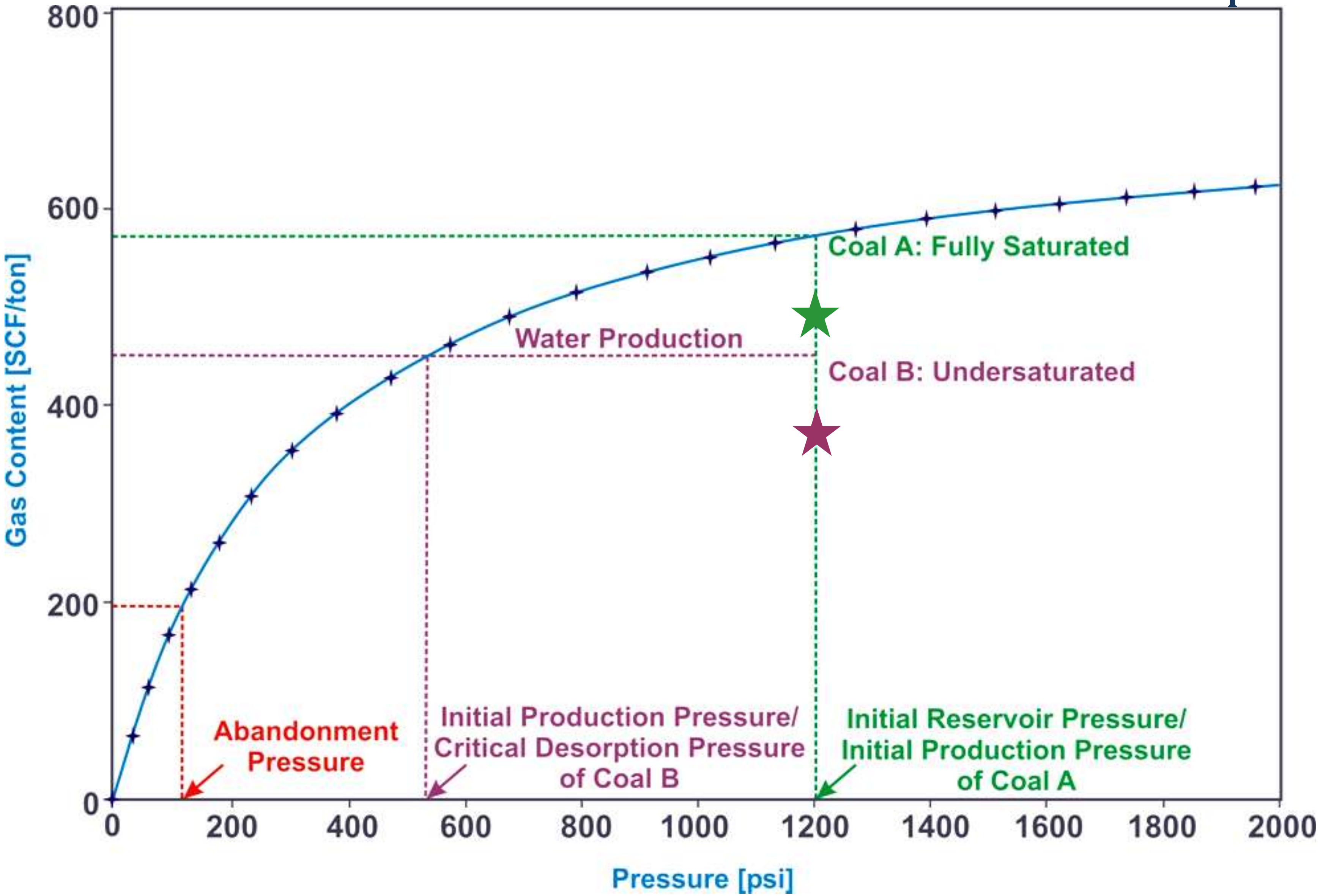

COAL MATRIX
Cleat
Reduce methane partial pressure in cleat
Wellbore, Master Cleat, or Fault
Reduce cleat pressure by producing water
Methane desorbs from matrix and diffuses to cleat
Methane and water flow to wellbore
Methane gas
Water
Nitrogen gas
Carbon dioxide gas

