Risking resources
- geological risk analysis

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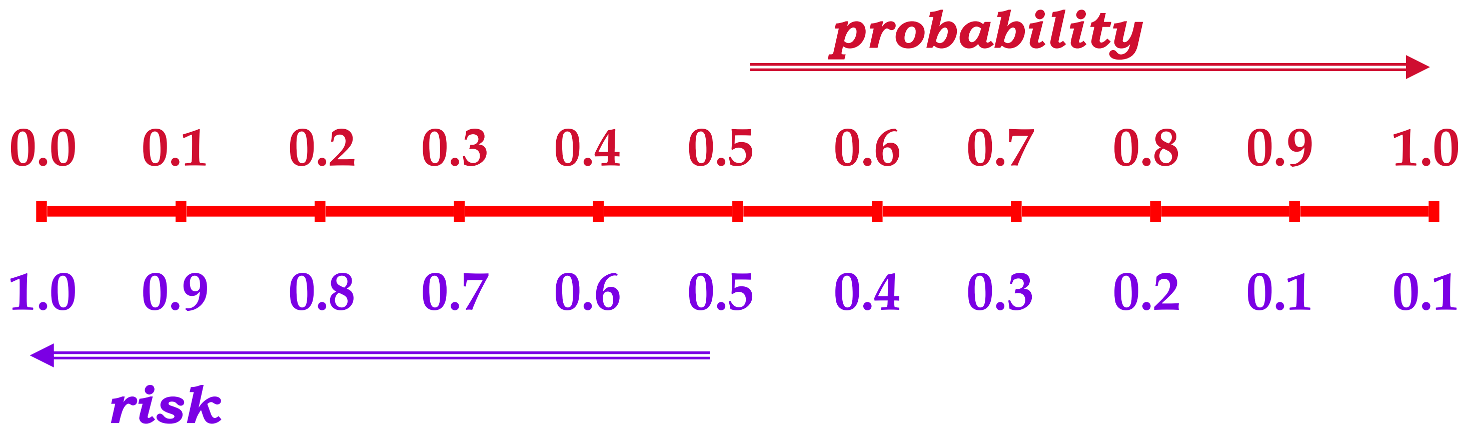
Risk analysis

What is the chance of finding the minimum amount of recoverable hydrocarbons as estimated in the prospect assessment ?

Some Definitions

"There is a *RISK* that I am going to fall off this cliff and I am *UNCERTAIN* how far it is to the bottom!"

Risk - Probability



Probability = 1 - Risk

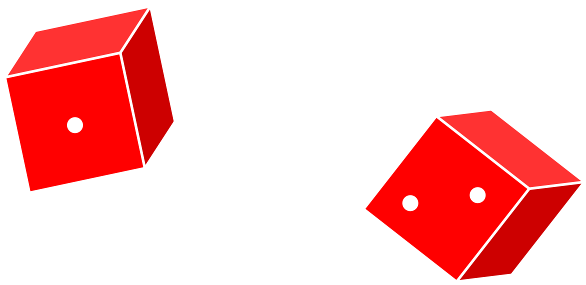
The addition rule

Probability of one of several mutually exclusive events:

Either outcome A, outcome B or outcome C, then:

$$P = P_A + P_B + P_C$$

Example - the addition rule



Throwing dices:

What is the probability of throwing either 1 or 2, when throwing a die only once ?

$$P_{1or2} = P_1 + P_2 = {}^1/_6 + {}^1/_6 = {}^2/_6 = 0.33$$

The multiplication rule

Probability of simultaneously occurence of several independent events:

Both outcome A, outcome B and outcome C, then:

$$P = P_A \times P_B \times P_C$$

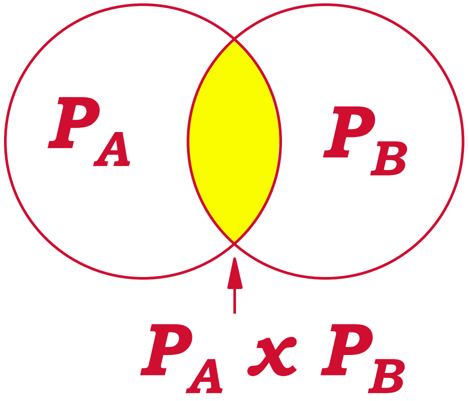
Combination of rules

"Either one or another event, or both events"

