→ universe = H > He > O > Ne > N > C > SI

→ earth (whole) = fe > O > SI > Mg > ca > Al > Na > K > H = f = Ba > Ti = Mn > ?

↳ plage > Alkali feldspar > Qtz > Pyx > amphibole > mica > clay

→ crust - O > SI > Al > fe > ca > Na > K > mg > Ti > H > P > Mn > S > C

→ moon - O > SI > Mg > fe > ca

→ mantle - O > mg > SI > fe > ca > Al > Na > K = Mn > H = f > Ba > P

→ major constituent - Cl^- > Na^+ > SO_4^{2-} > Mg^{2+} > Ca^{2+} > K^+ >
Bicarbonate > Bromide (Br^-) > strontium > Boric > acid fluoride

→ Nutrients (PPM) - Silicon > Nitrogen > phosphate > Iron
(3) (0.5) (0.07) (0.002)

→ Gases - (A) for Dry air (%) - N_2 > O_2 > CO_2 > Ar, H_2, Ne, He

(B) for surface ocean (%) - N_2 > O_2 > CO_2 > Ar, H_2, Ne, He
(47.5) (36) (15.1) (1.4)

(C) water air Ratio - CO_2 > O_2 > Ar, H_2, Ne, He > N_2
(503.3) (1.7) (1.5) (0.6)

→ Trace element (seawater PPb) -
Li > I > Mo > Zn > fe > Al > Cu > Mn > Co > Pb > Hg > Au

→ organic compound - lipids, protein, carbohydrates, Hormones, vitamins

→ stream (PPM) - HCO_3^- > Ca^{2+} > SiO_2 > SO_4^{2-} > Cl^- > Na^+ > Mg^{2+} > K^+

→ Residence time -

→ pointstart

Cl^- > Na^+ > Li^+ > Sr^{2+} > K^+ > Ca^{+2} > Zn^{2+} > Ba^{2+} > Co^{2+} > Cr > Al

conservation element ⌐ ⌐ Non conservation element

→ (A) Absolute stability = ELR < WALR < DALR

(B) conditional stability = WALR < ELR < DALR

(C) Absolute Instability = WALR < DALR < ELR

Type A - $\rho_1 < \rho_2 < \rho_3$
Type Q - $\rho_1 > \rho_2 > \rho_3$
Type K - $\rho_1 < \rho_2 > \rho_3$
Type H - $\rho_1 > \rho_2 < \rho_3$
→ HH and KK type curve not Bedrock

→ $PH \propto \frac{1}{[H^+]}$ and $PH \propto \frac{1}{CO_2}$ but $PH \propto [OH]$

→ (A) permanent Gases - N_2 > O_2 > Ar > Ne > He > H_2 > Xe

→ (B) variable gases - H_2O > CO_2 > CH_4 > N_2O > O_3 > dust > CFCs

→ salinity = Dead sea > Great salt lake (Utah) > Redsea > mediterran.sea > Black sea > Baltic sea

→ plank function -

$$\boxed{M_\lambda = \frac{2hc^2}{\lambda^5\left[e^{\left(\frac{hc}{K_\beta \lambda T}\right)} - 1\right]}} \quad \boxed{w.m^{-2}.sr^{-1}\ \mu m^{-1}}$$

λ - wavelength (μm)
h - plank constant
K_β - Boltzman constant
= 1.38×10^{-23} J K^{-1}

$c = 3 \times 10^8$ m/s
T = absolute temp (K)

→ solid angle - $\boxed{\Omega = \frac{S}{r^2}}$ unit = steradian (Sr)

→ spectoral exitance (m_b)

$$\boxed{m_b = \sigma_b \cdot T^4}$$ watts m^{-2}

↓ stephan Boltzman constant
$\sigma_b = 5.6697 \times 10^{-8}$ w m^{-2} K^{-4}

→ Emissivity (ε) $\boxed{\varepsilon = \frac{m_r}{m_b}}$ ← Radiating body ← Black body

