Importance for Seal Evaluation in Oil/Gas Exploration

—How to distinguish Methane-rich Traps from CO_2-rich Traps—

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(FGI)

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SEAL!! Important Feature on Petroleum Systems Analysis

Todays Menu (Key Words)

- (Sarawak Offshore) How to find Gas Field (CH_4 or CO_2)
- Importance of Seal for trapping Oil/Gas (>Generation or Migration)
- How to evaluate Top Seal Capacity ?

Importance for Seal Evaluation in Oil/Gas Exploration

1. **Introduction**（Toy experiment, Curious Distributions of Oil and Gas Fields）
2. **Oil and Gas Trap System** (Source, Reservoir, Cap-rock)
3. **Contents in Trap**（Oil or Gas？）
4. **How to Evaluate Sealing Capacity**（EGS-Method）
5. **Case Studies** (Sakhalin, Iraq)
6. **How to distinguish CO_2-rich Gas Traps**

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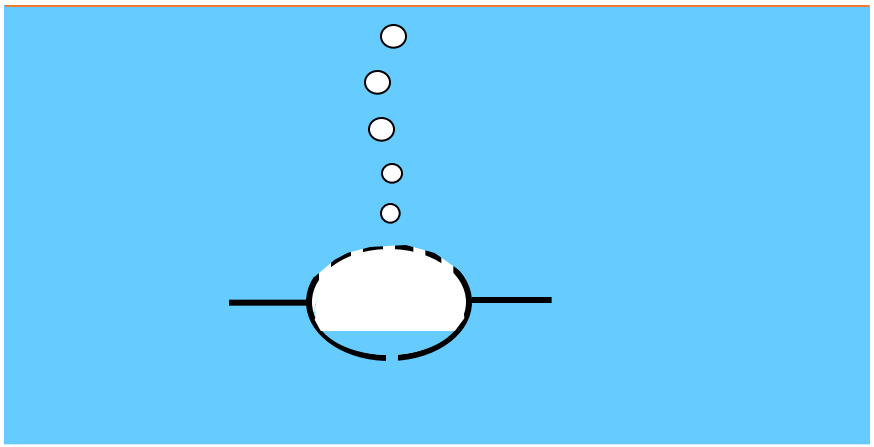
Gravitational Force under 1-Phase Flow

Bubbles come out from only one hole

Buoyancy Force against Capillary Force (2-Phase)



Lessons from Toy Experiment

- Oil/Gas leaks only from weakest point in the trap !
- Such point should be detected for Seal Evaluation ← Impossible!

- Micro-view (Analysis by Core, Logging)

or

- Macro-view (Gas/oil/water contact, Pressure distribution) ← More Important!

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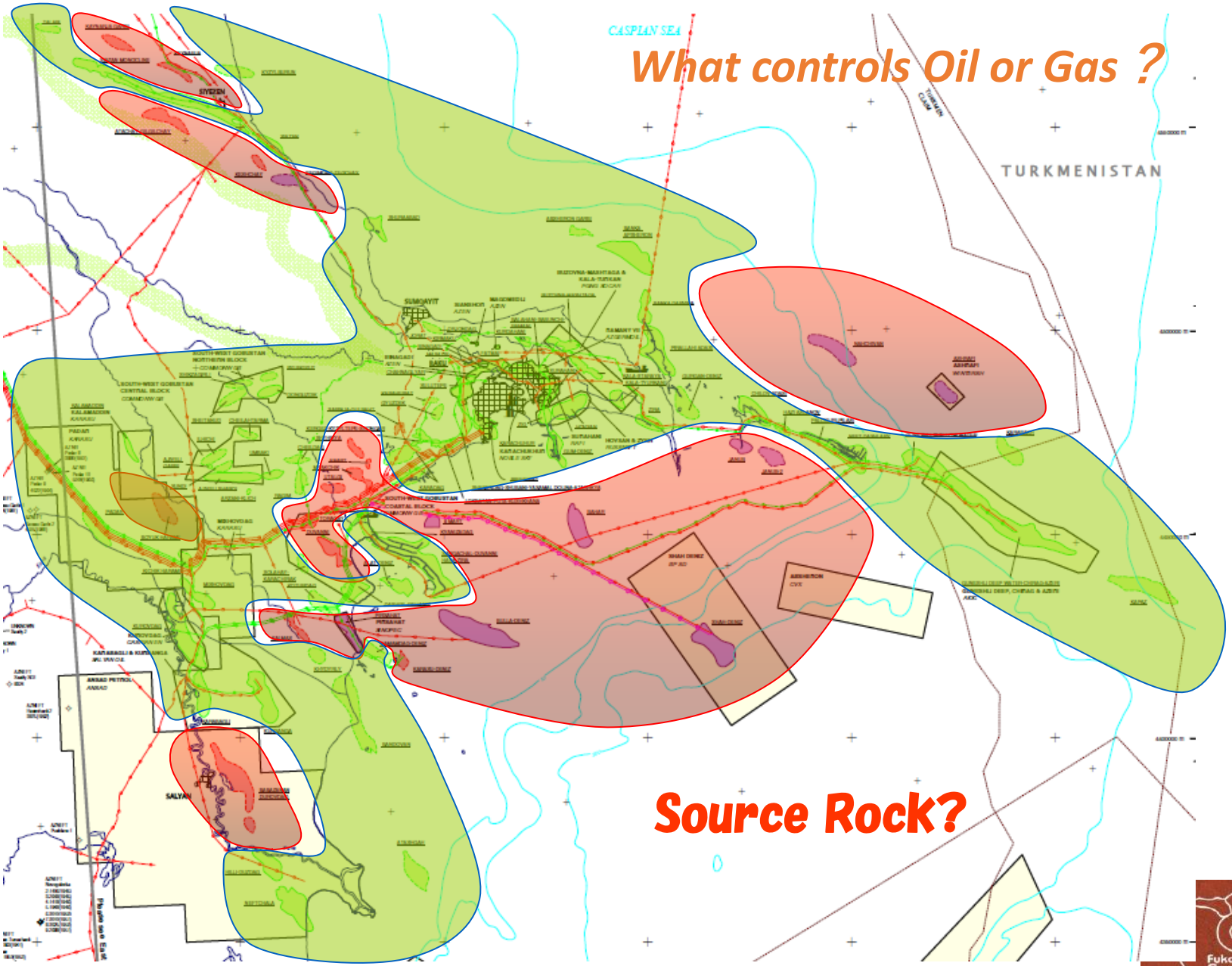
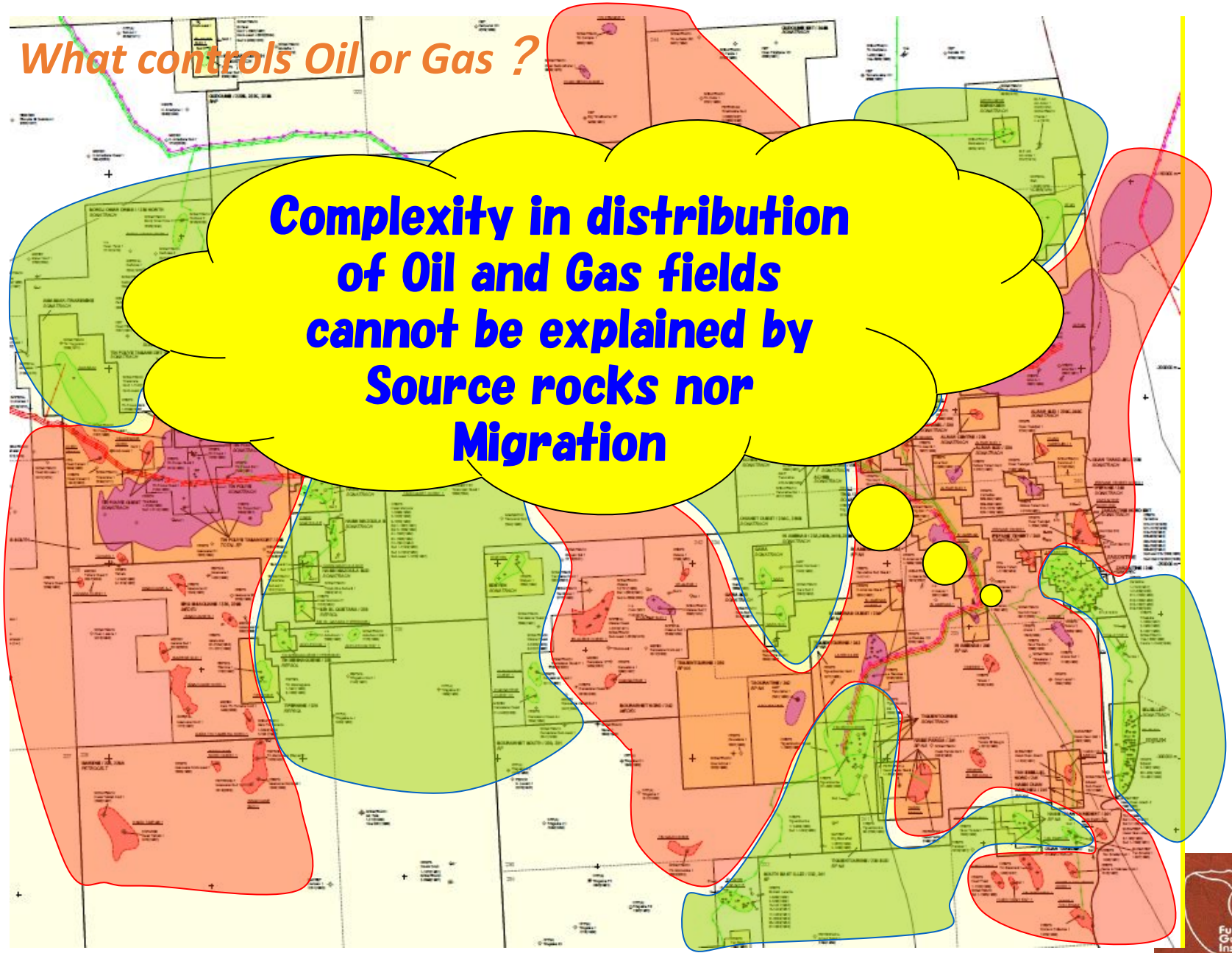
Curious Distribution of Oil and Gas fields (Caspian Sea)



Curious Distribution of Oil and Gas fields (Algeria)



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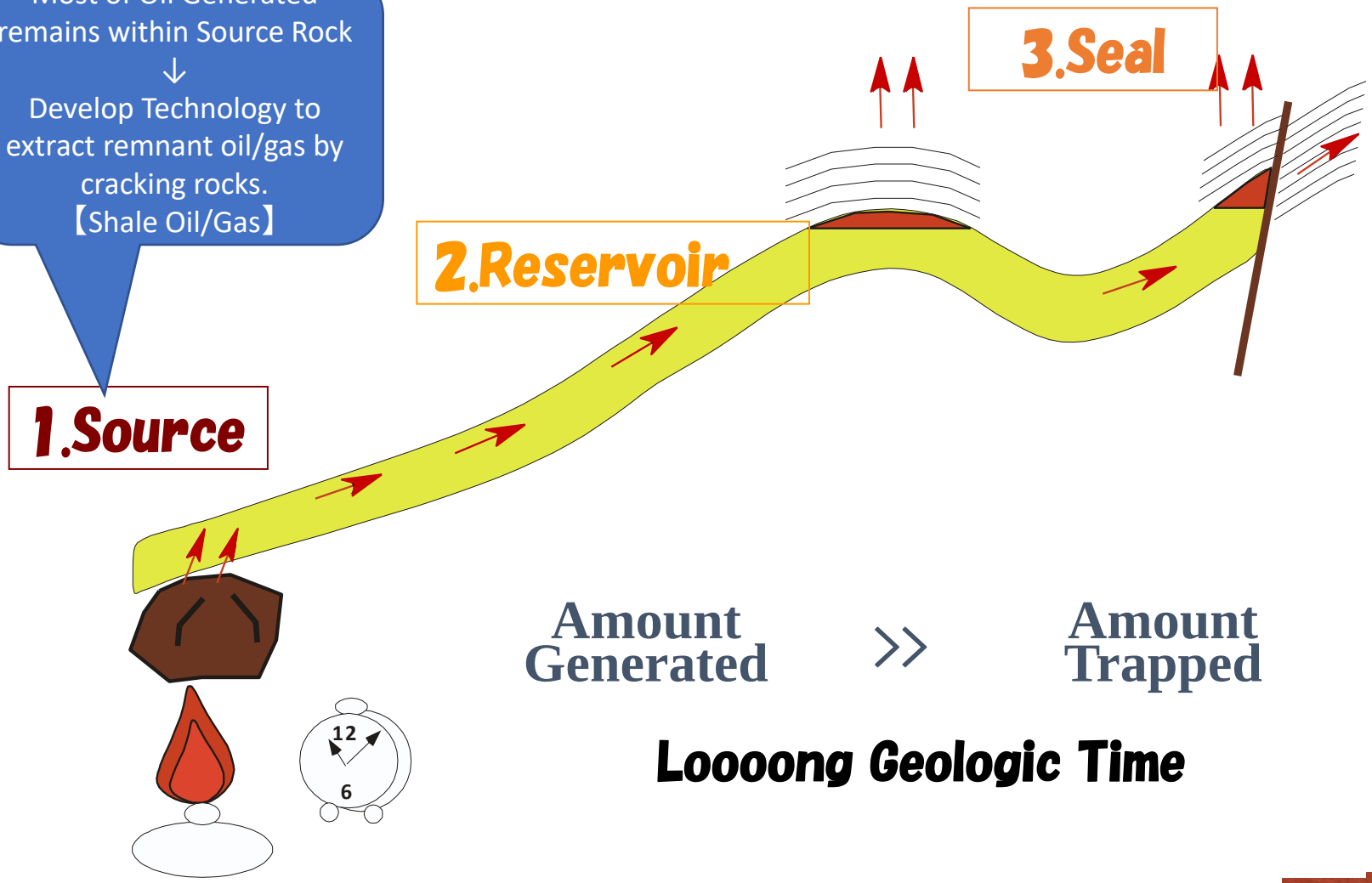
3 Elemets for Oil/Gas Trapping

Most of Oil Generated remains within Source Rock
↓
Develop Technology to extract remnant oil/gas by cracking rocks.
【Shale Oil/Gas】



Amount Generated >> Amount Trapped

Loooong Geologic Time

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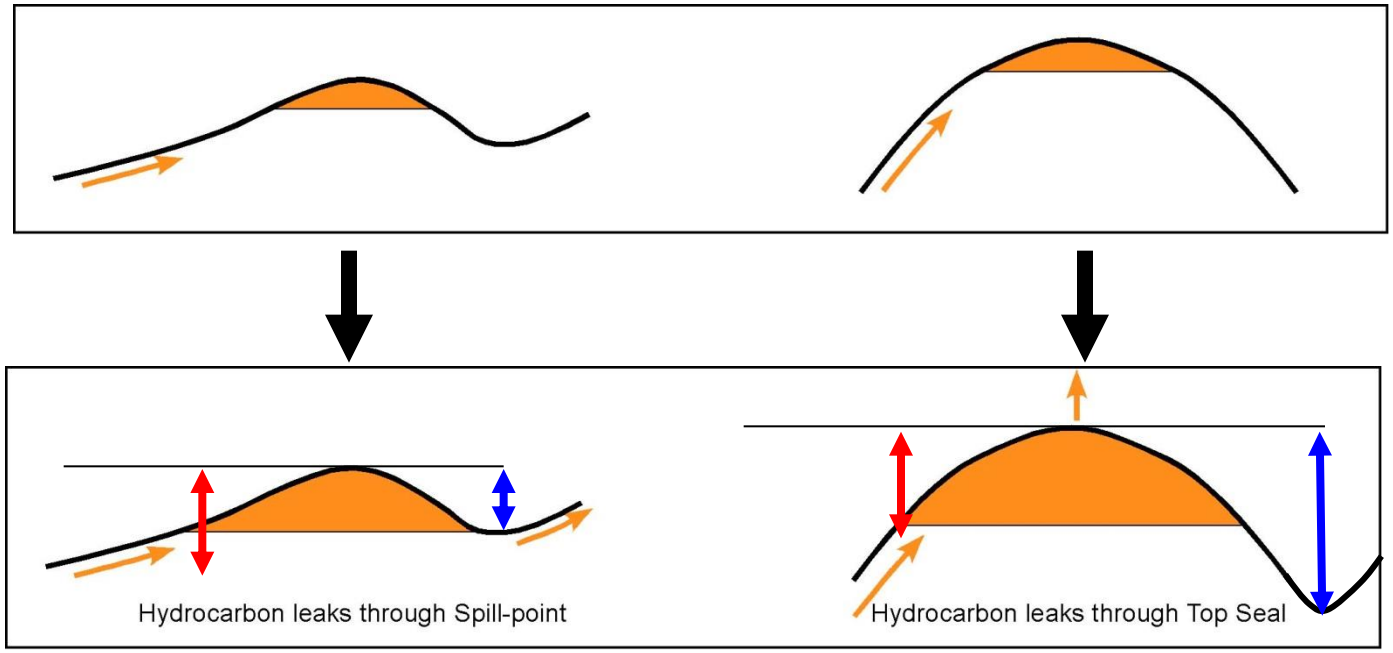
By Macro-View

- How to understand Sealing Mechanism ? -

"Sealing Capacity is not infinitive ! "



Spill-point Limited Trap

Max Seal Capacity > Height of Trap *

Capillary Limited Trap

Max Seal Capacity < Height of Trap *

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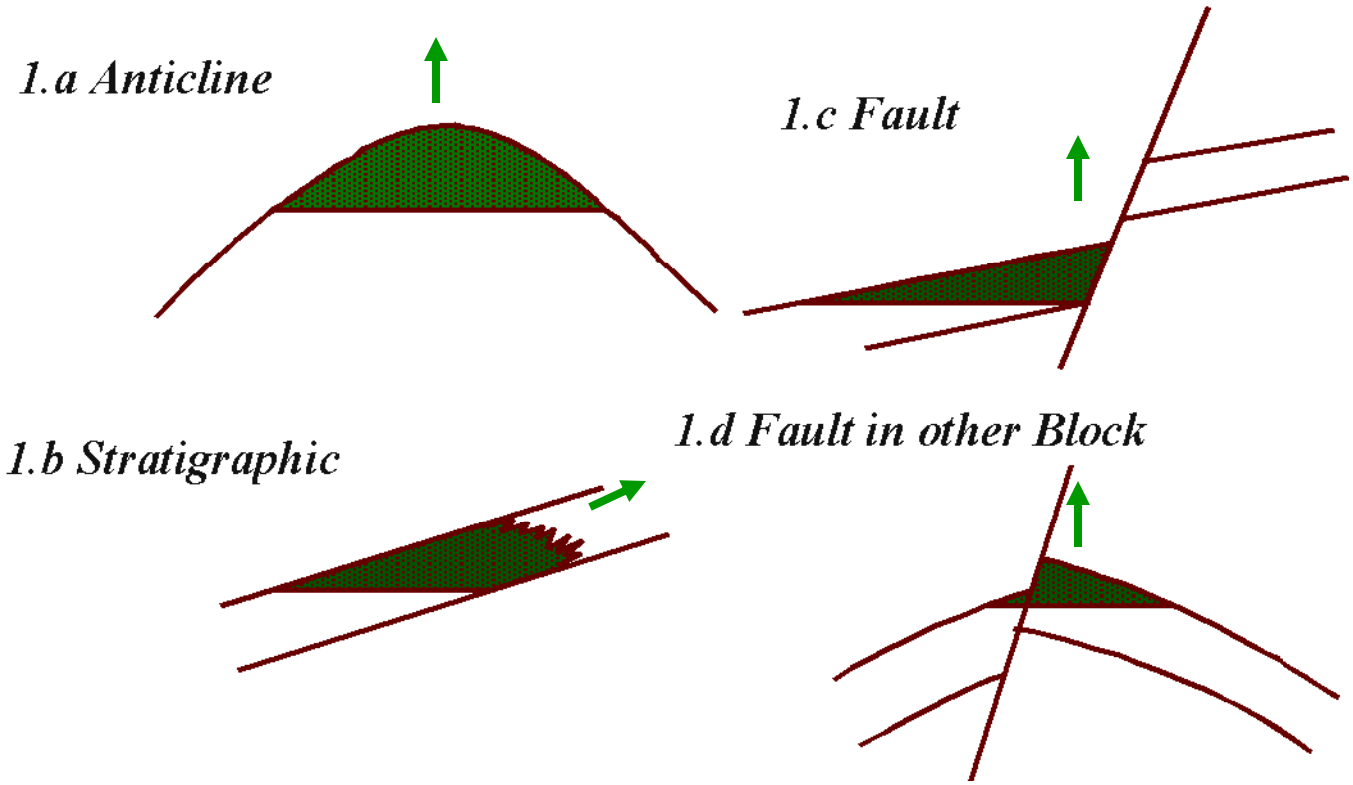
Capillary Limited Traps

Pc = Pb: Hc Column Height is controlled by Seal Capacity

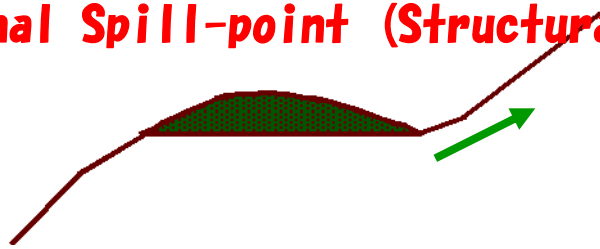


Spill-Point Limited Traps

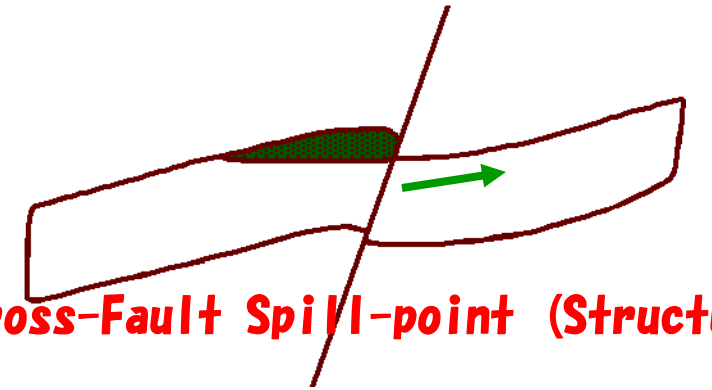
Pc > Pb: Hc Column Height is controlled by Spill-Point

2.a Anticline

Synclinal Spill-point (Structural)

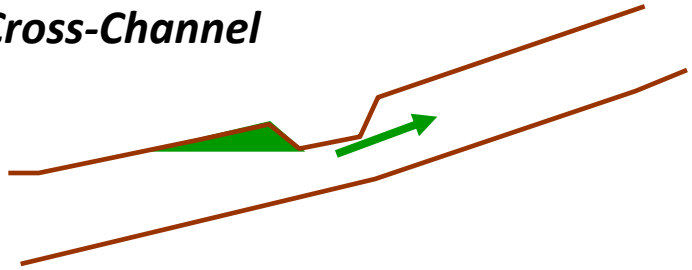


2.b Fault

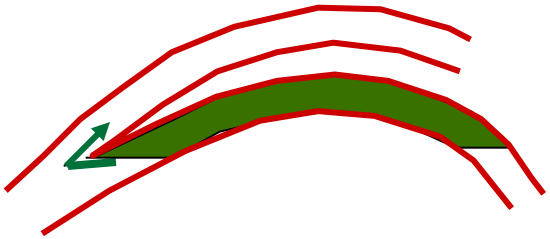


Cross-Fault Spill-point (Structural)

Cross-Channel



Stratigraphic Contact

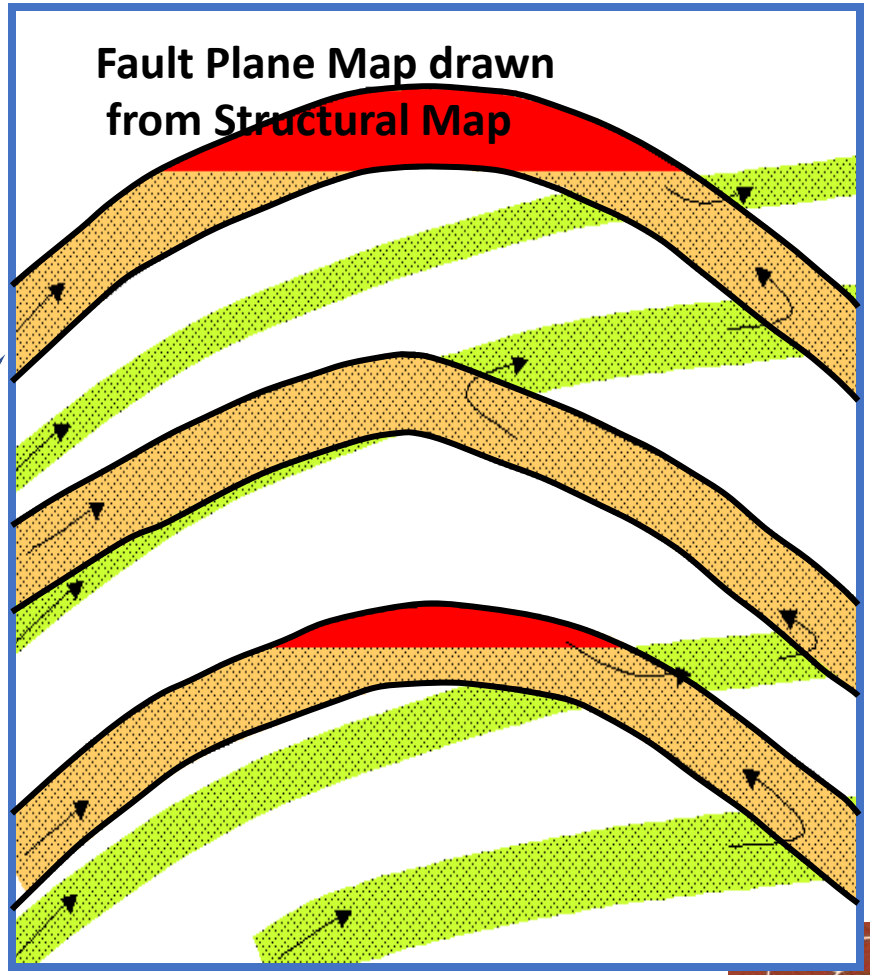


Stratigraphic Spill-point

Migration Path: Analyzed by Fault Plane Map

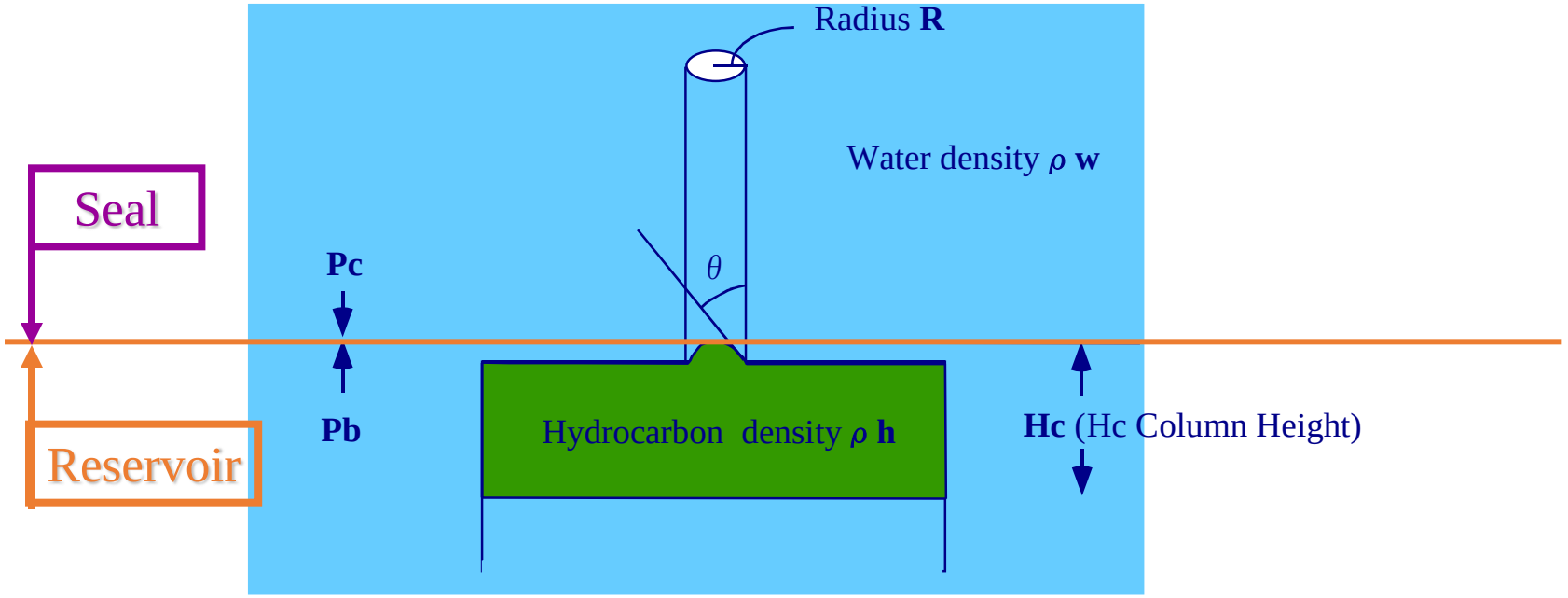
Sandstones (reservoir) in hanging wall contact with sandstone in footwall through normal fault. Hydrocarbon migrates (spills out) through fault plan

This type of Traps can often be observed in Gulf of Thailand.
➡They estimate the reserves assuming Net thickness is 30% or 60% of Gross thickness.