The "risk" approach: $1 - P = (1 - P_A) \times (1 - P_B)$

Quantity considerations:

$$P = P_A + P_B - (P_A \times P_B)$$



Probability categories

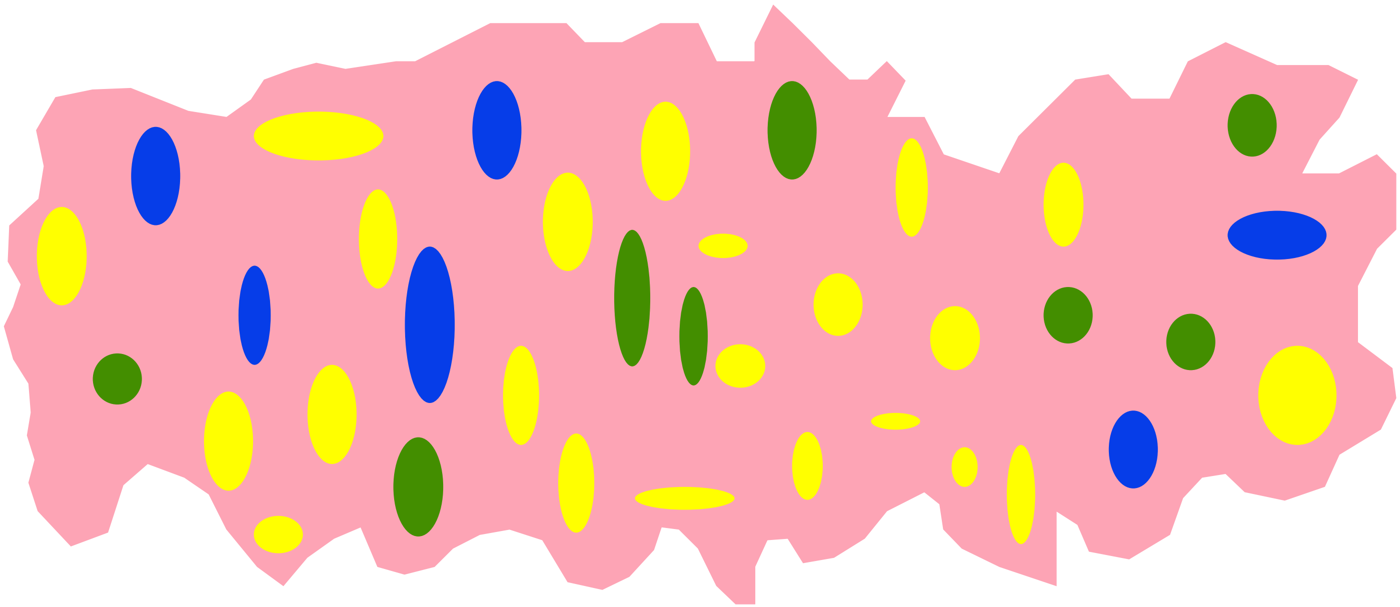
Stochastic probabilities

- *measured values*
- *success rates, etc*

Objective probabilities

Subjective probabilities

Success rate



$$\text{Success rate} = \frac{\text{no. of hits}}{\text{no. of trials}} = 8/14 = 0.57$$

Probability categories

Stochastic probabilities

- *measured values*
- *success rates, etc*

Objective probabilities

- *logical arguments,*
- *analogue events, etc*

Subjective probabilities

- *beliefs,*
- *"guts feeling", etc*

The independent risk factors
- NPD's risk factors

Probability of discovery:

$$P = P1 \times P2 \times P3 \times P4$$

...where:

