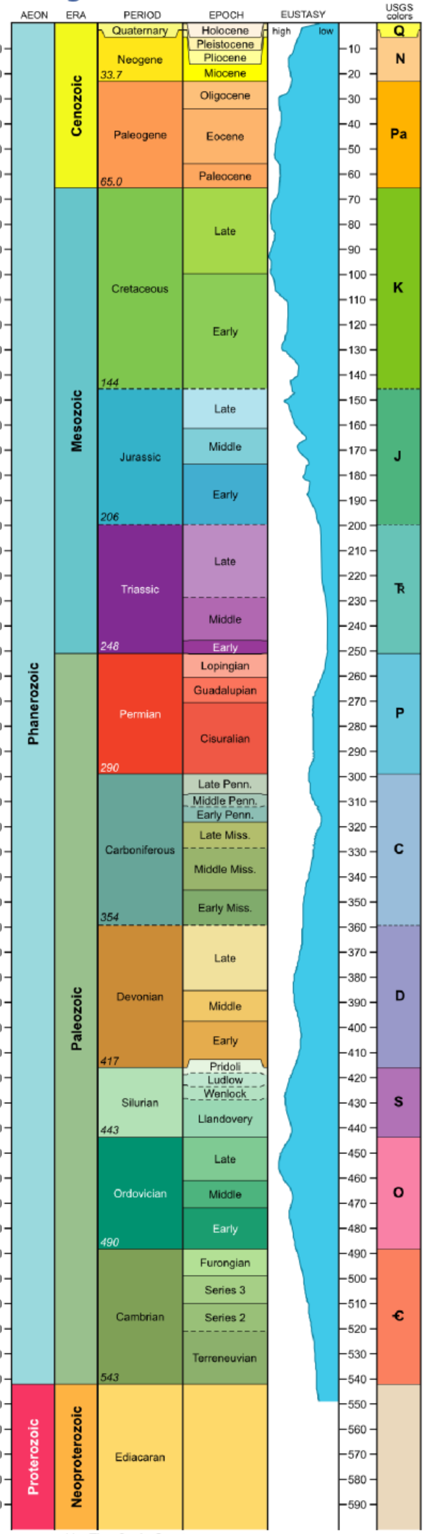
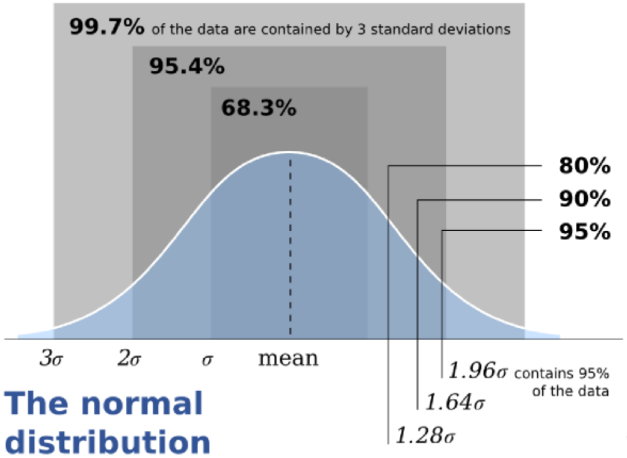
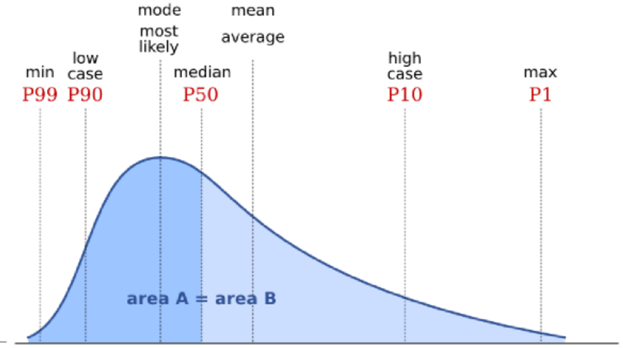
Geological timescale



generated by TimeScale Creator



The normal distribution



Skewed distributions

For a log-normal distribution
Mode (most likely) < Median (P50) < Mean

SI prefixes

short scale is used in most English-speaking countries

Prefix	Symbol	1000^m	10^n	Decimal	Short scale	Long scale
yotta	Y	1000^8	10^{24}	1 000 000 000 000 000 000 000 000	Septillion	Quadrillion
zetta	Z	1000^7	10^{21}	1 000 000 000 000 000 000 000	Sextillion	Trilliard
exa	E	1000^6	10^{18}	1 000 000 000 000 000 000	Quintillion	Trillion
peta	P	1000^5	10^{15}	1 000 000 000 000 000	Quadrillion	Billiard
tera	T	1000^4	10^{12}	1 000 000 000 000	Trillion	Billion
giga	G	1000^3	10^9	1 000 000 000	Billion	Milliard
mega	M	1000^2	10^6	1 000 000	Million	
kilo	k	1000^1	10^3	1 000	Thousand	
hecto	h	$1000^{2/3}$	10^2	100	Hundred	
deca	da	$1000^{1/3}$	10^1	10	Ten	
		1000^0	10^0	1	One	
deci	d	$1000^{-1/3}$	10^{-1}	0.1	Tenth	
centi	c	$1000^{-2/3}$	10^{-2}	0.01	Hundredth	
milli	m	1000^{-1}	10^{-3}	0.001	Thousandth	
micro	µ	1000^{-2}	10^{-6}	0.000 001	Millionth	
nano	n	1000^{-3}	10^{-9}	0.000 000 001	Billionth	Milliardth
pico	p	1000^{-4}	10^{-12}	0.000 000 000 001	Trillionth	Billionth
femto	f	1000^{-5}	10^{-15}	0.000 000 000 000 001	Quadrillionth	Billiardth
atto	a	1000^{-6}	10^{-18}	0.000 000 000 000 000 001	Quintillionth	Trillionth
zepto	z	1000^{-7}	10^{-21}	0.000 000 000 000 000 000 001	Sextillionth	Trilliardth
yocto	y	1000^{-8}	10^{-24}	0.000 000 000 000 000 000 000 001	Septillionth	Quadrillionth

