Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Geologic – Coal Seams (1)

Opportunities and constraints on carbon dioxide sequestration and enhanced coalbed methane recovery in coal in British Columbia

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This talk will cover

- **Some of the practicalities of CO_2 adsorption in coal**
- **Distribution of coal in British Columbia**

Influences on CO_2 sequestration of

- **Rank**
- **Coal petrography**
- **Temperature/pressure conditions below the critical point**

Practicalities

carbon dioxide sequestration in coal seams

is assumed to mean

adsorption of CO_2 on coal

not

absorption of CO_2 (solution of CO_2 in coal)

Or

injection of super critical CO_2 fluid into coal

ZERO IN ON

CO_2 Sequestration and adsorption of gases on coal

Coal adsorbs gases

The sticky scale

Nitrogen methane carbon dioxide hydrogen sulphide

→ **Very sticky**

Adsorbed = Sticking to surface with density of a liquid

Absorbed = Entering solid and changing its solid properties?

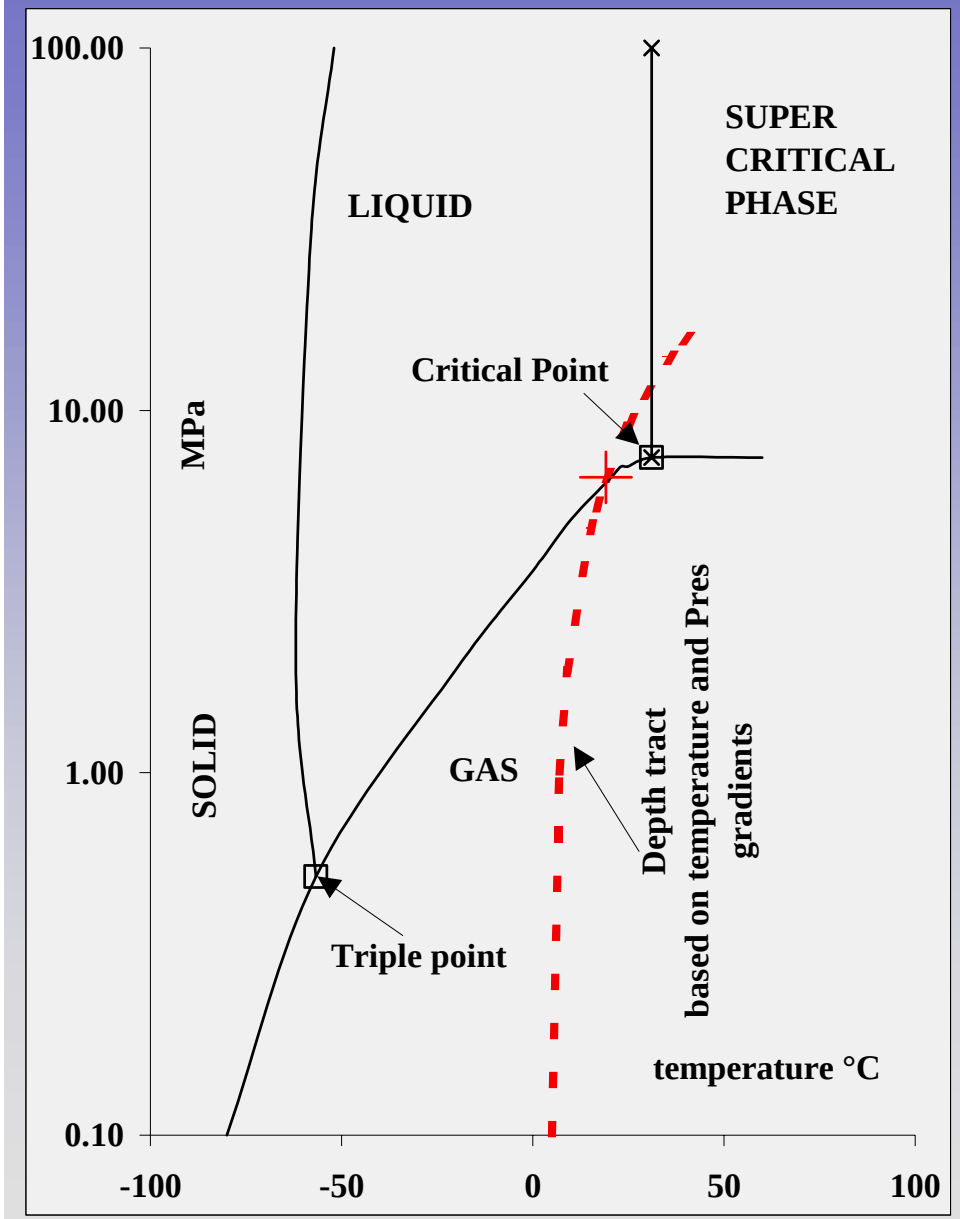
CO_2 is not always a gas

First need to define range over which CO_2

Is a gas and can be adsorbed by coal

This means overlying the CO_2 phase diagram with realistic geo thermal and geo pressure gradients

Now superimpose a Depth Tract based on geothermal temperature and pressure gradients



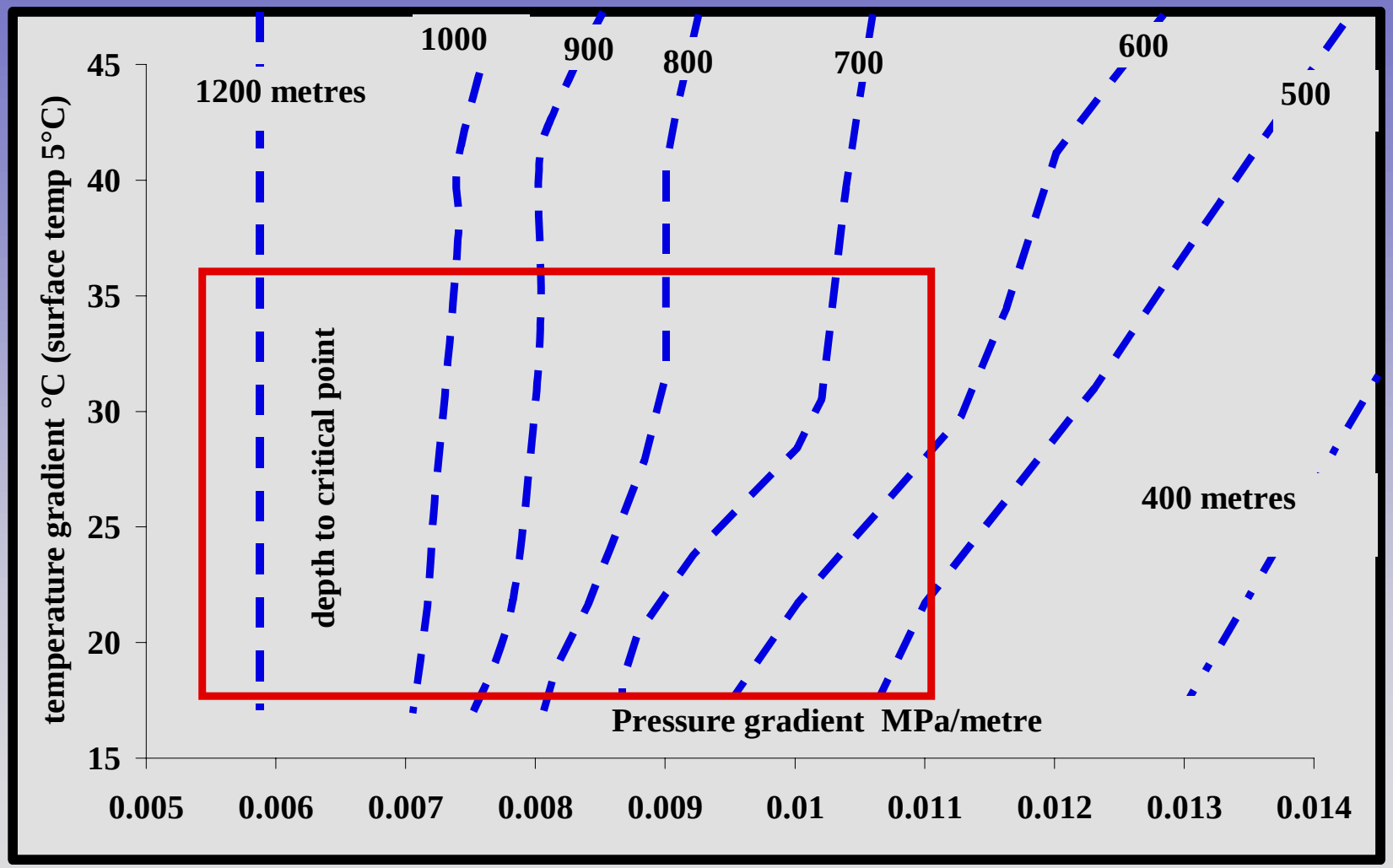
enter data over red only
drag red cross on chart to intersection point of phase diagram and depth tract