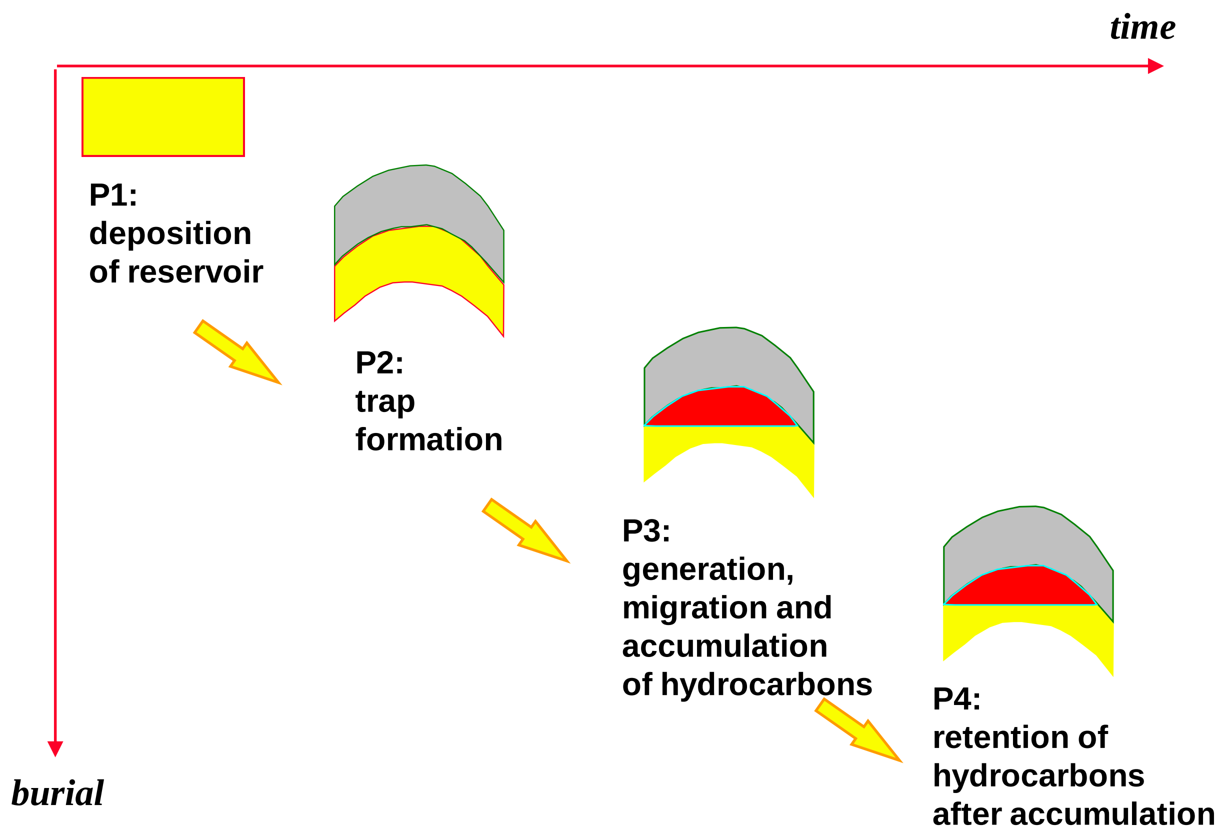
- **P1 -** probability of efficient reservoir
- **P2 -** probability of efficient trap
- **P3 -** probability of efficient source & migration
- **P4 -** probability of efficient retention after accumulation

Probability of discovery

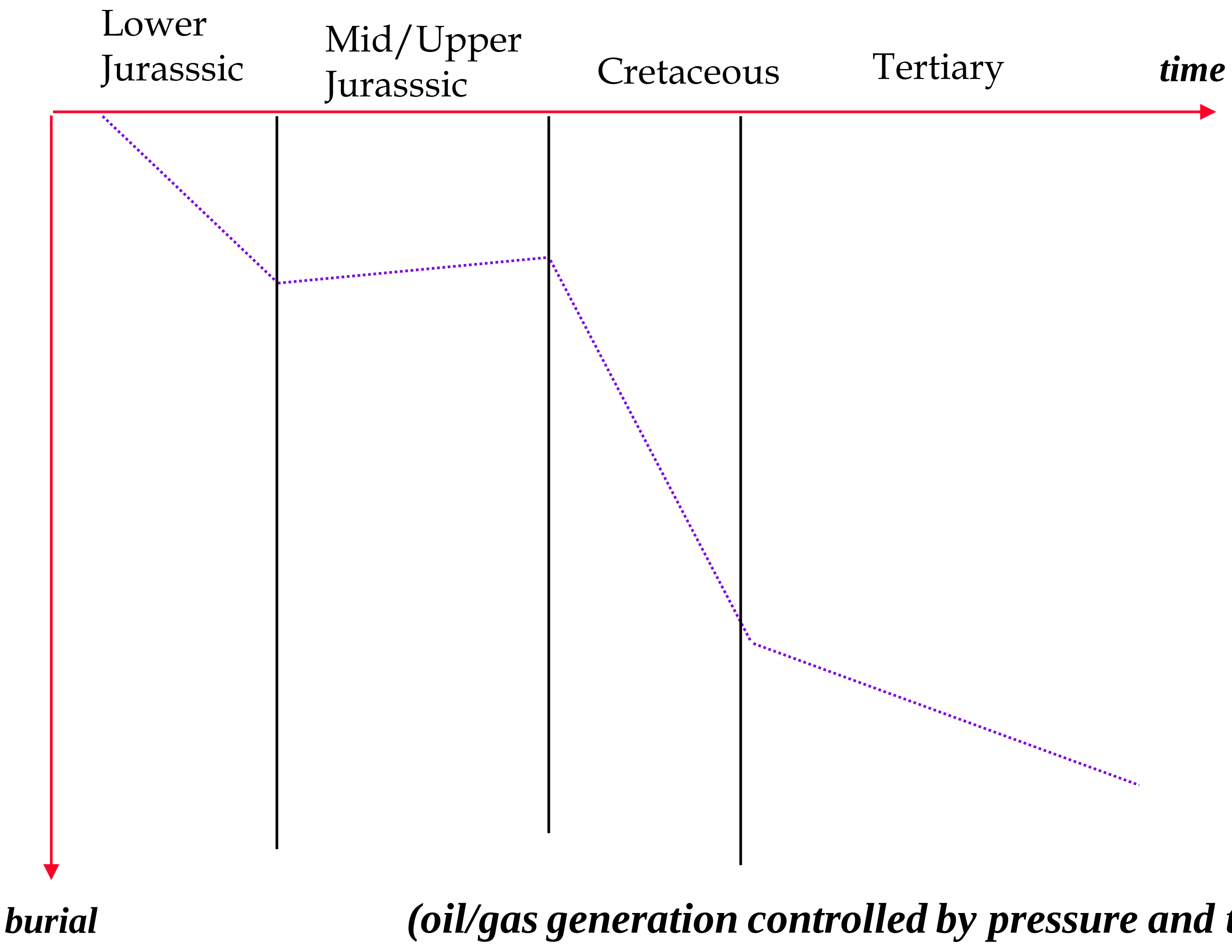
The estimated prospect probability is not the probability of making a discovery, but:

➡ ***The probability of finding at least the minimum quantity of hydrocarbons we estimated in the resource assessment.***

Reconstruction of the hydrocarbon accumulation process

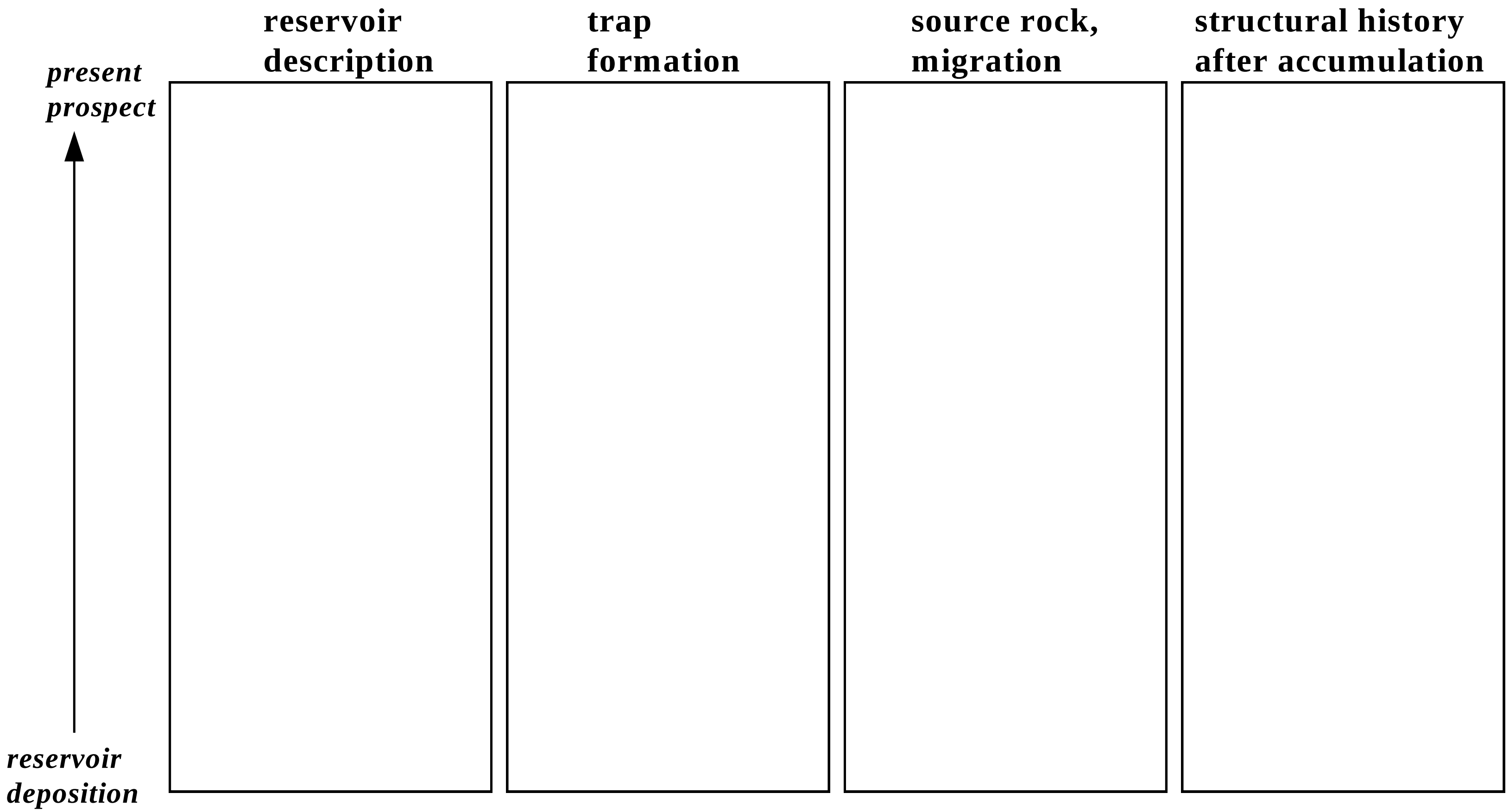


Burial profile, 35/4



(oil/gas generation controlled by pressure and temperature)