SI derived units

SI units: metre, kilogram, second, kelvin, ampere, candela, mole

Name	Symbol	Quantity	Expression in terms of other units	Expression in terms of SI base units
hertz	Hz	frequency	1/s	s^{-1}
radian	rad	angle	$m \cdot m^{-1}$	dimensionless
steradian	sr	solid angle	$m^2 \cdot m^{-2}$	dimensionless
newton	N	force, weight	$kg \cdot m/s^2$	$kg \cdot m \cdot s^{-2}$
pascal	Pa	pressure, stress	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
joule	J	energy, work, heat	N·m = C·V = W·s	$m^2 \cdot kg \cdot s^{-2}$
watt	W	power, radiant flux	J/s = V·A	$m^2 \cdot kg \cdot s^{-3}$
coulomb	C	electric charge or quantity of electricity	s·A	s·A
volt	V	voltage, electrical potential difference, electromotive force	W/A = J/C	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
farad	F	electric capacitance	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
ohm	Ω	electric resistance, impedance, reactance	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
siemens	S	electrical conductance	1/Ω	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
weber	Wb	magnetic flux	J/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
tesla	T	magnetic field strength, magnetic flux density	$V \cdot s/m^2 = Wb/m^2 = N/(A \cdot m)$	$kg \cdot s^{-2} \cdot A^{-1}$
henry	H	inductance	V·s/A = Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Celsius	°C	Celsius temperature	K – 273.15	K – 273.15

Conversion

from	to	× by
ft	m	0.3048
m	ft	3.281
in	mm	25.40
bbl	m^3	0.1590
m^3	bbl	6.290
lb	kg	0.4536
mile	km	1.609
acre	ha	0.4047
ha	acre	2.471
sq mi	ha	259.0
sq mi	km^2	2.590
sq mi	acre	640.0
Pa	Nm^2	1
bar	kPa	100
psi	kPa	6.895
at[1]	kPa	98.07
atm	kPa	101.3
Torr	kPa	0.1333

[1] technical atmosphere

Rule of 70

A quantity growing at *r*% per period doubles in size roughly every 70/*n* periods. For example, 10% growth per year means a doubling in ~7 yr.

Types of error

I or α	false positive: erroneously reject null hypothesis
II or β	false negative: erroneously accept null hypothesis
III	reject null hypothesis correctly, but for wrong reason

Null hypothesis: scenario to be refuted in order to support another

Greek alphabet

Αα	Alpha	Νν	Nu
Ββ	Beta	Ξξ	Xi
Γγ	Gamma	Οο	Omicron
Δδ	Delta	Ππ	Pi
Εε	Epsilon	Ρρ	Rho
Ζζ	Zeta	Σσς	Sigma
Ηη	Eta	Ττ	Tau
Θθ	Theta	Υυ	Upsilon
Ιι	Iota	Φϕ	Phi
Κϰ	Kappa	Χχ	Chi
Λλ	Lambda	Ψψ	Psi
Μμ	Mu	Ωω	Omega

Bayes' theorem

$$P(A|B) = \frac{\overbrace{P(B|A)}^{\text{likeliood}} * \overbrace{P(A)}^{\text{prior}}}{\underbrace{P(B)}_{\text{normalizing constant}}}$$

posterior

Fundamental principles of analytical design

Edward Tufte (2006), Beautiful Evidence, Cheshire, CT: Graphics Press

1 Show comparisons, contrast, differences | **2** Show causality, mechanism, explanation, systematic structure
3 Show multivariate data (more than two variables) | **4** Completely integrate words, numbers, images, diagrams
5 Thoroughly describe the evidence & your sources | **6** Ensure the quality, relevance & integrity of the content

Basic trig

sin	cos	tan	=
0°	90°	0°	0
1°	89°	0.9998°	0.01745
30°	60°	27.57°	0.5
35.26°	54.74°	30°	0.5774
45°	45°	35.26°	0.7071
60°	30°	40.89°	0.8660
89°	1°	45.00°	0.9998
90°	0°	45°	1
		60°	1.7321
		89°	57.29
		90°	∞

Keyboard shortcuts

[1] Alt + keypad, NumLock on
[2] Option

Symbol	Name	Win | Alt	Mac | Opt	HTML	LaTeX
×	times	0215 [1]		×	*
‰	permil	0137	Shift R [2]	‰	
–	en-dash	0150	-	–	-
—	em-dash	0151	Shift -	—	
°	degrees	0176	k	°	^\circ
±	plus or minus	0177	Shift =	±	\pm
²	squared	0178		²	^2
³	cubed	0179		³	^3
¼	quarter	0188		¼	\tfrac{1}{4}
½	half	0189		½	\tfrac{1}{2}
α	alpha	224		α	\alpha
π	pi	227	p	π	\pi
δ	delta	235	d	δ	\delta
∞	infinity	236	5	∞	\infty
ϕ	phi	237		φ	\phi
≥	greater or equal	242	.	≥	\geq
≤	less or equal	243	,	≤	\leq
≈	approx. equal	247	x	≈	\approx
√	square root	251	v	√	\sqrt{...}

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Aki-Richards equation

as given in Fatti et al (1994), Geophysics 59 (9)

$$R_{\mathrm{PP}}(\theta) = (1+\tan^2\theta)\,\frac{\Delta I_{\mathrm{P}}}{2I_{\mathrm{P}}} - 8\left(\frac{V_{\mathrm{S}}}{V_{\mathrm{P}}}\right)^2 \sin^2\theta\,\frac{\Delta I_{\mathrm{S}}}{2I_{\mathrm{S}}} - \left[\frac{1}{2}\tan^2\theta - 2\left(\frac{V_{\mathrm{S}}}{V_{\mathrm{P}}}\right)^2 \sin^2\theta\right]\frac{\Delta\rho}{\rho}$$

Shuey's approximation

Shuey, RT (1985), Geophysics, 50, 609-614

$$R(\theta) \approx A + B\sin^2\theta \qquad A = R_{\mathrm{P}} \approx \frac{1}{2}\left(\frac{\Delta V_{\mathrm{P}}}{V_{\mathrm{P}}} + \frac{\Delta\rho}{\rho}\right) \qquad B \approx R_{\mathrm{P}} - 2R_{\mathrm{S}}$$

Power and amplitude

dB level	Power	dB level	Amplitude
–30 dB	1/1000 = 0.001	–30 dB	$\sqrt{1/1000} = 0.03162$
–20 dB	1/100 = 0.01	–20 dB	$\sqrt{1/100} = 0.1$
–10 dB	1/10 = 0.1	–10 dB	$\sqrt{1/10} = 0.3162$
–3 dB	ca. 1/2 = 0.5	–3 dB	$\sqrt{1/2} = 0.7071$
3 dB	ca. 2	3 dB	$\sqrt{2} = 1.414$
10 dB	10	10 dB	$\sqrt{10} = 3.162$
20 dB	100	20 dB	$\sqrt{100} = 10$
30 dB	1000	30 dB	$\sqrt{1000} = 31.62$