Output				
temp	Mpa	Depth		
19.1	6.5	707.8		
Pressure gradient		0.0091	Mpa/m	0.401 psi/ft
surface temp		5		
temp gradient C/Km		20		
Atmospheric		.10129Mpa		14.69 psi
normal hydostatic=0.43 psi/ft or .009805Mpa/metre				
max depth for CO2 gas				
max depth to S Critical based on P grad				803.93

maximum depth for sequestration occurs when geothermal gradient is high
and pressure gradient is low

changes in either gradients can change
from adsorption to super critical condensation
underpressuring allows for easier matrix swelling
to accommodate CO2

By imposing various combinations of T and P gradients on the phase diagram one can outline all possible combinations of T and P gradients and maximum depth of sequestration



Realistically CO2 Sequestration by adsorption is only possible down to depths of about 900 metres

Pressure gradient data is difficult to locate

But temperature gradient data are available from most log suites

location	S temp	Grad	location	S temp	Grad
Vancouver Island			**Southeast BC**		
Comox	7	20.8	Crowsnest area	8	25.4
Naniamo	7	27.5	"	8	20.5
"	7	28.3	"	8	18
"	7	23.3	Elk Valley	8	23.6
"	7	22.1	Elk Valley	8	36.2
Northeast BC			**Northeast BC**		
Bullmoose area	4	23.1	Willow Creek	5	25.6
"	4	30.2	Hudson Hope	5	30
"	4	31.5	"	5	28.6
Grizzly area	5	26	"	5	36.4
"	5	25.7	"	5	22.8

S temp = average surface temperature ºC surface
Grad = ºC/kilometre

°C	5	10	20	25	30
°F	41	50	68	77	86

25°C/km = 72°F/mile

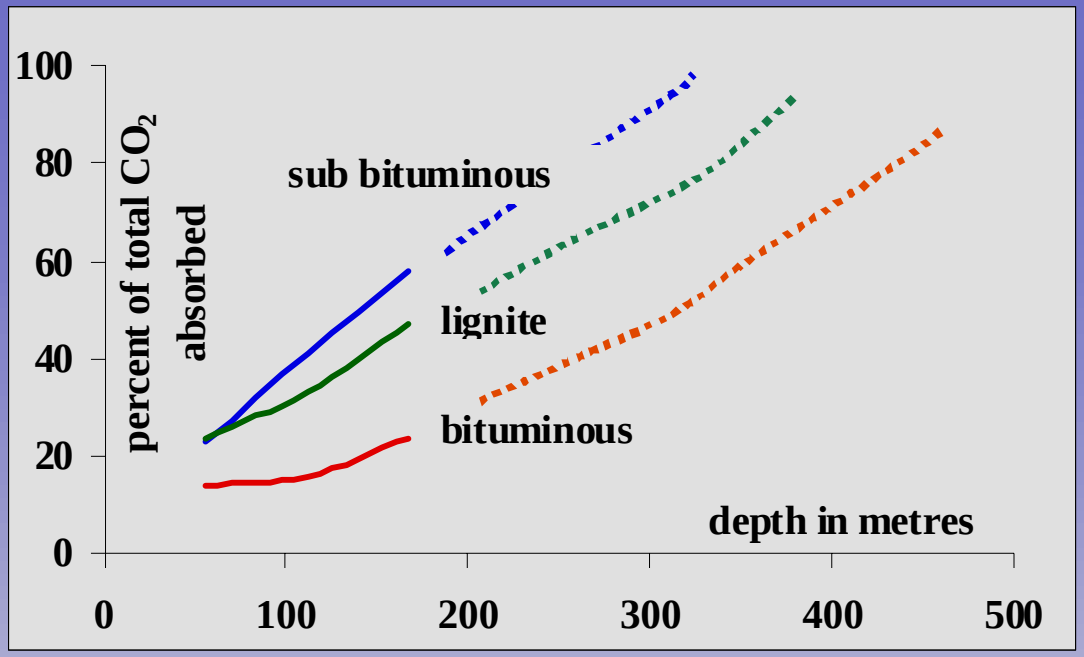
If we talk only of adsorption then there is a limited depth window available for sequestration

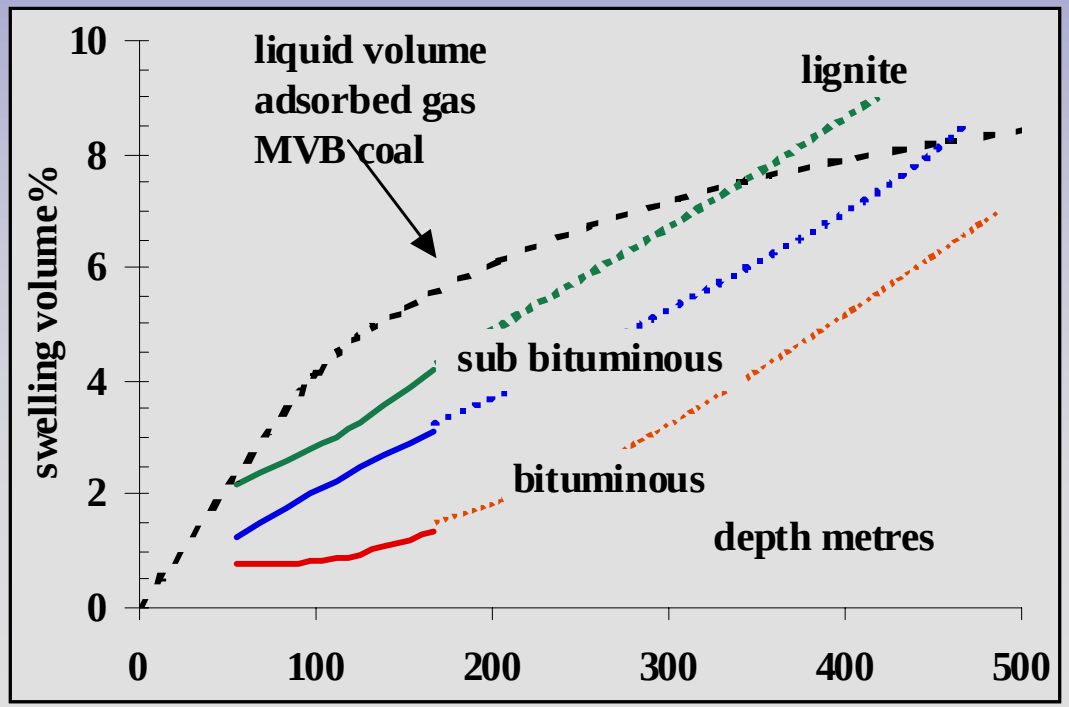
The window is defined by the phase diagram and actual temperature and pressure gradients in the stratigraphic column

but is life that simple

In an atmosphere of CO_2 coal adsorbs CO_2 but also CO_2 goes into solution(absorbed)

Both these processes cause volume increase probably in the same order of magnitude