Geo-chronological prospect analysis scheme



Probability of efficient reservoir

NPD

$P = P_a$ (modified by P_b)

a) **Existence of efficient reservoir rock with minimum net reservoir thickness.**

b) **Existence of efficient pore volume (porosity and permeability).**

Efficient reservoir facies

Database:

- *well data*
- *seismic analysis*

Reservoir rock model (depositional environment):

- *gross thickness*
- *net/gross ratio*

Reservoir rock model

Proved extension:	
- large regional/lateral deposition systems	*0.9 - 1.0*
- more local/discontineous deposits	*0.5 - 0.8*
Deterioration of proven reservoir rock:	
- facies changes	*0.4 - 0.7*
- uncertain/restricted database	*0.3 - 0.8*
Theoretical model for reservoir rock:	
- very likely/relevant analogue model	*0.5 - 0.7*
- good/possible analogue model	*0.4 - 0.5*
- potential analogue model	*0.1 - 0.3*

Efficient pore volume

- well data
- reservoir depth; diagenesis
- porosity/permeability plots
- facies related to porosity trends
- permeability/water saturation plot
- seismic velocities

... should be taken care of in the volumetric assessment

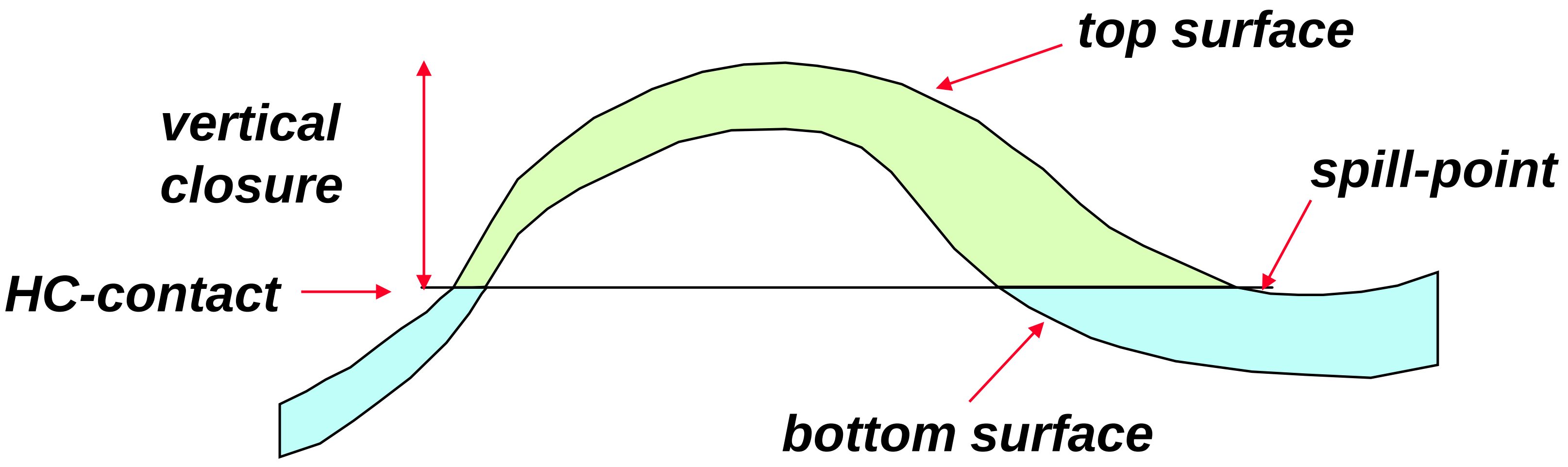
Probability of efficient trap

$$P = P_a \times P_b$$

a) Existence of a well defined and mapped structural/geometrical body.

b) Existence of efficient top-, side- and bottom seal.