Types of mean average

Arithmetic[1]	the sum divided by the population size, *n* — used when the sum is of interest
Geometric [1][2]	the *n*th root of the product — used when the product is of interest
Harmonic [1]	*n* divided by the sum of the reciprocals — used for rates and ratios
Quadratic or **RMS**	the square root of the arithmetic mean of the squares — used for magnitudes

[1] Pythagorean means, for which A ≥ G ≥ H

[2] Only defined for +ve numbers

Meetings

Dates, place, and actual or estimated abstract deadline

EGU 9 Jan 2013
7 to 12 Apr 2013
Vienna, AUT

GeoCon Jan 2013
6 to 10 May 2013
Calgary, CAN

AAPG 11 Oct 2012
19 to 22 May 2013
Pittsburgh, USA

EAGE 15 Jan 2013
10 to 13 Jun 2013
London, GBR

SEG Apr 2013
22 to 27 Sep 2013
Houston, USA

GSA Aug 2013
27 to 30 Oct 2013
Denver, USA

AGU Aug 2013
9 to 13 Dec 2013
San Francisco, USA

SEG '14 Apr 2013
26 to 31 Oct 2014
Denver, USA

Seismic resolution

Tuning thickness is usually computed as one quarter of the wavelength, the Rayleigh criterion:

$$\text{tuning thickness} = \frac{v}{4f}$$

where *v* is interval velocity and *f* is the maximum frequency (at –20 dB). Only forward modelling can really address the question of tuning in your data.

Note that the minimum thickness for which you can interpret separate events for top and base is greater than the tuning thickness. Note also that even though you cannot interpret top and base events, it may be possible to model thickness from amplitude around the tuning thickness.

Spatial resolution (Fresnel diameter after migration) is often computed a one half of the wavelength:

$$\text{spatial resolution} = \frac{v}{2f}$$

Powers of 2 (bit depth)

Bit-depth	Values		Range
1	2^1	2	0, 1
2	2^2	4	–1 *to* +2
3	2^3	8	–3 *to* +4
4	2^4	16	–7 *to* +8
5	2^5	32	–15 *to* +16
6	2^6	64	–31 *to* +32
8	2^8	256	–127 *to* +128
16	2^{16}	65 536	-32 767 *to* +32 768
24	2^{24}	16 777 216	–8 388 607 *to* +8 388 608
32	2^{32}	4 294 967 296	–2 147 483 647 *to* +2 147 483 648
64	2^{64}	1.8×10^{19}	$\pm 9 \times 10^{18}$
128	2^{128}	3.4×10^{38}	$\pm 1.7 \times 10^{19}$

Nyquist frequency

$$f_{\mathrm{N}} = \frac{1}{2} \times \frac{1000}{S}$$

where S is sample interval
e.g. for S = 4 ms, f_{N} = 125 Hz

Common rock properties

Rock	Fluid	Porosity	Density	Velocity
Sandstone		0.0	2650 kg/m^3	3000–5500 m/s
Sandstone	wet	0.1	2500	2500–4500
Sandstone	wet	0.2	2500	2000–3500
Sandstone	oil	0.2	2320	2000–3500
Sandstone	gas	0.2	2320	1800–3500
Limestone	wet	0.0	2710	4500–7000
Limestone	wet	0.1	2540	3800–6500
Dolomite	wet	0.0	2870	4500–7500
Dolomite	wet	0.1	2680	3800–7000
Shale			2000–2800	1800–5000
Salt			2030	4200–4800
Coal			1200–1500	1800–3200

Filter kernels

Mean
$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Gauss
$$\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

Sharp
$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Unsharp
$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 17 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Edge
$$\begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

Sobel
$$\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

Horizon filters

\+ Good performance ++ Excellent performance

Hall (2007), Smooth operator: smoothing seismic interpretations and attributes, The Leading Edge 26 (1)

	Random noise	Spiky noise	Edges preserved	Comments
Mean	+			Gaussian is a better choice
Gaussian	+			Less affected by spikes than mean
Conservative		+	+	Only removes very sparse spikes
Trimmed mean	++	++		Best if edges not present or not wanted
Mode	+	+	+	Only use on discrete or class attributes
Median	++	++	+	Good all-rounder
SNN	++	++	++	Best all-rounder
Kuwahara	+	++	++	Enhances edges, but use median filter first

GEOPHYSICS cheatsheet

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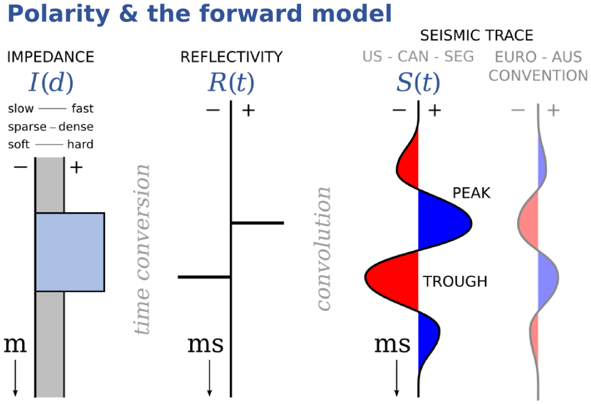
Acoustic impedance