$m_r = \sigma_b T^4 . \varepsilon$ — ①
$m_b = \sigma_b T^4$ — ②

→ stephan Boltzmann law -

$$\boxed{m_\lambda = \sigma T^4}$$

→ wian's displacement law -

$$\lambda_{max} = \frac{K}{T} = \frac{2898}{T}\ \mu m.K$$ ✭

→ the value of exitance at peak wavelength (λ_{max})

$$\boxed{M_{\lambda max} = bT^5}$$ $b = 1.286 \times 10^{-11}$ w m^{-2} μm^{-1} K^{-5}

→ Quantum theory of EMR -

$$\boxed{Q = h \times \nu}$$

→ frequency of the radiation

↓ plank constant
$= 6.626 \times 10^{-34}$ J.S

→ particle model of electromagnetic energy -

$$\lambda = \frac{hc}{h\nu} = \frac{hc}{Q}$$

$$\boxed{Q = \frac{hc}{\lambda}}$$

- the energy of a Quantum is ~~f~~ Inversely propotional to its wavelength.

→ Rayleigh scattering cross-section

$$\boxed{\tau_m = \frac{8\pi^3 (n^2-1)^2}{3N^2\lambda^4}}$$

n = refractive index
N = No. of air molecules per unit volume
λ = wavelength

* Terrain Energy matter interactions -

Radiation budget equation -

$$\boxed{\phi_{i\lambda} = \phi_{\text{reflected } \lambda} + \phi_{\text{absorbed } \lambda} + \phi_{\text{transmitted } \lambda}}$$ watt.

(A) Hemispherical reflectance (ρ_λ) -

$$\boxed{\rho_\lambda = \frac{\phi_{\text{reflected}}}{\phi_{i\lambda}}}$$

(B) Hemispherical transmittance (τ_λ) -

$$\boxed{\tau_\lambda = \frac{\phi_{\text{transmitted}}}{\phi_{i\lambda}}}$$

(C) Hemispherical absorptance (α_λ) -

$$\boxed{\alpha_\lambda = \frac{\phi_{\text{absorbed}}}{\phi_{i\lambda}}}$$

(D) percent reflectance ($\rho\%$) -

$$\boxed{\rho\% = \frac{\phi_{\text{reflected } \lambda}}{\phi_{i\lambda}} \times 100}$$

→ Radiant energy (Q) = Jules

→ Radiant flux (ϕ) = $\boxed{\phi_\lambda = \frac{\partial Q_\lambda}{\partial t}}$

* Radiant flux density - irradiance and Exitance -

(A) irradiance (E_λ) - Radiant flux incident

$$\boxed{E_\lambda = \frac{\phi_\lambda}{A}}$$

Both unit $\underline{W m^{-2}}$

(B) Exitance (M_λ) - $\boxed{M_\lambda = \frac{\phi_\lambda}{A}}$ - Radiant flux leaving

→ Radiant intensity (I) -

$$I_\lambda = \frac{\phi_\lambda}{\Omega} \quad \text{then} \quad \Omega = \frac{A}{R^2}$$

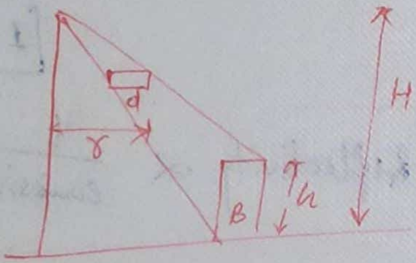
$$\boxed{I_\lambda = \frac{\phi_\lambda}{A/R^2}}$$

$\underline{\text{watts} \cdot sr^{-1}}$

→ Radiance (L) - $\boxed{L_\lambda = \frac{\frac{\phi_\lambda}{\Omega}}{A\cos\theta}}$