COAL AS A RESERVOIR AND TRAP ROCK

Sorption: Gas Retention/Transportation Mechanism



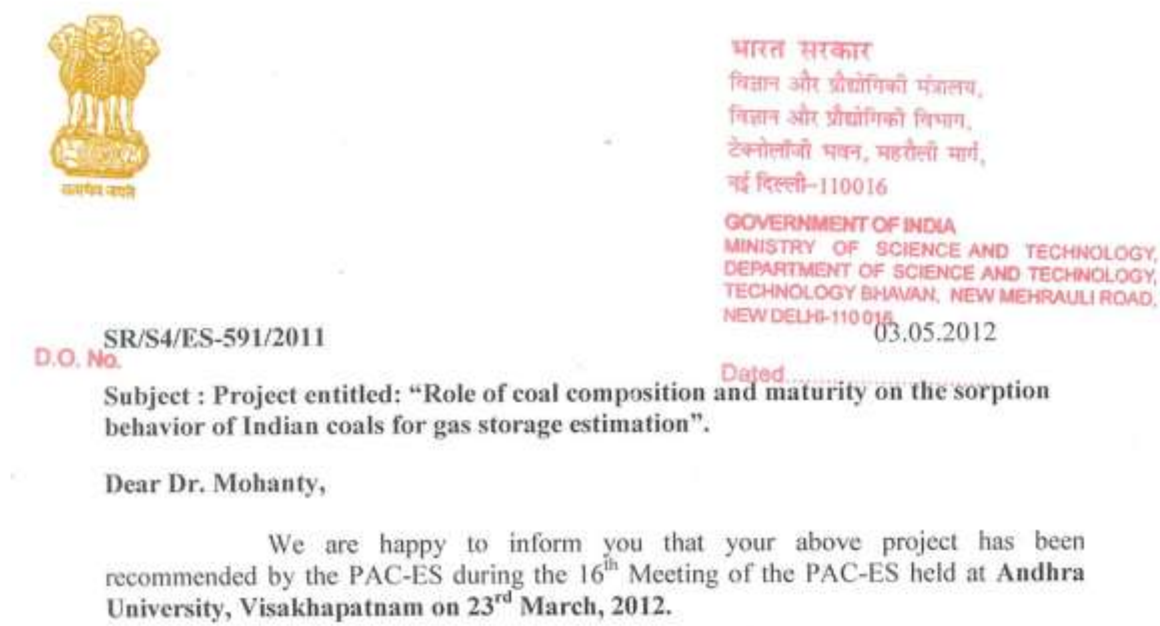
IUPAC classification of gas adsorption isotherms



Adsorption Isotherm for Reservoir Modeling

DST Sponsored Project:

Role of coal composition and maturity on sorption behavior of Indian coals for gas storage estimation **PI: Dr. Debadutta Mohanty**


भारत सरकार
विज्ञान और प्रौद्योगिकी मंत्रालय,
विज्ञान और प्रौद्योगिकी विभाग,
टेक्नोलॉजी भवन, महरौली मार्ग,
नई दिल्ली-110016

GOVERNMENT OF INDIA
MINISTRY OF SCIENCE AND TECHNOLOGY,
DEPARTMENT OF SCIENCE AND TECHNOLOGY,
TECHNOLOGY BHAVAN, NEW MEHRAULI ROAD,
NEW DELHI-110016

D.O. No. SR/S4/ES-591/2011

Dated 03.05.2012

Subject : Project entitled: "Role of coal composition and maturity on the sorption behavior of Indian coals for gas storage estimation".