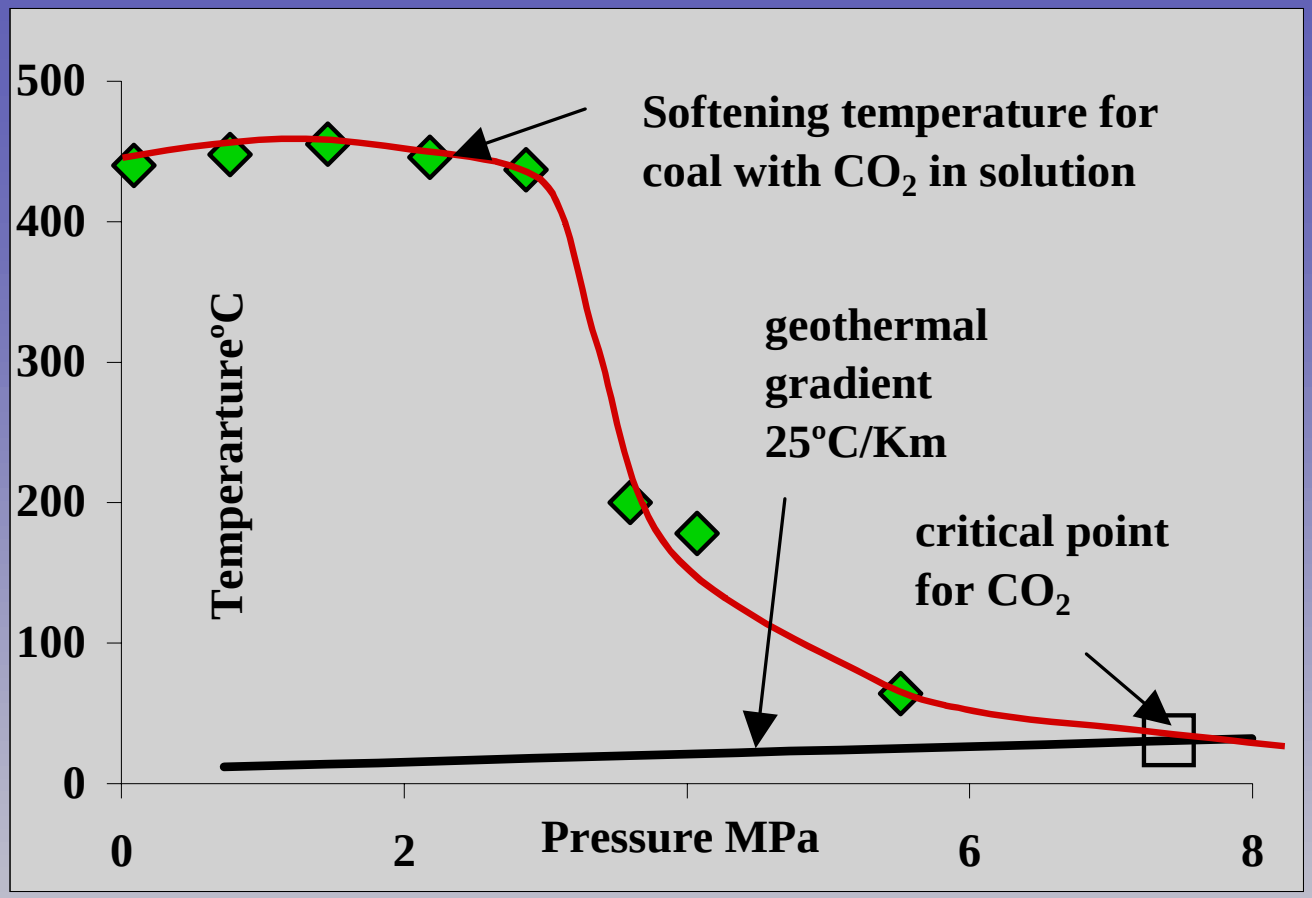


When performing isotherm measurements it is not clear if adsorption or solution (absorption) is being measured

If CO_2 goes into solution what effect does this have on CH_4 adsorption

Reucroft and Patel 1986

Low volatile bituminous coal



Absorption or solution of CO_2 in coal softens the coal such that at critical point conditions the coal is plastic

It will deform and not support any fracture network ie no permeability and may also deform like a salt dome

Plot adapted from Larson (2003) IJCG

Can investigate adsorption of CO_2 below critical point conditions

But remember

- On isotherm plots projections above critical temperature or pressure using Langmuir constants are not real
- As isotherm conditions approach critical point temperature and pressure results are confused by absorption
- Isotherm experiments are done on unconfined coal particles that can swell without restriction. This is not the case in the real world

Study the CO_2 and CH_4 adsorption characteristics of British Columbia coals

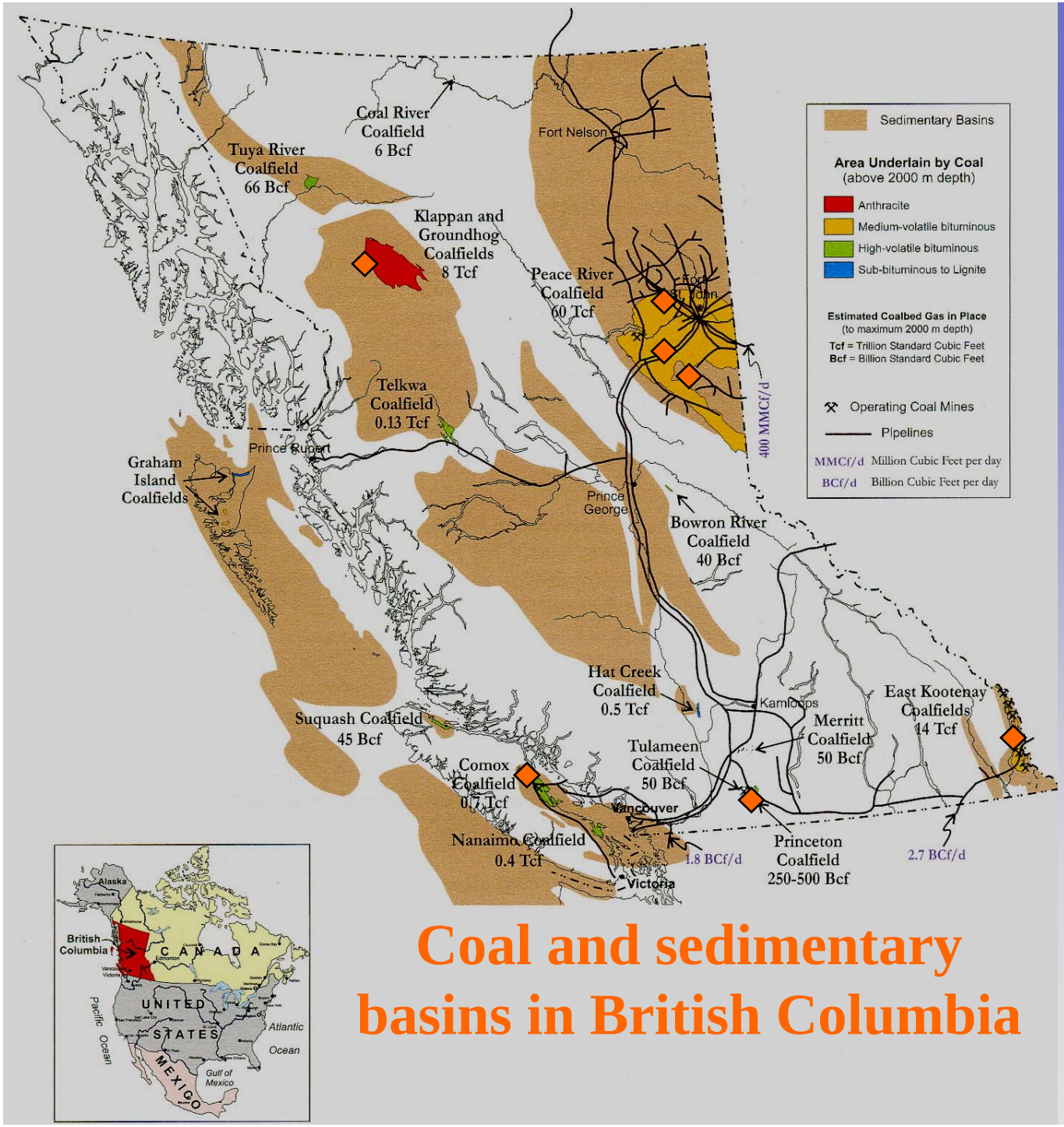
Variations related to

- **Rank**
- **Petrography**
- **Different sub critical pressure temperature conditions**

What are the implications for permanent sequestration of CO_2

Samples were collected from different formations with different ranks

Isotherms were run at three temperatures



Coal and sedimentary basins in British Columbia

British Columbia has a coal resource available for mining of about 23 billion tonnes and a resource available for CBM exploration of about 250 billion tonnes