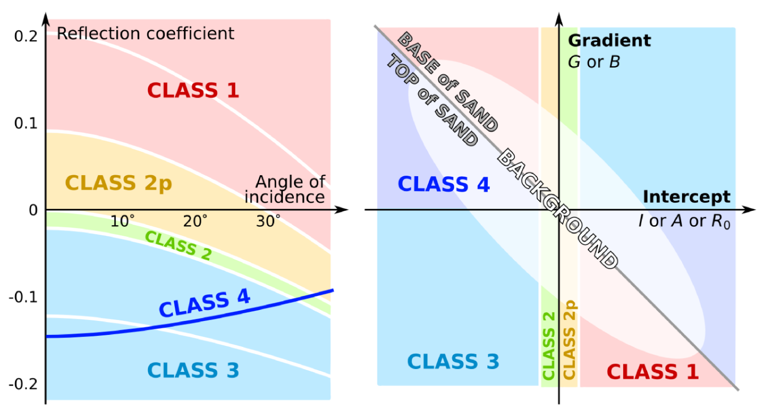
$$Z = V \times \rho$$

Polarity & the forward model

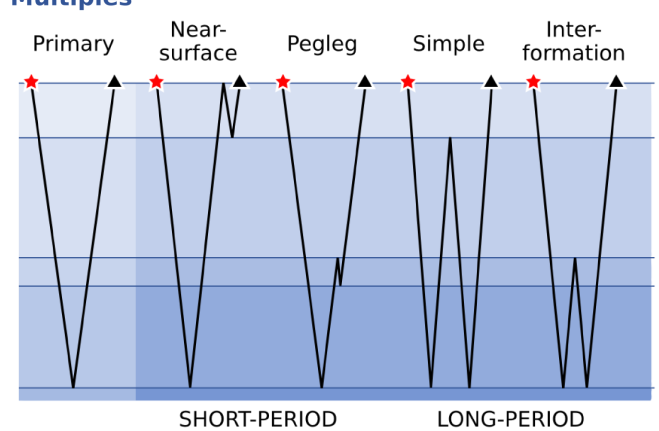


reflectivity ∗ wavelet + noise = seismic

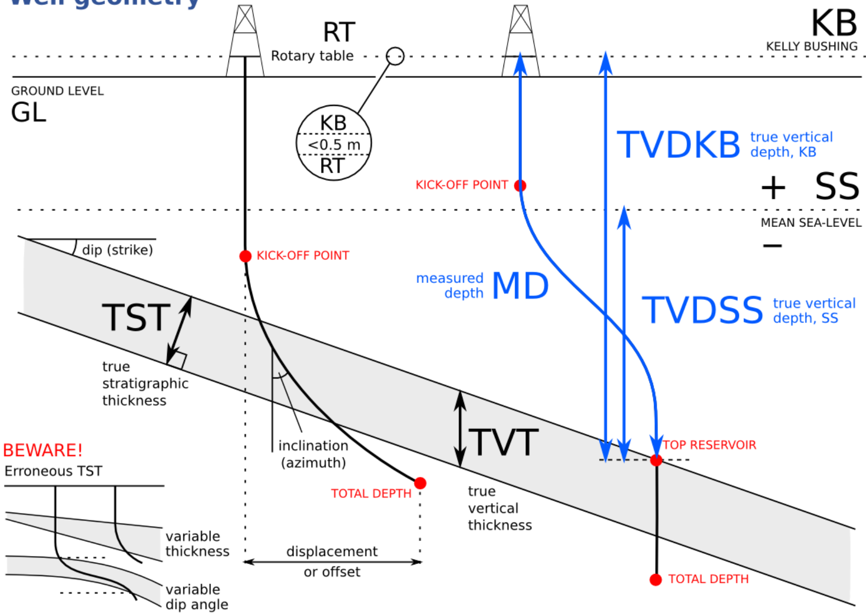
AVO classes



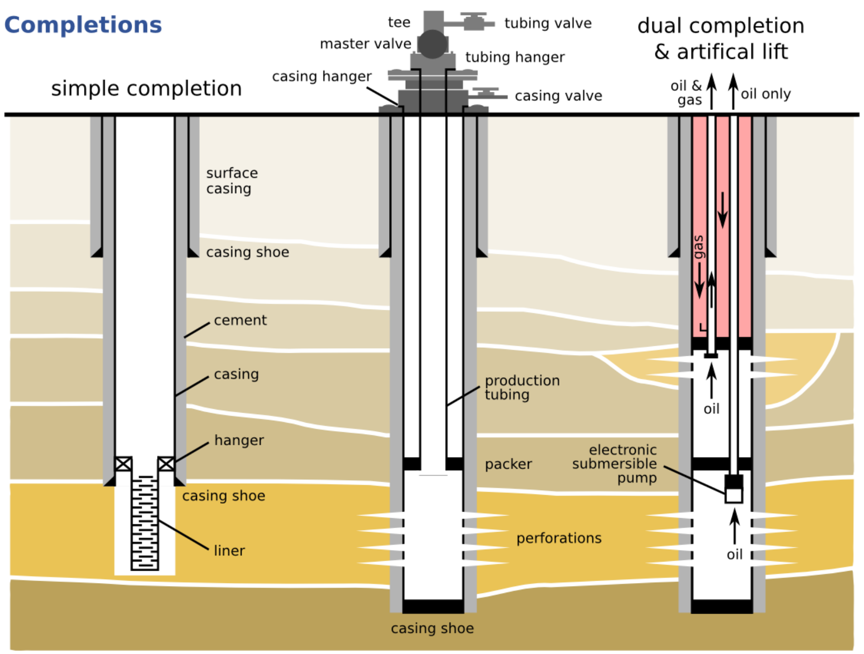
Multiples



Well geometry



Completions



Volumetrics

Stock tank oil initially in place

$$\mathrm{STOIIP} = A \times T \times G \times \mathrm{N{:}G} \times \phi \times S_O \times \frac{1}{B_O}$$

Area A, mean thickness T, Geometric correction factor G, Net to Gross N:G, porosity Φ, saturation S, volume factor B

Typical B_O: high GOR oil 1.4, low GOR oil 1.2, bitumen 1.05

Darcy equation

Fluid flux in $m^3.m^{-2}.s^{-1}$

$$F = \nabla P \cdot k/\mu = v \cdot \phi$$

Fluid flux or Darcy velocity F, pressure gradient ∇P, permeability k, viscosity μ, absolute velocity v, porosity Φ

PETROLEUM cheatsheet

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Conversion factors

The barrel of oil equivalent is a unit of energy, not volume. 1 boe = *ca.* 6.1 GJ. It is, however, used as a pseudo-volume, especially to compare oils with different gravities, or oil with gas volumes. There are no standard conversion factors.
http://subsurfwiki.org/wiki/Volume_conversion

from	to	× by
ft	m	0.3048
m	ft	3.281
in	mm	25.40
mile	km	1.609
acre	ha	0.4047
ha	acre	2.471
sq mi	ha	259.0
sq mi	km^2	2.590
sq mi	acre	640.0
bbl	m^3	0.1590
m^3	bbl	6.290
scf	m^3	0.02832
m^3	scf	35.31
boe[1]	Btu	ca. 5.80×10^6
scf	Btu	ca. 1050
scf	boe	ca. 1.79×10^{-4}
boe	scf	ca. 5600[2]
lb	kg	0.4536
Pa	Nm^2	1
bar	kPa	100
psi	kPa	6.895
at[3]	kPa	98.07
atm	kPa	101.3
Torr	kPa	0.1333

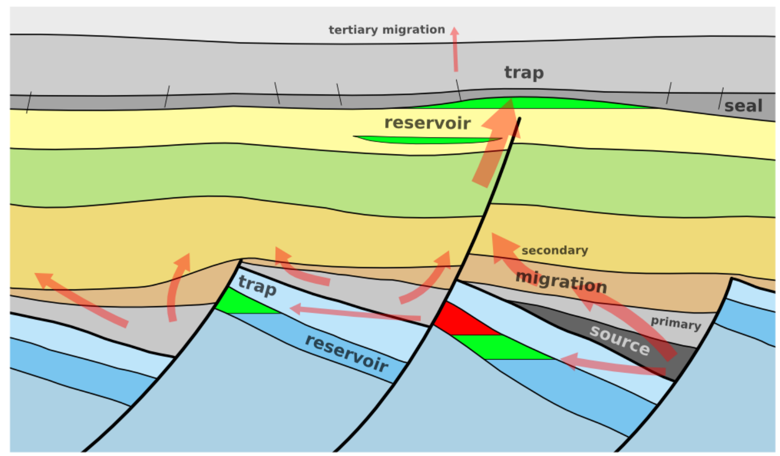
1. ↑ See note above
2. ↑ Some sources round to 6000.
3. ↑ http://en.wikipedia.org/wiki/Technical_atmosphere