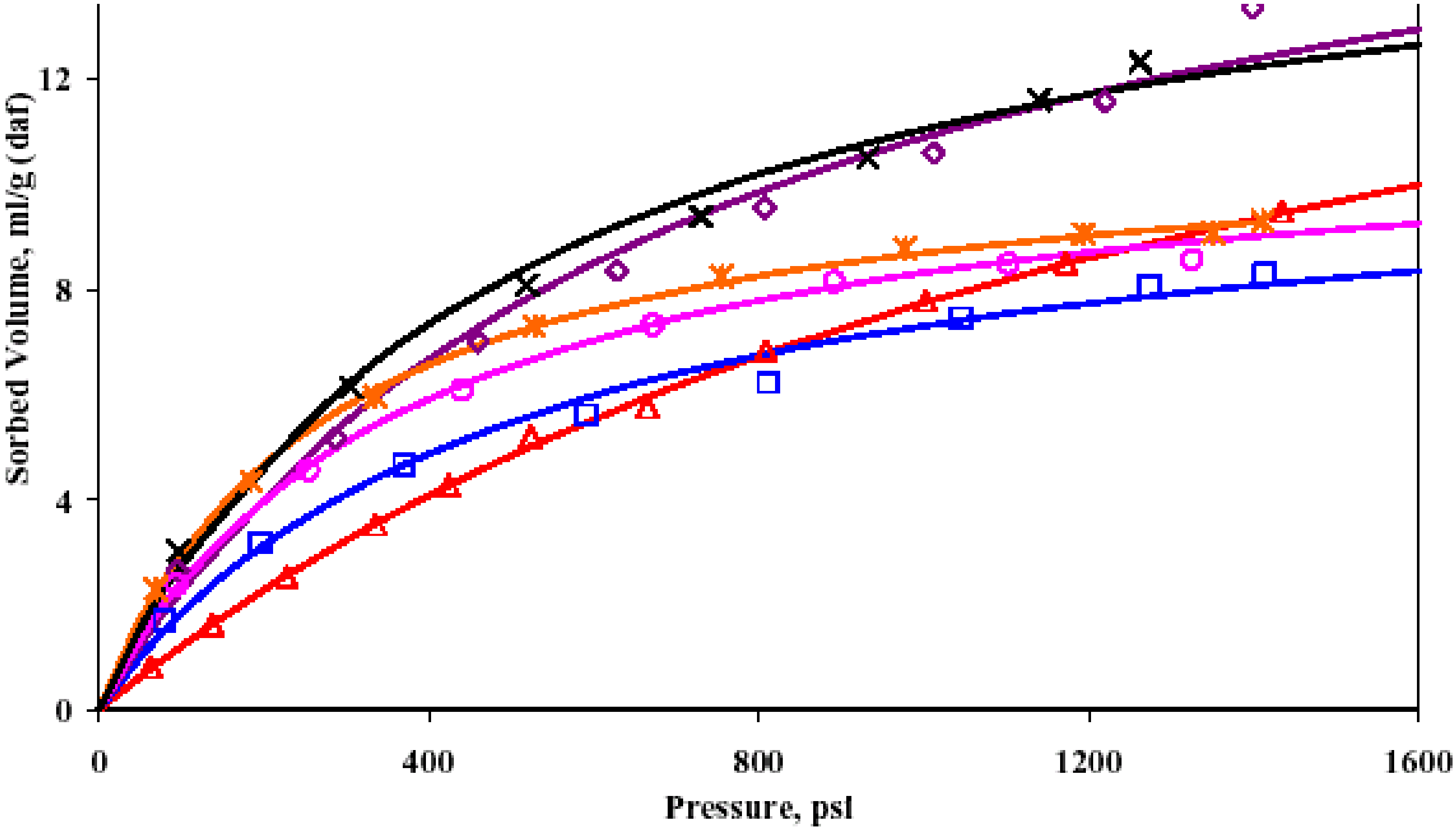
Dear Dr. Mohanty,

We are happy to inform you that your above project has been recommended by the PAC-ES during the 16th Meeting of the PAC-ES held at **Andhra University, Visakhapatnam on 23rd March, 2012.**

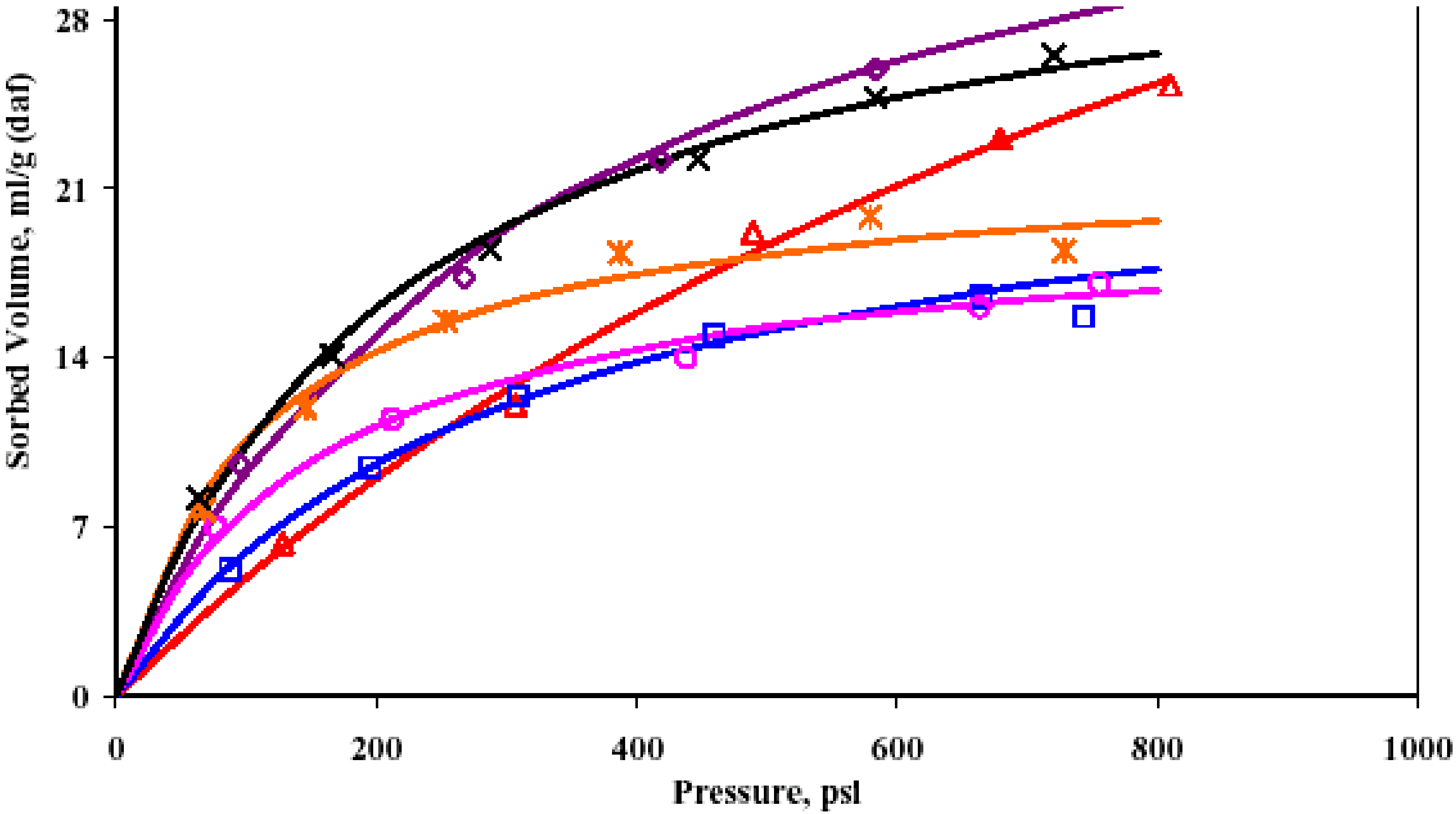
Deliverables

- **Basin-wise empirical equations and constants to estimate sorption capacity from chemical data**
- **National Facility for high pressure adsorption study (up to 35MPa or 350bars)**
- **Papers/Patents**