Sample data and locations

Temperature

rank

Petrography

Table 6: CO_2 isotherm

	AR Lang Vol CC/g	DAF Lang Vol cc/g	Lang Pres Mpa	temperture°C	Ash % ADB	EQ moisture %	SG	Rmax%
Anthracite NW BC								
	31	55.85	1.059	25	42.3	3.8	1.860	3.68
Gething NE BC								
7 seam -7	45.56	48.49	1.34	30	2.7	3.31	1.339	1.64
-7	48.15	51.25	1.23	25	2.7	3.31	1.345	1.64
-2	50.54	55.59	1.48	25	6.2	2.83	1.382	1.64
-4	54.66	57.49	1.27	25	1.1	3.85	1.338	1.64
-3	50.02	53.33	1.44	25	2.5	3.69	1.369	1.64
-8	51.95	55.69	1.44	25	2.9	3.88	1.369	1.64
-5	47.31	49.81	1.35	25	1.3	3.76	1.359	1.64
Hudson Hope	38.47	40.85	2.09	25	2.9	2.93	1.388	1.21
Gates NE BC								
B seam fine	31.14	34.45	1.15	25	6.9	2.74	1.370	1.06
B seam coarse	31.60	35.09	1.28	25	7.5	2.48	1.407	1.06
J seam	23.58	34.28	2.45	25	20.4	10.77	1.528	1.23
Mist Mountain SE BC								
10 seam	28.17	35.28	2.04	25	17.8	2.37	1.468	1.28
Comox Vancouver Island								
Quinsam 1 seam	41.80	48.99	4.27	30	8.4	6.28	1.466	0.68
Quinsam 1 seam	31.40	36.80	1.32	25	8.4	6.28	1.444	0.68
Quinsam 3 seam	40.35	47.12	2.61	25	8.5	5.92	1.375	0.71
Quinsam 1R seam	34.09	45.60	4.60	20	20.4	4.82	1.472	0.68
Allenby South central BC								
Black-jack zone	44.44	55.98	4.65	25	8.5	12.15	1.351	0.7

The best way of comparing adsorption characteristics of CO_2

is to use a fixed depth (210 metres) and temperature (25°C

below critical conditions of

31.1 º C and 7.405 Mpa

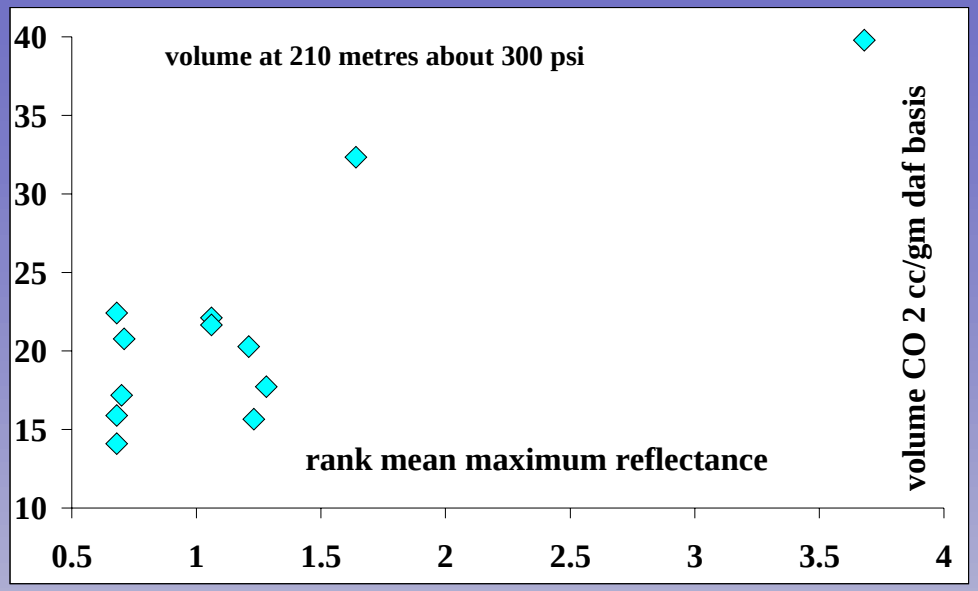
Rank

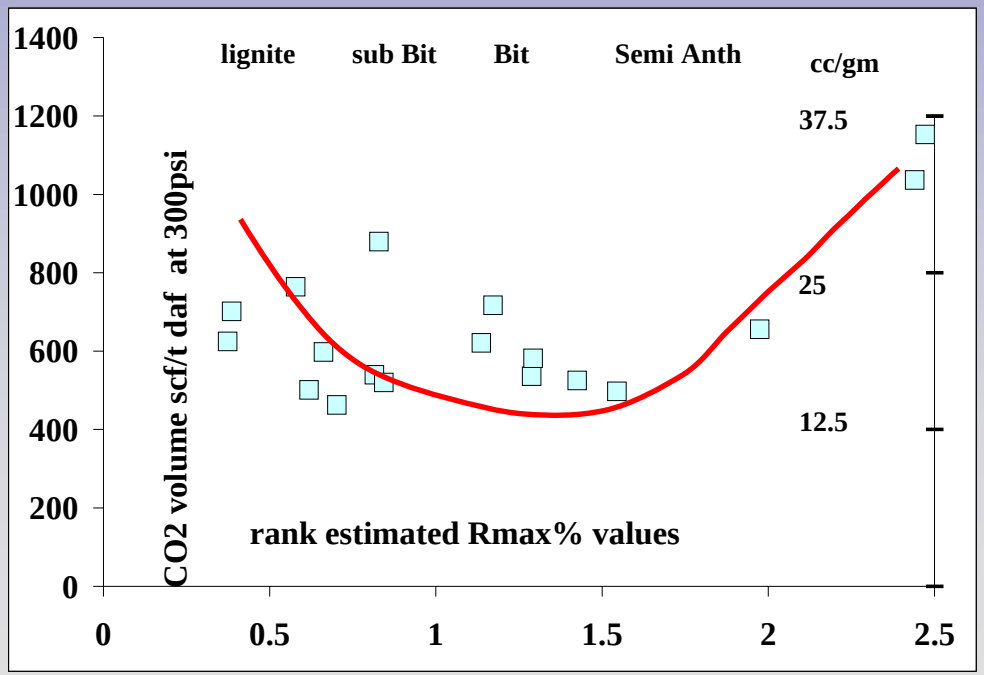
Sub bituminous bituminous anthracite

Vitrinite reflectance Rmax%

0.5% 1.4% 2.5%

CO2 adsorption versus rank





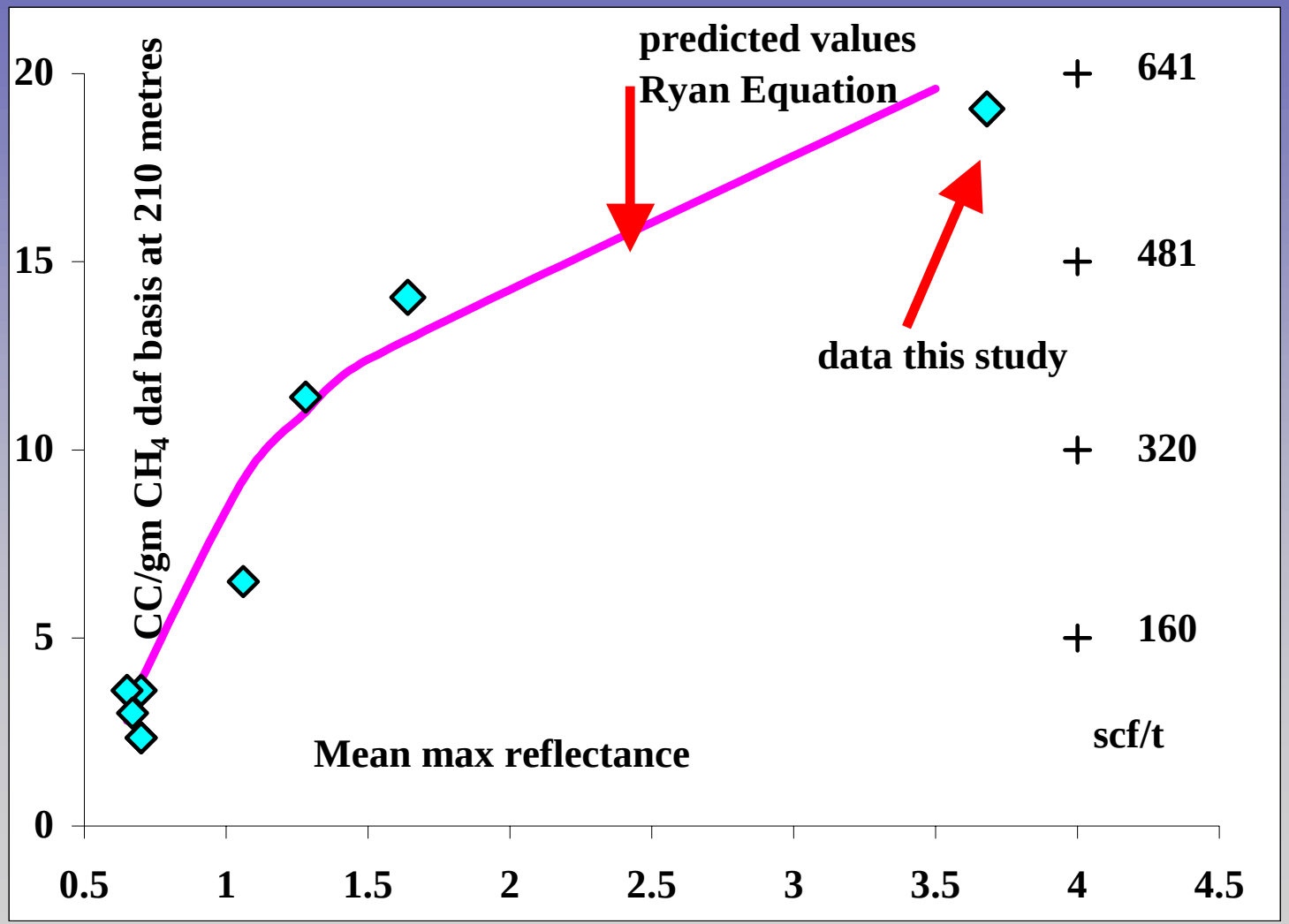
CO_2 adsorption decreases then increases with increasing rank