Oil companies

Please take with a pinch or two of salt

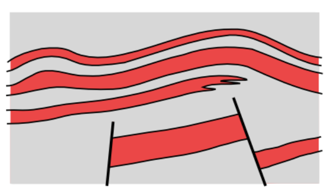
Company	Country	Production	Reserves	Res/Prod	Revenue	Net	Staff
Saudi Aramco	Saudi Arabia	9.5 Mboe/d	306000 Mboe	32.2 y	USD 403 B	USD ? B	75000
ExxonMobil	USA	4.2	12600	8.2	464	49.1	107000
BP	UK	3.8	12100	8.6	380	28.9	97600
Royal Dutch Shell	Netherlands	3.7	6700	5.0	484	37.6	104000
Chevron	USA	2.7	7100	7.2	272	23.9	65000
Total	France	2.4	10400	11.9	315	16.8	96400
ConocoPhillips	USA	1.6	8300	14.0	184	12	29800
Statoil	Norway	1.9	5300	7.6	98	7	30000

Conventional petroleum system



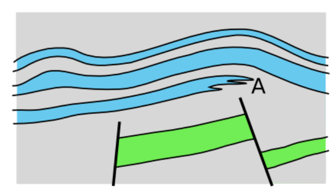
Categories

One petroleum system

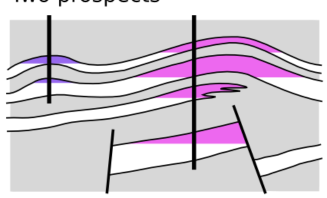


Two plays

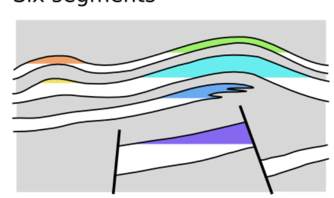
Depending on the circumstances, you might count sand A as a third



Two prospects



Six segments



Gravity & density

$$\text{API gravity} = 141.5/\rho - 131.5$$

for density ρ $[g/cm^3]$ @ 15°C

Trivia

Number of wells drilled since 1859	7 million
Percentage of well in the United States	50%
Number of producing wells worldwide	1 million
Average production of US oil wells	20 bpd
Average production of Middle East oil wells	7000 bpd
Number of producing fields worldwide	40 000
Number of drilling rigs worldwide	5000
Annual global oil consumption	30 Gboe
Annual discovery rate	4–8 Gboe
Cumulative global consumption	1050 Gboe
Conventional global reserves Campbell & Laherrère 1998	850 Gboe
Conventional global reserves BP Statistical Review 2007	1208 Gboe
Conventional global reserves Various sources Wikipedia 2011	>1240 Gboe
Conventional global reserves USGS 2000	2311 Gboe
Unconventional global reserves Highly uncertain	1900 Gboe