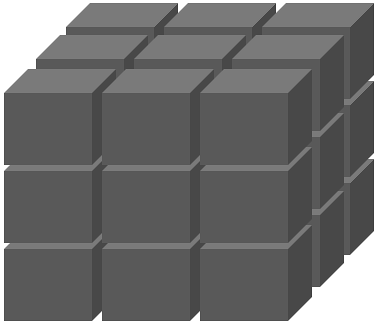
Methane adsorption



Carbon dioxide adsorption



Shrinkage and swelling behavior of coal is critical in CO_2 enhanced CBM recovery



TECTONIC AND DEPOSITIONAL SETTING

Major Tectonic Setup of Coal Basins

- Foreland basin setting
- Rift valley setting
- Cratonic setting
- Passive margin setting

Major Coal Depositional Systems

- Coal-bearing alluvial fan systems
  - Intermotane extensional and transtensional
  - Orogenic margins of foreland basins
- Coal-bearing fluvial fan systems
  - Usually suspended load or mixed-load; bed-load
  - Thickest seams between channel axes
- Coal-bearing deltaic systems
  - Tide –dominated deltas
  - Wave –dominated deltas
  - Fluvially dominated deltas
- Coal-bearing shore-zone
  - Back-barrier and tidal flat settings
  - Coal-bearing lacustrine systems

INDIAN COALFIELDS

- Coal deposits in India are of two distinct geologic ages:

  Gondwana coals of Permian age (~270myr)

  Tertiary coals (30 - 60myr)

- 57 Gondwana and 14 Tertiary coalfields considered as the national inventory of coal in India

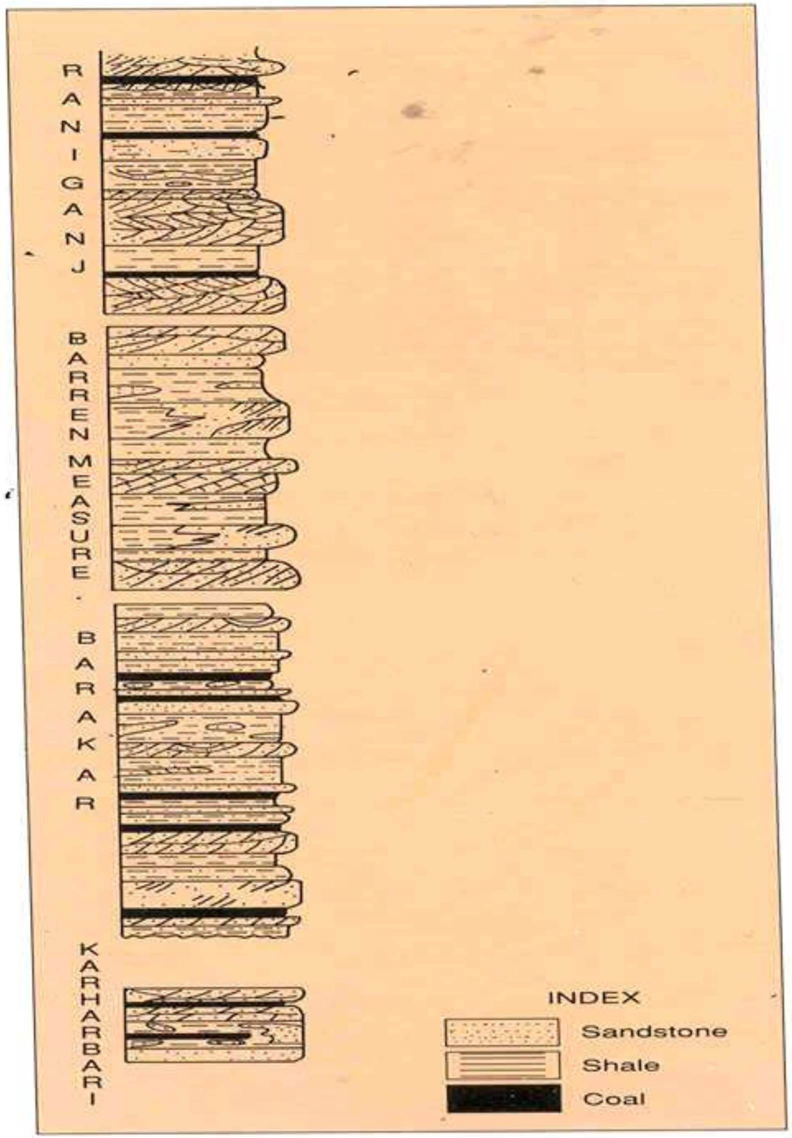
- 99% of coal production comes from the Gondwana which are found in three geologic units i.e. Raniganj, Barakar and Karharbari formations

- Three Gondwana master basins

  Damodar-Koel valley basin

  Son-Mahanadi valley basin and

  Pranhita-Godavari valley basin



Typical Stratigraphic Sections of Karharbari, Barakar & Raniganj coal Measures

Extraneous Coal Deposits of India

Large tract of land in India is still not covered for regional exploration even in well delineated basins. Many a times, surface exposures are misleading, terrain is unfriendly or exploration is technically difficult and hence not included in potential coal basins.