Note gas contents at a depth equivalent of about 210 metres and a temperature of 25 °C

Lower plot data from Gluskoter et al (2002)

But what about methane CH_4

adsorption tends to increase more consistently with rank



CO_2 / CH_4 ratio versus rank

Variation of CO_2/CH_4 ratio with rank

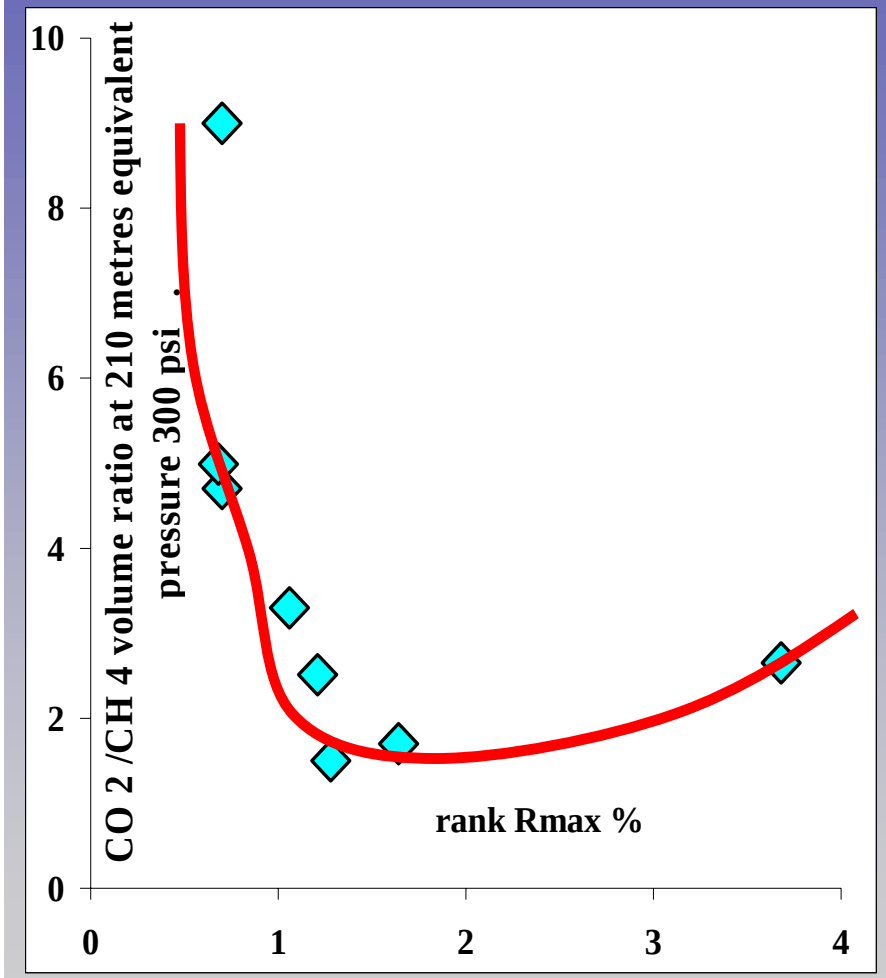
Rank	Rmax%	volume ratio	wt ratio	CO_2 scf/t daf	CO_2 cc/g	CH_4 cc/g
		Gluskoter				
lignite		9.4	25.9	800	25.0	2.7
sub bit		7.6	20.9	900	28.1	3.7
high vol		5	13.8	700	21.8	4.4
medium vol		2.4	6.6	600	18.7	7.8
low vol		2	5.5	800	25.0	12.5
Semi anth		2.6	7.2	1000	31.2	12.0
	this paper 25°C					
Anthracite	3.68	2.65	7.3	1150	35.9	13.6
Low vol	1.64	1.7	4.7	998	31.2	18.3
medium vol	1.21	2.51	6.9	625	19.5	7.8
medium vol	1.28	1.5	4.1	550	17.2	11.4
High vol A	1.06	3.3	9.1	685	21.4	6.5
High vol B	0.7	4.7	12.9	527	16.4	3.5
High vol B	0.7	9	24.8	611	19.1	2.1

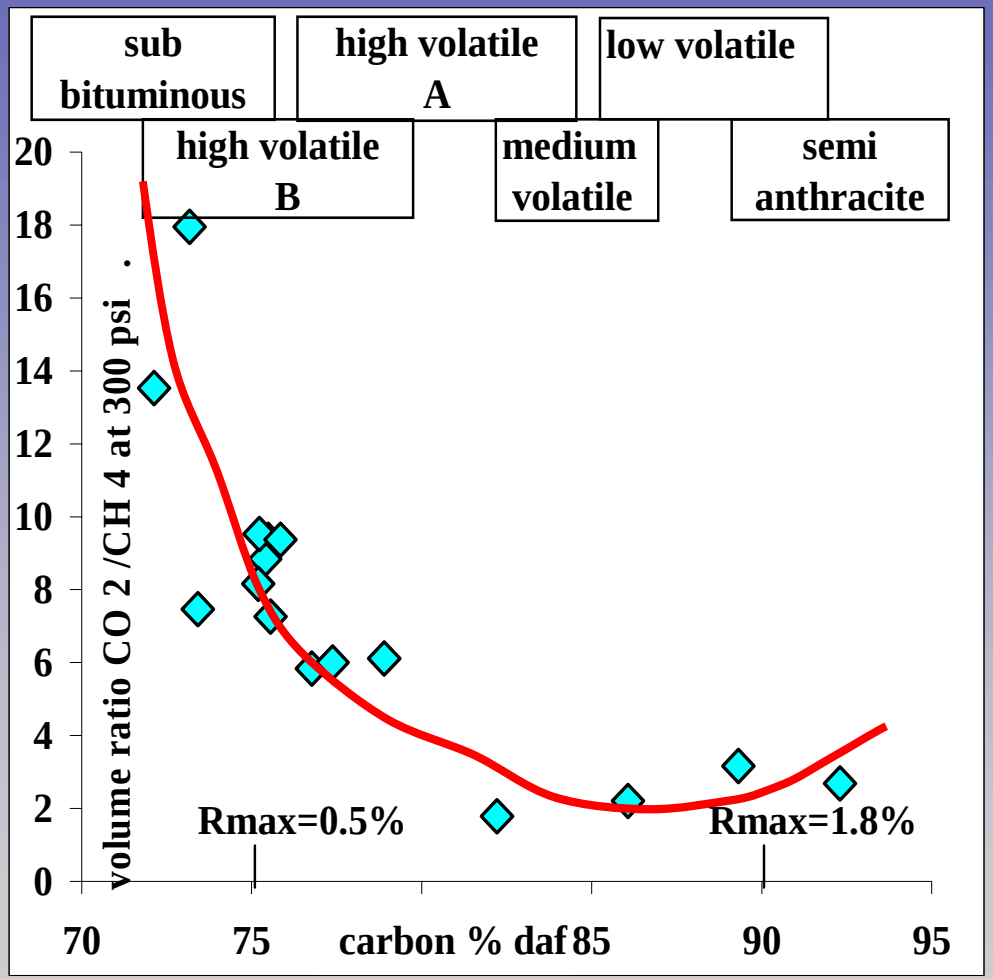
Data calculated at a pressure equivalent to 210 metres