* Relief displacement depend on -

$$\boxed{\frac{h}{H} = \frac{d}{r}}$$



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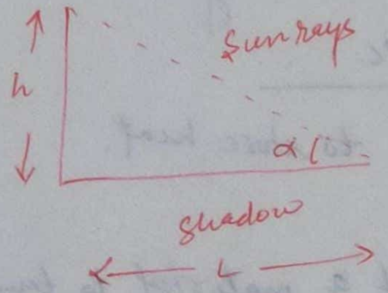


$$\tan\alpha = \frac{\text{opposite}}{\text{adjacent}} = \frac{\text{height}}{\text{shadow}} \frac{h}{L}$$

$$\boxed{h = L \times \tan\alpha}$$

* Resolution

1. spatial Resolution — Distance $\boxed{L = H \times Ifov}$
2. spectral " — wavelength μm or nm
3. Radiometric " — Energy $wm^{-2} sr^{-1} \mu m^{-1}$
4. Temporal " — Time

* NCP -

B → B.
G → G
R → R

FCP -

G — Blue
R — Green
NIR — Red.

*(A) Across track scanner (whiskbroom) - like Jhadoo.

- scane angle -

(A) Angular field of view = 2 × scan angle

(B) Ground swath width = 2×H× tan (scan angle)

(B) Along track scanner's (pushbroom scanners) - like wiper

→ Good absorbers are good emitters and good reflector's are poor emitters.

$$\boxed{1 = r_\lambda + \varepsilon_\lambda}$$

→ $\boxed{\text{Reflectivity} \propto \frac{1}{\text{emissivity}}}$

1. thermal conductivity (K)- heat will pass through a material.
unit- $cal. cm^{-1}. sec^{-1} °c$.

2. Thermal capacity (C)- Ability of material to store heat.
unit- $cal. g^{-1}. °c^{-1}$

3. thermal Inertia (P)- thermal response of a material to temp. changes. unit - $cal. cm^{-2}. sec^{-1/2}. °c^{-1}$

$$\boxed{P = \sqrt{K \rho C}}$$

→ Apparent thermal inertia –

$$\boxed{ATI = \frac{1-A}{\Delta T}}$$ Albedo (reflectance)

→ * (A) Rayleigh scattering = molecules of oxygen and Nitrogen.
$d << \lambda$

(B) mie scattering = pollen, watervapour, smoke, dust.
$d = \lambda$

(C) Non selective scattering = cloud and fog.
$d = 10\lambda$ $d > \lambda$

→ Normalized difference vegetation index –

$$\boxed{NDVI = \frac{\text{Near infrared} - \text{visible}}{\text{Near infrared} + \text{visible}}}$$

* Indexing toposheets No. –

An International series (within 4°N to 40°N latitude and 44°E to 124°E longitude) at the scale of $1:10^6$ is being considered as base map.

latitude ↓ longitude ↓

$53 - (4° \times 4° = 1:10^6 = 1000000$

$53N - 1° \times 1° = 1:250000 = 1:25 \times 10^4 = 250000$

$53\frac{N}{SE} - 30' \times 30' = 1:10^5 = 100000$

$53\frac{B}{3} - 15' \times 15' = 1:50000 \rightarrow 45\frac{D}{16}$ $1:5 \times 10^4 = 50000$

$53\frac{D}{14\,NE} - 7\frac{1}{2}° \times 7\frac{1}{2}° = 1:25000$ $= 1:25 \times 10^3 = 25000$

53/0/14/NE

$53\frac{0}{14}$ NE

Ex – on survey of india toposheet No. $45\frac{D}{16}$ the distance b/t two points is 18cm. the actual ground distance b/t these two points is – km

– scale 1:50000

$= \frac{50000}{1} \times 18\text{cm}$

$= 900000\text{cm} = 9\text{km}$ Ans

Swath distance

$$S_D = 2\times H \tan\frac{\theta}{2}$$

Band Ratio (TM)

5/7 = clay, carbonate, silica, mica group

3/1 = humatite, goethite, jarosite

5/4 = bare rock and soil.