Grey Areas of Coalfields

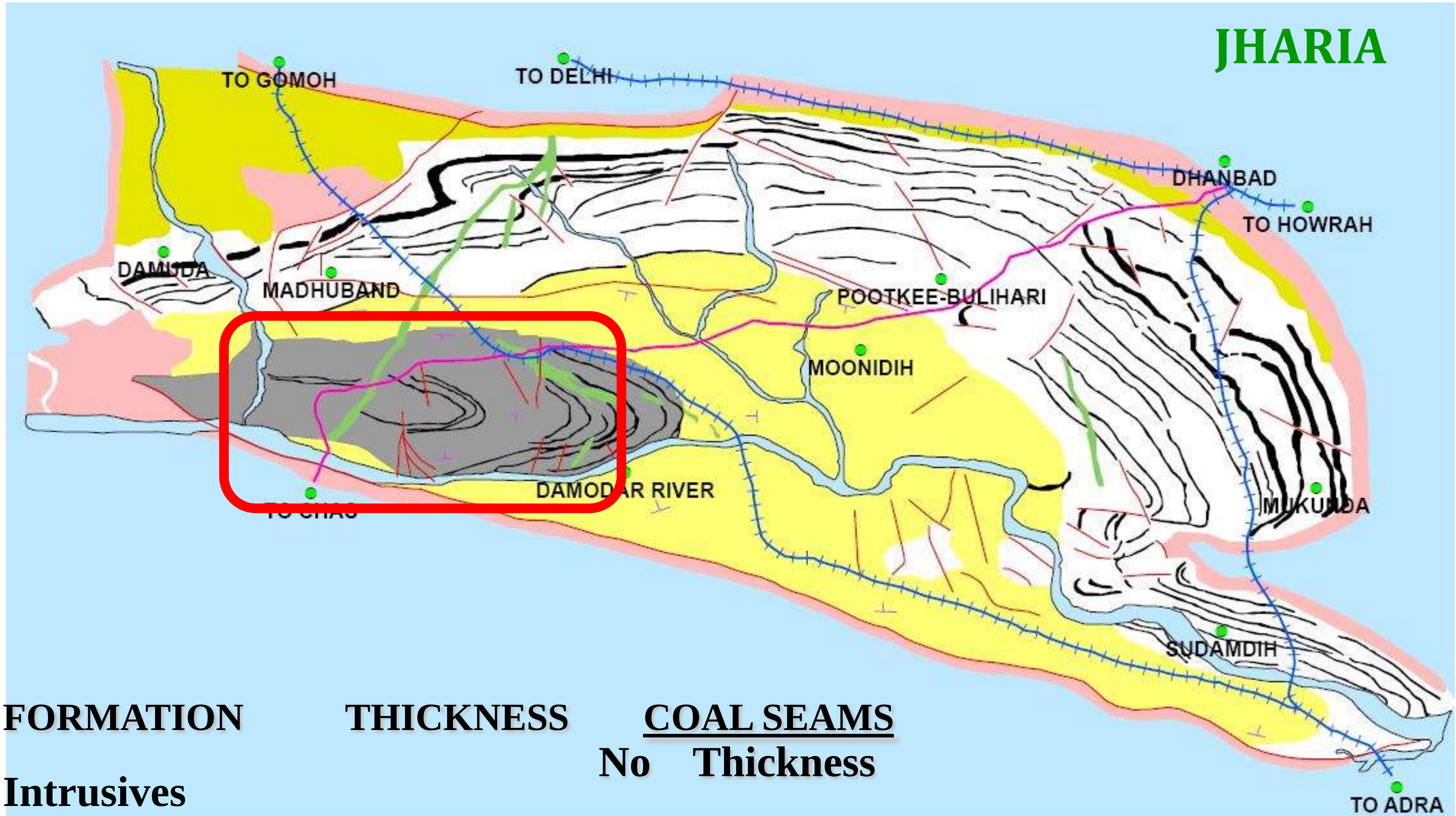
Well-delineated coalfields of nearly 37000 sq km area have a few patches under deep cover beyond the resource estimation and eventual mining limits.

Concealed coalfields

Concealed areas are of recent discovery and invariably under deep cover, underneath basalt or alluvial cover. The exact extension of most of these basins is just indicative by way of geophysical prospective and with skeleton boreholes drilled for oil and natural gas exploration.

Unmineable coal beds in well-delineated coalfields

The mining limit is decided with due consideration to quality, fuel value, market demand, market price, basin location and abundance of coal. The limit as such varies for different grades of coal and location of the coalfields.