Volume ratio is molecule for molecule

But remember we are interested in sequestering CO_2 by weight

Variation of CO_2/CH_4 ratio with rank





Data on right from Gluskoter et al (2002)

Variation of CO_2 and CH_4 with petrography

At constant rank

Measure the amount of reactive macerals (Vitrinite liptinites)

and inert macerals (fusinite semifusinite macrinite)

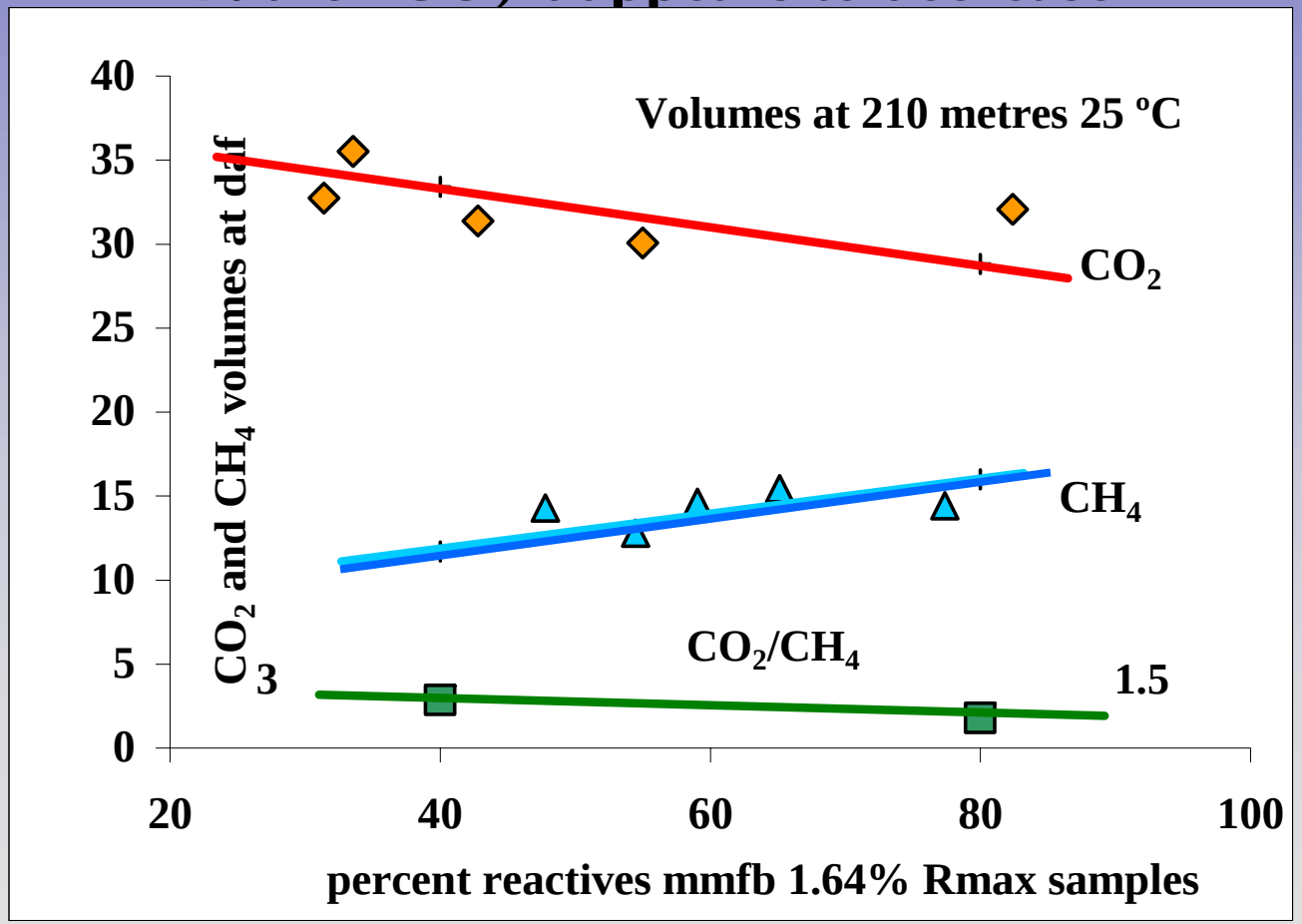
on a mineral matter free basis

Look for trends

Variation in petrography
At constant rank Rmax=1.64%

At a fixed rank adsorption of CH_4 increases as the amount of vitrinite in the sample increases

But for CO_2 it appears to decrease



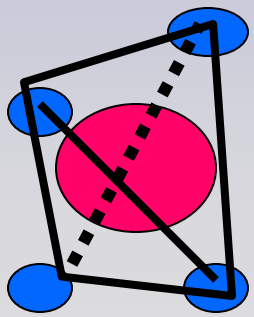
The maximum selectivity of CO_2/CH_4 may occur in

- coals with low vitrinite contents
- Coals with low or very high rank coals

This may relate to the pore size distribution and the type of adsorption (ie mono or multi layer) of the 2 molecules

Mono layer

not very polar

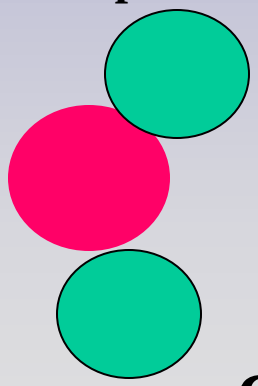


4.1A°

CH_4

Multilayer

more polar



4.7A °

CO_2

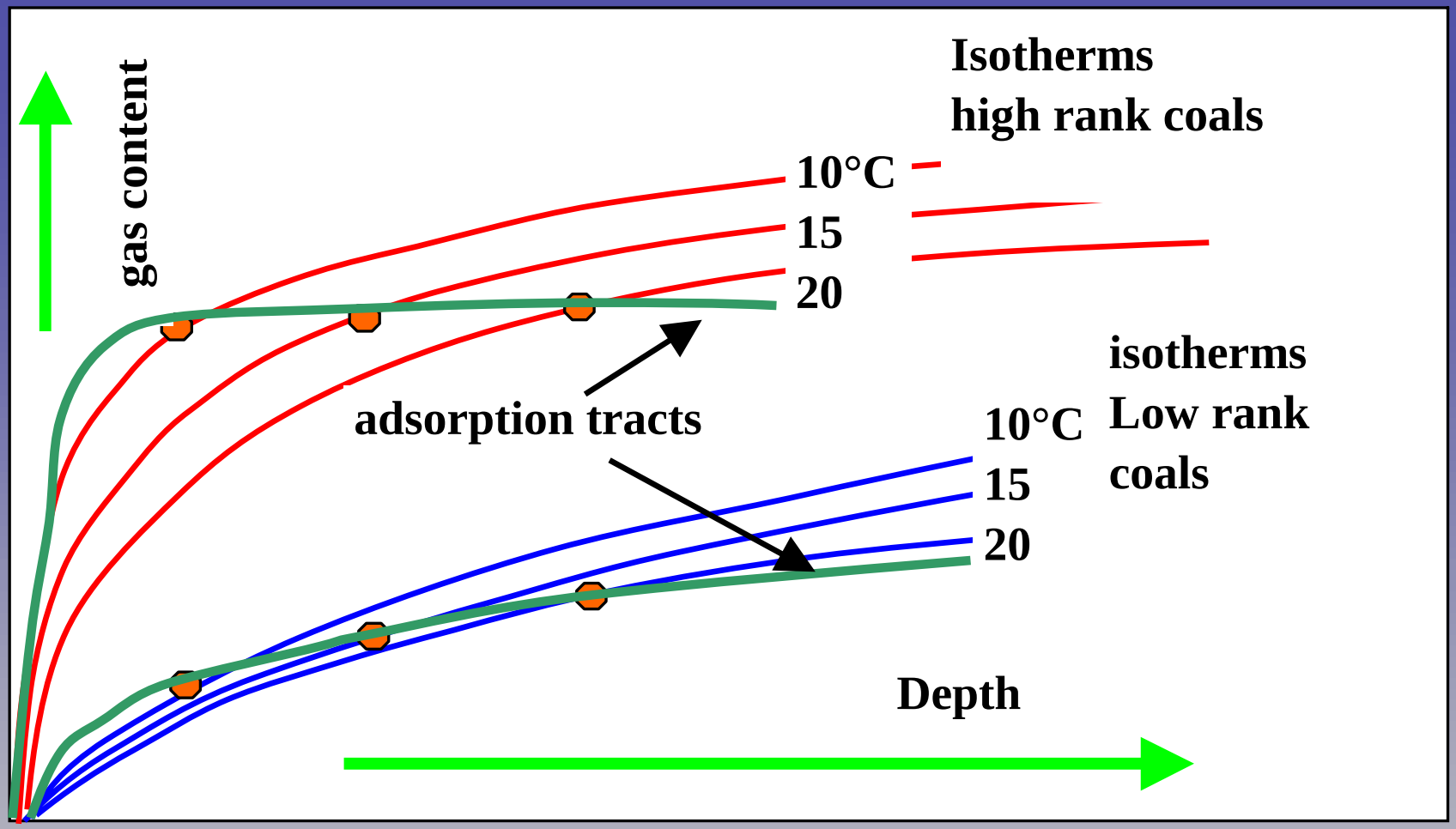
Porosity		
	Angstroms	Microns
	10^{-10} m	10^{-6} m
Micro	<12	< 0.0012
Meso	12 – 300	0 .0012 - 0.03
Macro	>300	>0.03