$f=\frac{1}{T}$ | $\bar{\nu}=\frac{1}{\lambda}$ | $c=\lambda\cdot f$

$h=6.6256\times10^{-34}$ J.S plank's constant

Ground Resolution cell (GRC) (GRE)

$$GRC = 2H\tan\left(\frac{IFOV}{2}\right)$$

Heat flow terrestrial

$$H = K\frac{\delta T}{\delta Z}\ (W/m^2)$$

H → earth surface

K → thermal conductivity of medium through heat is flowing $\left(\frac{W}{m.K}\right)$

$\delta T/\delta Z$ → thermal gradient perpendicular to surface $\left(\frac{K}{m}\right)$

Rigidity of lithosphere -

Flexural rigidity $D=\frac{E}{12(1-\nu^2)}h^3\ (N/m)$

$$\begin{cases} E = \text{young's modulus } (N/m^2) \\ v = \text{poisson ratio (dimensionless)} \end{cases}$$

Band-1 (Blue light) - scattered by atm, penetrate clear water better than other colour, absorbed by chlorophyll, so plant don't show up very brightly in this band, usefull for soil/vegetation discrimination, forest type mapping, and identifying man made features.
↳ 0.4-0.5μm (30m)

2. **Band-2 (Green light)** - penetrates clear water fairly well, gives excellent contrast B/t clear and turbid (muddy) water, helps find oil on the surface of water, and vegetation (plant life), reflected more green light than any other visible colour, man made feature still visible. → 0.5-0.6μm (30m)

3. **Red light (Band 3)** - useful for identifying vegetation type, soil, urban (city and town) features
↳ 0.63-0.69μm

4. NIR (Band 4) - good for maping shorelines and Biomass content, very good at detecting and analyzing vegetation. (0.76-0.90μm) (30m)

Hotspots lists

(A) Oceanic plate -

Azores (Eurasian plate)

canory island (African plate)

cape verde (A.P)

Reunion island (Af. P.)

St. Helena (Af P)

Tristan da Cunha (Af. P)

Hawaii (pacific plate)

pitcairn island (pa. P)

macdonalt/sea mount (pa. P)

Bermuda (Extinct) (Atlantic ocean)

(B) **plate Boundary** -

iceland (North America + Eurasian plate)

Afar (African plate)

prince Edward island (African + Antartic plate)

Amsterdam island (Indian + Antarctic)

Bouvet island (African + Antartic)

Galopagos (cocos + Nazca plate)

Easter island (Nazca plate)

Balleny island (Antartic)

(C) **Subduction zone** -

cobb seamount (pacific + North America)

Samoa (pacific plate)

(D) **volcanic Ridge / continents**

Eifel (Eurasian plate)

yellow stone national park - (North America plate)

5. **Shortwave IR (SWIR) Band 5** - usefull for measuring the moisture content of soil and vegetation, helps diff. B/t snow and cloud. (1.55-1.75μm)

6. thermal IR (TIR or LWIR) - observe temp and its effects, as daily and seasonally variation (10.4-12.5 μm)

7. Band 8 panchromatic (pan) - on Landsat 7, only has 15m resolution, used to sharpen images (0.52-0.9μm)

→ Ground water in ancient time was supplied from horizontal wells known, as quants.

→ Hydrologic budget/water budget/ water Balance –

surface water – $\boxed{P + Q_{in} - Q_{out} + Q_g - E_s - T_s - I = \Delta S_s}$ Q - surface water flow

Ground water sy. – $\boxed{I + G_{in} - G_{out} - Q_g - E_g - T_g = \Delta S_g}$

$$P + (Q_{out} - Q_{in}) - (E_s + E_g) - (T_s + T_g) - (G_{out} - G_{in}) = \Delta(S_s + S_g)$$