Why can Oil be trapped ?

Hydrostatic Trap Equilibrium Equation



Capillary Pressure = Buoyancy

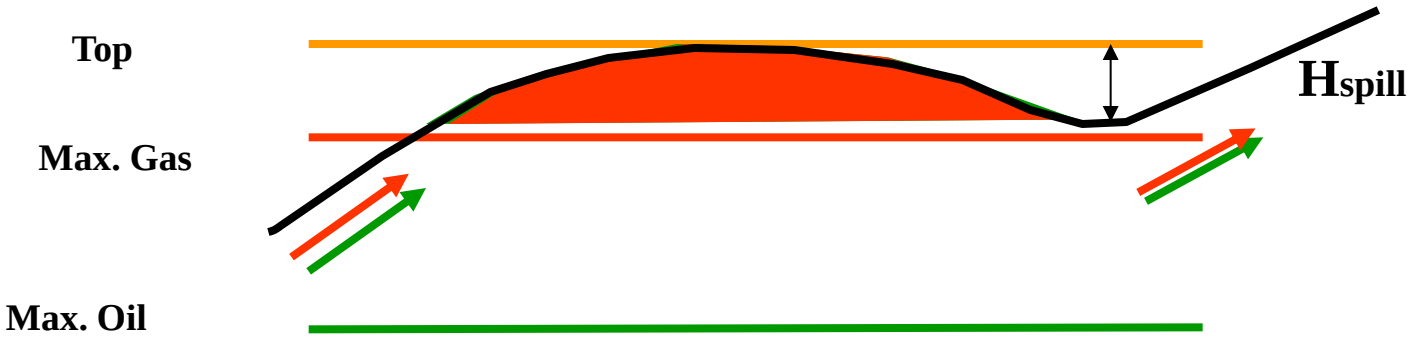
$$Hc = \{(2\,\gamma \cos\theta)/\,R\}/\{g\,(\rho w - \rho h)\}$$

Max Oil Column> Max Gas Column

γ : Interfacial Tension
θ : Wettability
g : Accerelation of gravity

I. Spill-point Limited Trap

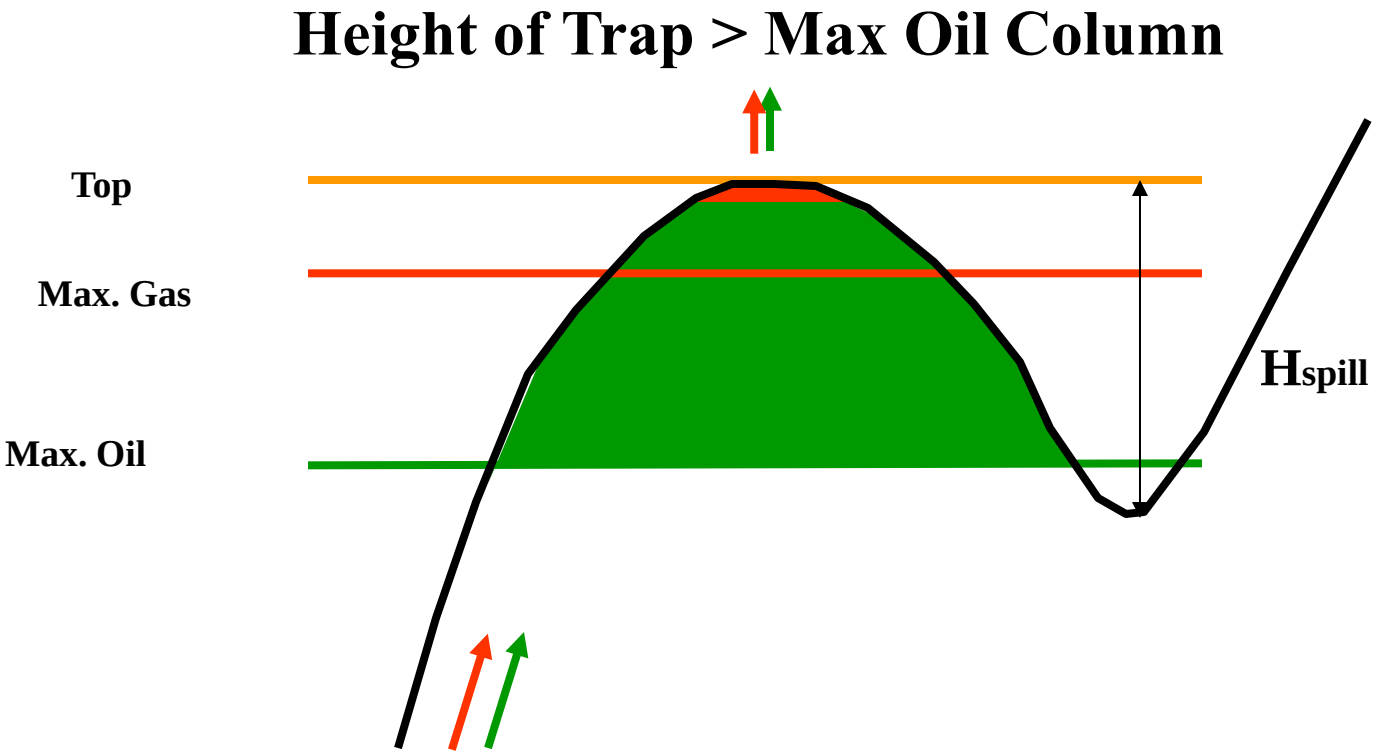
Height of Trap < Max Gas Column



Excess oil/Gas is leaking from Spill-point.

All Trapped Oil should be finally replaced by Gas.

II. Capillary Limited Trap



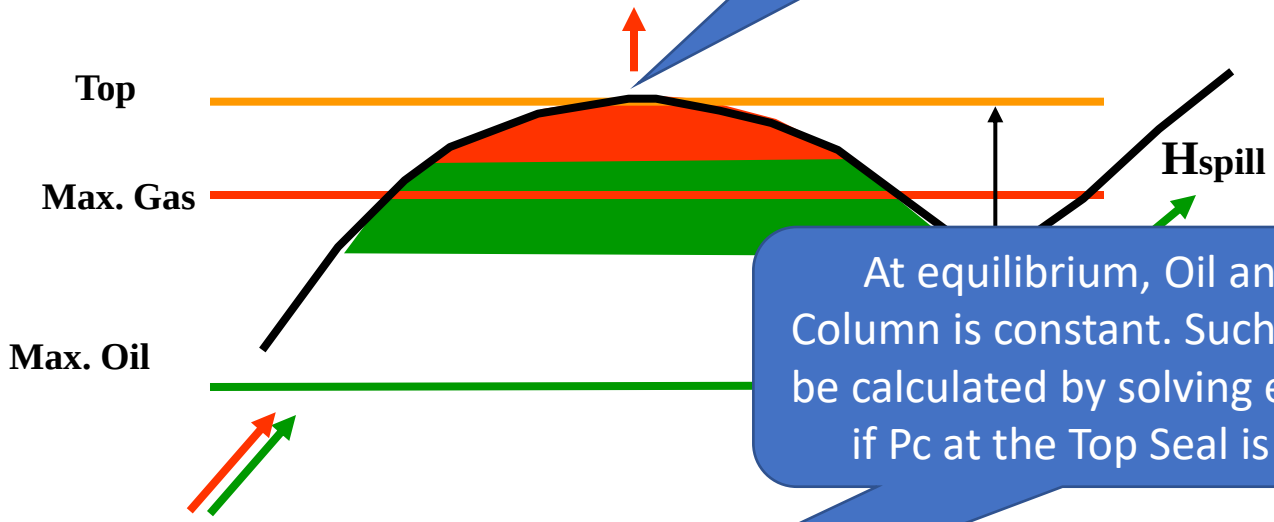
Excess Gas is leaked from Top Seal.

Excess Oil is also leaked from Top Seal, and only Oil should be remained.

III. Mixed Type Trap

Oil and Gas are leaked from different point at this Type of Trap.
→Create Different Migration Path

Max Gas Column < Height of Trap < Max Oil Column



At equilibrium, Oil and Gas Column is constant. Such ratio can be calculated by solving equations if Pc at the Top Seal is given.

Migrated Gas occupies at the Top of Trap, then Oil should be spilled out from the bottom.

After Equilibrium Condition is attained, Excess Gas is leaked from Top of the Trap.

$$\begin{cases} Pc = Pb\,(Hgas) + Pb\,(Hoil); \\ Hspill = Hgas + Hoil \end{cases}$$

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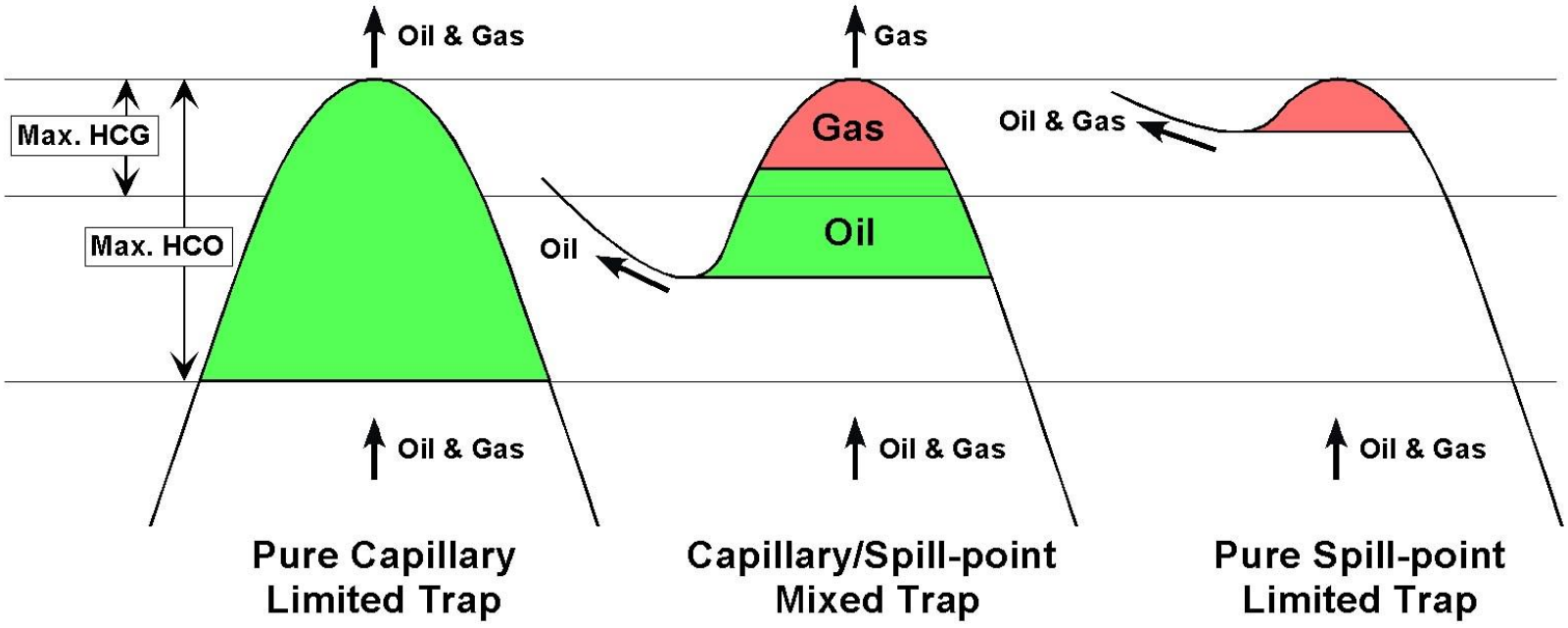
Oil/Gas Accumulations are determined by Top Seal capacity vs Height of Trap !



Oil Accumulation **Oil/Gas Mixed Type** **Gas Accumulation**

(Sawamura & Nakayama, 2005: modified after Sales, 1997)

Schematic cross section showing three types of traps classified by the relation between the height of a trap and the maximum hydrocarbon column height to be held by the top seal, modified after Sales (1997).

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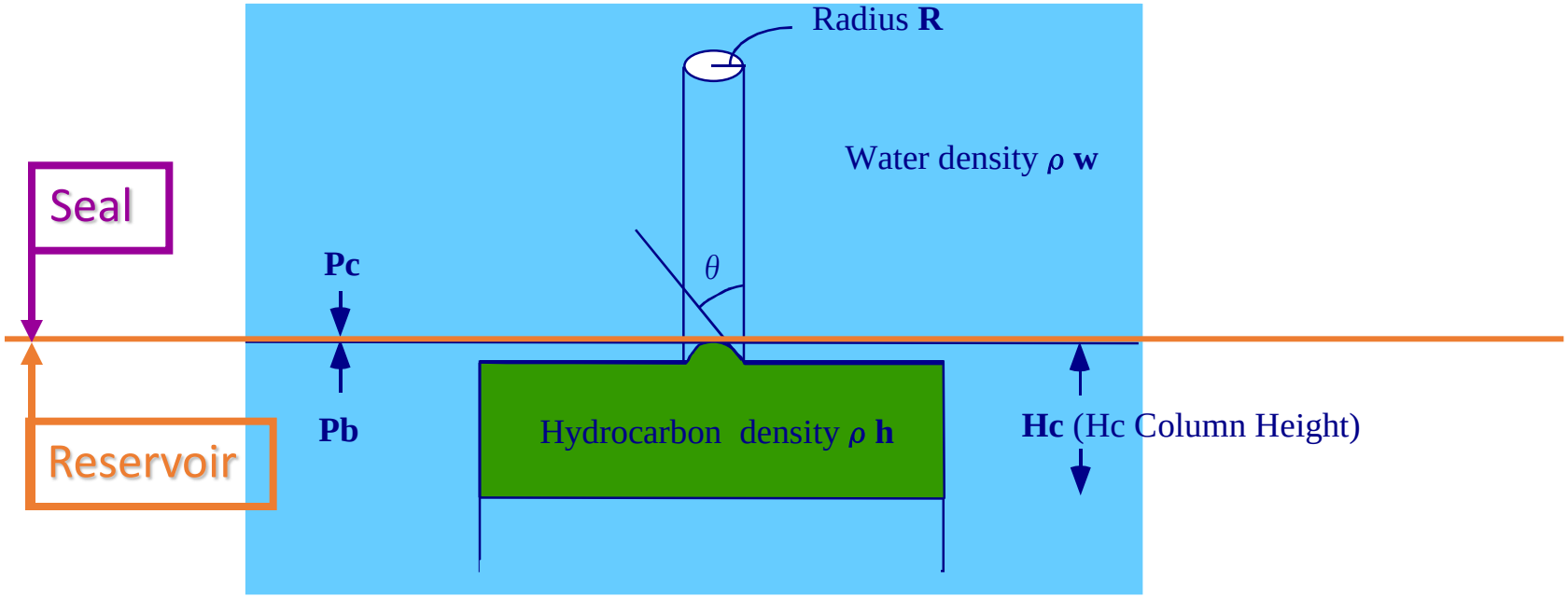
Equivalent Grain Size Method

Hydrostatic Trap Equilibrium Equation



Capillary Pressure = Buoyancy

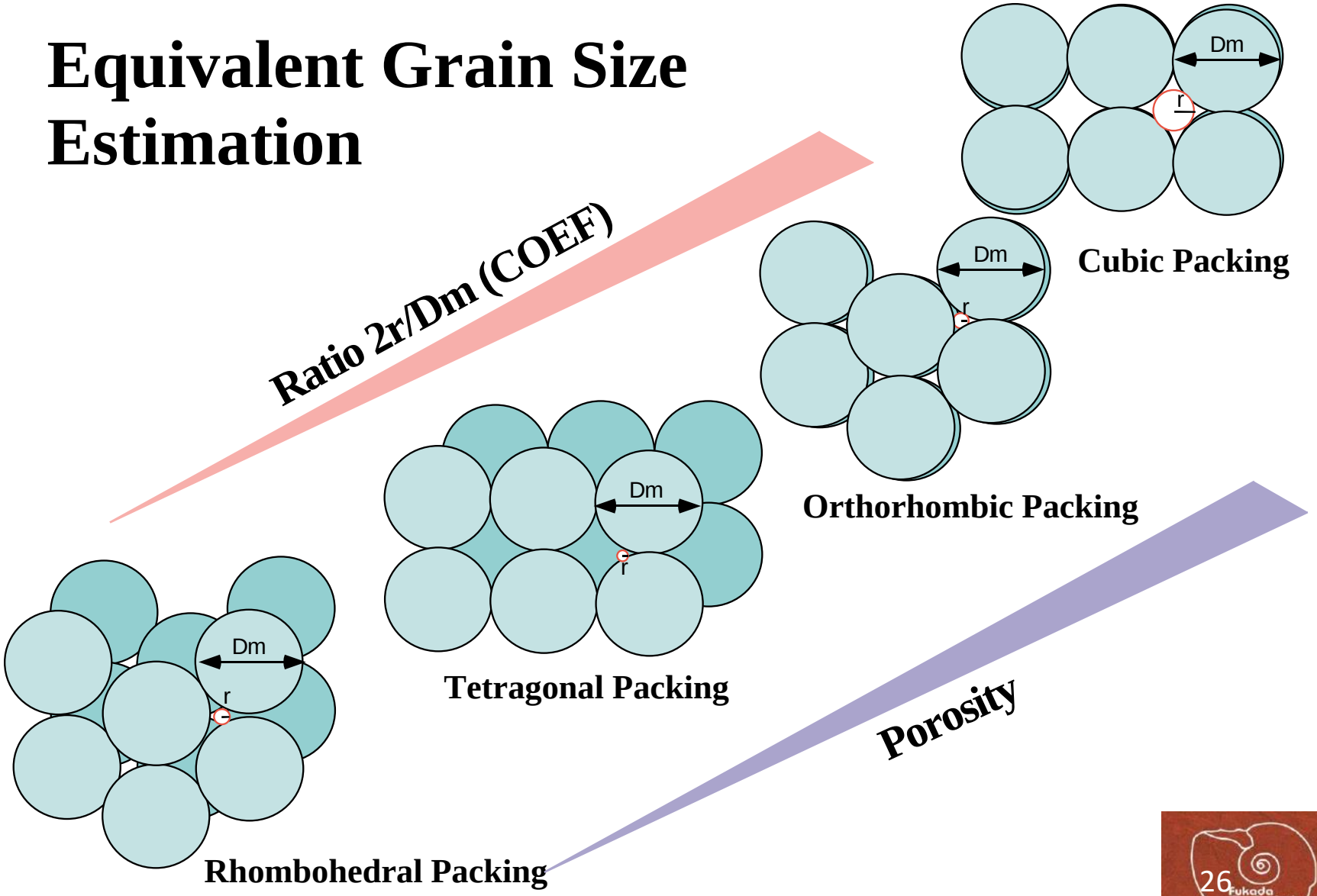
$$Pc = (2 \cdot \gamma \cdot \cos\theta) / R = g \cdot Hc \cdot (\rho w - \rho h) = Pb$$

$$Hc = \{(2\gamma \cos\theta)/ R\}/\{g (\rho w - \rho h)\}$$

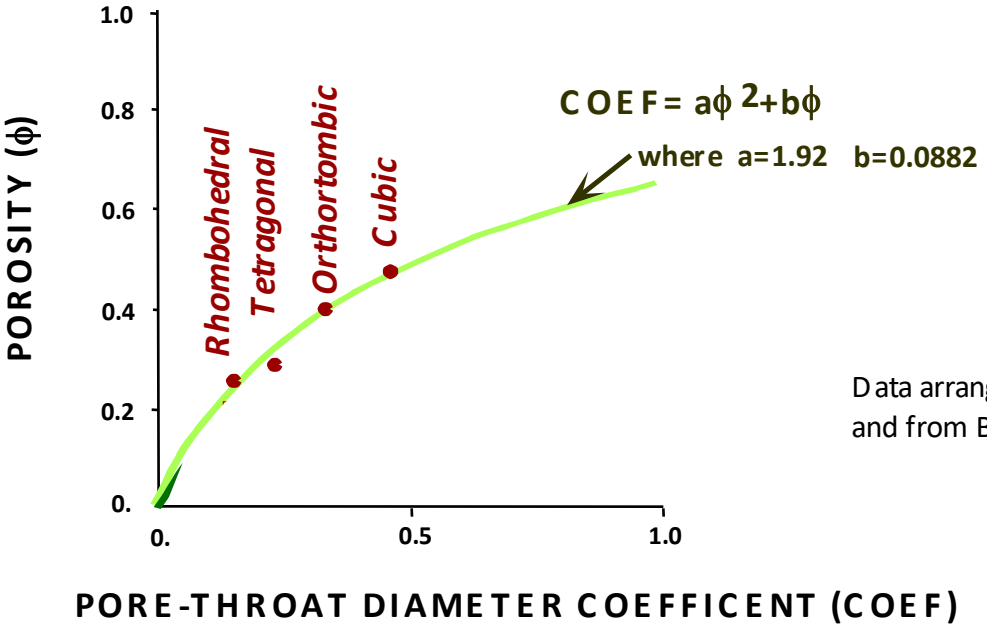
Hc is a function of R: $Hc = f_1(R)$

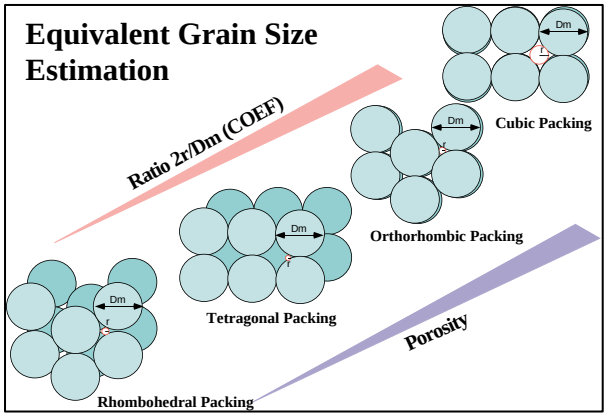
γ : Interfacial Tension
θ : Wettability
g : Accerelation of gravity

Equivalent Grain Size Estimation



Theoretical Relation between Porosity and COEF according to Packing Types

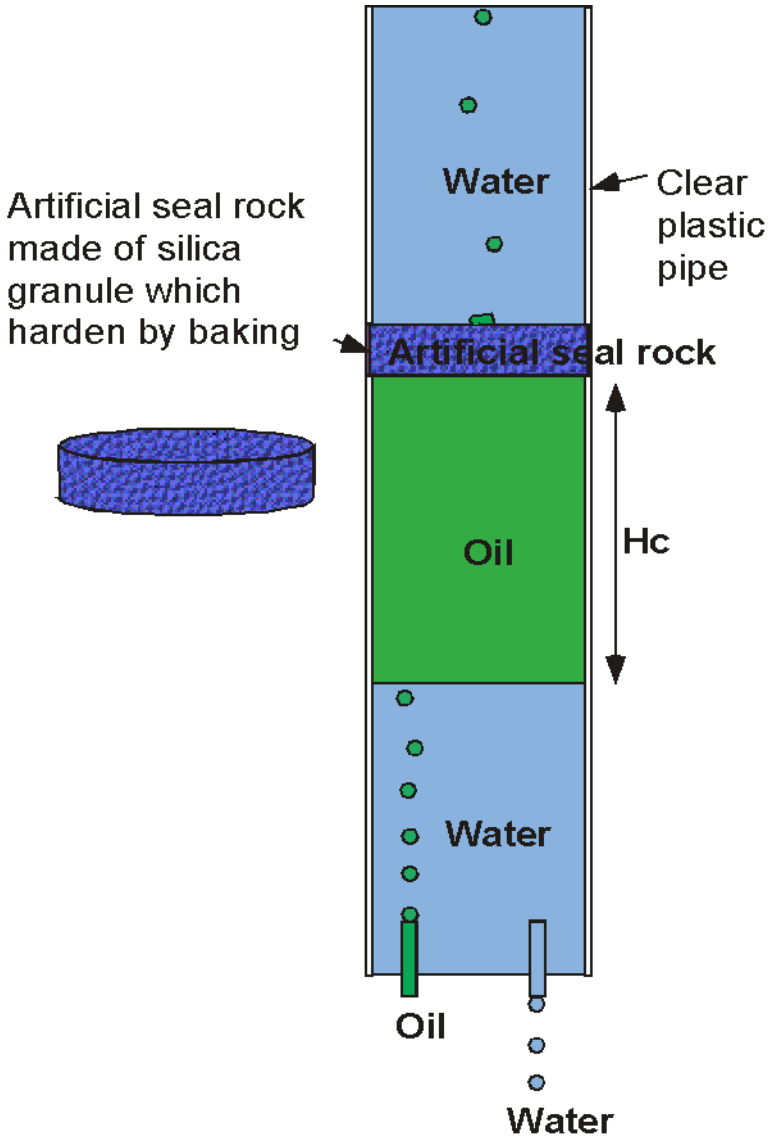


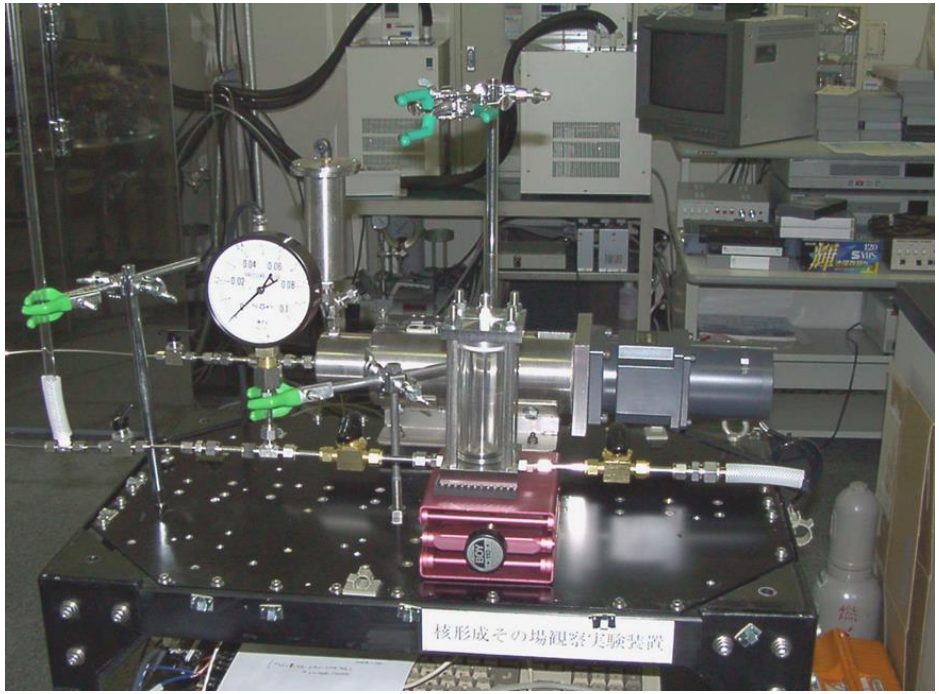


Data arranged from Berg (1975) for rhombohedral and from Berg (1970) for others.