The real world

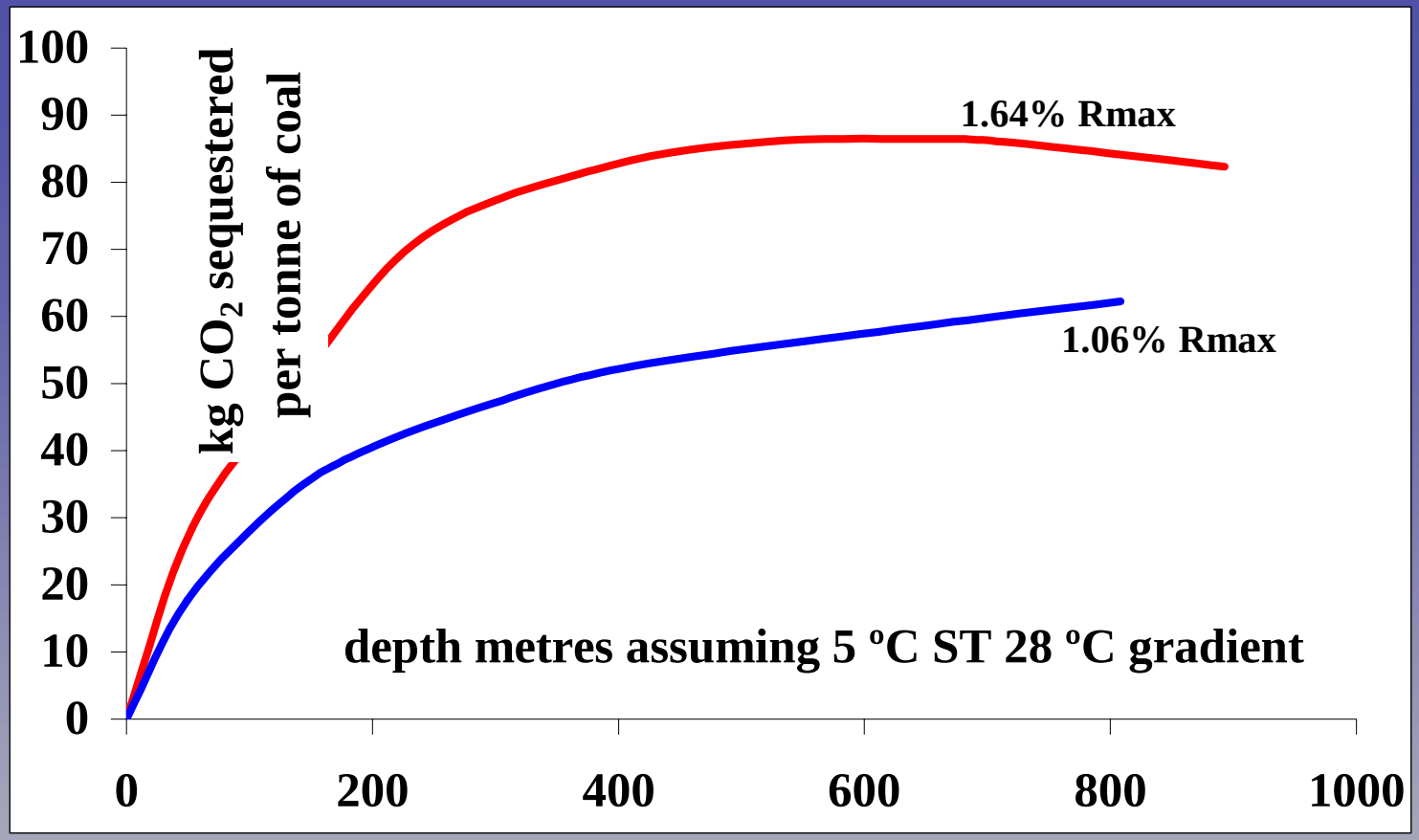
Varying

temperature and pressure

Isotherms indicate adsorption at constant temperature as depth increases But temperature increases with depth Therefore need to estimate how adsorption behaves as depth (pressure) and temperature increase



Because of the shape of isotherms adsorption tends to increase with depth for low rank coals and decrease with depth for high rank coals



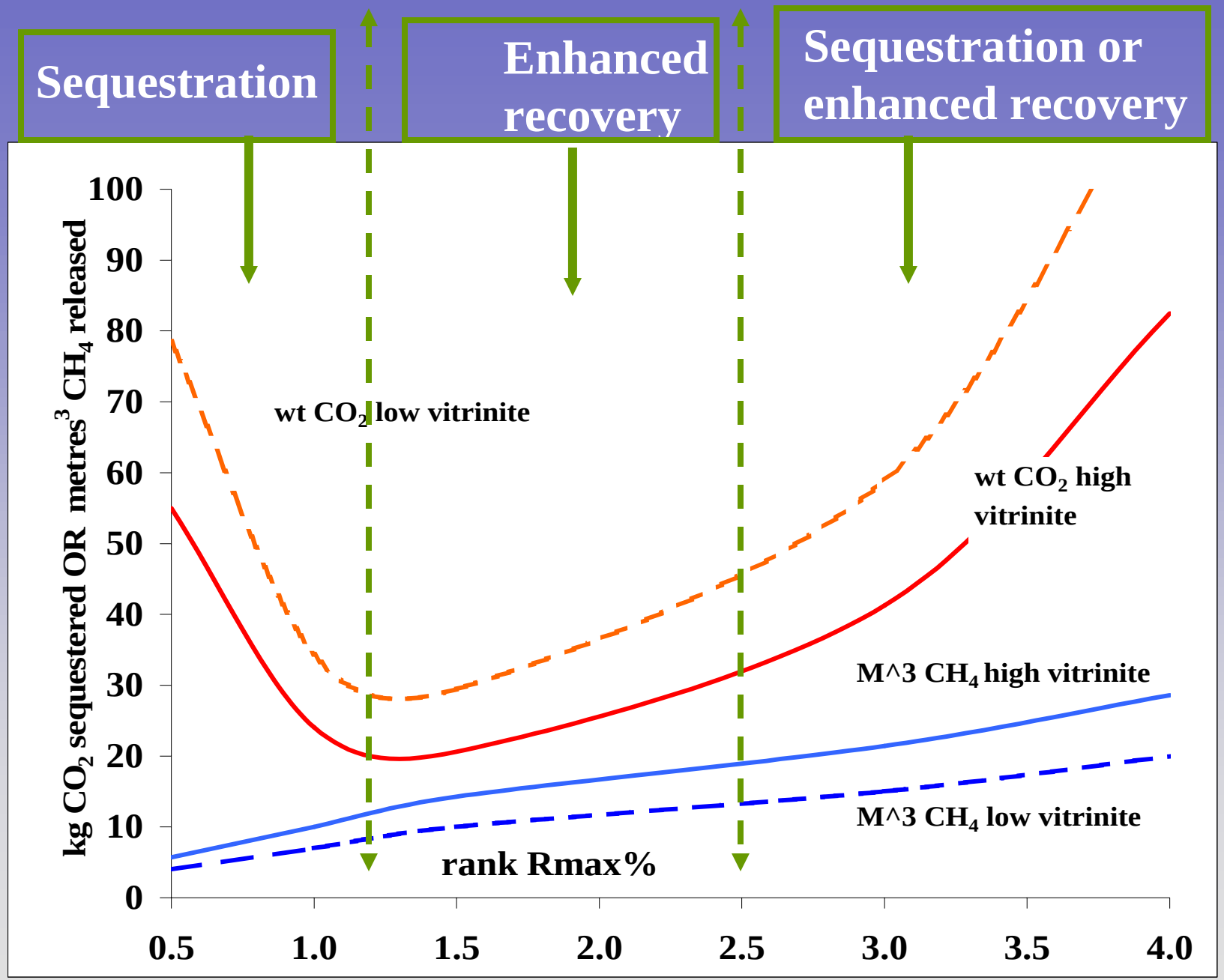
So what does all this mean

If coal is un saturated to start then on a per tonne basis

How much CO_2 could it sequester The plot is very rough but indicates the influence of rank, pressure and temperature