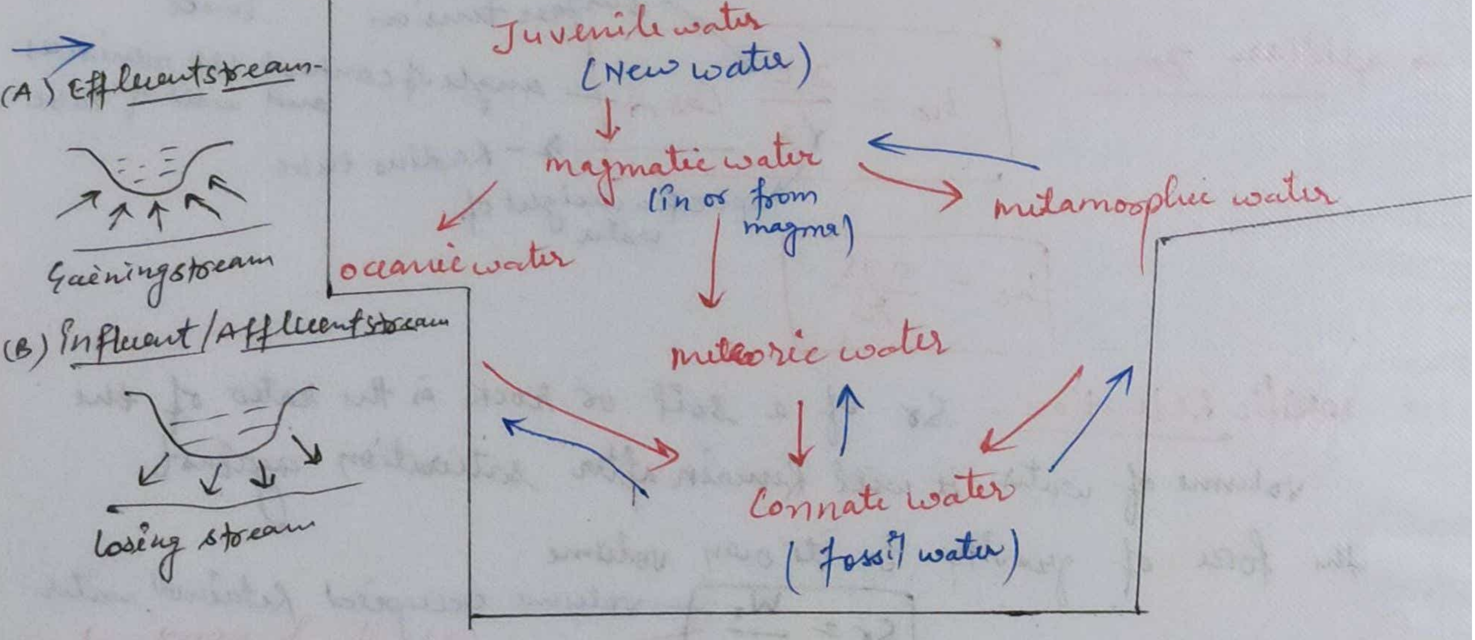
$$\boxed{P - Q - G - E - T = \Delta S}$$

→ Age of ground water – Hydrogen-3 (tritium) and carbon-14 are two isotopes that have proved most Radiation, carried to earth by rainfall and hence underground, this natural level of tritium begins to decay as a function of time –

$$\boxed{\underbrace{A}_{\text{observed Radioactivity}} = \underbrace{A_0}_{\text{Activity At the time water entered the aquifer}} e^{-\alpha t}}$$

t – Age of the water

α – Decay constant



→ Porosity – $\boxed{\alpha = \frac{V_v}{V_T} \;,\; = \frac{V_t - V_s}{V_T}}$

$$\boxed{\alpha = \frac{\rho_m - \rho_d}{\rho_m} = 1 \cancel{- \frac{\rho_{Bd}}{\rho_{pd}}} \\ = 1 - \frac{\rho_{Bd}}{\rho_{pd}}}$$

→ Void Ratio – $e = \frac{V_v}{V_s}$, $V_v = V_t - V_s$

$$e = \frac{V_t - V_s}{V_s} = \frac{V_t}{V_s} - 1 \Rightarrow \frac{V_t}{V_s} = 1 + e \quad ①$$

$$\alpha = \frac{V_t - V_s}{V_T} = \left(1 - \frac{V_s}{V_T}\right) \Rightarrow \left(1 - \frac{1}{1+e}\right)$$

$$\boxed{\alpha = \frac{e}{1+e}}$$

→ uniformity coefficient (U_c) $\boxed{U_c = \frac{d_{60}}{d_{10}}}$

– uniform material – then Low U.C. (dune sand)
well graded – then high U.C. (Alluvim)

→

(A) Zone of Aeration – { vadose water (Shallow) } <
- soil water zone
- Immediate vadose zone
- capillary zone

(B) Zone of saturation – Below the water level. { groundwater or phreatic water (well)

→ capillary Zone – $\boxed{h_c = \frac{2\tau}{\gamma r} \cos\alpha}$

surface tension

angle of contact b/t meniscus and wall of tube

r – Radius tube

specific weight of water

$$\boxed{h_c = \frac{0.15}{r}}$$

→ specific Retention – Sr of a soil or rock is the ratio of the volume of water it will Remain after saturation against the force of gravity to its own volume.