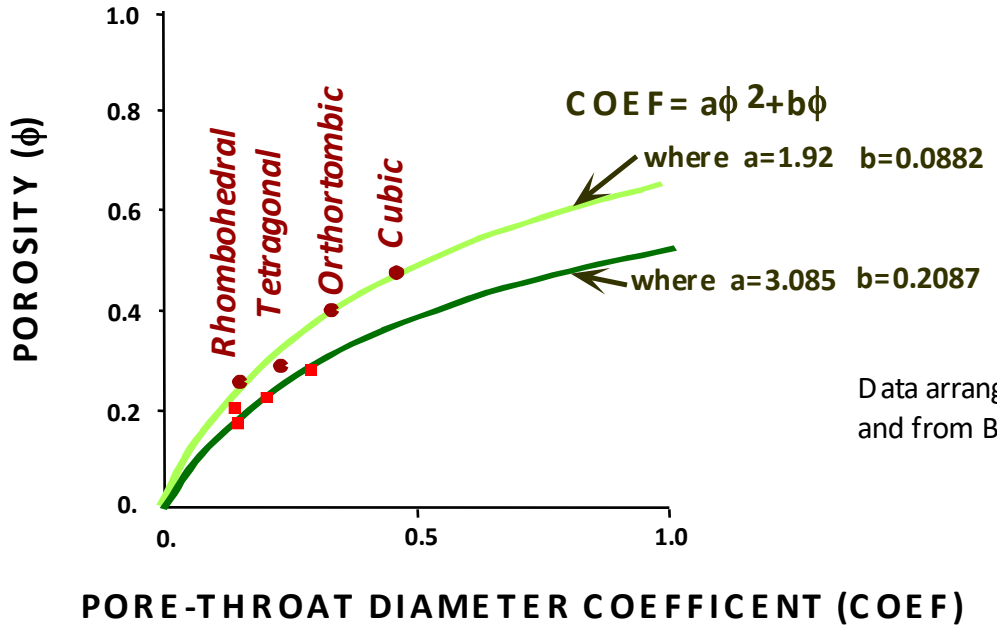
$$\underline{2R/Dm = 1.92\phi^2 + 0.0882\phi}$$

Concept of Experiment





Experimental Relation between Porosity and COEF according to Packing Types



Data arranged from Berg (1975) for rhombohedral and from Berg (1970) for others.

$$\underline{2R/Dm = 3.085\phi^2 + 0.2087\phi}$$

R is a function of Dm: $R = f_2(Dm)$

Hc is a function of R, then Dm: $Hc = f_1(R) = f_1(f_2(Dm))$

Excel Sheet for Top Seal Evaluation

Excel Sheet No.										*CalcSeaCap.BN v.4.0*	
Seal Capacity Estimation(Quick Version)								Field Name:	East field		
Density of Fm Water	ρ0	1.060	(g/cc)		*subsurface*	1.04					
Density of Oil	ρ1	0.950	(g/cc)		*subsurface*	0.87	Rs	852.1	Bo	1.0926	
Gas Specific gravity	ρ2	0.700	(frac)		*subsurface*	0.19					
Z-factor	Z	0.90		Acceleration of Gravity	γ	981	(cm/sec2)	AMW	20.13		
Oil Interfacial Tension	γ1	24.12	(mN/m)		*subsurface*	24.12	Δρ	0.17			
Gas Interfacial Tension	γ2	38.50	(mN/m)		*subsurface*	38.50	Δρ	0.85	Tr	1.79	
Contact Angle	θ	0.00	(degree)	0 : Water Wet					A	3.51739886	
						26.00	**Surface Temperature [C]**				
Grain Size of Rock	dm	8.31	(phi)			2.00	**Geothermal Gradient [C/100m]**				
	dm	0.00031	(m/m)	**Porosity-surface**	50	0.000600	**Compaction Factor**				
Porosity	ϕ	4.88	(%)			2020.00	**Depth(m)**				
			Gas Eff x0.7			66.40	Temperature[C]				
Pore Throat Diameter	PTD	0.00031	(mm)	COEF		0.099	(-)				
Oil Column H.	Hco	185.55	(m)	**C for Effective PTD**	C	1.00	(-)				
Gas Column H.	Hcg	59.07	(m)					Cinv			
				Observed Oil Col.	Ho	186.00	(m)	1.00			
				Observed Gas Col.	Hg	0.00	(m)	#DIV/0!			
										JGI, Inc.	

1st Step: Knowing O/G Column Height → Find out EGS

2nd Step: Knowing EGS → Find out O/G Column Height

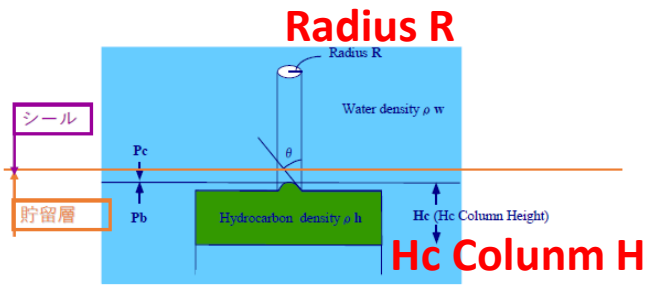
Phi Scale for Grain Size of Sedimentary Rocks

The Relationship; $\varphi = -\log_2 D$ [or $D = 2^{-\varphi}$]

Grain	Particle diameters [D] (mm)	Corresponding φ values
boulder	> 256	< –8
cobble	64–256	–6 to –8
pebble	4–64	–2 to –6
granule	2–4	–1 to –2
very coarse sand	1–2	0 to –1
coarse sand	0.5–1.0	1 to 0
medium sand	0.25–0.50	2 to 1
fine sand	0.125–0.250	3 to 2
very fine sand	0.0625–0.125	4 to 3
silt	0.0038–0.0625	8 to 4
clay	< 0.0039	> 8*

* Some use 2 microns (9φ) as the silt-clay boundary

How to evaluate Sealing Capacity ?



Capillary Pressure = Buoyancy

$Hc = \{(2\gamma\cos\theta)/R\}/\{g(\rho w-\rho h)\}$

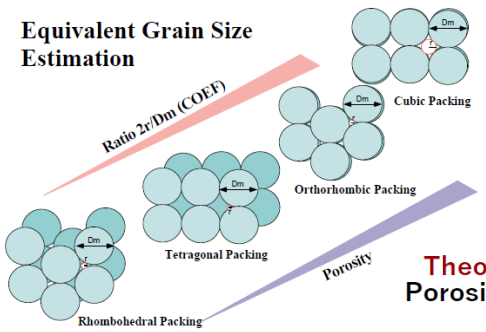
最大石油コラム > 最大ガスコラム

Interfacial Tension
Wettability
Accerelation of gravity

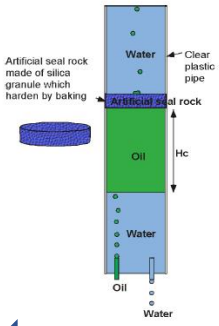
Hc=\{(2γcosθ)/R\}/g(ρw-ρh)\}

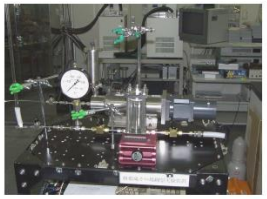
Hc Columm Height

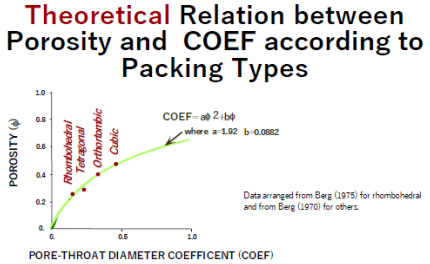
If shale is constructed by equal sized sediments,



Concept of Experiment







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						26.09	Surface Temperature [C]			
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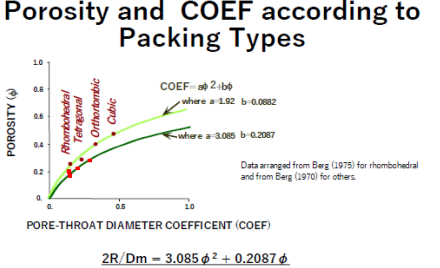
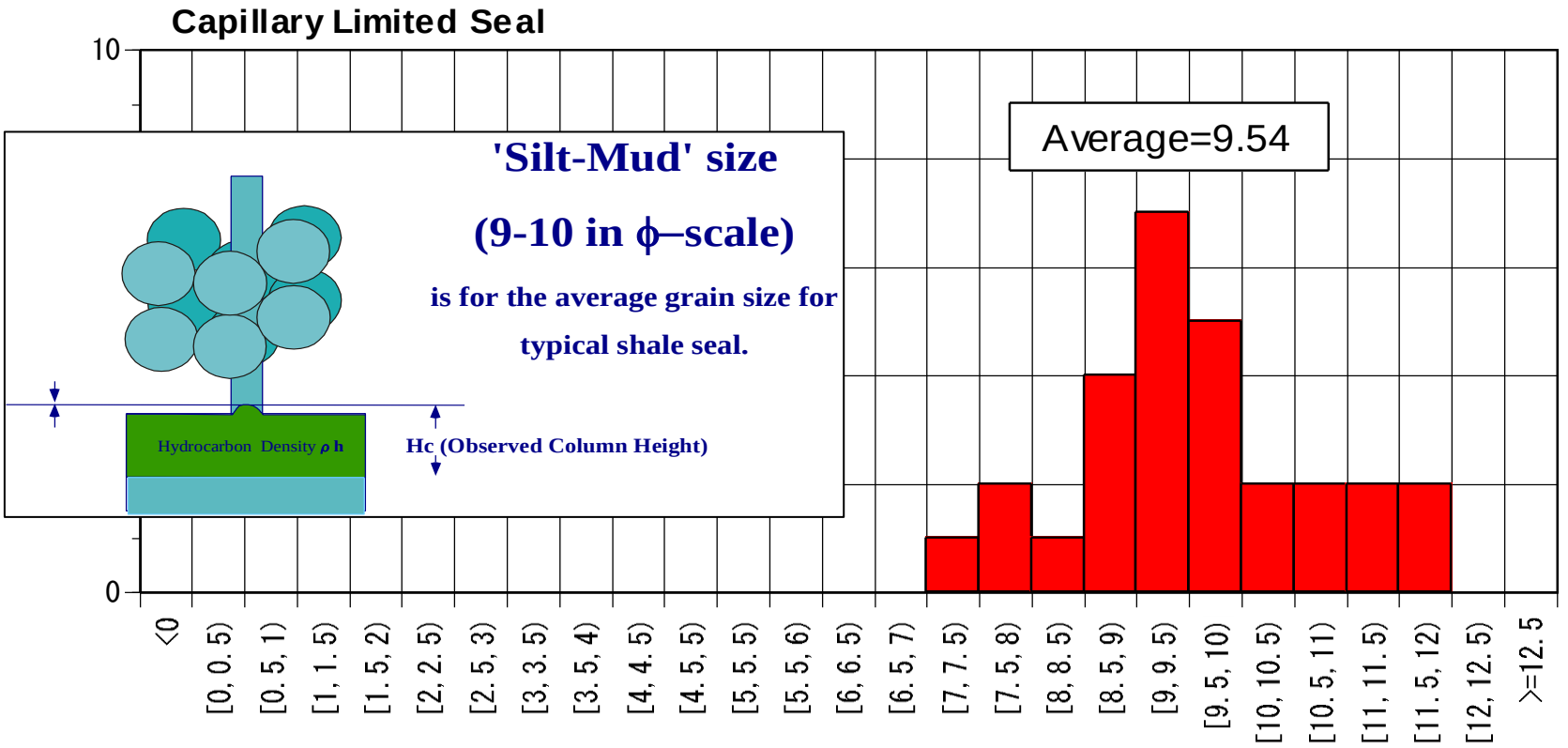
EGS(Equivalent Grain Size)



Basics for Top Seal by Capillary Pressure

Statistics from 90 Fields



*In most of the cases, there is enough amount of generation to fill up traps.

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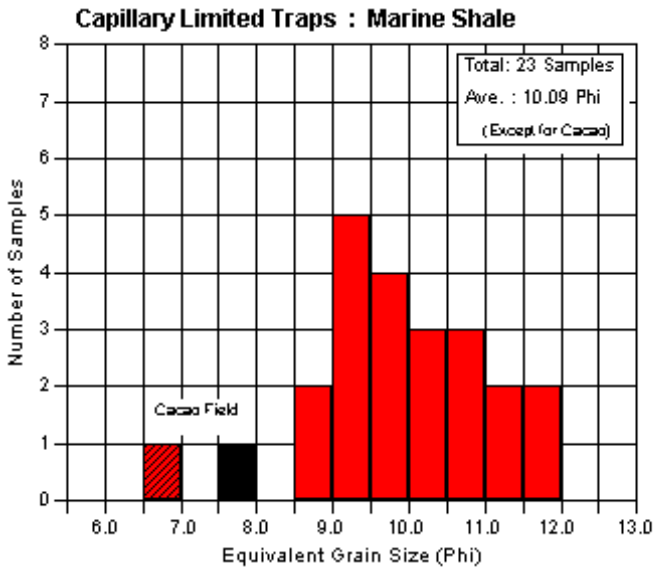
Difference on E.G.S.

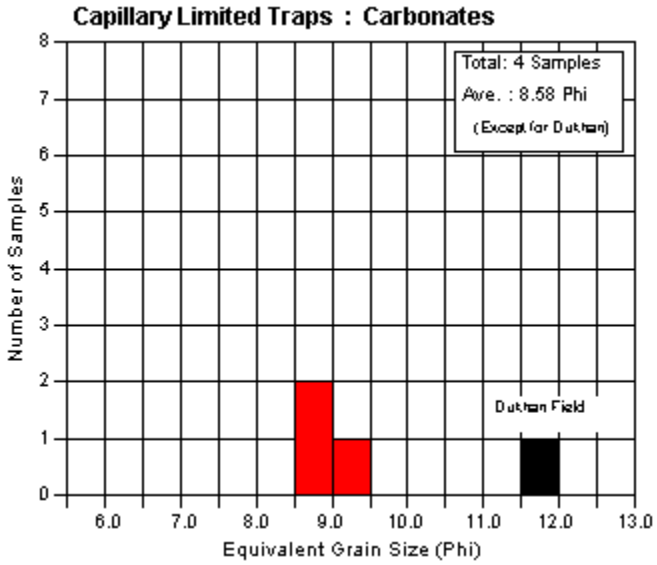
for

Sedimentary Environment

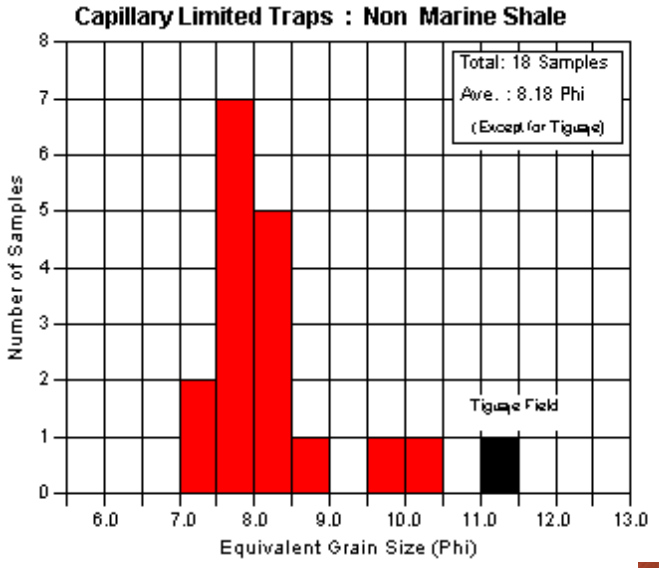
Marine



Carbonate



Non-Marine



Q & A

Applications (How to use the concept?)
And Distinguish Methane from CO_2

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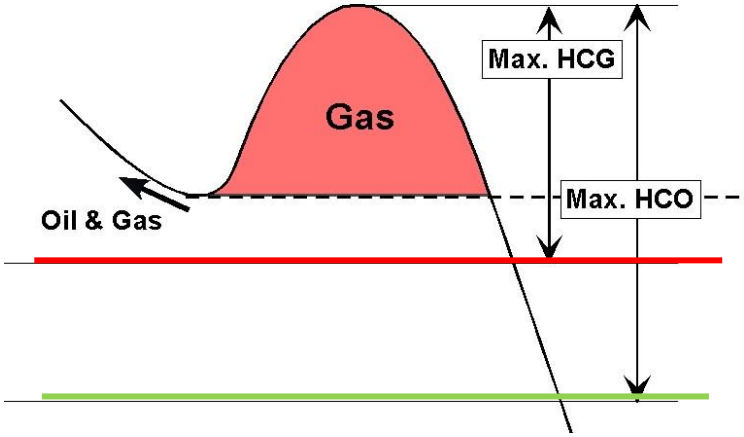
Ex. 1
Effect on Reserves by Seals

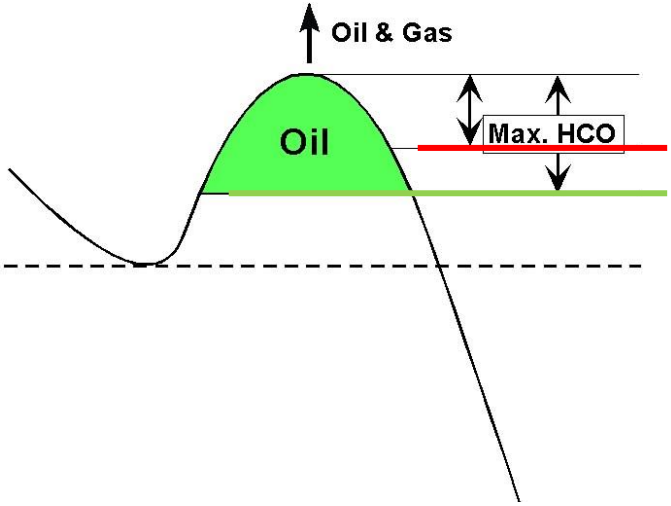
Amount of Oil/Gas reserves by Top Seal Capacity vs Trap Height !

Top Seal Capacity(L)
EGS(S) or Depth(D)



Nice Guy
Loose Expensive Oil

Top Seal Capacity(S)
EGS(L) or Depth(S)



Non working poor Guy
Keep a lot of Oil !

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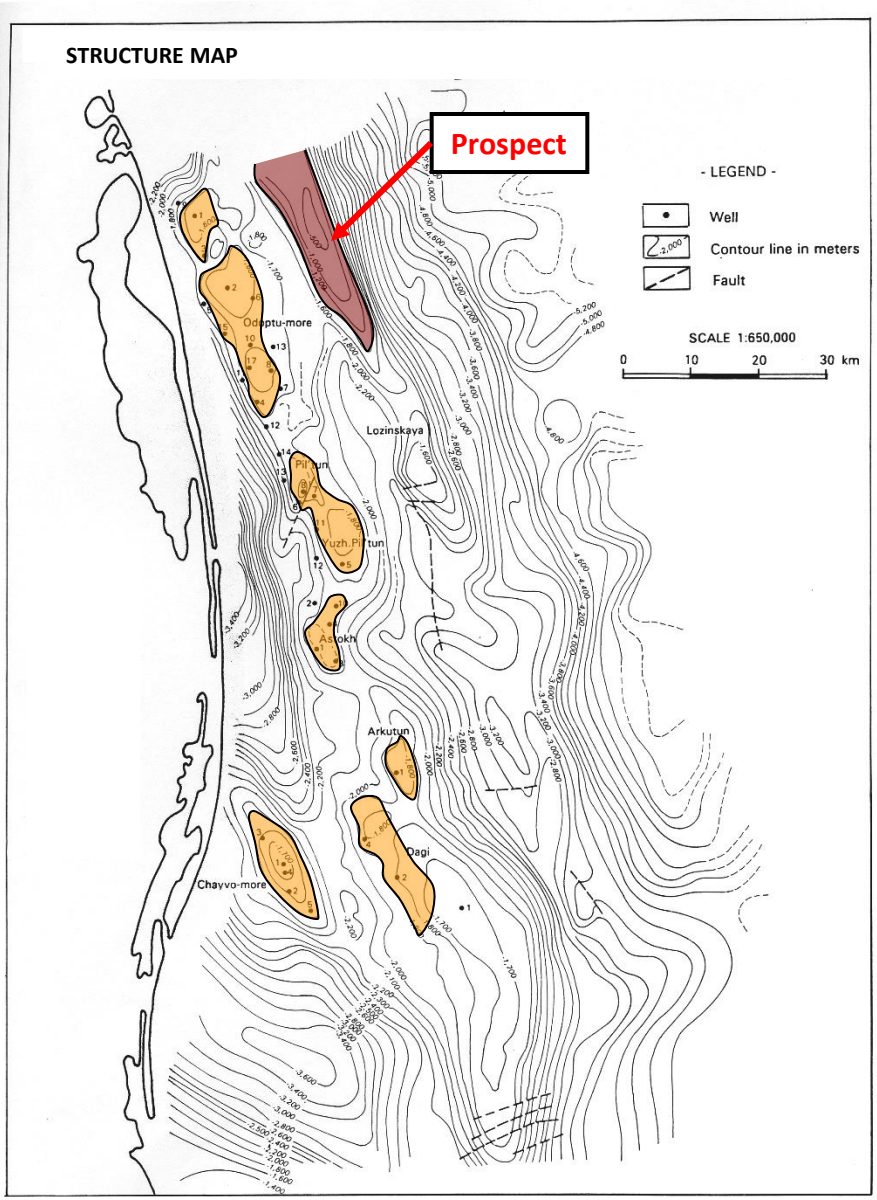
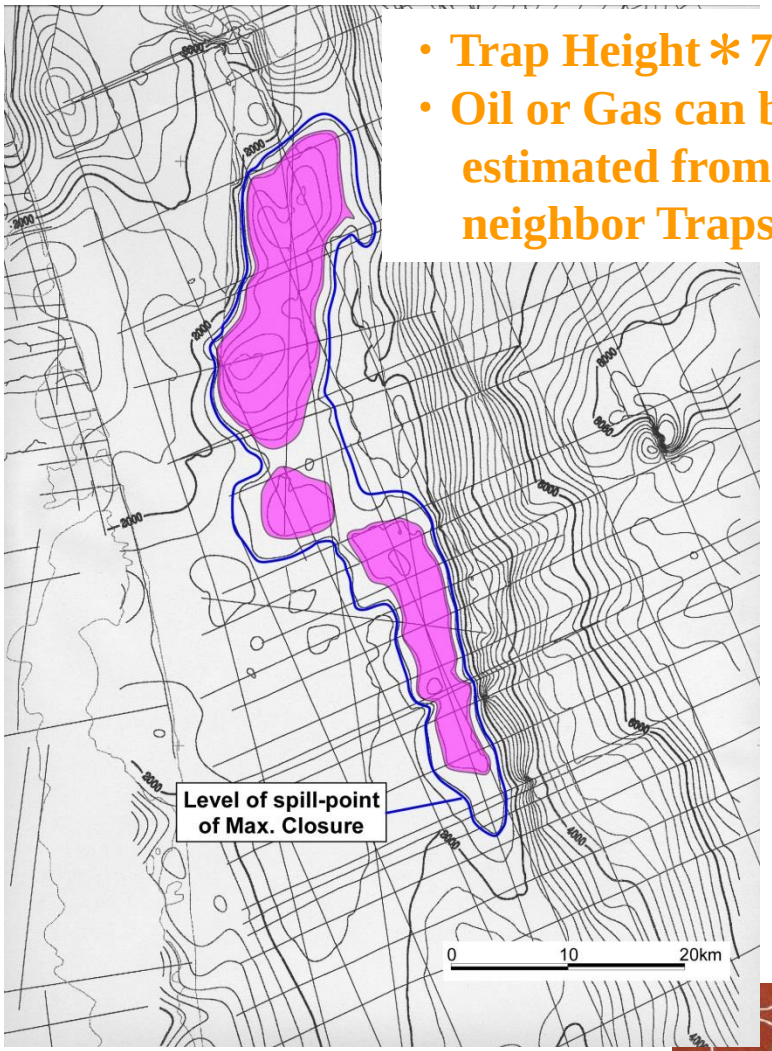
ケーススタディ –サハリン(樺太)沖合-



Estimation of Expected Oil/Gas Column height

- Trap Height＊70％
- Oil or Gas can be estimated from neighbor Traps.