Wireline logs

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Log	Name	Measures	Units	Range	Typical plot range	Precision	Vertical resolution at normal logging speed, ~1000 m/hr	Depth of investigation	Env correction	Composition	Texture	Stratigraphy	Faults & fractures	Shale & source rx	Fluid	Pressure	Seismic analysis	Quality reducers	Tool names and mnemonics	Mud	Casing
CAL	caliper	hole diameter	mm or in	50–600 mm or 2–24 in	250 mm or 10 in	±1 mm	sample interval	0 m	●		○		○			○		High logging speed	CALI; Four-arm dual caliper, 4CAL [BHI]; CL, or Four Arm Caliper Tool, FACT [HAL]; Borehole Geometry Tool, BGT [SLB]; X and/or Y are opposite and perpendicular to DEN tool	Any	Open or cased
TEMP	temperature	tool temperature	˚C or ˚F	5–300˚C	10–150˚C	±1˚C but accuracy perhaps ±10 ˚C	low	—	●									Operational conditions, time for equilibration	Integral part of most tools	Any	Open or cased
GR	gamma ray	natural radioactivity	API units	0–250	0–150	±4 API units	0.5 m	50%: 0.1 m 90%: 0.3 m		◐	○	●	○	◐				Large hole, high mud weight, centered tool decrease count; KCl in mud causes baseline shift	Computed Gamma Ray, CGR; Uranium-free gamma-ray, GRS, SGR, or KTH	WBM or OBM	Open or cased
SGR POTA, K THOR, Th URAN, U	spectral gamma ray	natural radioactivity	K permil (‰) or percent (%), Th ppm, U ppm	K 0–100 ‰, Th 0–40 ppm, U 0–30 ppm	K 0–100 ‰, Th 0–40 ppm, U 0–30 ppm	±5 API units	0.5 m	50%: 0.1 m 90%: 0.3 m		●	○	◐	○	●				Large caves, KCl in mud (baseline shift on K), spurious tool temperature correction	Natural Gamma Tool, NGT, or Natural Gamma Spectrometry, NGS [SLB]; Spectralog, SL [BHI]; Natural Gamma Ray Tool, NGRT, or Compensated Spectral Natural Gamma Ray, CSNG [HAL]	WBM or OBM	Open or cased
ECS	elemental capture spectroscopy	induced radioactivity spectrum	converted to volume percent Fe, Ca, S, Ti, Gd, Cl, Ba, Si, and H	0–100%	0–100% cumulative	±2% for the major elements; proportional to abundance	0.5 m	0.15–0.23 m		●	○			◐				Hole rugosity, mud salinity	ECS [SLB], GEM [HAL], SpectraLog [BHI]	Any	Open; cased with specialist tool
PE	photoelectric	photoelectric absorption index	barns/electron	1.5–18 b/e	0–10 (half track) or 0–20 (full track), often displayed with neutron-density	±0.02 b/e	0.3–0.5 m	<0.5 m		●		○	○					Caved hole, rugose hole, barite in mud system	On density tool	Any, except barite-bearing	Open or cased
RHOB	bulk density	bulk density	kg/m^3 or g/cm^3	1500–3500 kg/m^3	2000–3000 kg/m^3 in most basins	±20 kg/m^3	0.1 m for deflection but 0.5–1.0 m for true value	0.10–0.15 m (shallower for higher density)		◐	●	○	○	◐	◐	○	●	Caved hole, rugose hole	RHOZ, DEN; ZDEN [BHI]; high-res RHO8 [SLB]; DPHI, PHID, DPOR converted to porosity	Any	Open; cased under some circumstances
NPHI	compensated neutron	hydrogen index converted to neutron porosity	dimensionless	–15 to +45 pu	0–30 pu	±1 pu	0.6–1.0 m	Varies with φ: 30% φ means 16.5 cm depth, 20% 23 cm, 10% 34 cm, 0% 60 cm		◐	◐	◐	○	○	●			Hole rugosity increases Nphi, mud salinity (corrected), T & P (corrected)	CNL [SLB], Ultra CN [BHI]	Any	Open or cased
NMR	nuclear magnetic resonance	T2 relaxation time distribution (often converted to free-fluid porosity)	ms (porosity in pu)	0.1–10 000 ms	0.3–3000 ms	±1 pu for total porosity, ±0.5 pu for free-fluid porosity	0.15 m (high-res), or 0.7 m (standard)	50%: 28 mm, 95%: 38 mm		○	◐				●			Hole rugosity	CMR [SLB], MRIL [HAL], MREX [BHI]	Any	Open
SP	spontaneous (self) potential	electric potential	mV	relative	relative, 100 mV wide, curve deflection to left opposite sandstones	±1 mV	Poor; do not use for bed boundaries	Shallow, <0.3 m		●	○	○	○	○	◐			Caved hole, rugose hole	Static Spontaneous Potential, SSP	WBM (must be conductive)	Open
IL	induction log	whole rock conductivity, converted to resistivity	mS/m but converted to Ωm	0.2–2000 Ωm	0.2–20 Ωm	±0.25 mS/m (accuracy reduced above 500 Ωm)	0.7 m (deep), 0.5 m (shallow)	50%: 0.5 m (shallow) 3.0 m (deep)			○			○	●		○	Hole rugosity, high resistivity formations or low low resistivity mud	ILD, ILM, AHT (10 to 90) or AHO (10 to 90) [SLB]; HDIL (M2R1 to M2R9) [BHI]; High-Resolution Induction, HRI [HAL]	Any	Open
usually considered identical																					
RT	resistivity	whole rock resistitivity	Ωm	0.2–2000 Ωm	0.2–20 Ωm	±1%	0.7 m	50%: 1.5–2.0 m (deep) 0.7–1.0 m (med)			○			○	●		○	Hole rugosity	Laterolog (LL), micro-log (ML), HALS, HRLD, HRLS [SLB]; Dual laterolog, DLL [HAL]	WBM (must be conductive)	Open
MI	micro-image resistivity	hi-resolution 2D conducivity, but converted to res	mS/m but converted to Ωm	0.2–2000 Ωm	normalized to relative values	±0.1 Ωm	25 mm	50%: 40 mm		○	●	●	●	◐			○	Hole rugosity	FMI [SLB], EMI [HAL]	WBM; specialist tools for OBM	Open
DT Δt	sonic	P-wave travel-time at ca. 18 kHz	μs/m or μs/ft	120–750 μs/m or 40–250 μs/ft	150–450 μs/m or 50–150 μs/ft	±6 μs/m or 2 μs/ft	0.3–0.5 m, depending on receiver spacing	0.12–1.0 m (shallower for high velocity)		○	○	○	○	◐	○	●	●	Caved hole, high logging speed results in cycle skipping (high Δt), uncentered tool	Δt; Acoustic, AC or ACL [BHI]; Borehole Compensated Sonic, BHC [SLB] or BCS [HAL];	Any	Open; cased hole for cement bond log
DTS	shear sonic	S-wave travel-time	μs/m or μs/ft	200–1400 μs/m or 60–425 μs/ft	150–450 μs/m or 50–150 μs/ft (plotted with DT)	±3 μs/m or 1 μs/ft	0.3–0.5 m, depending on receiver spacing	0.12–1.0 m (shallower for high velocity)		○	○	○	○	◐	○	◐	●	Caved hole, high logging speed results in cycle skipping (high Δt), uncentered tool	Dipole Shear Sonic Imager, DSI [SLB]; Full Wave Sonic, FWS [HAL]	Any	Open

v1.1

SOURCES

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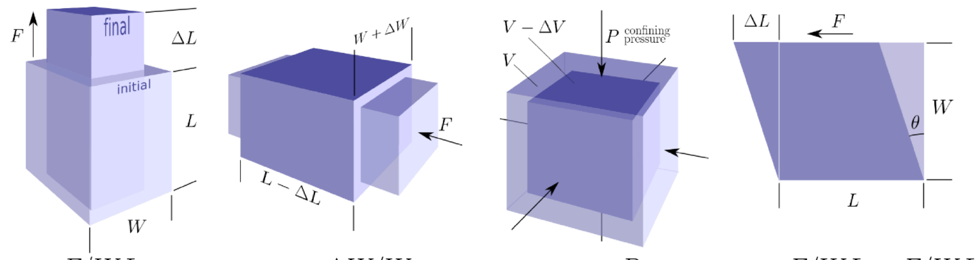
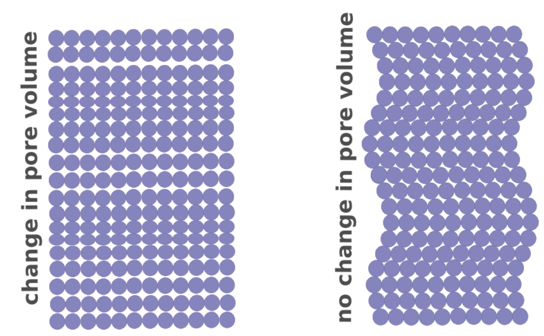
Elastic parameters	E Young's modulus [$\mathrm{kg \cdot m^{-1} s^{-2}}$]	ν Poisson's ratio [dimensionless] aka σ	K bulk modulus [$\mathrm{kg \cdot m^{-1} s^{-2}}$] aka volumetric modulus	μ shear modulus [$\mathrm{kg \cdot m^{-1} s^{-2}}$] aka rigidity, G	λ 1st Lamé parameter [$\mathrm{kg \cdot m^{-1} s^{-2}}$] aka incompressibility	V_P P-wave velocity [m/s] aka compressional vel	V_S S-wave velocity [m/s] aka shear velocity	Γ V_P:V_S ratio [dimensionless]
Engineers... (E, ν)			$\dfrac{E}{3(1-2\nu)}$	$\dfrac{E}{2(1+\nu)}$	$\dfrac{E\nu}{(1+\nu)(1-2\nu)}$	$\sqrt{\dfrac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}}$	$\sqrt{\dfrac{E}{2\rho(1+\nu)}}$	$\sqrt{\dfrac{1-\nu}{\frac{1}{2}-\nu}}$
Fluid substitution... (K, μ)	$\dfrac{9K\mu}{3K+\mu}$	$\dfrac{3K-2\mu}{2(3K+\mu)}$			$K-\dfrac{2}{3}\mu$	$\sqrt{\dfrac{K+\frac{4}{3}\mu}{\rho}}$	$\sqrt{\dfrac{\mu}{\rho}}$	$\sqrt{\dfrac{K+\frac{4}{3}\mu}{\mu}}$
Rock physicists... (μ, λ)	$\dfrac{\mu(3\lambda+2\mu)}{\lambda+\mu}$	$\dfrac{\lambda}{2(\lambda+\mu)}$	$\lambda+\dfrac{2}{3}\mu$			$\sqrt{\dfrac{\lambda+2\mu}{\rho}}$	$\sqrt{\dfrac{\mu}{\rho}}$	$\sqrt{\dfrac{\lambda+2\mu}{\mu}}$
Geophysicists... $(V_\mathrm{P}, V_\mathrm{S})$	$\rho V_\mathrm{S}^2 \dfrac{(3V_\mathrm{P}^2-4V_\mathrm{S}^2)}{V_\mathrm{P}^2-V_\mathrm{S}^2}$	$\dfrac{V_\mathrm{P}^2-2V_\mathrm{S}^2}{2(V_\mathrm{P}^2-V_\mathrm{S}^2)}$	$\rho\left(V_\mathrm{P}^2-\dfrac{4}{3}V_\mathrm{S}^2\right)$	ρV_S^2	$\rho\left(V_\mathrm{P}^2-2V_\mathrm{S}^2\right)$			$\dfrac{V_\mathrm{P}}{V_\mathrm{S}}$