$\boxed{S_r = \frac{W_r}{V_T}}$ – volume occupied Retained water

→ **specific yield** – S_y of a soil or rock is the Ratio of volume of water that, after saturation, can be drained by gravity to it own volume.

$$\boxed{S_y = \frac{W_y}{V_t}}$$

Volume of water drained

→ $V_v = w_r + w_y$

$$\boxed{\alpha = S_r + S_y}$$

All pores are Interconnecting

→ **Darcy's law** –

$$\boxed{Q = -KA\frac{dh}{dl}}$$

$$\boxed{v = \frac{Q}{A} = -K\frac{dh}{dl}}$$

→ **Reynolds Number**

$$\boxed{N_R = \frac{\rho v D}{\mu}}$$

fluid density

v – velocity

Diameter (pipe)

dynamic viscosity of fluid

→ Darcy law is valid for $N_R < 1$

→ **Intrinsic permeability** –

$$\boxed{k = \frac{K\mu}{\rho g}}$$

Hydraulic conductivity [m/day]

dynamic viscosity

gravity

fluid density

[unit = m^2

$$\boxed{1 \text{ darcy} = 0.987\,(\mu m)^2}$$

→ **Transmissivity** –

$$\boxed{T = Kb} = \overset{K}{\frac{m}{day}} \times \overset{b}{m} = \frac{m^2}{day}$$

→ **Laboratory method** –

$$\boxed{K = \frac{VL}{Ath}}$$

v – flow volume in time t

L – length of sample

A – Horizontal sample Area

h – height of sample

(Constant head)

(4-3)

$$\boxed{K = \frac{r_t^2 L}{r_c^2 t} \ln \frac{h_1}{h_2}}$$

→ length of sample
r_c - sample core
L - sample length
h_1, h_2 hight
r_t - radius tube

{falling Head

→ Tracer test -

$$\boxed{V_\alpha = \frac{K}{\alpha} \cdot \frac{h}{L}}$$

Average interstitial velocity

α - porosity
L - distance b/t sample and tracer

$$\boxed{V_\alpha = \frac{L}{t}}$$

$$\boxed{K = \frac{\alpha L^2}{ht}}$$

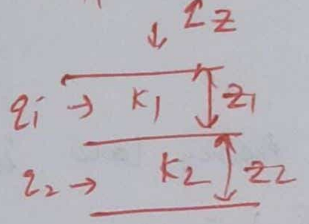
t - travel time

→ Auger Hole tests -

$$\boxed{K = \frac{C}{864} \frac{dy}{dt}}$$

$\frac{dy}{dt}$ Rate of Rise (cm/s)
C - dimensionless constant.

→ (A) Two Horizontal strata, each isotropic, with different thickness and hydraulic conductivities

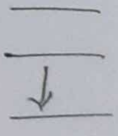


★ $$\boxed{K_x = \frac{K_1 Z_1 + K_2 Z_2 + \cdots + K_n Z_n}{Z_1 + Z_2 + Z_3 + \cdots + Z_n}}$$

Z - thickness
K - hydraulic cond.