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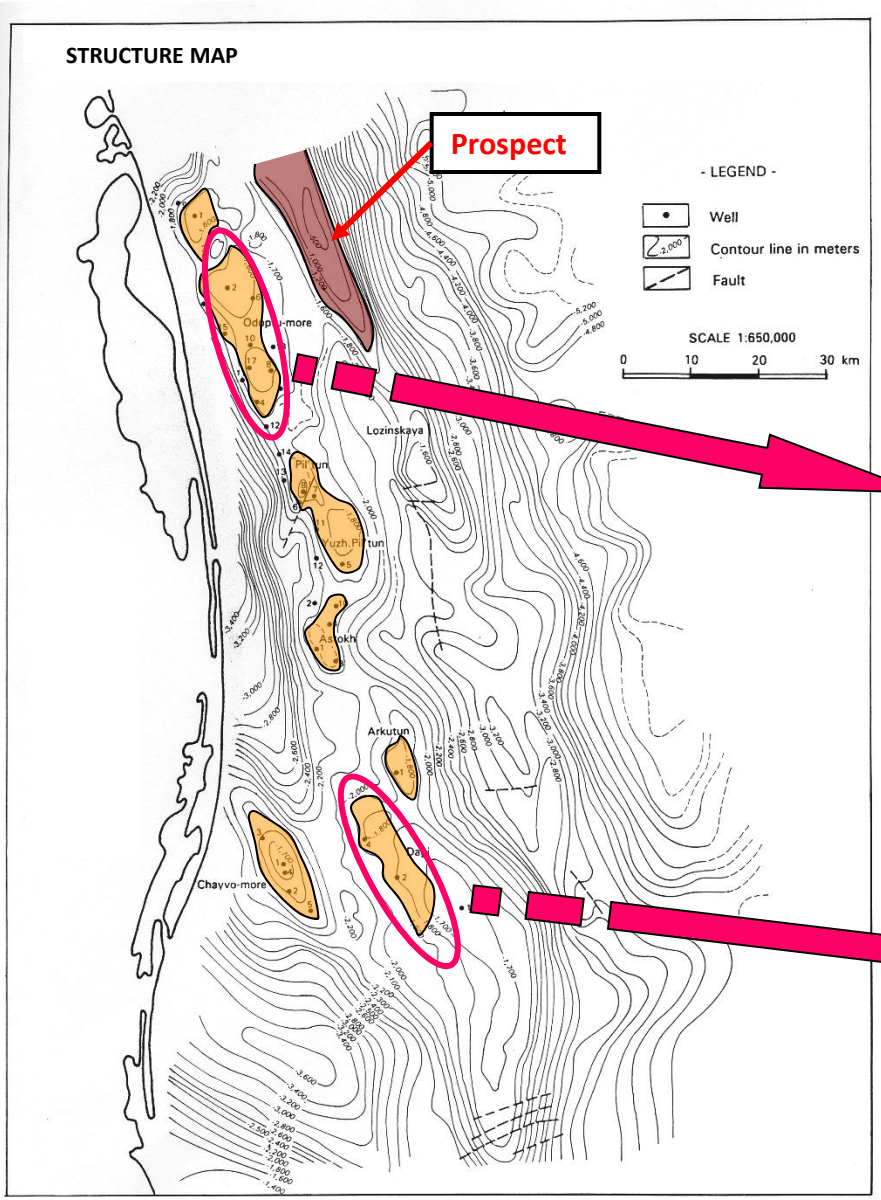
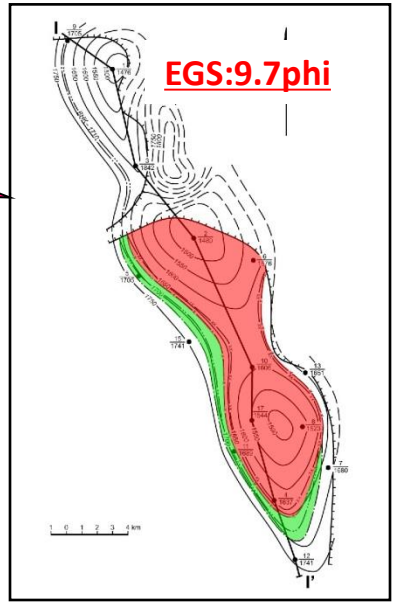
Case Study-Offshore Sakhalin-



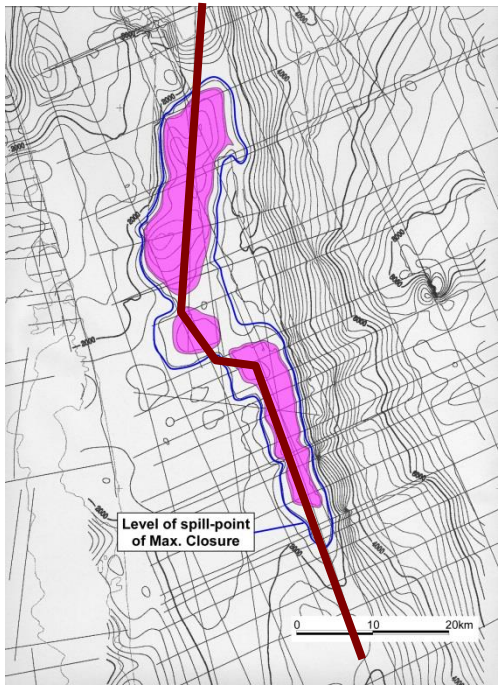
Estimation of Expected Oil/Gas Column height

-Estimate Seal Capacity that is calculated from neighbor fields.



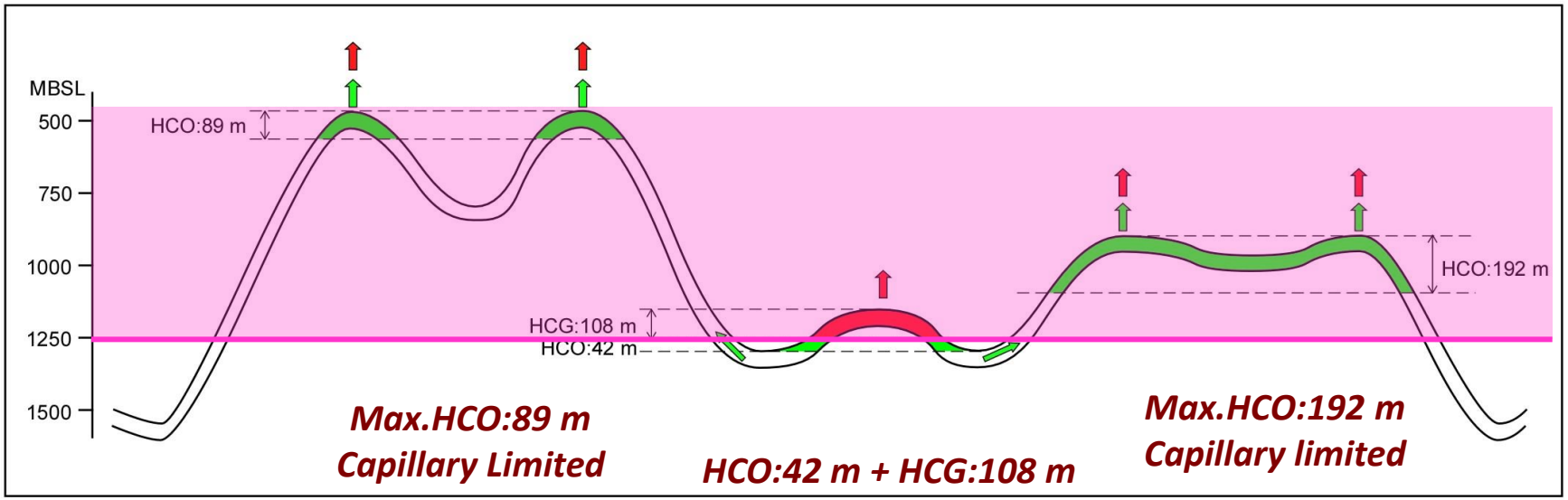
Case Study-Offshore Sakhalin-

Seal Capacity（EGS=9.7phi）を仮定

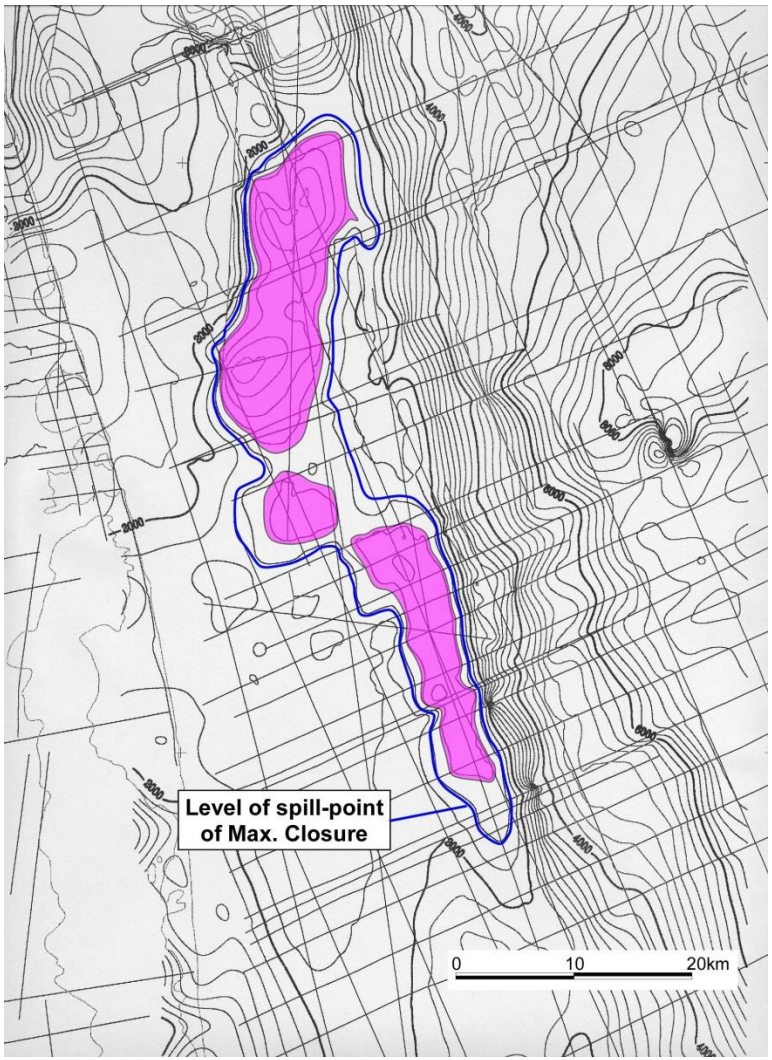


N

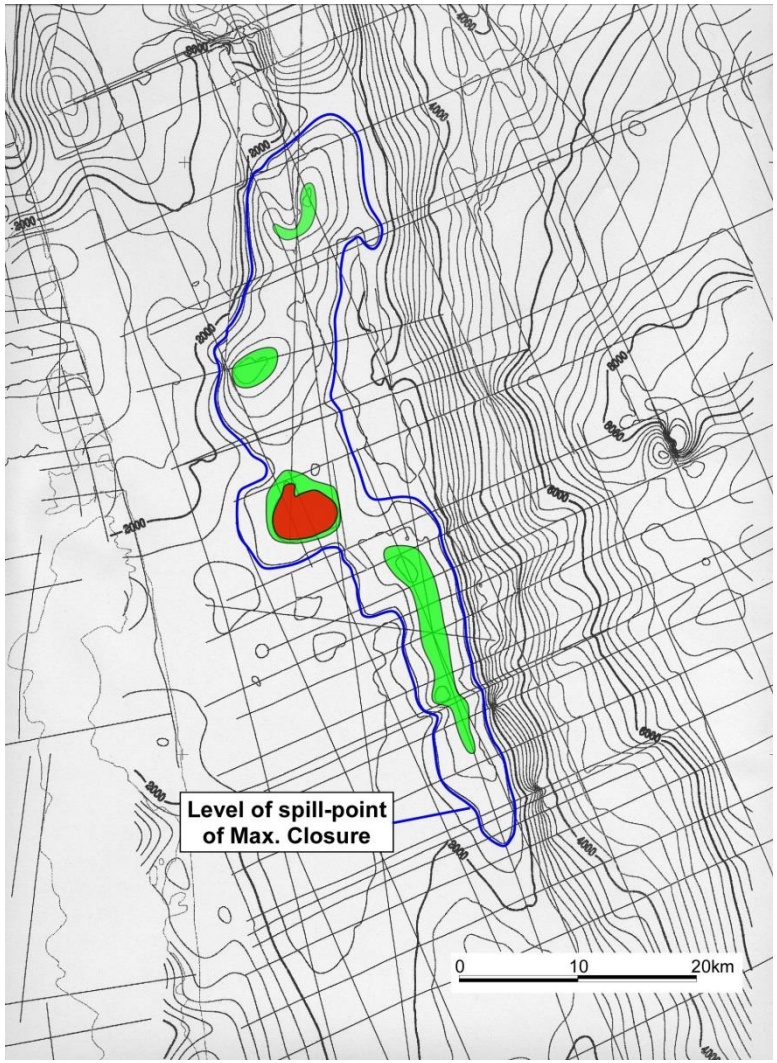
S



Case Study-Offshore Sakhalin-



Before



After

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Prediction of Fluid Contents
(Oil or Gas)

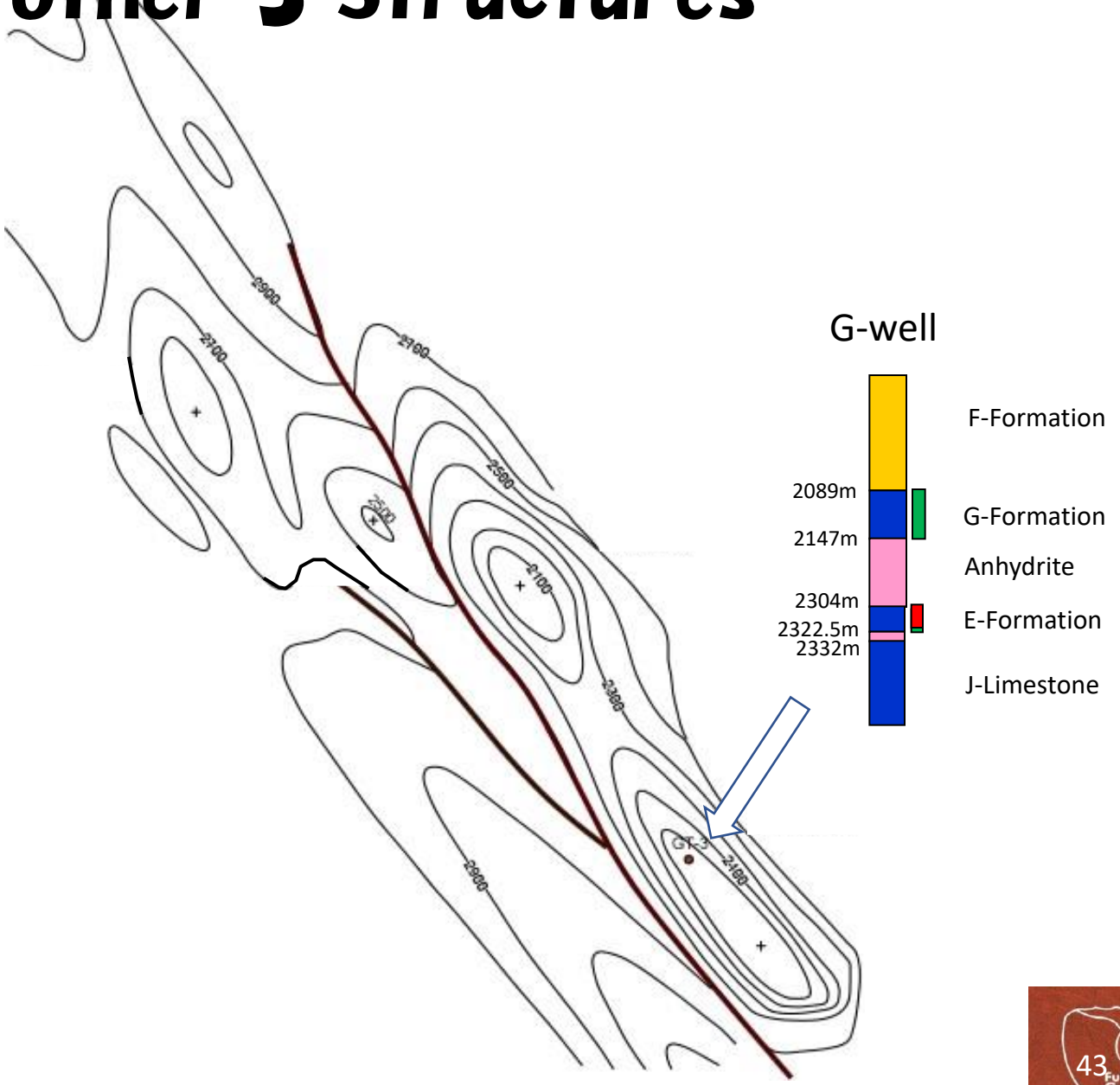
Seal Analysis in G-Field

-Practical Application of EGS Method- (Example)

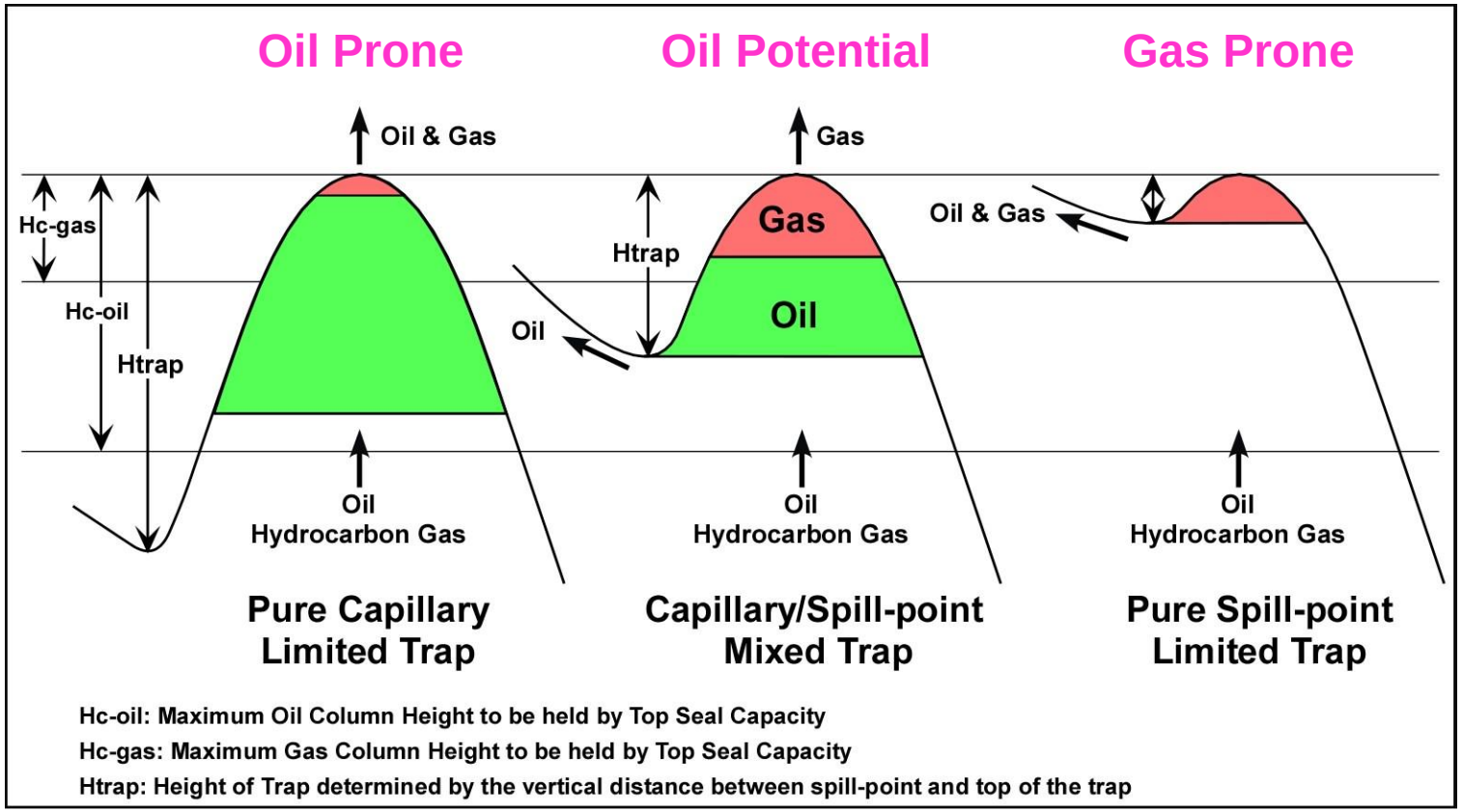
Examples from Central Iraq

- **1. Oil/Gas Columns for J-Formation. & E-Formation.**
- **2. Estimation of EGS (J- & E-Formations)**
- **3. Possible Explanation of Oil/Gas Accumulation**
- **4. Estimation of Oil/Gas Occurrence in the neighbor fields**

G-Str. & other 3 Structures

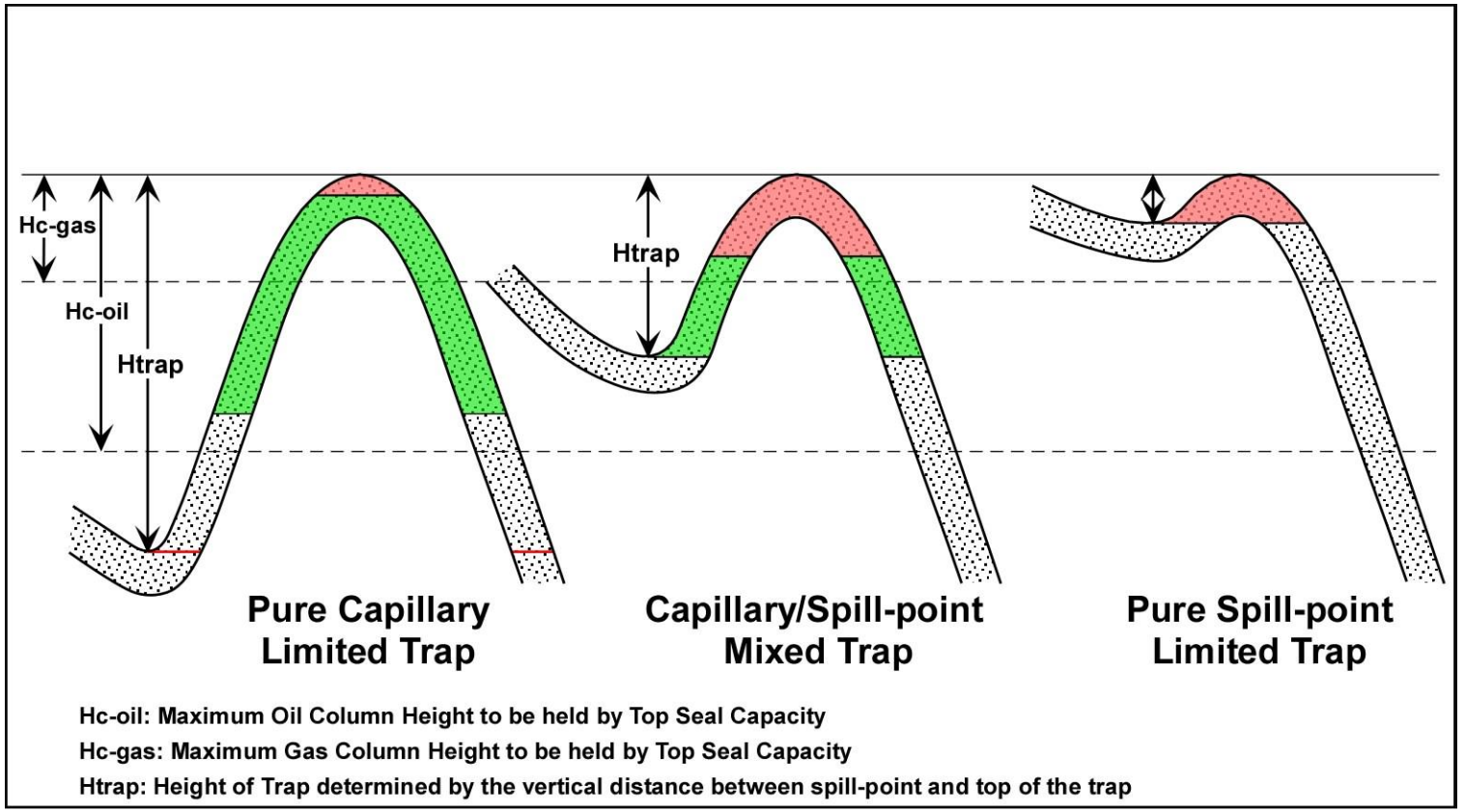


Oil & Gas Accumulation Controlled by Top Seal Capacity-Trap Height

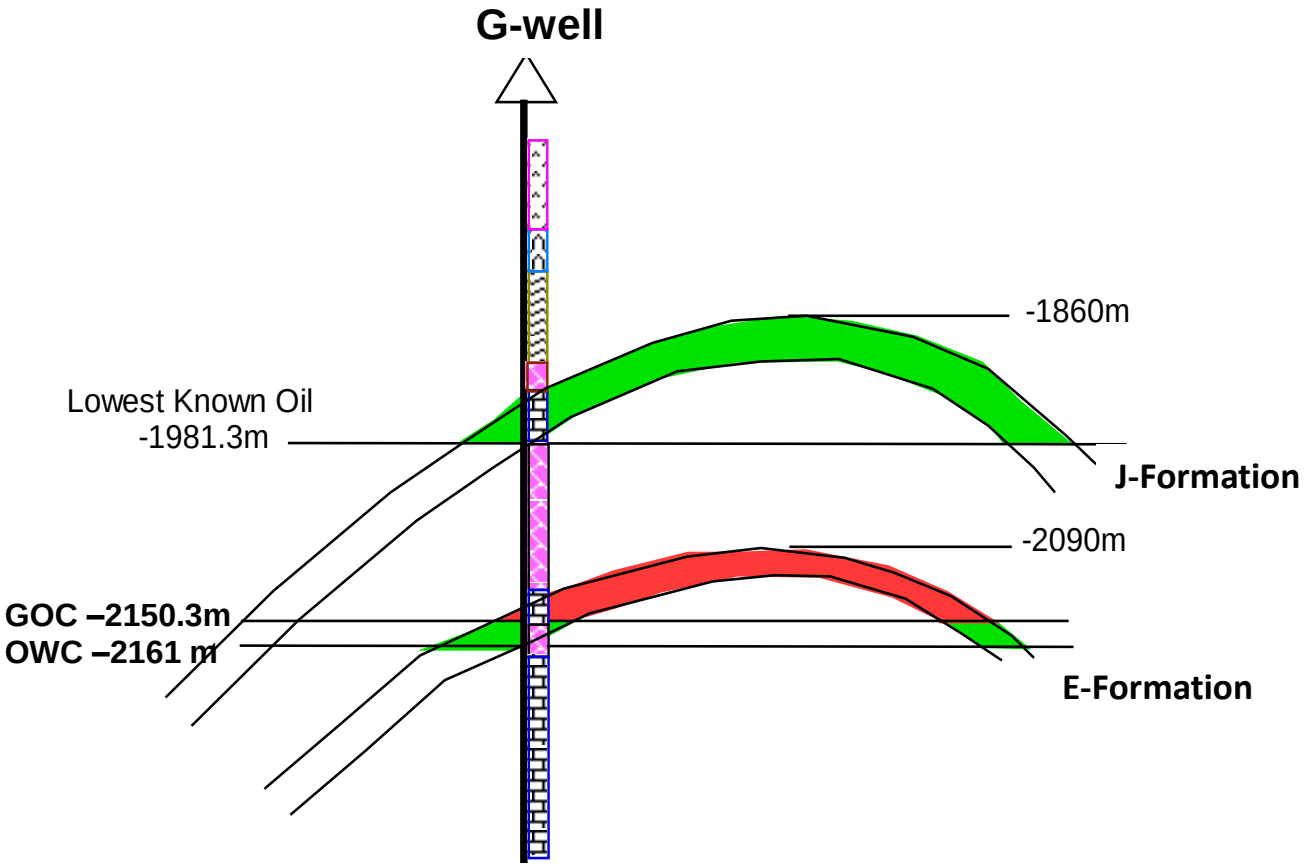


(Sawamura & Nakayama, 2005: modified after Sales, 1997)