Trap and spill-point relations



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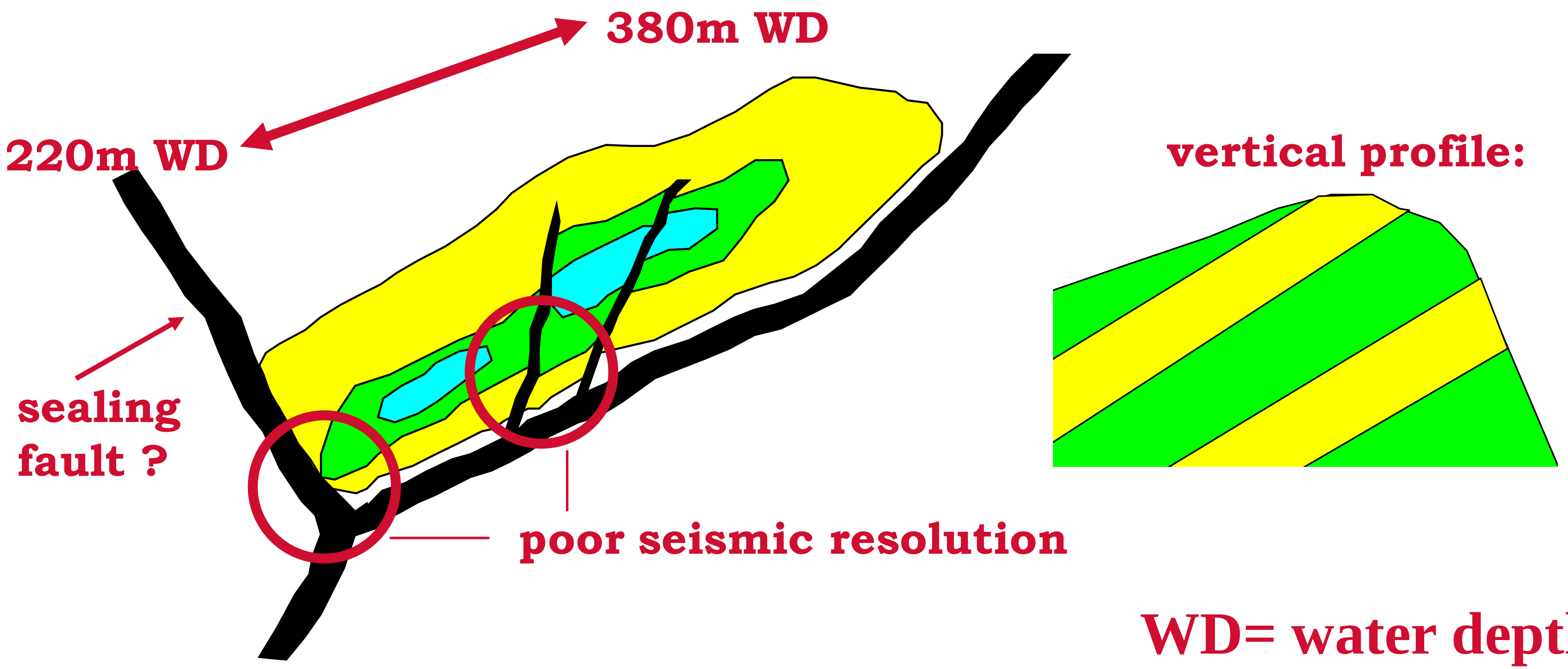
An example of trap definition



WD= water depth

... what is the probability of a minimum closure ?

Structural/geometrical body

Following elements should be examined:

- ***seismic data quality***
- ***seismic coverage***
- ***seismic interpretation***
- ***identification of top (base) reservoir surface***
- ***time-depth conversion***

Identification of top/base reservoir

Reliable id. and sufficient data coverage/quality: *(downgrading if questionable...)*	*0.9 - 1.0*
Reliable correlation of top/base reservoir, but pick of seismic reflectors uncertain: *(downgrading if coverage/quality questionable...)*	*0.6 - 0.9*
Based on regional knowledge (i.e. parallel shift): *(downgrading if coverage/quality questionable...)* *(upgrading if all strat. levels represent a closure)*	*0.4 - 0.8*
Based on a depositional model: *- proven/analogue model in adjacent areas* *- theoretical model in frontier areas*	*0.1 - 0.5*

Top-, side- and bottom seal

Simple top seal mechanisms:

- anticlines	*0.7 - 1.0*
- build-up structures	*0.7 - 1.0*
- buried highs, erosion products	*0.5 - 0.9*
- faulted structures (conform top seal)	*0.7 - 1.0*
- faulted structures (inconform top seal)	*0.5 - 0.9*

Combined seal mechanisms:

- pinch-out (subcrop)	*0.1 - 0.8*
- pinch-out (onlap, lowstand wedge)	*0.1 - 0.8*
- down-faulted structures	*0.1 - 0.8*
- shale out, diagenetic structures	*0.1 - 0.8*

Sealing properties

Salt/carbonate rocks:	***...very good***
Thick shales:	***...good***
Thin shales:	***...poor to acceptable***
Basalt:	***...acceptable to good***
Unknown caprock:	***...analogue model*** ***...theoretical model***
Fault throw:	***...sand/shale contact ?***
Faults cutting the top surface:	***...poor to acceptable***