→ (B) equivalent vertical hydraulic conductivity for a stratified material -

★ $$\boxed{K_Z = \frac{Z_1 + Z_2 + Z_3 + \cdots + Z_n}{\frac{Z_1}{K_1} + \frac{Z_2}{K_2} + \frac{Z_3}{K_3} + \cdots + \frac{Z_n}{K_n}}}$$



→ flow $q = W_1 V_1 = W_2 V_2$

v is velocity and W is the width of flow section perpendicular to the flow - $\boxed{W_1 K_1 i_1 = W_2 K_2 i_2}$

$$\boxed{\frac{K_1}{K_2} = \frac{W_2 i_2}{W_1 i_1}}$$

i - hydraulic gradient
K - hydraulic conductivity

→ flow Across a Hydraulic conductivity Boundary -

$$\boxed{\frac{k_1}{k_2} = \frac{\tan\theta_1}{\tan\theta_2}}$$

$$\frac{\text{vertical Hydraulic conductivity}}{\text{Horizontal hydraulic conductivity}} = \frac{\text{anglewith verticle}}{\text{angle with Horizontal}}$$

→ thies method of solution

$$\boxed{s = \frac{Q}{4\pi T} W(u)}$$ — well function

$$\boxed{\frac{r^2}{t} = \frac{4T}{S} u}$$

$$\boxed{S = \frac{4T.u}{r^2/t}}$$

→ cooper - Jacob method of Solution -

$$\boxed{s = \frac{Q}{4\pi T}\left(-0.5772 - \ln \frac{r^2 S}{4Tt}\right)}$$

$$\boxed{S = \frac{2.25\ T.t_0}{r^2}}$$

$$\boxed{T = \frac{2.30\ Q}{4\pi \Delta s}}$$ — Δs drawdown

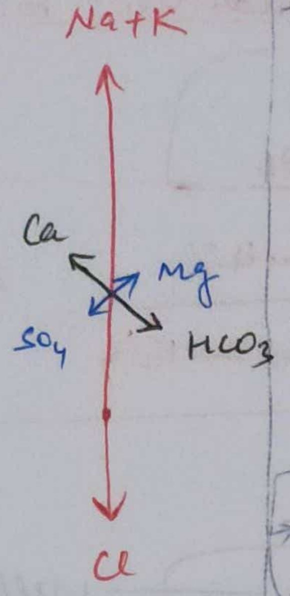
→ Chow method of Solution -

$$\boxed{F(u) = \frac{s}{\Delta s}}$$

→ Hardness (H_T) - $H_T = Ca \times \frac{CaCO_3}{Ca} + Mg \times \frac{CaCO_3}{Ca}$

$$\boxed{H_T = 2.5\ Ca + 4.1\ Mg}$$

→



1 Specific storage (S_s) = volume of water released from storage from a unit volume of aquifer per unit decline in hydraulic head. [1/L].

2 Storativity (S) dimensionless

$$S = S_s \times B$$ ☆

→ $V_{drained} = S_s \Delta h A$ ☆

→ $S_s = \delta(\alpha + \phi\beta)$

$$S = S_y + B S_s$$

→ Irrigation water criteria –

(A) Soluble sodium percentage -

$$\boxed{\% Na = \frac{Na + K}{Ca + mg + Na + K} \times 100}$$

(B) Sodium Adsorption Ratio (SAR)

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + mg)}{2}}}$$

→ 1. Resistivity logging –

- Resistivity logs may be used to determine specific resistivities of strata, or they may indicate qualitatively changes of importance.
- Resistivity of an unconsolidated aquifer is controlled primarily by porosity, packing, water resistivity, degree of saturation and temp.

→ Inverse relation exists b/t resistivity and temp.

→ field formation factor - F

$$\boxed{F = \frac{\rho_o}{\rho_w}}$$

ρ_o → Resistivity of saturated aquifer

ρ_w → Res. of ground water

M-6

① porosity - $\phi = \frac{V_v}{V_T}$, $\phi = 1 - \frac{\rho_b}{\rho_m}$

② Darcy's law (laminar flow)

$$(m/sec)\ q = \frac{Q}{A} = \frac{K(h_1 - h_2)}{\Delta l} \quad \begin{cases} K = m/s \\ Q = m^3/s \end{cases}$$

- Hydraulic gradient, i (Dimensionless)

3. Linear Ground water velocity or pore velocity

$$\text{true velocity} = \frac{q}{\phi e} = \frac{\text{Darcy velocity}}{\text{effective porosity}} = \frac{Ki}{\phi e}$$