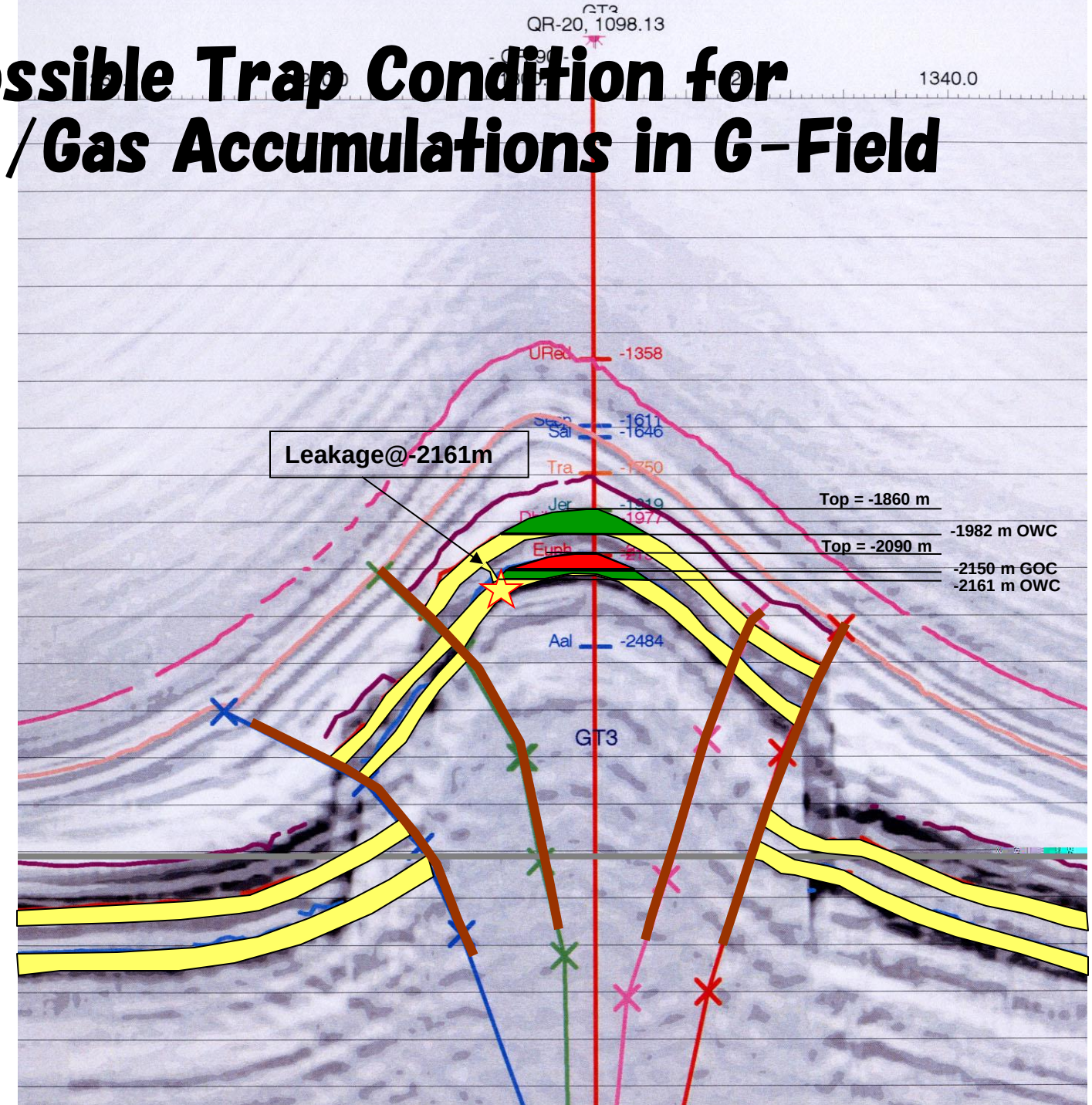
Oil & Gas Accumulation Controlled by Top Seal Capacity-Trap Height



Possible Explanation for Oil/Gas Accumulations in G-Field



Possible Trap Condition for Oil/Gas Accumulations in G-Field



Estimated EGS for J-Reservoir in G-Field

Excel Sheet No. *CalcSeaCap.BN v.6.0*

Seal Capacity Estimation(Quick Version)

Field Name: G-Field(J-Formation)

Density of Fm Water	r0	1.040	(g/cc)		*subsurface*	1.02				
Density of Oil	r1	0.826	(g/cc)		*subsurface*	0.76	Rs	795.3	Bo	1.0898
Gas Specific gravity	r2	0.753	(frac)		*subsurface*	0.18				
Z-factor	Z	0.90		Acceleration of Gravity g		981	(cm/sec2)	AMW	21.63	
Oil Interfacial Tension	γ1	27.23	(mN/m)		*subsurface*	27.23	Dr	0.26		
Gas Interfacial Tension	γ2	37.83	(mN/m)		*subsurface*	37.83	Dr	0.84	Tr	1.79
Contact Angle	q	0.00	(degree)	0 : Water Wet					A	3.560988
Grain Size of Rock	dm	7.85	(phi)							
	dm	0.00433	(mm)	**Porosity-surface**	40					
Porosity	ϕ	13.10	(%)							
			Gas Eff x0.7			67.78	Temperature[C]			
						0	**Water Depth (m)**			
Pore Throat Diameter	PTD	0.000348	(mm)	COEF		0.080	(-)			

				25.00	**Surface Temperature [C]**	
				2.30	**Geothermal Gradient [C/100m]**	
				0.000600	**Compaction Factor**	
				1860.00	**Depth(m)**	

Oil Column H.	Hco	121.36	(m)	**C for Effective PTD** C	1.00	(-)
Gas Column H.	Hcg	53.01	(m)			Cinv
				Observed Oil Col. Ho	121.30	(m) 1.00
				Observed Gas Col. Hg	0.00	(m) #DIV/0!

Estimated EGS for E Reservoir in G-Field

Excel Sheet No. *CalcSeaCap.BN v.6.0*

Seal Capacity Estimation(Quick Version)

Field Name: G-Field(E-Formation)

Density of Fm Water	r0	1.040	(g/cc)	*subsurface*	1.02				
Density of Oil	r1	0.836	(g/cc)	*subsurface*	0.76	Rs	876.95	Bo	1.0938
Gas Specific gravity	r2	0.753	(frac)	*subsurface*	0.20				
Z-factor	Z	0.90		Acceleration of Gravity g	981	(cm/sec2)	AMW	21.63	
Oil Interfacial Tension	γ1	26.23	(mN/m)	*subsurface*	26.23	Dr	0.25		
Gas Interfacial Tension	γ2	36.64	(mN/m)	*subsurface*	36.64	Dr	0.82	Tr	1.82
Contact Angle	q	0.00	(degree)	0 : Water Wet				A	3.606206

Grain Size of Rock	dm	7.81	(phi)			
	dm	0.00446	(mm)	**Porosity-surface**	40	0.000600 **Compaction Factor**
Porosity	ϕ	11.41	(%)			2090.00 **Depth(m)**
			Gas Eff x0.7			73.07 Temperature[C]
						0 **Water Depth (m)**
Pore Throat Diameter	PTD	0.000285	(mm)	COEF		0.064 (-)

25.00 **Surface Temperature [C]**
2.30 **Geothermal Gradient [C/100m]**

Oil Column H.	Hco	147.52	(m)	**C for Effective PTD** C	1.00 (-)
Gas Column H.	Hcg	63.65	(m)		Cinv
				Observed Oil Col. Ho	10.70 (m) 13.79
				Observed Gas Col. Hg	60.30 (m) 1.06

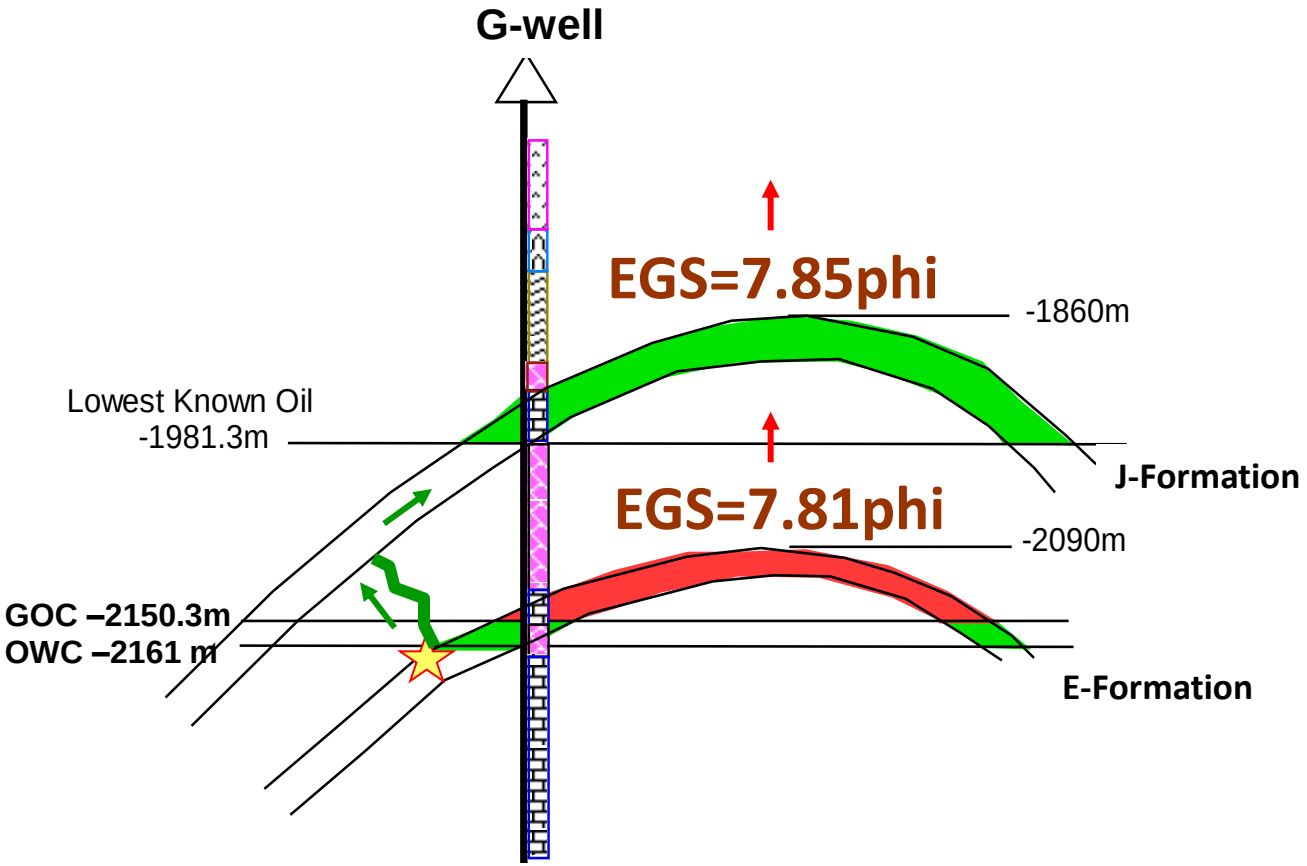
JGI, Inc.

Pb = 513.42
Pc = 2*γ/R/1000
Pb=Pc -->2R = 0.000285

for Mixed Type only

HCG	HCO	Pb	Pc
60.30	10.70	513.42	513.80

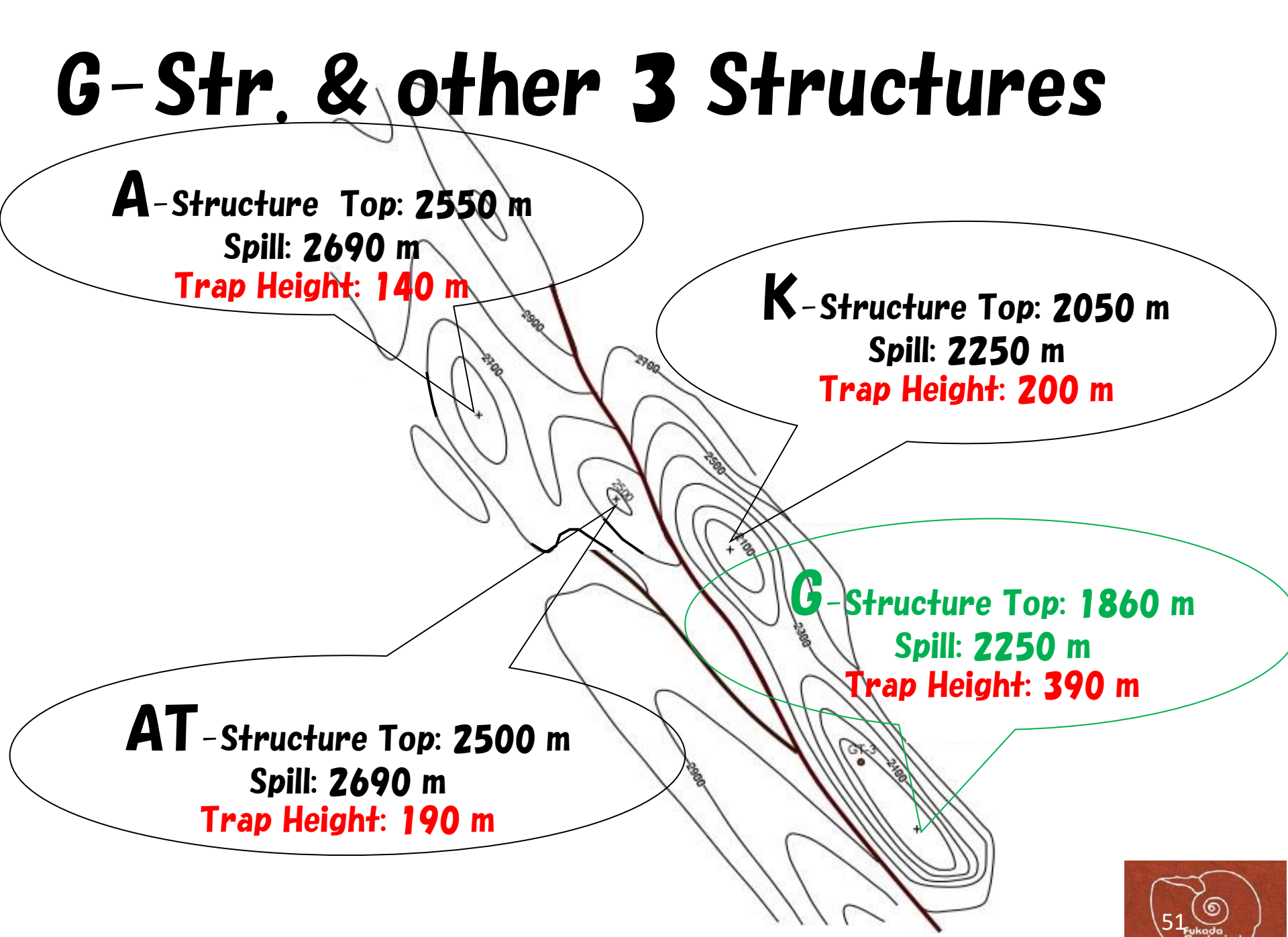
Possible Explanation for Oil/Gas Accumulations in G-Field



G-Str. & other 3 Structures

A-Structure Top: 2550 m
Spill: 2690 m
Trap Height: 140 m

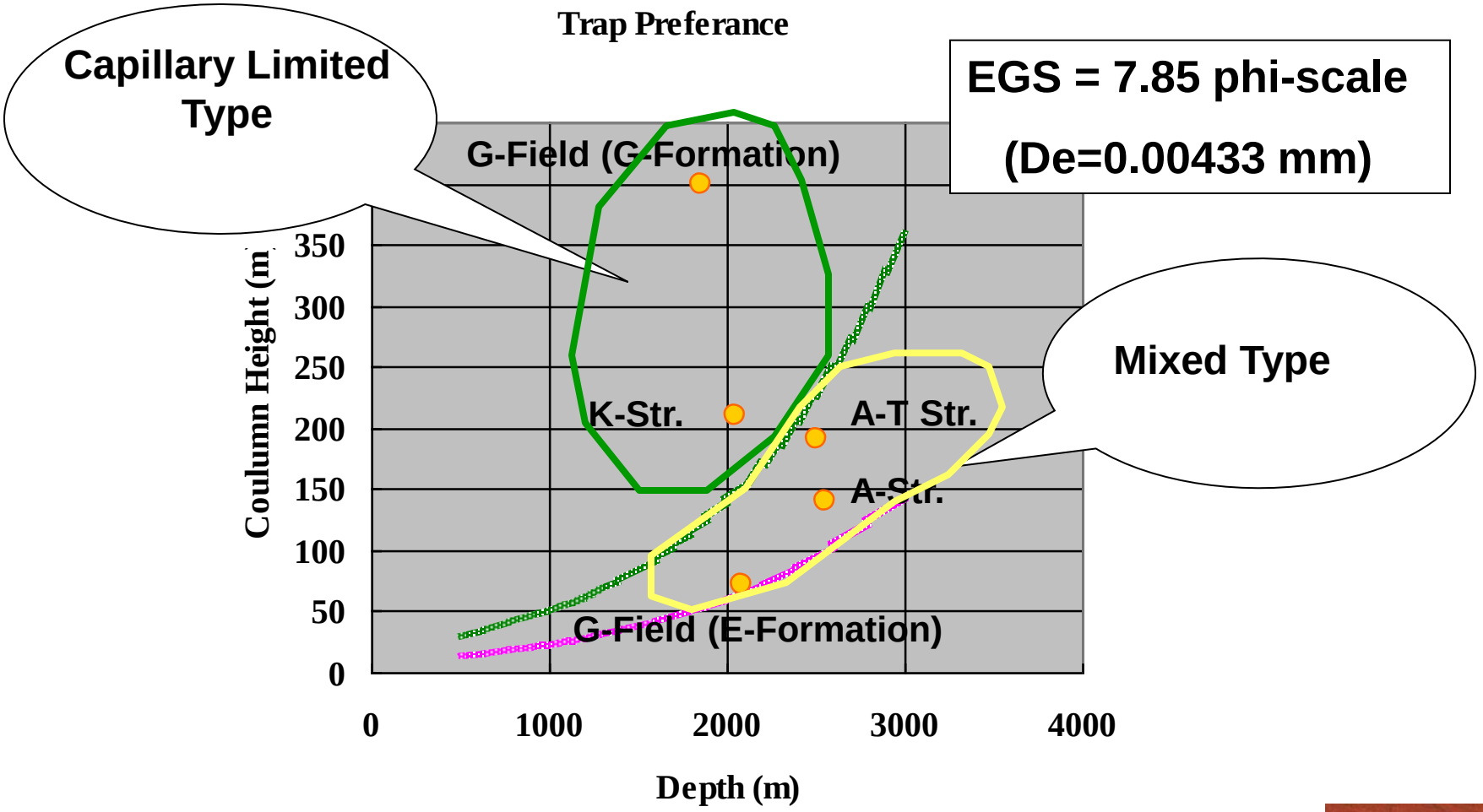
K-Structure Top: 2050 m
Spill: 2250 m
Trap Height: 200 m



G-Structure Top: 1860 m
Spill: 2250 m
Trap Height: 390 m

AT-Structure Top: 2500 m
Spill: 2690 m
Trap Height: 190 m

Oil/Gas Preference for other fields



Estimated Column Height at K-Structure

Excel Sheet No. *CalcSeaCap.BN v.6.0*

Seal Capacity Estimation(Quick Version)

Field Name: G-Field(K-Str.)

Density of Fm Water	r0	1.040	(g/cc)	*subsurface*	1.02				
Density of Oil	r1	0.826	(g/cc)	*subsurface*	0.76	Rs	862.75	Bo	1.0931
Gas Specific gravity	r2	0.753	(frac)	*subsurface*	0.19				
Z-factor	Z	0.90		Acceleration of Gravity g	981	(cm/sec2)	AMW	21.63	
Oil Interfacial Tension	γ1	27.28	(mN/m)	*subsurface*	27.28	Dr	0.26		
Gas Interfacial Tension	γ2	36.84	(mN/m)	*subsurface*	36.84	Dr	0.83	Tr	1.82
Contact Angle	q	0.00	(degree)	0 : Water Wet				A	3.598567

Grain Size of Rock	dm	7.85	(phi)			
	dm	0.00433	(mm)	**Porosity-surface**	40	0.000600
Porosity	ϕ	11.69	(%)			
				Gas Eff x0.7		
Pore Throat Diameter	PTD	0.000288	(mm)	COEF	0.067	(-)

25.00	**Surface Temperature [C]**	
2.30	**Geothermal Gradient [C/100m]**	
	Compaction Factor	
2050.00	**Depth(m)**	
72.15	Temperature[C]	
0	**Water Depth (m)**	

Oil Column H.	Hco	146.46	(m)	**C for Effective PTD**	C	1.00	(-)
Gas Column H.	Hcg	63.11	(m)				
				Observed Oil Col.	Ho	146.00	(m)
				Observed Gas Col.	Hg	0.00	(m)

Cinv
1.00
#DIV/0!

Trap Height = 200m

Estimated Column Height at A-Structure

Excel Sheet No. *CalcSeaCap.BN v.6.0*

Seal Capacity Estimation(Quick Version)

Field Name: G-Field(A-Str.)

Density of Fm Water	r0	1.040	(g/cc)	*subsurface*	1.01					
Density of Oil	r1	0.826	(g/cc)	*subsurface*	0.75	Rs	1040.25	Bo	1.1020
Gas Specific gravity	r2	0.753	(frac)	*subsurface*	0.21					
Z-factor	Z	0.90		Acceleration of Gravity g	981	(cm/sec2)	AMW	21.63		
Oil Interfacial Tension	γ1	27.41	(mN/m)	*subsurface*	27.41	Dr	0.26			
Gas Interfacial Tension	γ2	34.49	(mN/m)	*subsurface*	34.49	Dr	0.80	Tr	1.88
Contact Angle	q	0.00	(degree)	0 : Water Wet				A	3.688143

				25.00	**Surface Temperature [C]**	
Grain Size of Rock	dm	7.85	(phi)	2.30	**Geothermal Gradient [C/100m]**	
	dm	0.00433	(mm)	**Porosity-surface** 40	0.000600	**Compaction Factor**
Porosity	ϕ	8.66	(%)		2550.00	**Depth(m)**
			Gas Eff x0.7		83.65	Temperature[C]
					0	**Water Depth (m)**
Pore Throat Diameter	PTD	0.000179	(mm)	COEF	0.041	(-)

Oil Column H.	Hco	236.73	(m)	**C for Effective PTD**	C	1.00	(-)
Gas Column H.	Hcg	98.41	(m)				Cinv
				Observed Oil Col.	Ho	62.00	(m) 3.82
				Observed Gas Col.	Hg	78.00	(m) 1.26

JGI, Inc.

Pb	=	772.88
Pc	=	2*γ/R/1000
Pb=Pc -->2R	=	0.000179

for Mixed Type only

HCG	HCO	Pb	Pc
78.00	62.00	772.88	772.33

Trap Height = 140m

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Estimated Column Height at AT-Structure

Excel Sheet No. *CalcSeaCap.BN v.6.0*

Seal Capacity Estimation(Quick Version)

Field Name: G-Field(AT-Str.)

Density of Fm Water	r0	1.040	(g/cc)	*subsurface*	1.01					
Density of Oil	r1	0.826	(g/cc)	*subsurface*	0.75	Rs	1022.5	Bo	1.1011
Gas Specific gravity	r2	0.753	(frac)	*subsurface*	0.21				
Z-factor	Z	0.90		Acceleration of Gravity g	981	(cm/sec2)	AMW	21.63	
Oil Interfacial Tension	γ1	27.40	(mN/m)	*subsurface*	27.40	Dr	0.26		
Gas Interfacial Tension	γ2	34.71	(mN/m)	*subsurface*	34.71	Dr	0.80	Tr	1.87
Contact Angle	q	0.00	(degree)	0 : Water Wet				A	3.679717

Grain Size of Rock	dm	7.85	(phi)			
	dm	0.00433	(mm)	**Porosity-surface**	40	0.000600 **Compaction Factor**
Porosity	ϕ	8.93	(%)			2500.00 **Depth(m)**
			Gas Eff x0.7			82.50 Temperature[C]
						0 **Water Depth (m)**
Pore Throat Diameter	PTD	0.000187	(mm)	COEF		0.043 (-)

Oil Column H.	Hco	225.85	(m)	**C for Effective PTD**	C	1.00 (-)
Gas Column H.	Hcg	94.23	(m)			Cinv
				Observed Oil Col.	Ho	143.00 (m) 1.58
				Observed Gas Col.	Hg	47.00 (m) 2.00

JGI, Inc.