Probability of efficient source rock and migration

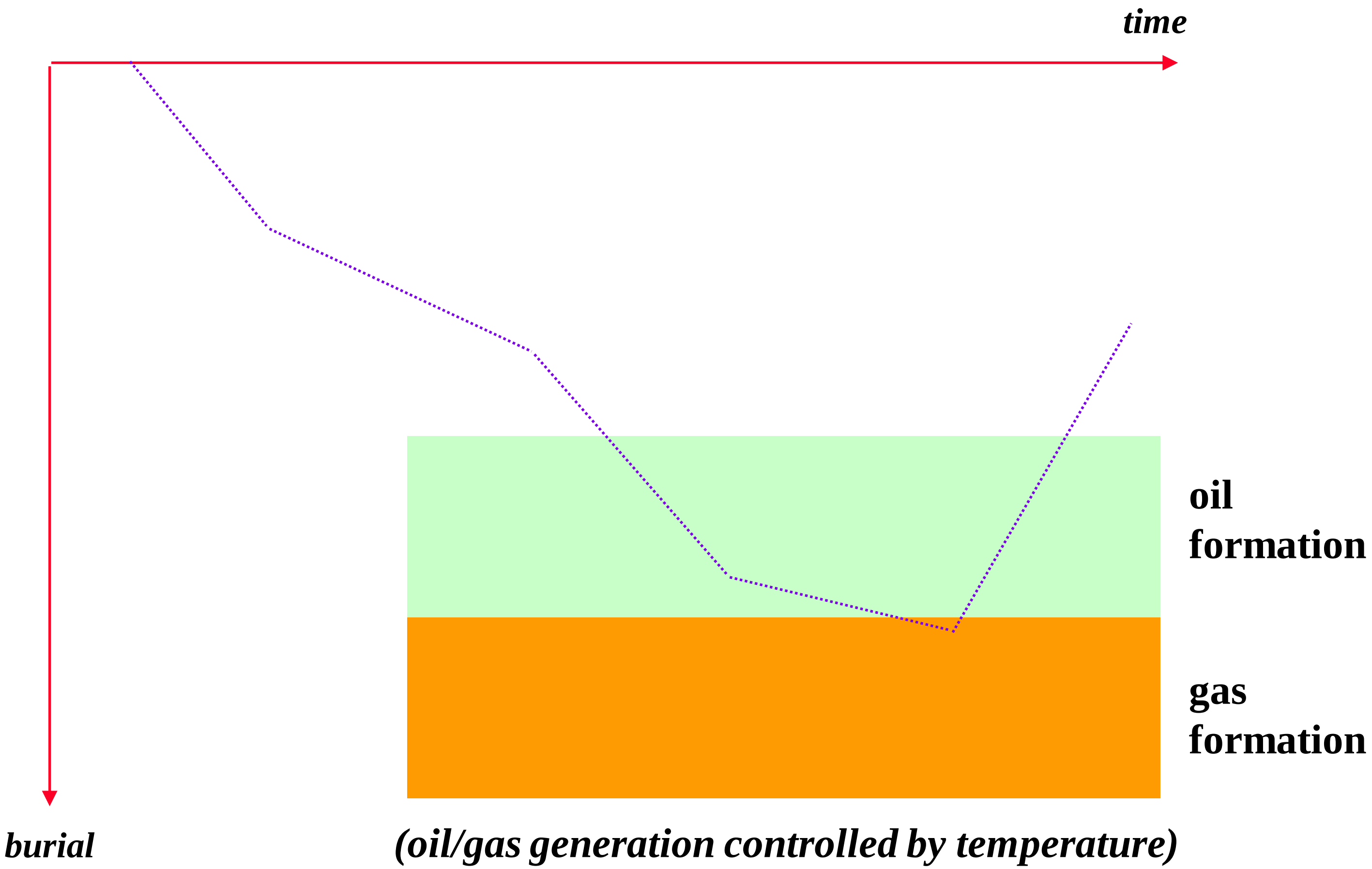
NPD

$$P = P_a \times P_b$$

a) **Existence of sufficient quality and volume of mature source rock in the drainage area**

b) **Efficient migration from source to defined trap, including efficient overlap in time between migration and trap existence**

The hydrocarbon accumulation process - burial profile



(oil/gas generation controlled by temperature)

Sufficient source rock quality

proven extension	0.9 - 1.0
quality reduction	0.5 - 0.8
known, but not proven	0.5 - 0.8
good analogue model	0.5 - 0.7
good theoretical model	0.4 - 0.5
possible theoretical model	0.1 - 0.3

Volume mature source rock within the drainage area

sufficient volume of mature s.r.	0.9 - 1.0
marginal volume of mature s.r.	0.6 - 0.8
marginal mature source rock	0.4 - 0.5
theoretical mature source rock	0.1 - 0.3