FORMATION	THICKNESS	COAL SEAMS No	COAL SEAMS Thickness
Intrusives			
Raniganj	725m	22	(0.1m-4.7m)
Barren Measures	850m		
Barakar	1130m	46	(0.3m-33.0m)
Talchir	225m		
Basement	--		

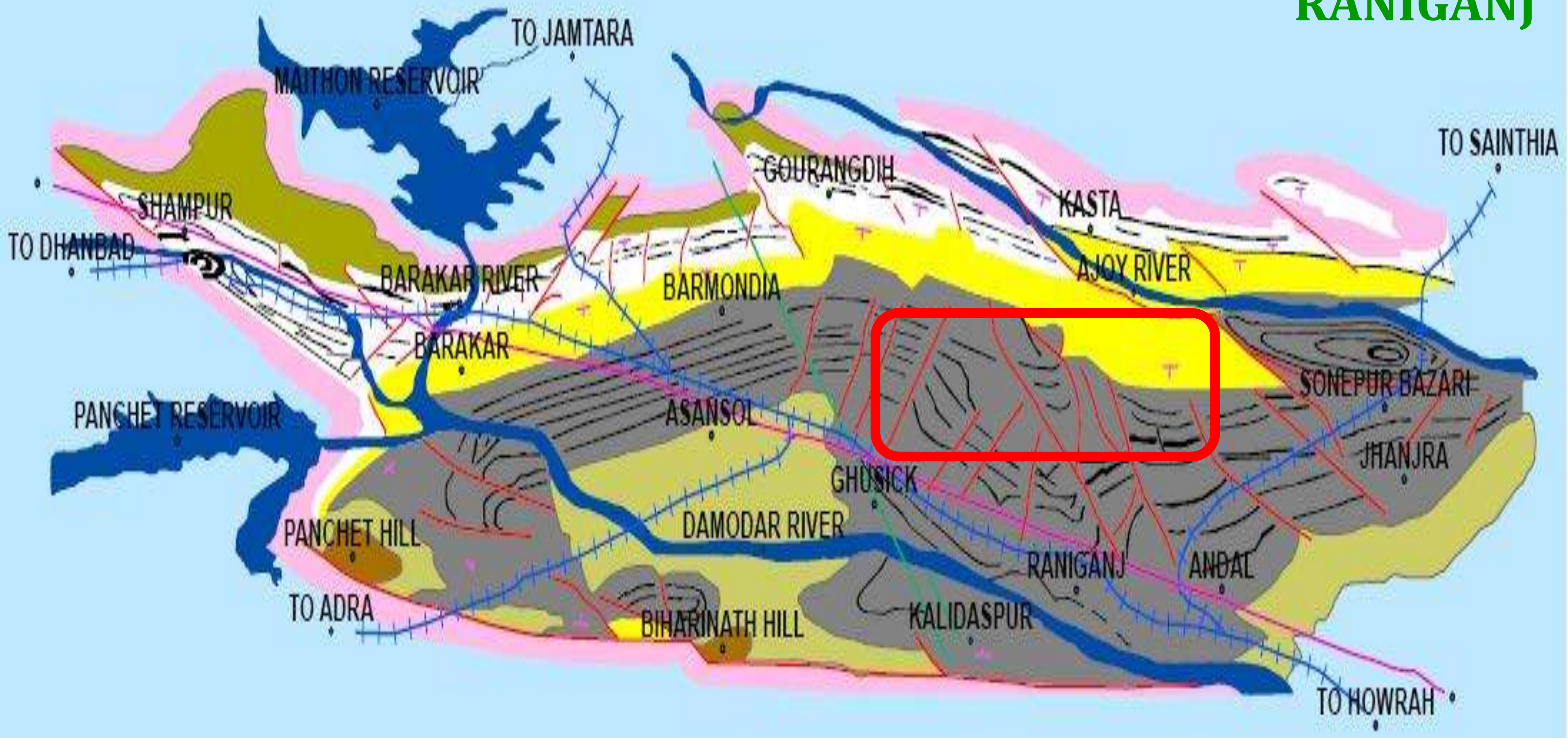
COAL RESOURCE

0-600m -- 14.2 bt

600m-1200m -- 5.2 bt

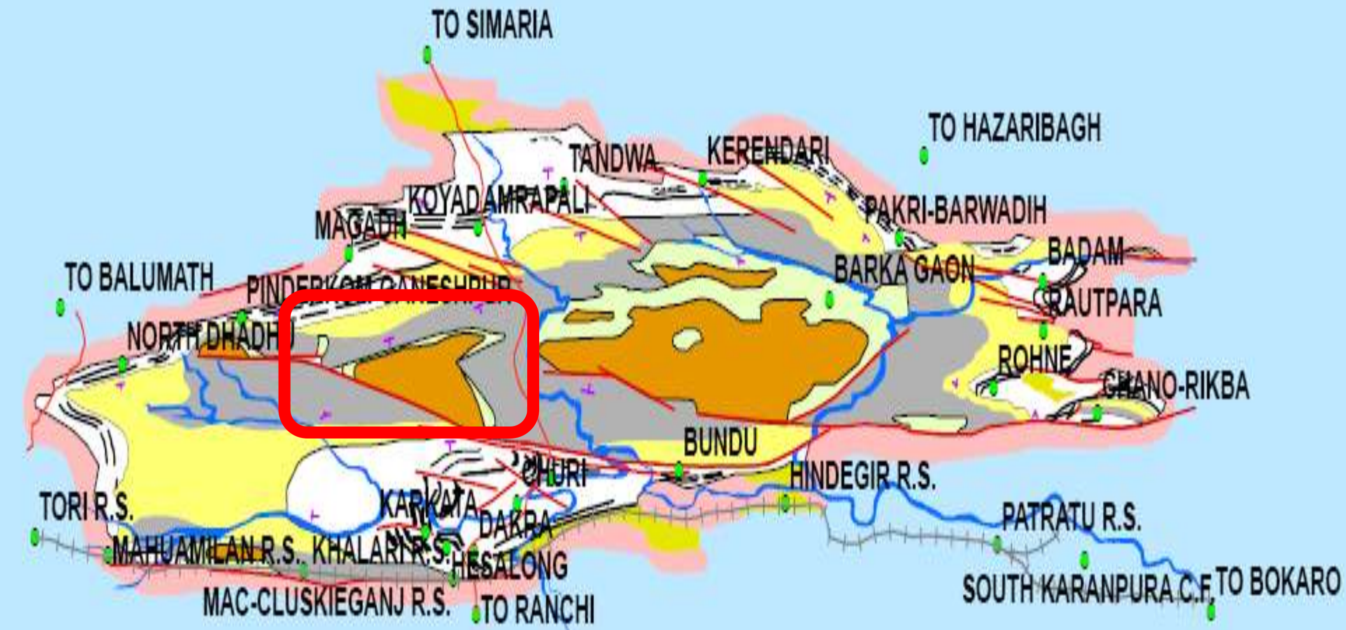
0 – 1200m – 19.4 bt

RANIGANJ



Raniganj Coalfield: Cumulative coal thickness (42.27m) and development of thicker seams(9.77m)

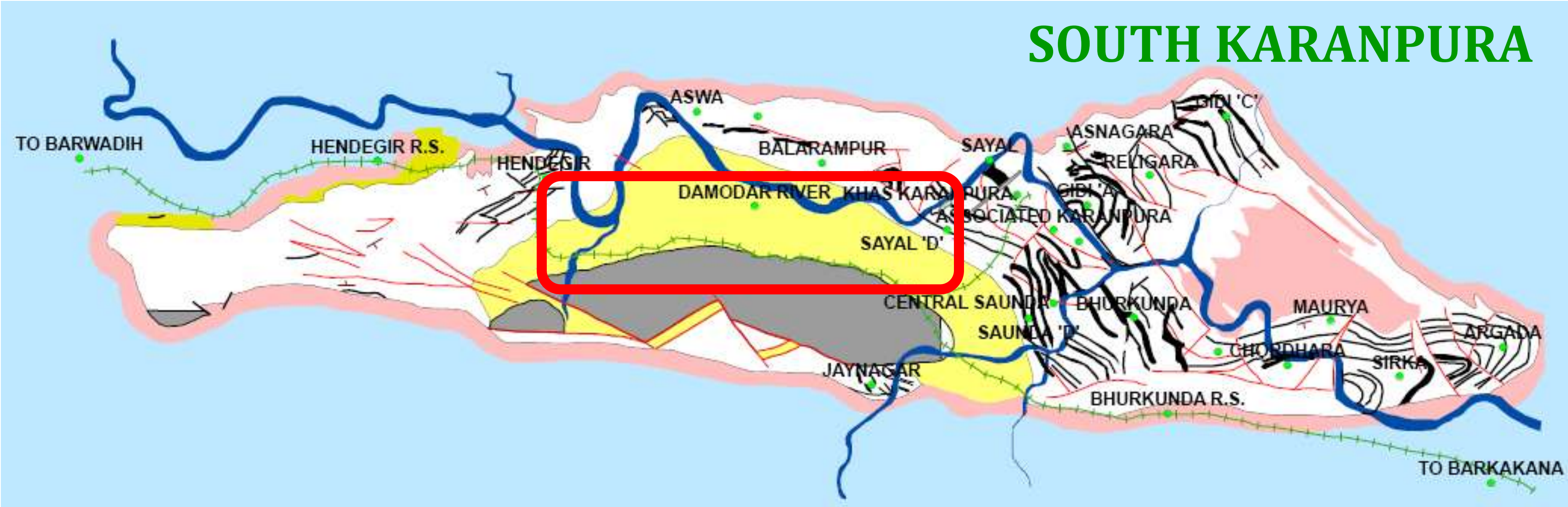
NORTH KARANPURA



FORMATION	THICKNESS	COAL SEAMS No Thickness
Mahadeva	165m	
Panchet	225m	
Raniganj	400m	thin bands
Barren Measure	385m	
Barakar	500m	5 (0.5m-35.2m)
Karharbari	200m	1 (0.5m-10.5m)
Talchir	180m	
Basement	--	

COAL RESOURCE

0-300m -- 10.3 bt
300m-600m -- 4.3 bt
0 – 1200m – 14.6 bt



FORMATION	THICKNESS	COAL SEAMS No	Thickness
Raniganj	360m	7	(0.8m-3.3m)
Barren Measures	385m		
Barakar	1050m	42	(0.5m-54.2m)
Talchir	180m		
Basement	--		