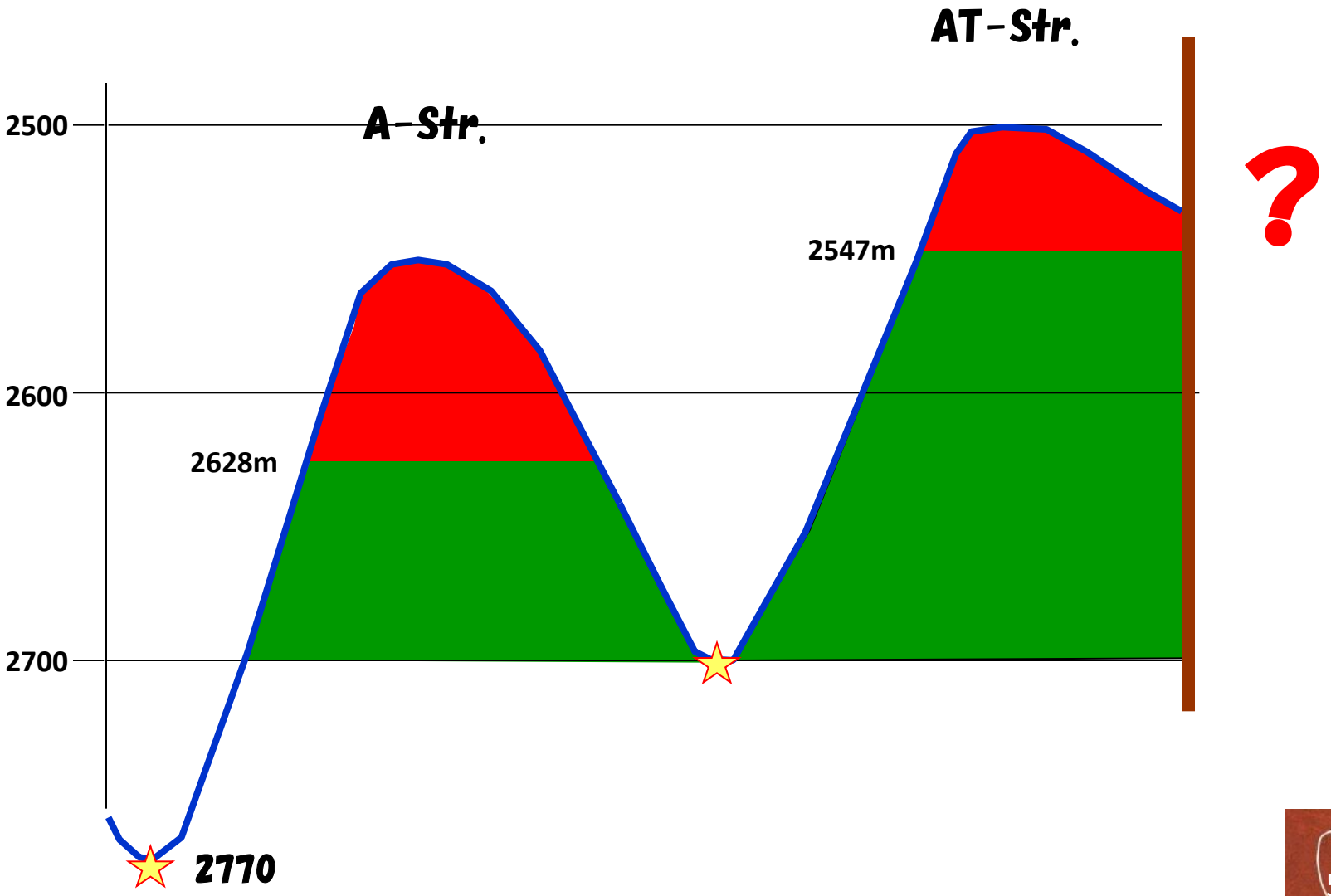
Pb	=	740.51
Pc	=	2*γ/R/1000
Pb=Pc -->2R	=	0.000187

for Mixed Type only

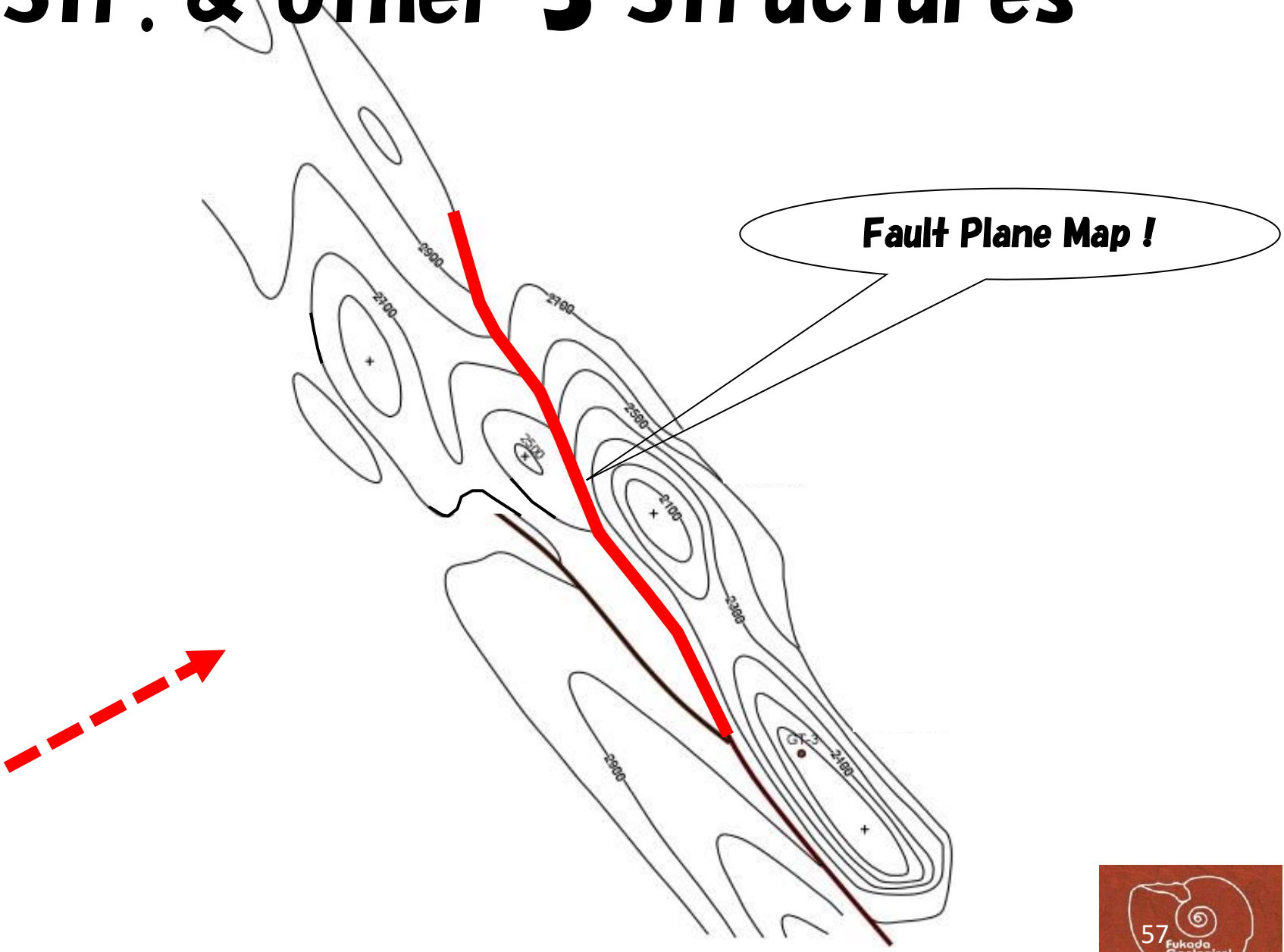
HCG	HCO	Pb	Pc
47.00	143.00	740.51	741.59

Trap Height = 190m

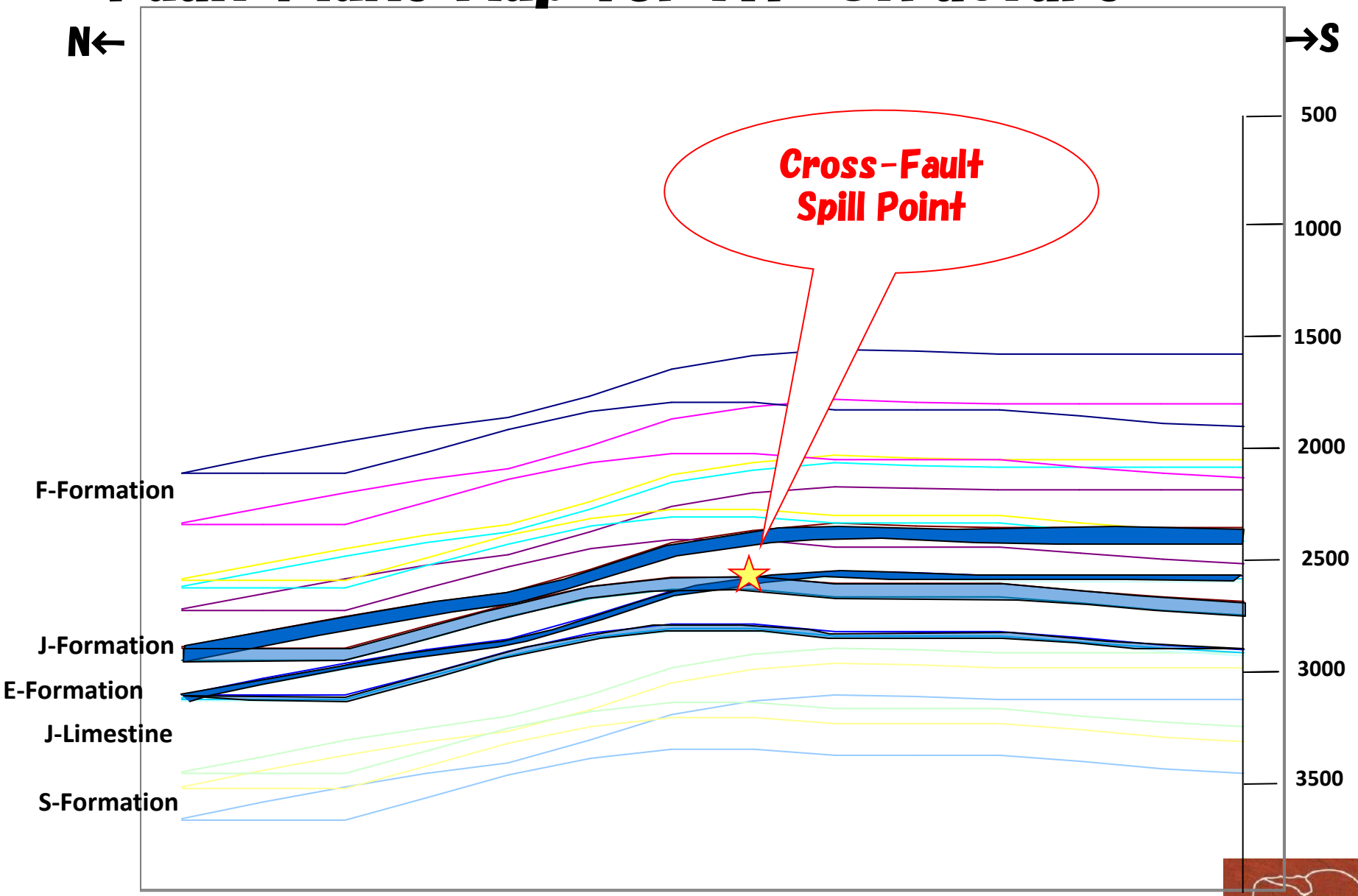
Possible Status for Oil/Gas Trapping (1)



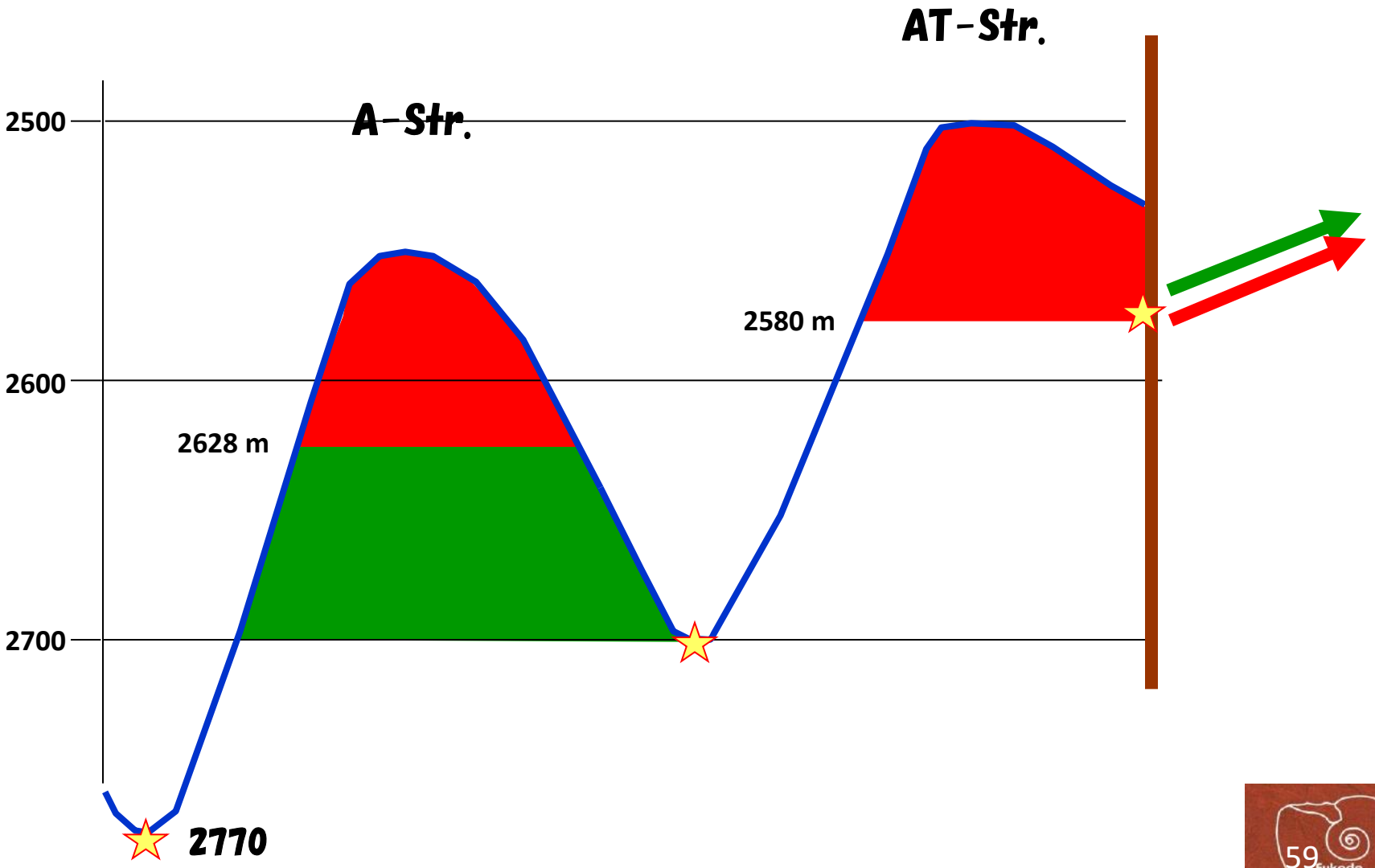
G-Str. & other 3 Structures



Fault Plane Map for AT-Structure



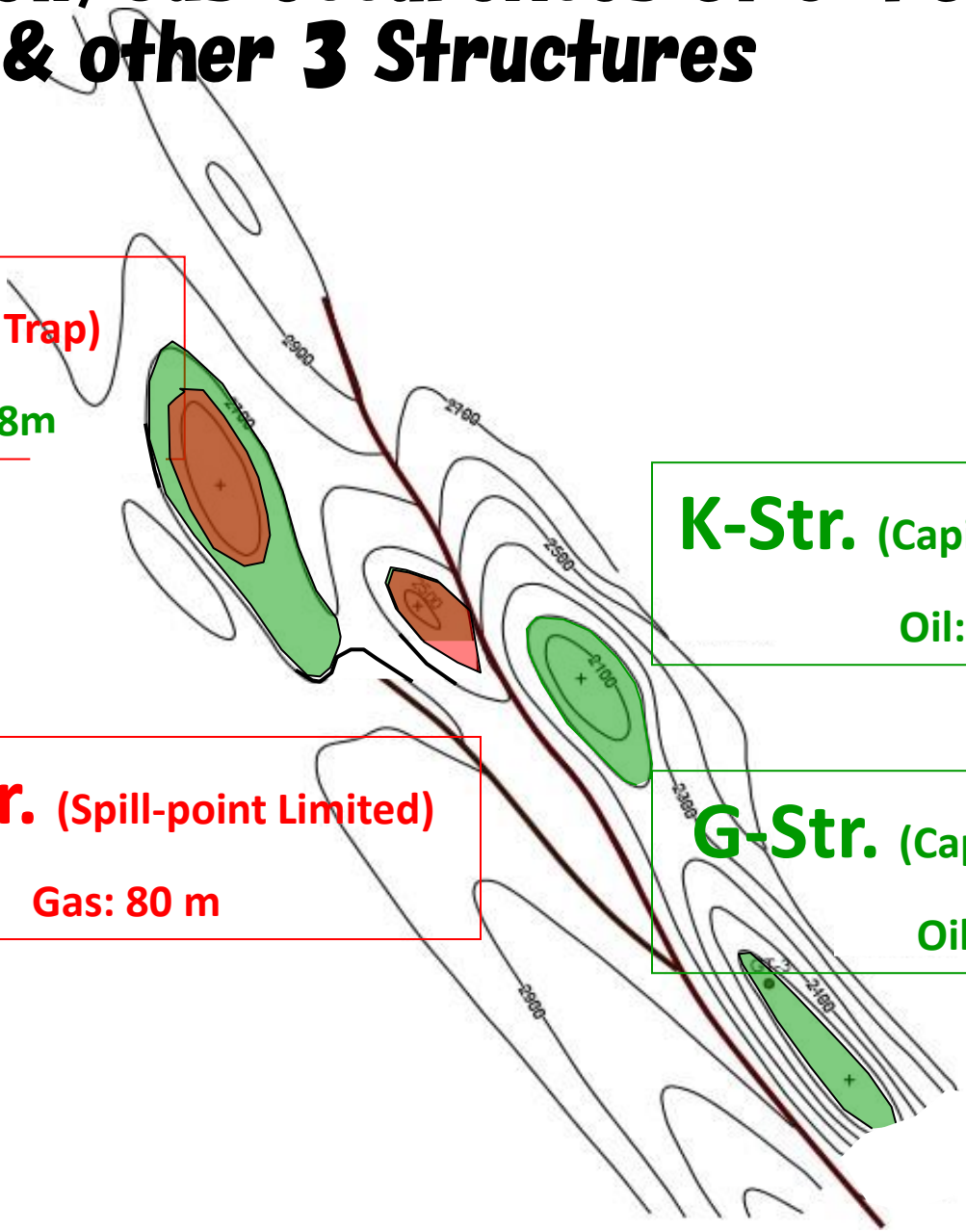
Possible Status for Oil/Gas Trapping (2)



Estimated Oil/Gas Occurences of J-Formation for G-Str. & other 3 Structures

A-Str. (Mixed Trap)

Gas: 78m/ Oil 68m



K-Str. (Capillary Limited trap)

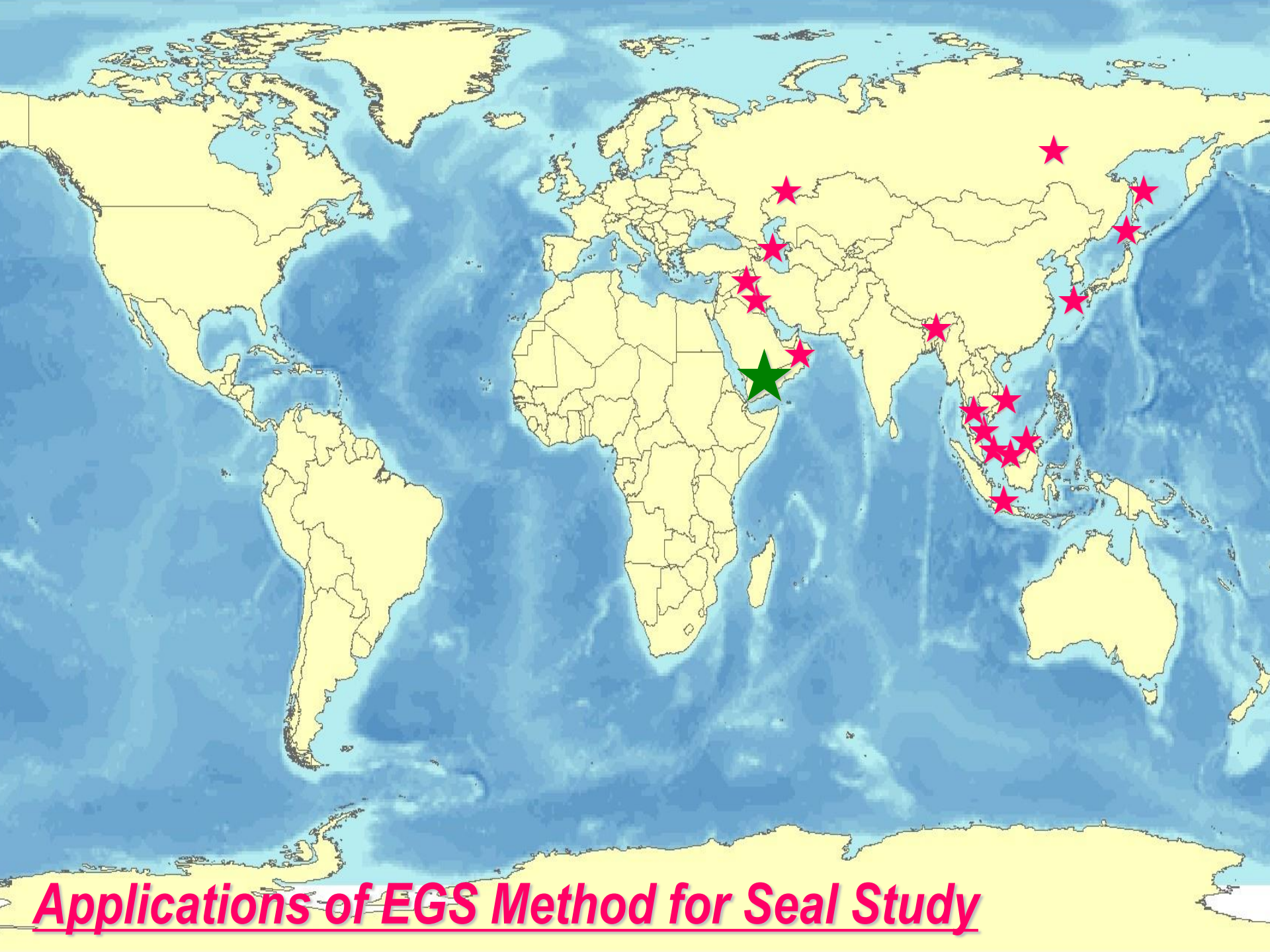
Oil: 146 m

AT-Str. (Spill-point Limited)

Gas: 80 m

G-Str. (Capillary Limited trap)

Oil: 121 m



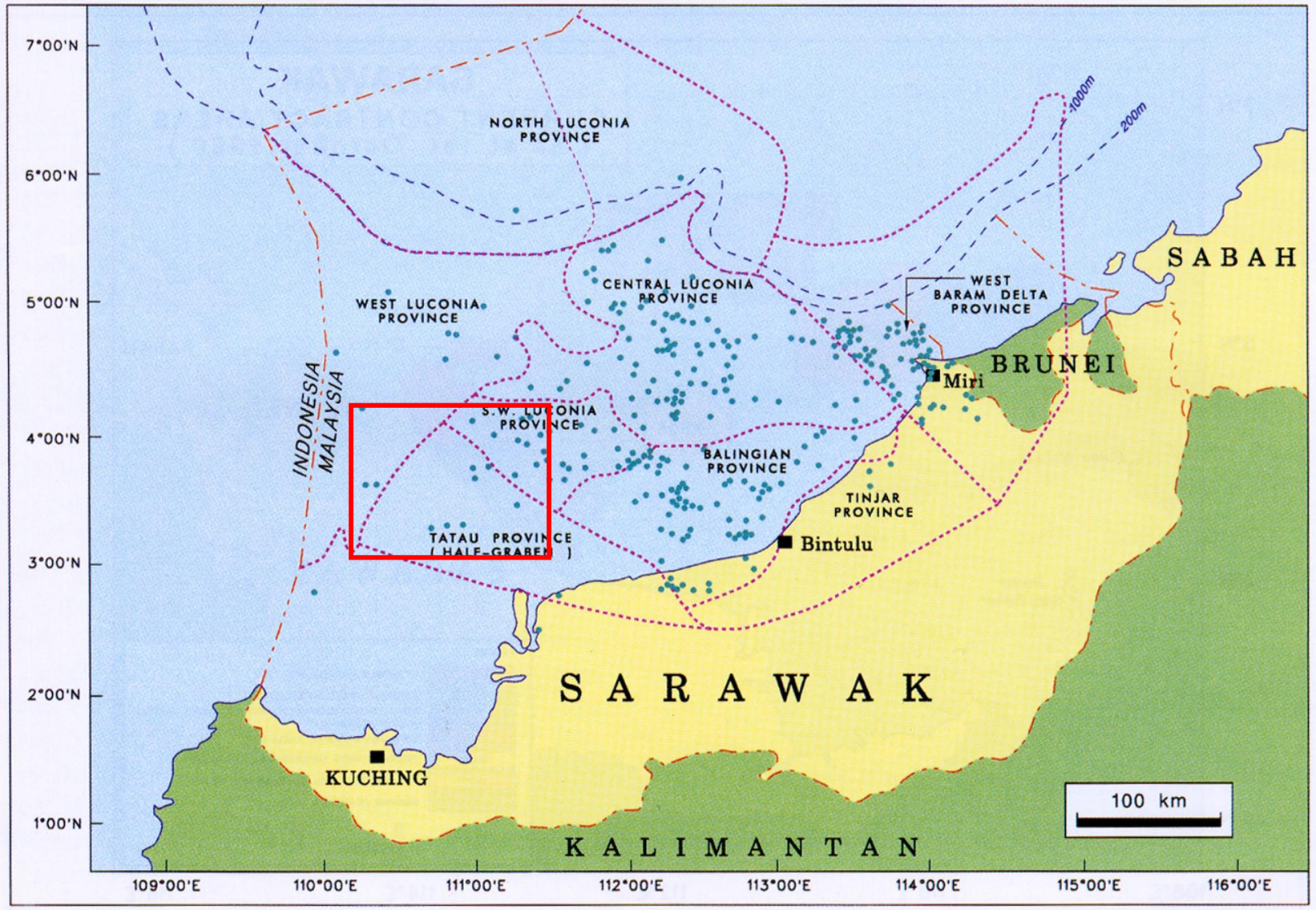
Applications of EGS Method for Seal Study

Importance for Seal Evaluation in Oil/Gas Exploration

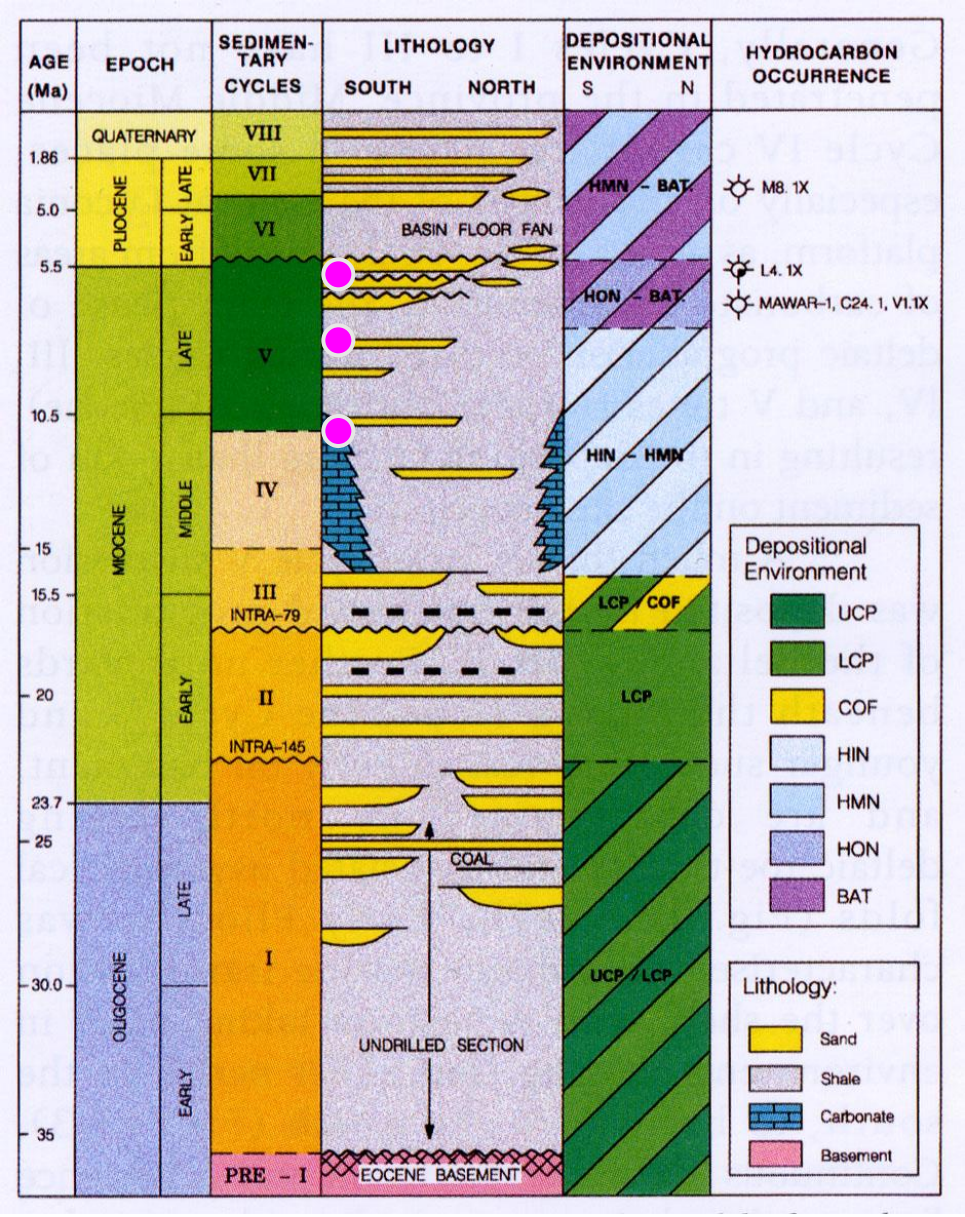
1. **Introduction** (Toy experiment, Curious Distributions of Oil and Gas Fields)
2. **Oil and Gas Trap System** (Source, Reservoir, Cap-rock)
3. **Contents in Trap** (Oil or Gas？)
4. **Case Studies** (Sakhalin, Iraq)
5. **How to distinguish CO_2-rich Gas Traps**