Volume and quality of source rock - two partly dependent factors

The uncertainty in source rock assessment may lead to "double-risking". Based on our experience from Norwegian waters we therefore have established a "dependency matrice":

EFFICIENT SOURCE ROCK QUALITY

SUFFICIENT S. R. VOLUME

	1,0	0,9	0,8	0,7	0,6	0,5	0,4	0,3	0,2	0,1	0,0
1,0	1,00	0,90	0,85	0,75	0,70	0,60	0,50	0,40	0,30	0,20	0,00
0,9	0,90	0,85	0,80	0,70	0,65	0,55	5,00	0,40	0,30	0,20	0,00
0,8	0,85	0,80	0,70	0,65	0,60	0,50	0,45	0,35	0,30	0,20	0,00
0,7	0,75	0,70	0,65	0,60	0,55	0,45	0,40	0,35	0,25	0,15	0,00
0,6	0,70	0,65	0,60	0,55	0,50	0,40	0,35	0,30	0,25	0,15	0,00
0,5	0,60	0,55	0,50	0,45	0,40	0,40	0,30	0,25	0,20	0,15	0,00
0,4	0,50	0,50	0,45	0,40	0,35	0,30	0,30	0,25	0,20	0,10	0,00
0,3	0,40	0,40	0,35	0,35	0,30	0,25	0,25	0,20	0,15	0,10	0,00
0,2	0,30	0,30	0,30	0,25	0,25	0,20	0,20	0,15	0,10	0,10	0,00
0,1	0,20	0,20	0,20	0,15	0,15	0,15	0,10	0,10	0,10	0,05	0,00
0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Efficient migration and timing related to trap formation

$$P_{migr./timing} = P_{migr.\ proc.} \times P_{timing}$$

The migration process:

trapped reservoir

carrier bed → *fill* → trapped reservoir

trapped reservoir → *fill/spill* → carrier bed

carrier bed → *secondary migration* → trapped reservoir

ΔT ↓ source rock → *primary migration* → carrier bed

The migration process

local migration	**0.9 - 1.0**
lateral migration without barriers	**0.8 - 0.9**
lateral migration with barriers	**0.5 - 0.8**
vertical migration	**0.1 - 0.6**
the trap is in the “shadow” of migration	**0.1 - 0.4**

We have to consider:

distance from source rock to trap
local pressure relations (area factors ?)

Time of migration related to time of trap formation

The trap is formed before start migration of hydrocarbons	**0.9 - 1.0**
Trap formation and hydrocarbon migration overlap in time	**0.4 - 0.8**
The trap is formed when the source rock is supposed to be “overcooked	**0.1 - 0.4**

Probability of efficient retention after accumulation

NPD

Efficient post-accumulation history which have contributed to preservation of potential accumulated hydrocarbons.

Retention in trap

NPD

Biodegradation to asphaltenes	**0.9 - 1.0**
Erosion of overlying sediments:	
the trap is in connection with the source rock which still generates HC's	**0.8 - 0.9**
the trap is no longer in connection with a HC-generating source rock	**0.5 - 0.8**
Tilting of trap after accumulation:	
the trap (form, volume and top-point) is not considerably changed	**0.6 - 0.9**
the trap is considerably changed	**0.3 - 0.6**
Late reactivation of faults	**0.1 - 0.4**

Direct hydrocarbon indicators (DHI's)

Definition:

A change in seismic reflection character (seismic anomaly) which can be explained either direct or indirect when a reservoir is changed from water bearing to hydrocarbon bearing.

Geological determined anomalies

Real HC-indicators:

- chimney, seismic chaos
- dimspot
- bright spot
- flatspot
- polarity shift
- absorption
- diffraction
- blanking effects
- AVO anomalies
- low velocity (pull down)

False HC-indicators:

From sedimentary facies:
lithology, porosity and early diagenesis

Burial effects:
porosity, diagenesis, consolidation, pressure and incconformity

Migration/accumulation:
paleo-liquid contacts, gas hydrates and low gas saturation

Geophysical determined anomalies

= always false HC-indicators

Seismic phenomena:

- amplitude change
- energy density
- noise
- side reflection
- multiple reflection
- critical reflected wave
- converted wave
- aliased energy
- critical refracted wave

Processing effects:

- scaling
- stacking process
- eliminated/generated reflections
- uncomplete trace migration
- filter effects
- uncorrect phase- or polarity shift

Probability of oil versus gas

Given a discovery, what is the probability that the accumulation is *dominantly* a gas discovery or an oil discovery ?

The evaluation of the source rock and the migration process should form the basis for this probability estimate…

Sum up - Main principles

Independent risk factors for:

The probability of finding at least the minimum quantity of hydrocarbons we estimated in the resource assessment.