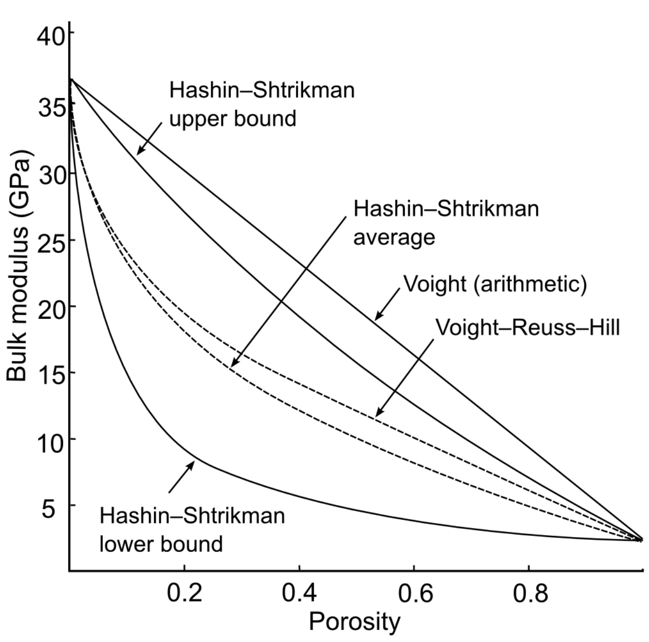
	E	ν	K	μ
	$=\dfrac{F/WL}{\Delta L/L}$	$=\dfrac{\Delta W/W}{\Delta L/L}$	$=\dfrac{P}{\Delta V/V}$	$=\dfrac{F/WL}{\tan\theta}=\dfrac{F/WL}{\Delta L/L}$
	longitudinal stress / longitudinal strain	transverse strain / longitudinal strain	volume stress / volume strain	shear stress / shear strain

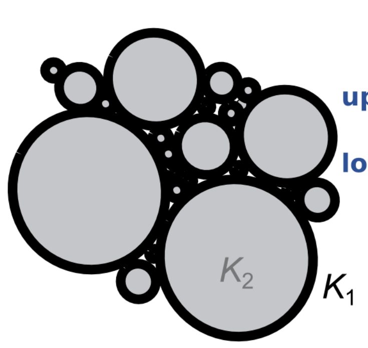


	Density [$\mathrm{kg/m^3}$]	[GPa]	[dimensionless]	[GPa]	[GPa]	[GPa]	[m/s]	[m/s]	[dimensionless]
Quartz	2650	95	0.07	37	44	8	6008	4075	1.47
Feldspar (mean)	2620	40	0.32	37.5	15	28	4685	2393	1.96
Plagioclase	2630	70	0.35	76	26	59	6487	3144	2.06
Calcite	2710	84	0.32	77	32	56	6645	3436	1.93
Dolomite	2870	117	0.30	95	45	65	7349	3960	1.86
Anhydrite	2980	72	0.23	45	29	26	5299	3120	1.70
Siderite	3960	135	0.32	124	51	90	6963	3589	1.94
Pyrite	4930	305	0.15	147	132	59	8094	5174	1.56
Sandstone, 10 p.u.	2500	32-105	~0.05-0.10	15-18	7-24	1-3	2500-4500	1725-3103	~1.45-1.5
Limestone, 10 p.u.	2540	97-280	~0.33	37-71	9-26	18-53	3800-6500	1900-3250	~2.0
Shale, 5 p.u.	2500	20-160	~0.27	16-36	2-19	3-24	1800-5000	1000-2777	~1.8
Water (brine)	1030	0	0.5	2.3	0	2.3	1507	0	undefined
Oil (40 API)	830	0	0.5	1.6	0	1.6	1226	0	undefined

Hashin–Shtrikman

Upper and lower bounds





upper bound when $K_1 > K_2$
lower bound when $K_1 < K_2$

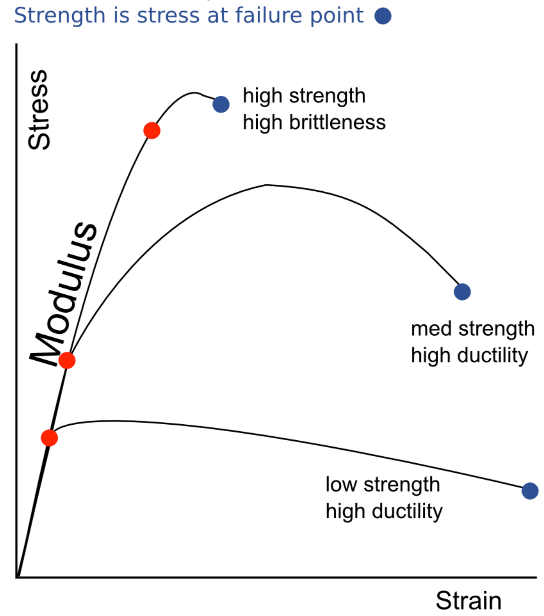
$$K^{\mathrm{HS}\pm} = K_1 + \frac{f_2}{(K_2-K_1)^{-1} + f_1(K_1+\frac{4}{3}\mu_1)^{-1}}$$

$$\mu^{\mathrm{HS}\pm} = \mu_1 + \frac{f_2}{(\mu_2-\mu_1)^{-1} + \frac{2f_1(K_1+2\mu_1)}{5\mu_1(K_1+\frac{4}{3}\mu_1)}}$$

Get upper bound and lower bounds by switching indices
upper: $K_1 = K_1$, $K_2 = K_2$ lower: $K_1 = K_2$, $K_2 = K_1$
f_1 and f_2 is volume fraction of constituent 1 and 2.