Examples
Oil / Gas / CO_2 Systems

Sarawak Well Density Map (modified after Petronas, 1999)



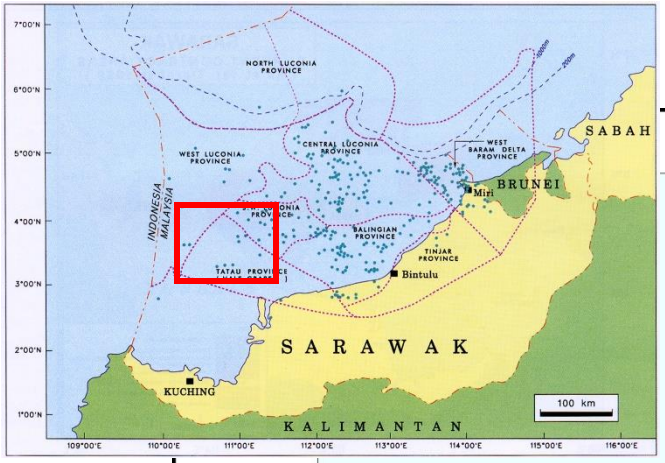
Stratigraphy in West Luconia Province (modified after Petronas, 1999)



Main Reservoir:
Cycle V Sandstone
Cycles IV/V Carbonate

Seal:
Cycle V Shale (Open Marine)

Study Area and Fields



K5 K5.1X(1970), K5.2(1997), K5.2RDR(1997)

CO2: 54 %

J1 J1.1X(1970)

J5 J5.1X(1978)

CO2: 87.3 %

T3 T3.1X(1970), T3.2(1997)

CO2: 62 %

J2 J2.1X(1978)

CO2: 2 %

3deg 30'N

CO2: 78 %(SS1)
1.9 %(SS5b)
11.9 % (SS8a)

H2 H2.1X(1970), H2.2X(1970)

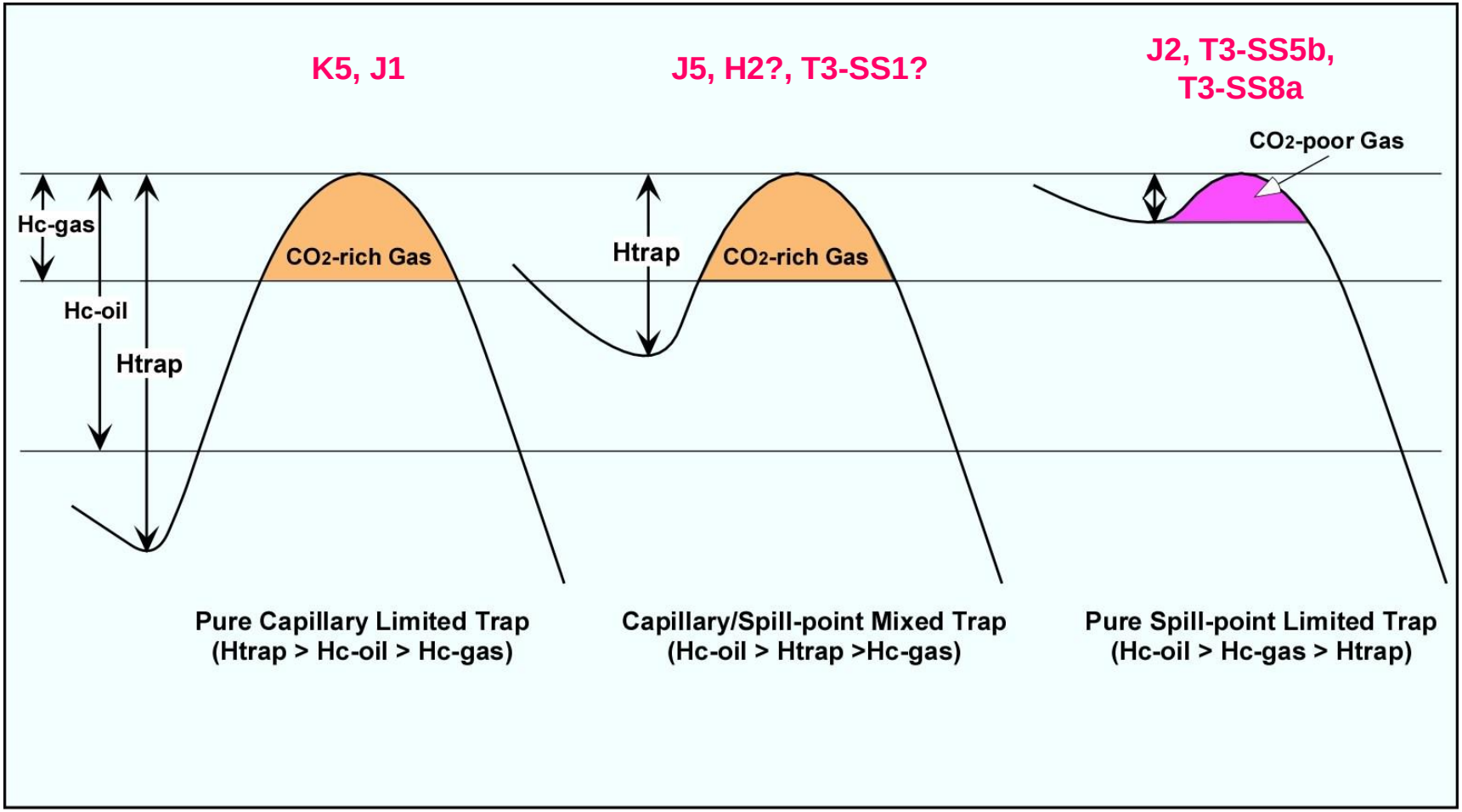
CO2:50 %

110deg 30'E 111deg 00'E 111deg 30'E

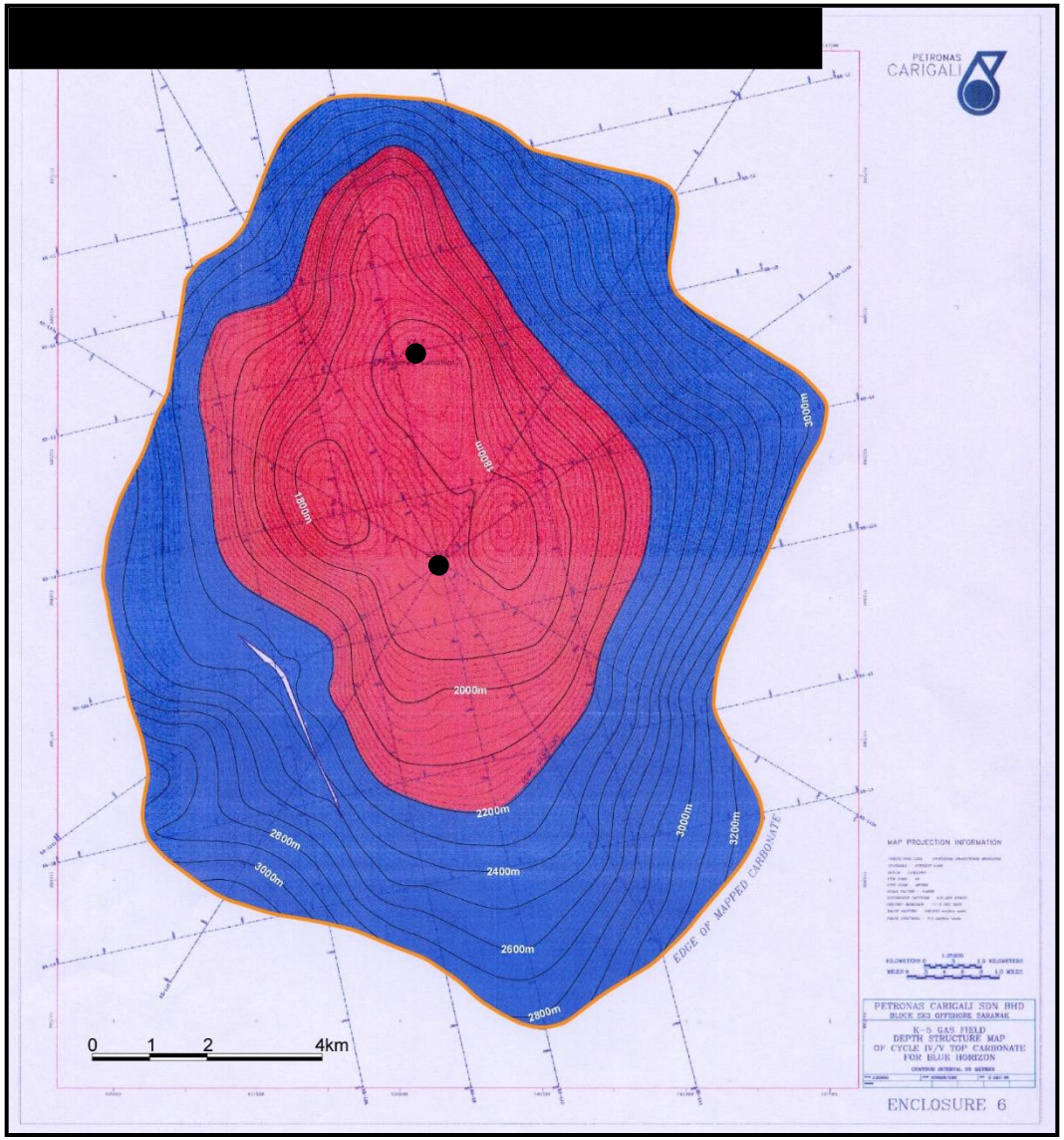
Co2含有率(● > ● > ●)

0 10 25 50KM

Relationship between CO2 Content and Trap Types
- Cycles IV/V Carbonate and Sandstone Reservoirs -



Excel Sheet No.										*CalcSeaCap.BN v.4.0*
Seal Capacity Estimation(Quick Version)								**Field Name:**	**K5 (Cycle IV Carbonate)**	
Density of Fm Water	ρ	**1.070**	(g/cc)	*subsurface*		1.05				
Density of Oil	ρ	**0.830**	(g/cc)	*subsurface*		0.76	Rs	752.7	Bo	1.0876
Gas Specific gravity	ρ	**1.200**	(frac)	*subsurface*		0.20				
Z-factor	Z	0.90		Acceleration of Gravity		981	(cm/sec2)	AMW	34.35	
Oil Interfacial Tension		30.94	(mN/m)	*subsurface*		30.94		0.29		
Gas Interfacial Tension		34.17	(mN/m)	*subsurface*		34.17		0.86	Tr	1.98
Contact Angle		**0.00**	(degree)	0 : Water Wet					A	3.494412
						26.00	**Surface Temperature [C]**			
Grain Size of Rock	dm	**11.66**	(phi)			**4.60**	**Geothermal Gradient [C/100m]**			
	dm	0.00031	(mm)	**Porosity-surface**	**55**	**0.000733**	**Compaction Factor**			
Porosity		16.29	(%)			**1740.00**	**Depth(m)**			
			Gas Eff x0.7			102.36	Temperature[C]			
					Water Depth (m)		**80.0**			
Pore Throat Diameter	PTD	0.000036	(mm)	COEF		0.116	(-)			
Oil Column H.	Hco	**1221.78**	(m)	**C for Effective PTD**	C	**1.00**	(-)			
Gas Column H.	Hcg	**454.69**	(m)					Cinv		
				Observed Oil Col.	Hc	**0.00**	(m)	#DIV/0!		
				Observed Gas Col.	Hg	**455.20**	(m)	1.00		
										JGI, Inc.
Pb	=	**3822.20**				HCG	HCO	Pb	Pc	
Pc	=	**2*34.17/R/1000**				455.00	0.00	**3820.53**	3817.96198	
Pb=Pc -->2R	=	**0.000036**								



K5 Field

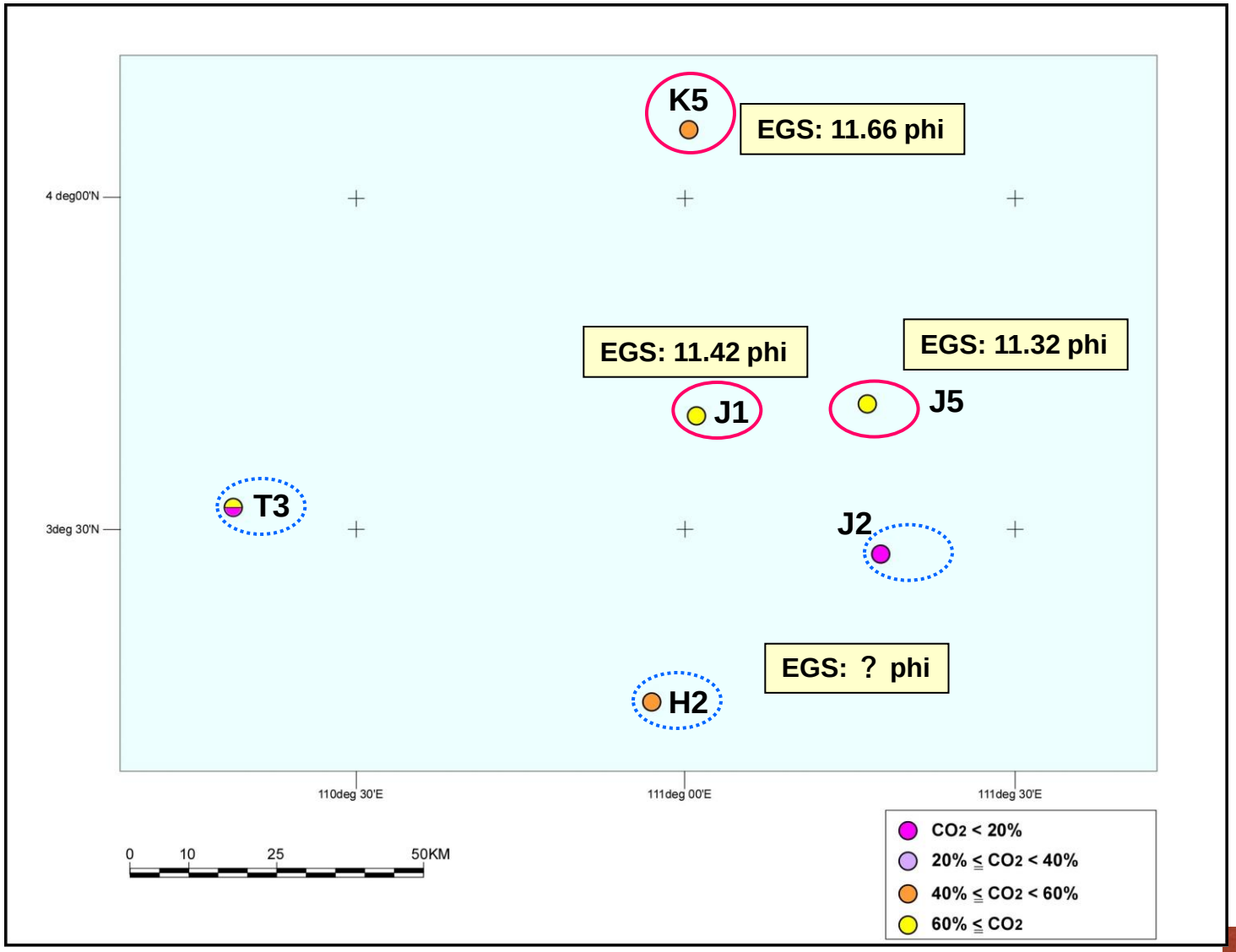
Main Reservoir: Cycle IV/V Carbonate

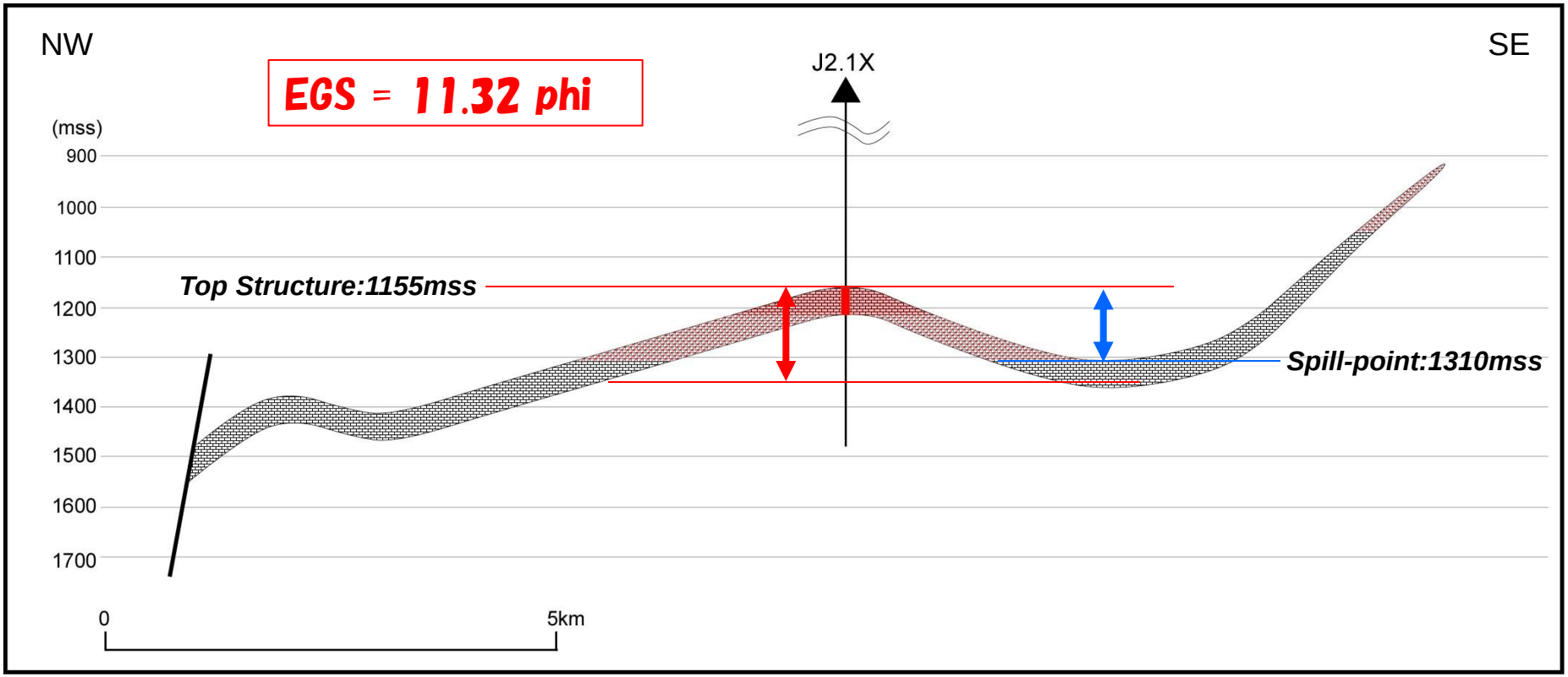
Trap Height: 1540 m (1740 - 3280 mss)
Gas Column: 455 m (1740 - 2195 mss)
Oil Column: Nil

Trap Height > Max. Gas Column Height
Trap Height > Max. Oil Column Height

→Pure Capillary Limited Trap
Estimated EGS: 11.66phi

Distribution of CO_2 Content of Natural Gases in the Study Area
- Cycles IV/V Carbonate and Sandstone Reservoirs -





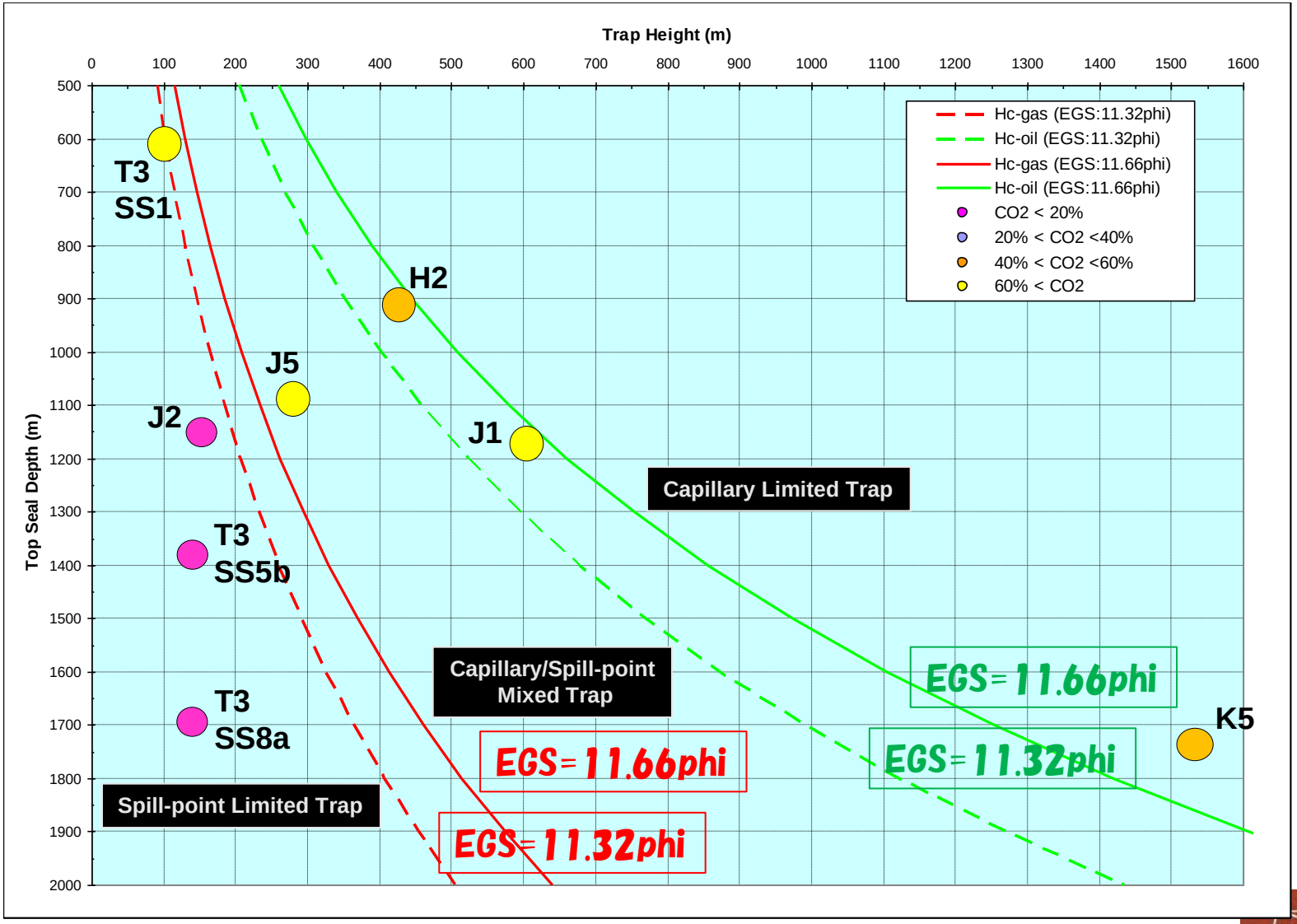
Applying 11.32 phi for EGS of Cap Rock……..