COAL RESOURCE

0-300m – 3.3 bt
300m-600m – 1.8 bt
600m-1200m – 0.9 bt
0 – 1200m – 6.0 bt

Category of coal beds	Grade of coal	Candidates /Basins
Unmineable coalbeds in well-delineated Coalfields	Power Grade coal	Singrauli, Mand Raigarh, Talcher, Godavari
Grey Areas	Coking coal	Jharia, East Bokaro, Sohagpur, S Karanpura
	Superior non coking coal	Raniganj South Karanpura
	Power grade coal	Talcher
Concealed Coalfields	Tertiary age coal	Cambay basin Barmer Sanchor basin*
	Power grade coal	West Bengal Gangetic Plain Birbhum, Domra Panagarh, Wardha Valley Extension, Kamptee basin Extension

Proximate analysis and rank of unmineable and grey area coalbeds

Coalfields	Basic parameters (mmf basis) VM(%)	FC(%)	Virinite reflectance R_o(%)
East Bokaro	28-36	85-90	0.85-1.05
South Karanpura	37-40	80-84	0.60-0.80
Jharia –Barakar	17-35	87-93	0.90-1.30
Raniganj	39-44	79-90	0.70-0.85
Rajmahal-Barakar	38-40	78-81	0.45-0.50
Singrauli- Barakar	37-45	78-81	0.45-0.50
Sohagpur	34-40	80-87	0.55-0.65
Pench valley	32-40	82-89	0.50-0.60
Wardha valley	35-40	78-82	0.55-0.60
Godavari Valley	35-42	78-83	0.55-0.60
Talcher	35-45	79-82	0.50-0.55

Proximate analysis and rank of concealed coalbeds

Coalfields	Basic parameters (mmf basis) VM(%)	FC(%)	Virinite reflectance R_o(%)
Cambay basin	45-58	52-68	0.32-0.44
Barmer	47-60	48-66	0.26-0.40
Sanchor Basin			
Birbhum	16-38	68-86	1.10-1.86
Wardha valley	24-35	72-88	0.54-0.68
Kamptee	26-36	75-92	0.52-0.66
Kanhan valley			

UNMINEABLE COAL RESERVE AND CO_2 STORAGE CAPACITY

Coalfield	Estimated adsorption capacity of CO_2 (m^3/t)	Coal Reserve (Mt)	CO_2 storage capacity (Bm^3)	CO_2 storage capacity (Mt)	CO_2 storage capacity (90%) (Mt)
Singrauli	Average 20.0	37.0	0.74	1.46	1.32
Mand Raigarh	Range 16.0-23.0 Average 19.0	79.0	1.50	2.97	2.67
Talcher	Range 17.2-24.8 Average 20.4	1017.0	20.80	41.18	37.06
Godavari	Range 16.8-22.2 Average 19.2	1976.0	38.02	75.28	67.75

ESTIMATED CO_2 ADSORPTION CAPACITY IN GREY AREA COALBEDS

Coalfield	Estimated CO_2 adsorption capacity (m^3/t)	Cumulative Coal seam thickness (m)	Block Area (km^2)	Coal Reserve (Bt)	CO_2 storage capacity (Bm^3)	CO_2 storage capacity (Mt)	CO_2 storage capacity (90%) (Mt)
South Karanpura	Range 19.5-28.0 mean 24.5	73.0	76.0	0.75	18.35	36.33	32.70
East Bokaro	Range 22.3-33.5 mean 28.1	100.0	113.0	1.53	42.90	84.94	76.45
Jharia	Range 22.0-56.0 mean 34.5	40.0	193.0	1.04	35.96	71.20	64.08
Raniganj	Range 20.8-29.0 mean 24.0	30.0	240.0	0.97	23.33	46.19	41.57
Sohagpur	Range 18.9-26.4 mean 22.6	15.0	450.0	0.91	20.59	40.76	36.69
Talcher	Range 17.2-24.8 mean 20.4	120.0	149.0	2.41	49.24	97.49	87.75

CONCEALED AREA COAL RESERVE AND CO_2 STORAGE CAPACITY

Coalfield	Estimated adsorption capacity (m^3/t)	Cumulative Thickness of coal seams (m)	Area of the block (km^2)	Coal reserve (Bt)	CO_2 storage capacity (Bm^3)	CO_2 storage capacity (Mt)	CO_2 storage capacity (90% (Mt)
mbay basin	Range 13.8-19.6 average 16.7	102.0	6900	63.0	1057.81	2094.45	1885.02
rmer Sanchor sin	Range 128-18.4 average 15.6	100.0	6700	60.0	936.00	1853.28	1667.95
B. Gangetic in	Range 16.4-23.2 average 18.3	---	---	7.2	131.76	260.88	234.80
bhum coalfield	Range 17.2-24.8 average 20.2	100.0	312.0	4.2	85.08	168.46	151.61
mra Panagarh	Range 18.6-25.8 average 21.8	48.0	116.0	0.751	16.39	32.45	29.20
rdha Valley ension	Range 15.7-22.8 average 17.8	13.0	212.0	0.37	6.62	13.11	11.80
mptee ension	Range 7.2-9.2 average 8.1	14.0	300	0.57	9.81	19.42	17.48

Conclusions

- **Indian coalbed are classified into grey, concealed and unmineable based on its depth of occurrence and grade characteristics.**
- **CO_2 storage potential in Indian coalbeds is estimated to be 4459 Mt.**

Thank You Very Much

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