Strength and brittleness

Modulus is the slope below the elastic limit
Strength is stress at failure point



Bulk density $\rho = (1-\phi)\rho_\mathrm{S} + \phi\rho_\mathrm{F}$

ρ_S density of the solid, ρ_F density of the fluid, ϕ is porosity

Fluid modulus $\dfrac{1}{K_\mathrm{f}(P,T)} = \sum_i \dfrac{S_i}{K_i(P,T)}$

for a mixture of fluids with fractions S_i, fluid bulk moduli depend on temperature T & pressure P

Gassmann's equation

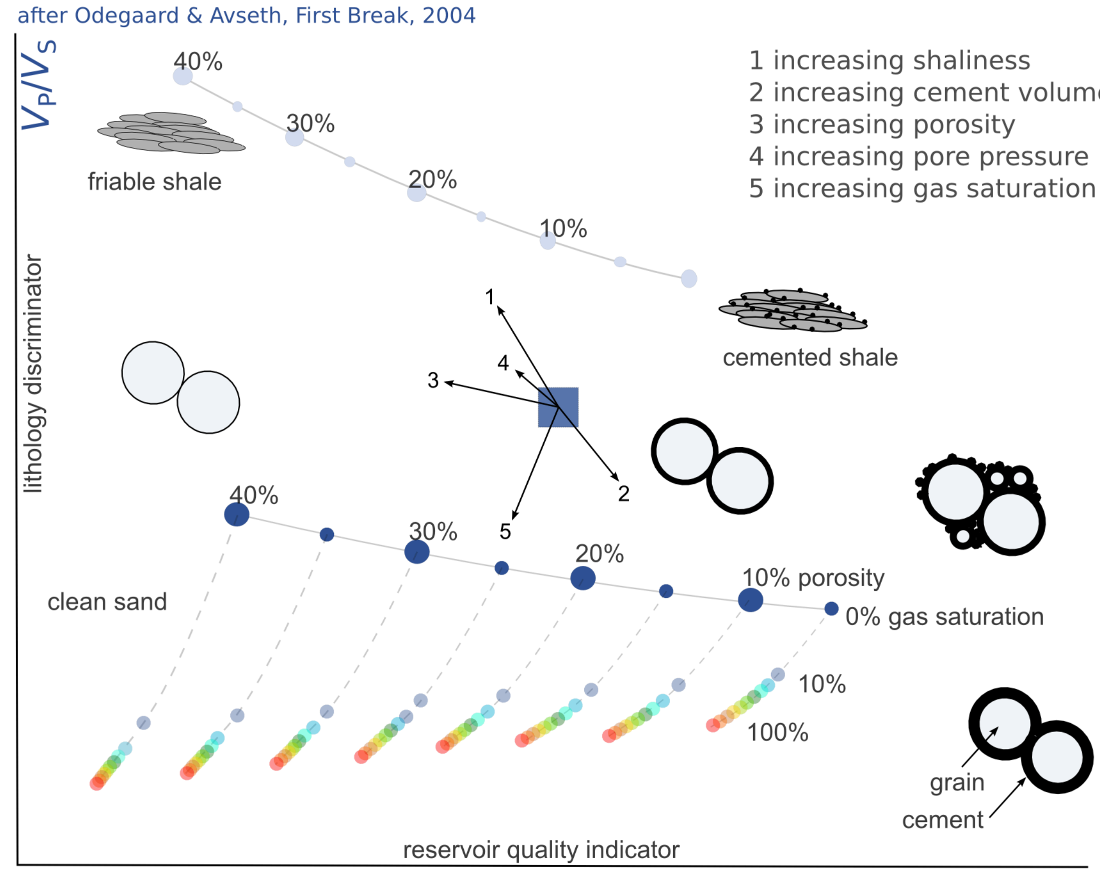
Fluid substitution

$$K_\mathrm{eff} = K_\mathrm{dry} + \frac{\left(1-\frac{K_\mathrm{dry}}{K_\mathrm{min}}\right)^2}{\frac{1-\frac{K_\mathrm{dry}}{K_\mathrm{min}}-\phi}{K_\mathrm{min}} + \frac{\phi}{K_\mathrm{f}}}$$

$$K_\mathrm{dry} = \frac{1+\left(K_\mathrm{eff}\left(\frac{\phi-1}{K_\mathrm{min}}\right)-\frac{\phi}{K_\mathrm{f}}\right)}{\frac{1-\frac{K_\mathrm{eff}}{K_\mathrm{min}}+\phi}{K_\mathrm{min}}-\frac{\phi}{K_\mathrm{f}}}$$

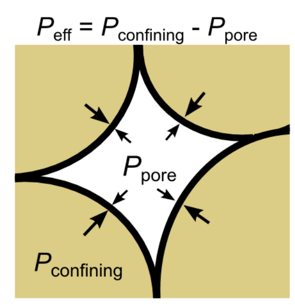
$V_\mathrm{P}/V_\mathrm{S}$ P-impedance template

Conceptual trends for siliciclastic lithologies at constant confining pressures
after Odegaard & Avseth, First Break, 2004

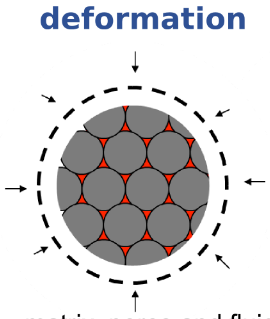


P-impedance: ρV_P

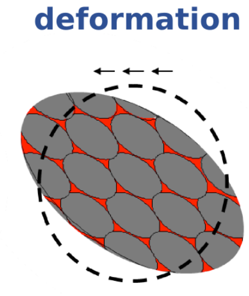
Effective pressure



Volumetric deformation



Shear deformation



ROCK PHYSICS cheatsheet
v 3.0

Agile
agilegeoscience.com