Max. Gas Column: 196 m (1155 - 1351 mss) > Trap Height: 155 m (1155 - 1310mss)

→J2 Prospect: Spill-point Limited Trap

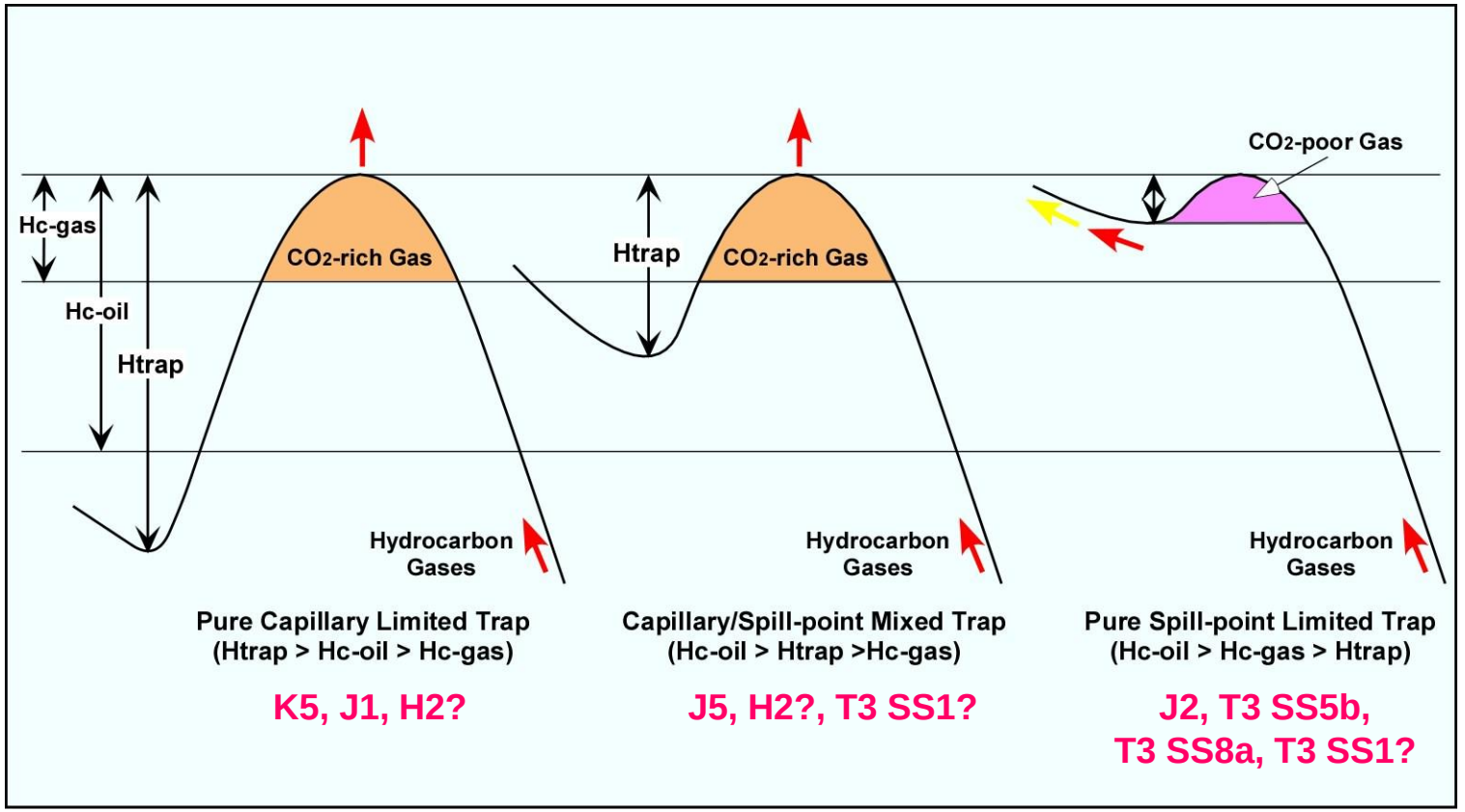
Trap Height vs. Top Seal Depth with the Maximum Oil & Gas Heights

- Cycles IV/V Carbonate and Sandstone Reservoirs -



スピルポイント制御型トラップは、CO_2が少ない。

Accumulation Model of "Hydrocarbon Gas - CO_2"
- Assuming Hydrocarbon Gas migration following CO_2-



Accumulation Model of "Hydrocarbon Gas – CO_2

- Explain the relation between CO2 content and trap types in Cycles IV/V carbonate and Cycle V sand plays

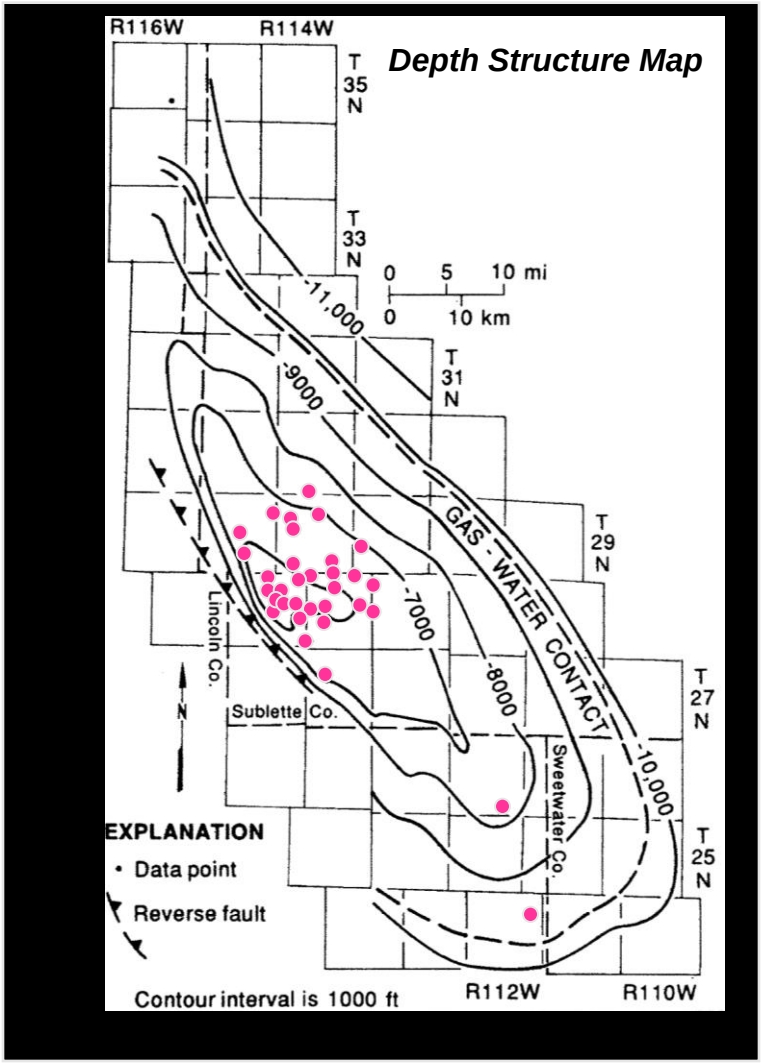
- Sequence of the migration of the gases (CO2 and Hydrocarbon gases) does not affect the entrapment

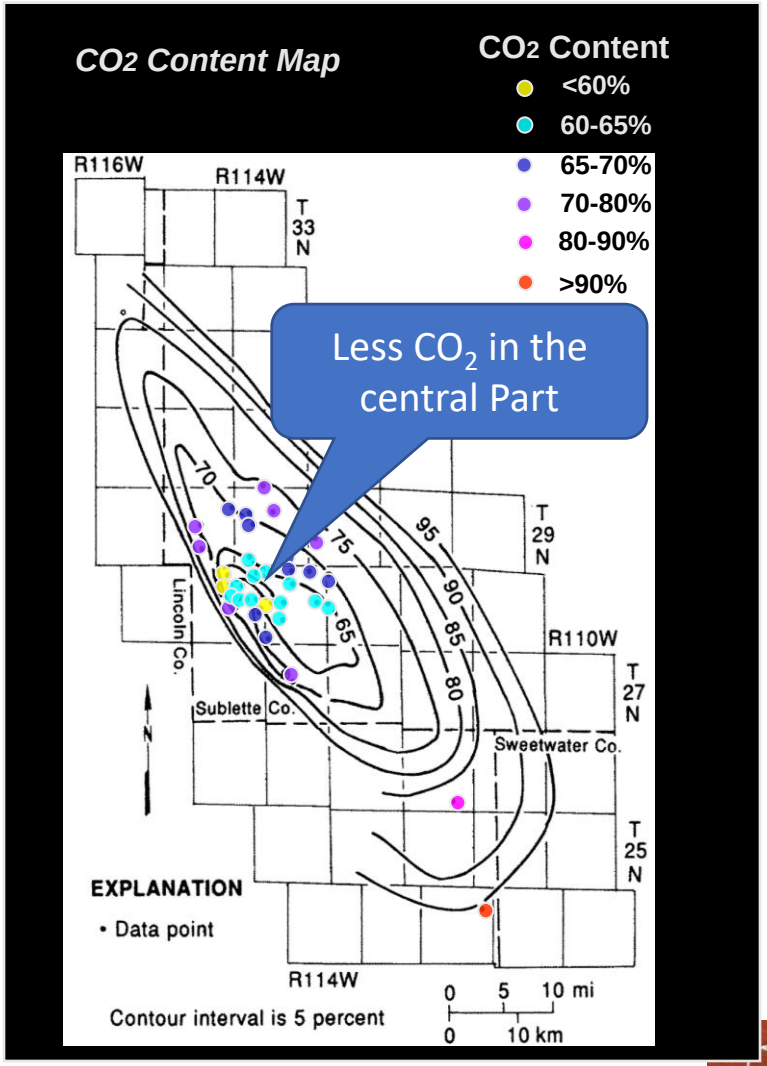
- Assuming……

  1) Migration of sufficient amount of CO2 and hydrocarbon gases

  2) Stratification of CO2 and hydrocarbon gases due to the difference in density

Stratification of CO_2 Content in Big Piney-La Barge Field in the Greater Green River Basin, USA (Allis et al., 2001)





modified after Allis et al. (2001)

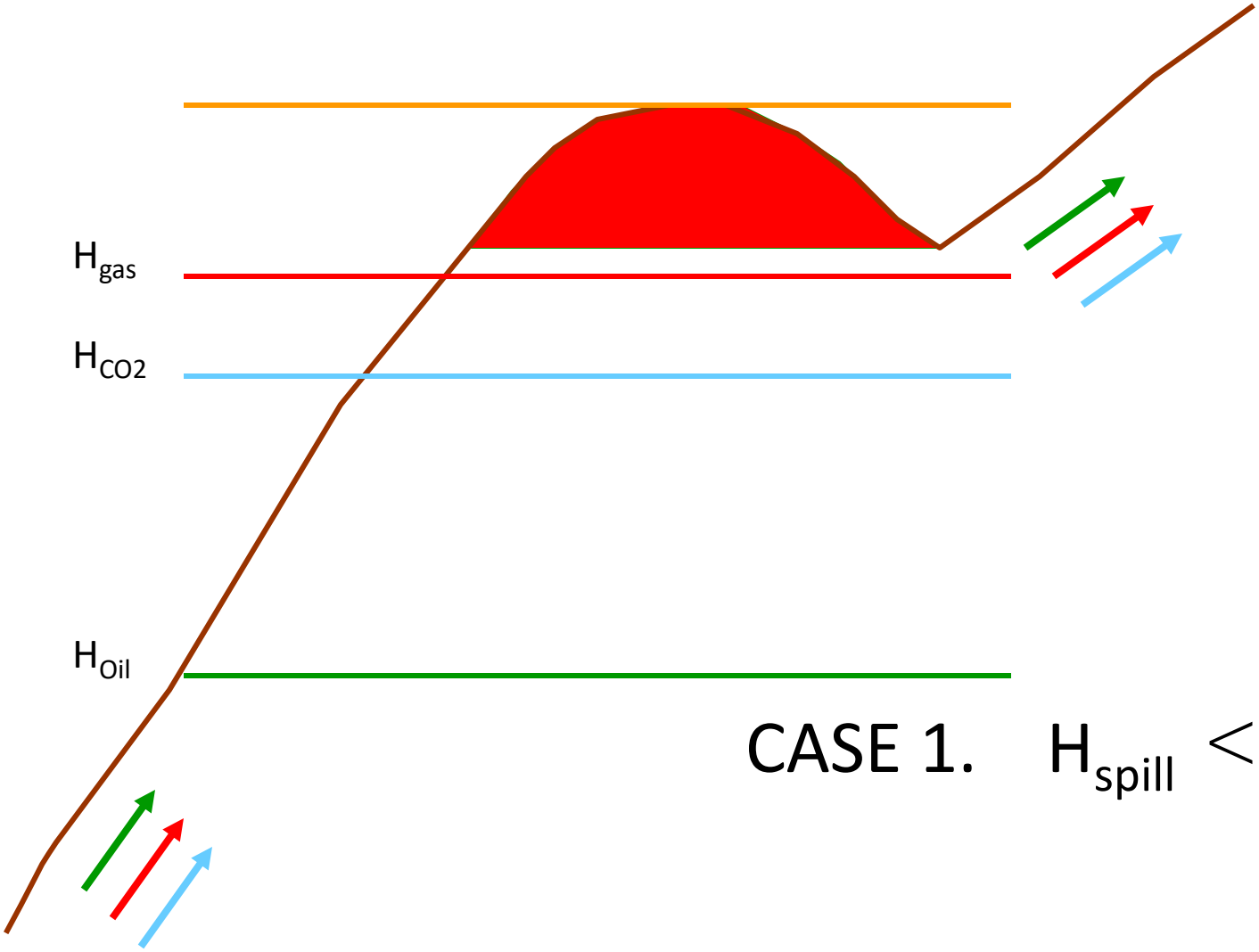
Proposal of Seal Evaluation by EGS for CO_2 rich basin

Seal Mechanism also strictly controls Trap Type in 3 Phase (Oil or Gas or CO_2) System.

H_{spill} should be compared to

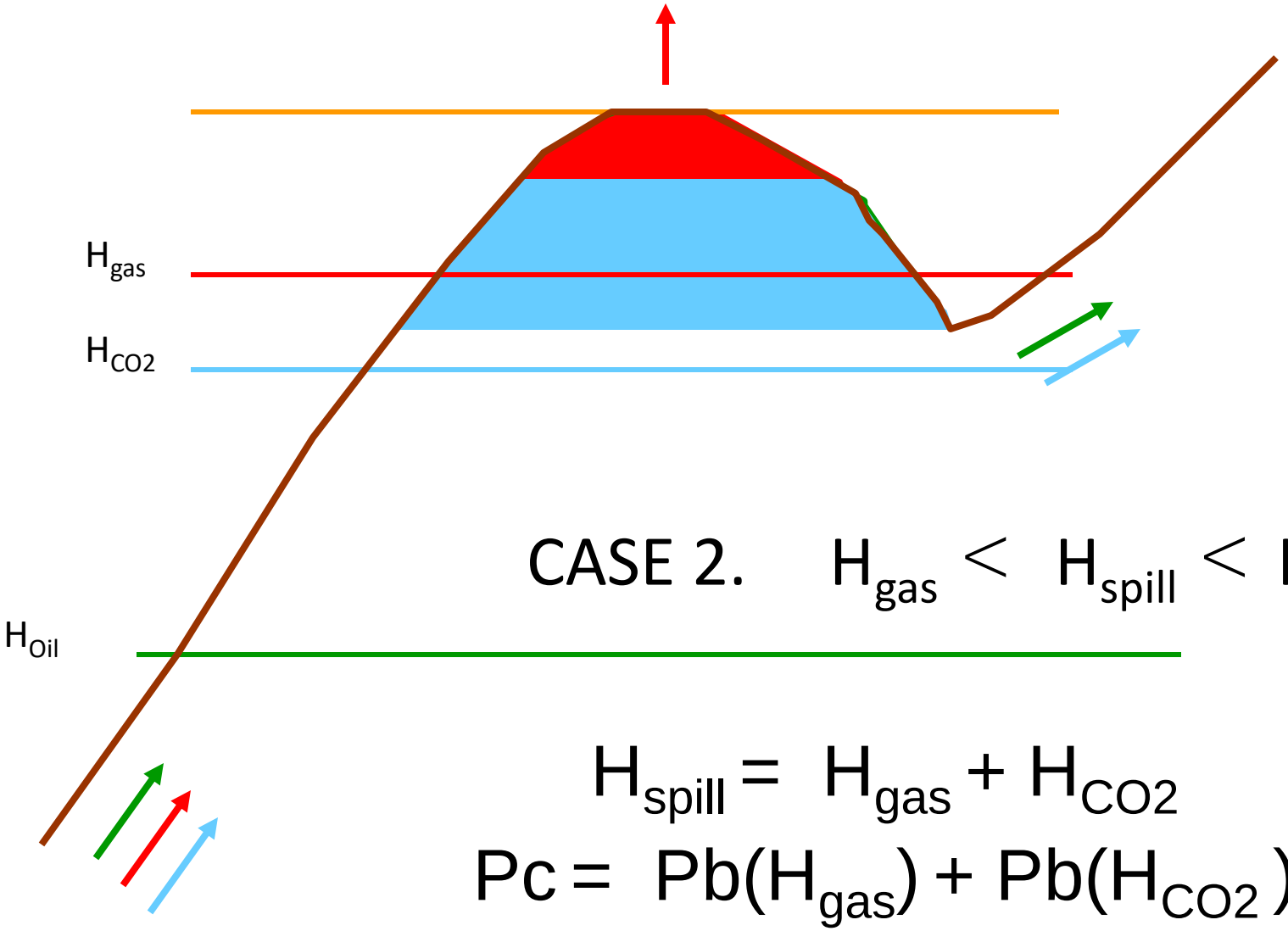
$H_{gas} < H_{CO2} < H_{oil}$

Seal Evaluation in 4 phase problem



CASE 1. $H_{spill} < H_{gas}$

Seal Evaluation in 4 phase problem

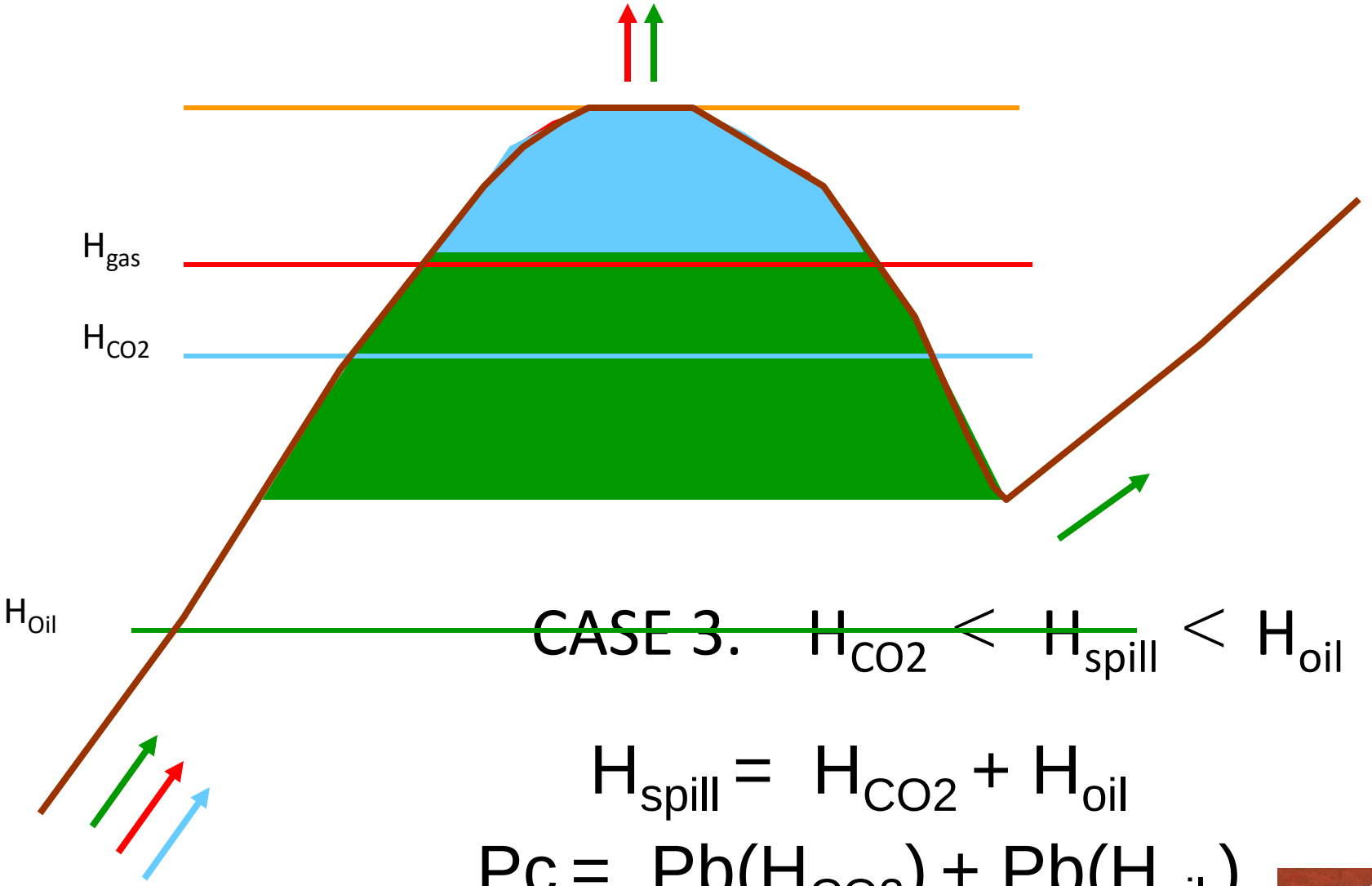


CASE 2. $H_{gas} < H_{spill} < H_{CO2}$

$$H_{spill} = H_{gas} + H_{CO2}$$

$$Pc = Pb(H_{gas}) + Pb(H_{CO2})$$

Seal Evaluation in 3 phase problem

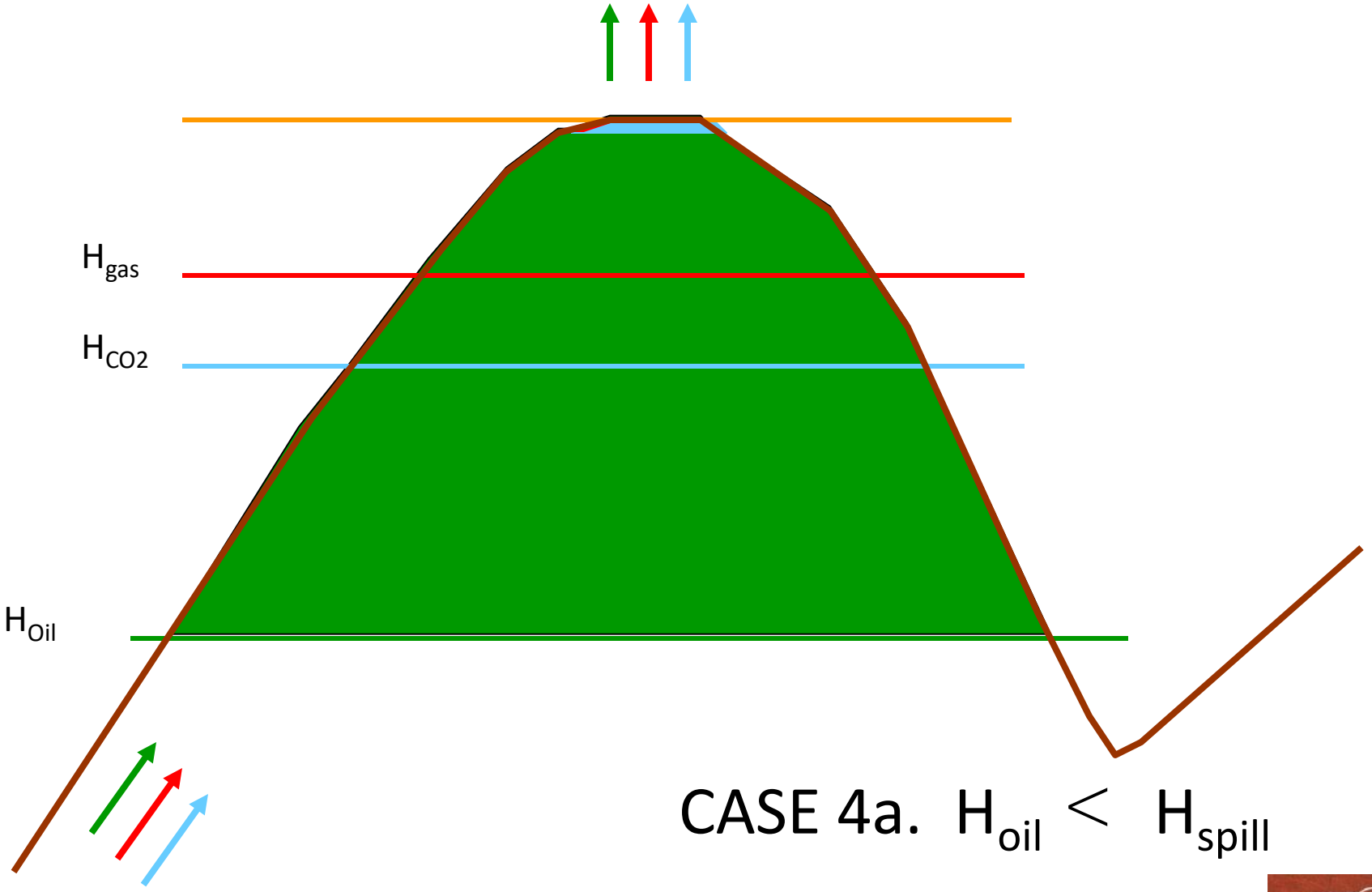


CASE 3. $H_{CO2} < H_{spill} < H_{oil}$

$$H_{spill} = H_{CO2} + H_{oil}$$

$$Pc = Pb(H_{CO2}) + Pb(H_{oil})$$

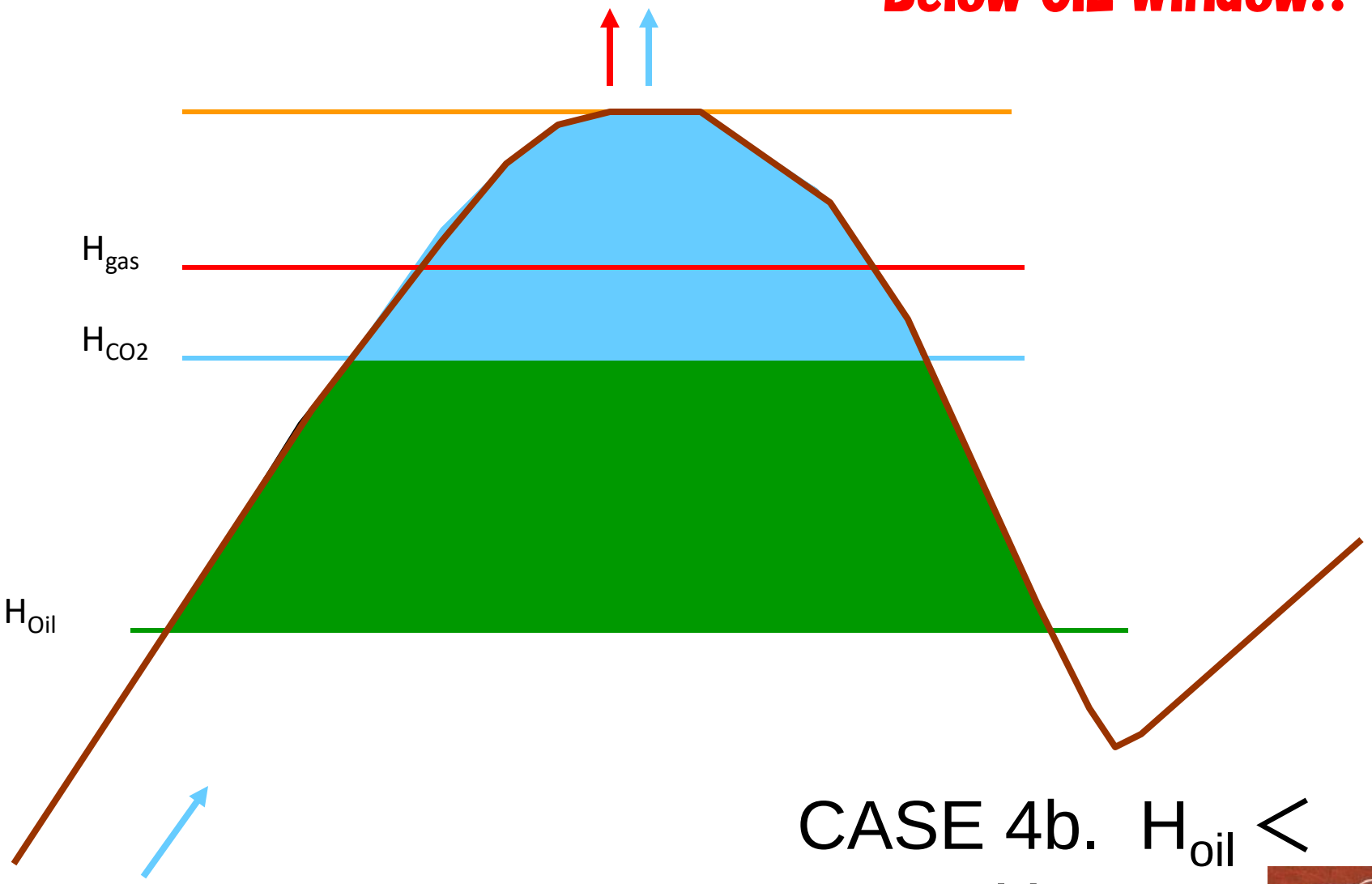
Seal Evaluation in 4 phase problem



CASE 4a. $H_{oil} < H_{spill}$

Seal Evaluation in 4 phase problem

Below OIL Window!!



CASE 4b. $H_{oil} < H_{spill}$

Final Conclusions

1. Seal Mechanism strictly controls Trap Type (Oil-Gas-CO_2 System).
2. EGS Method is effective to predict types and each column height.
3. Seal Evaluation by EGS Method can give a significant information on Oil/Gas/CO_2 system, which should change Company strategy for Oil/Gas