Remember burning 1 tonne of coal produces about 2750 kg CO_2

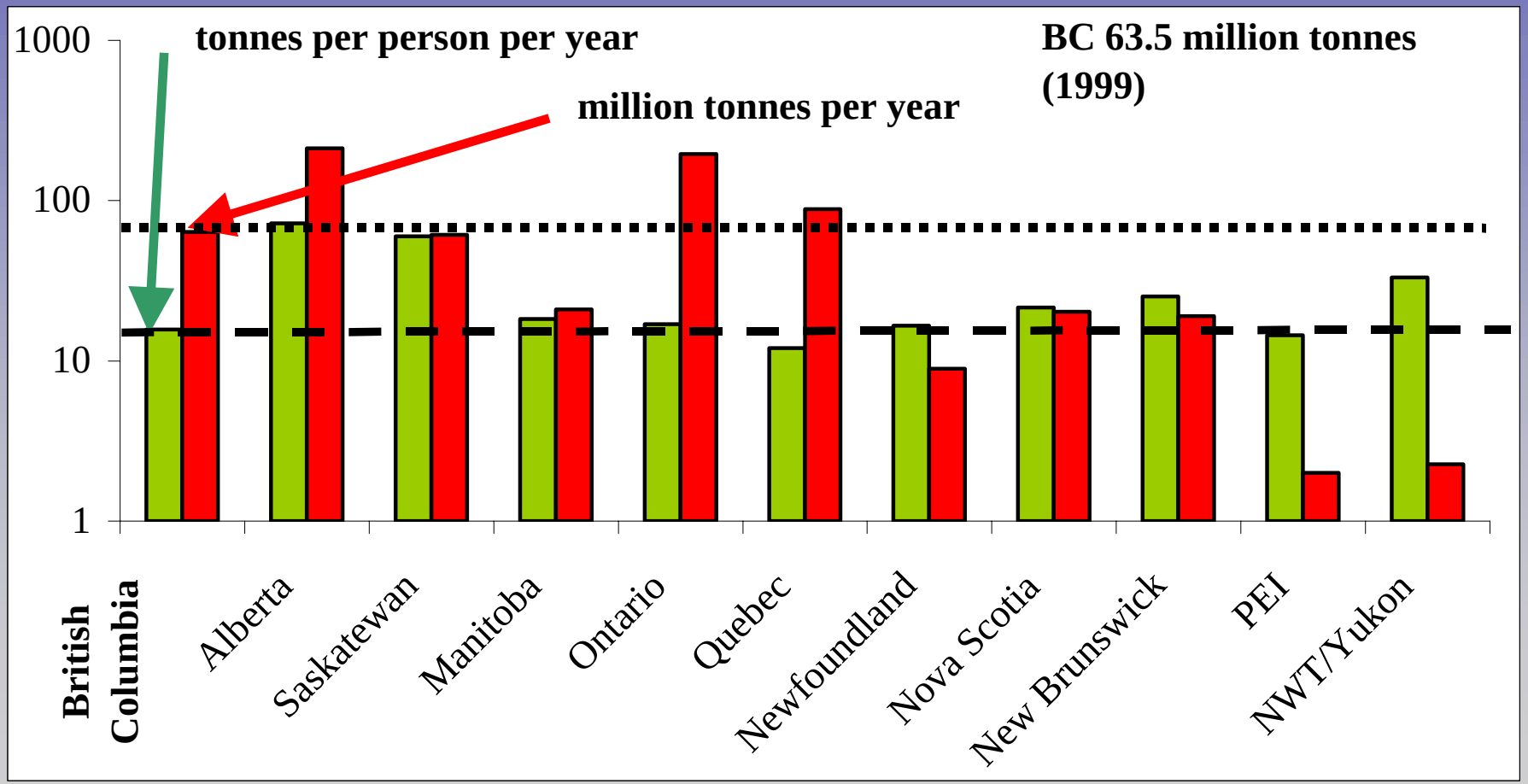
What does all this mean for sequestration and ECBMR



British Columbia compared to the rest of Canada

High in total emissions but low on a per person basis

Sources are very distributed



Putting CO_2 sequestration in perspective in British Columbia

We have a lot of coal But burning coal produces a lot of CO_2 that would require even more coal for sequestration

British Columbia CO_2 equivalent emissions million tonnes per year (1999)		63.8					
CO_2 produced billion cubic metres per year		32.5	estimated assuming all greenhouse gas CO_2				
depth metres	704	563	422	282	211	141	70
CO_2 adsorption cubic metres/tonne	18.9	18.3	17.5	15.9	14.6	12.5	8.8
billion tonnes of coal to sequester CO_2 produced in 1 year	1.72	1.77	1.86	2.04	2.23	2.60	3.68

The power plant discussion

A power plant burning coal produces more CO_2 than can realistically be sequestered in the coal resource adjacent to the power plant

coal fired power plant MW	360	Medium to small power plant based on average size in canada
Efficiency %	32	
Coal consumption/yr million tonnes	1.413	
% carbon	65	
CO_2 produced million tonnes	3.37	
CO_2 produced million cubic metres	1715	

depth metres	704	563	422	282	211	141	70
Adsorption cubic metres/tonne	18.9	18.3	17.5	15.9	14.6	12.5	8.8
Million tonnes of coal to sequester 1715 million cm CO_2	91	94	98	108	118	137	194
Ratio tonnes coal needed for sequestering versus tonnes burnt	64	66	69	76	83	97	137

Opportunities for sequestering CO_2 in British Columbia

Small CBM development where CBM is burnt on site and converted to CO_2

Gives opportunity to sequester CO_2 in depleted CBM wells

example for medium-volatile coal

depth metres	141	282	422	704
CH_4 cubic metres/tonne gas recovered	5.7	8.1	9.4	10.6
CO_2 wt Kg CO_2 from burning CH_4	11.3	15.9	18.4	20.8
CO_2 equivalent cubic metres/tonne	5.7	8.1	9.4	10.6
CO_2 cubic metre/tonne adsorbion capacity	12.5	15.9	17.5	18.9
tonnes required to sequester CO_2	0.46	0.51	0.54	0.56

There is an increase in volume when CH_4 is desorbed and CO_2 adsorbed

liquid volume CH_4 litres desorbed	8.8	12.4	14.4	16.3
percent volume of coal	1.2	1.7	1.4	1.9
liquid volume CO_2 litres adsorbed	11.3	15.9	18.4	20.8
percent volume of coal	1.5	2.1	2.5	2.8
Volume increase %	0.3	0.4	1.2	0.9

Confusions

CO_2 sequestration in Coal

- Is viable over a limited depth range
- May decrease CO_2 emissions at a point source but is unlikely to sequester all CO_2 produced from major sources
- May be viable at Hat Creek in BC
- CO_2 sequestration can replace CH_4 and aid in enhanced recovery but without recovering CH_4 may increase release of greenhouse gases because CH_4 is a much more potent greenhouse gas
- Absorption of CO_2 softens coal may cause a decrease in permeability
- Adsorption of CO_2 and desorption of CH_4 results in a volume increase and may decrease permeability
- Adsorption characteristics of CO_2 different than for CH_4 as rank and petrography change

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A very personal reason to believe in CO_2 sequestration

Sugar + yeast + time = alcohol or $C_6H_{12}O6 \rightarrow 2*CO_2+2*C_2H_5(HO)$

500 ml bottle requires 50gm of sugar to make 5% alcohol

Sugar	**50 gm**	
Wt CO_2 per bottle grams	**24.44**	
Number of Canadians 10^6	**30**	
Bottles per day	**3**	**its cold here**
Tonnes CO_2 produced/yr	**803000**	
Volume 10^6 at STP m^3	**410**	
CO_2 adsorption m^3/tonne	**14**	
Tonnes required 10^6	**29**	
Tonnes / Canadian / year	**1**	