4. Bernoulli's equation

$$E = PV + mgz + \frac{mv^2}{2} \ \Big| \ \underset{\hookrightarrow \text{constant}}{h} = \frac{P}{\rho_w \cdot g} + z + \frac{v^2}{2g}$$

5. Intrinsic permeability (k) $\underline{K = C \times d^2}$

$$K = \frac{k \cdot \rho_w \cdot g}{\mu} \ \Big| \ q = -\frac{k \cdot \rho_w \cdot g}{\mu} \times \frac{dh}{dl}$$

6. Horizontal Hydraulic conductivity

$$K_h = \frac{K_1 b_1 + K_2 b_2 + \cdots}{b_1 + b_2 + b_3 + \cdots}$$ ★

7. vertical Hydraulic conductivity

$$K_V = \frac{b_1 + b_2 + b_3 + \cdots}{\frac{b_1}{K_1} + \frac{b_2}{K_2} + \frac{b_3}{K_3} + \cdots}$$ ★

8. Hydraulic conductivity any other directions -

$$\frac{1}{K_\beta} = \frac{\cos^2\beta}{K_h} + \frac{\sin^2\beta}{K_z}$$

9. Refraction of flow lines -

$$\frac{K_1}{K_2} = \frac{\tan\alpha_1}{\tan\alpha_2}$$

10. Height of capillary Rise (h_c) due to capillary Force -

$$h_c = \frac{2\tau}{\gamma r}\cos\alpha \ \Big| \ h_c = \frac{2\tau\cos\alpha}{\rho g h} \ \Big| \ h_c = \frac{0.15}{r}$$

11. porosity and depth of burial -

$$\phi_z = \phi_0 e^{-az} \begin{cases} z - \text{depth},\ a = \text{constant} \\ \phi_z = \text{porosity at depth} \end{cases}$$

12. transmissivity (T) = L^2T^{-1} / m^2/day

$T = Kb$

13. storativity or storage coefficient (S)

$S = b \cdot S_s$ (Dimensionless) ★

14. specific storage (S_s) $\{L^{-1}\}$

$$S_s = \gamma(\alpha + \phi\beta) \begin{cases} \gamma = \text{specific weight of water } (N/m^3) \\ \beta = 4.7 \times 10^{-10}\ pa^{-1} \end{cases}$$

15. specific Retention (S_r) & specific yield (S_y)

$$S_r = \frac{V_r}{V_T} \ \Big| \ S_y = \frac{V_d}{V_T} \ \{ \phi = S_r + S_y)$$

16. Hydraulic diffusivity (K) ★

$$K = \frac{T}{S} = \frac{K}{S_s} \quad \{L^2T^{-1}\}$$

17. Leakage coefficient or Leakance $\{T^{-1}\}$

$$\text{Leakance} = \frac{K}{b}$$

18. Hydraulic Resistance (C) $\{T\}$

$$C = \frac{b}{K} = \frac{1}{\text{Leakance}} \begin{cases} C = \infty \\ \text{aquifer is confined.} \end{cases}$$

19. Leakage factor (B)

$$B = \sqrt{TC} \begin{cases} T = \text{transmissivity} \\ C = \text{Hydraulic Resistance} \end{cases}$$

20. Fick's first law

$$F = -D\frac{dc}{dx} \begin{cases} D = \text{diffusion coefficient} \\ C = \text{solute concentration } (ML^{-3}) \end{cases}$$

21. fick's second law -

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2}$$

22. movement of solute through Advection

$$v_x = -\frac{K}{\phi e}\frac{dh}{dl}$$

23. Hydrodynamic Dispersion.

$$D_L = a_L v_x + D^* \begin{cases} D_L = m^2/s \\ a_L = \text{dynamic dispersivity factor (m)} \end{cases}$$

v_x - avg. linear groundwater velocity (m/s)

24. freundlich isotherm

$$\log S = b\log C + \log K_d \ \Big| \ S = K_d C^b$$

$$K_d = \frac{dS}{dC}$$

25. Retardation of solute in groundwater

$$R_d = 1 + \frac{\rho_b}{\theta} \cdot K_d \begin{cases} \theta = \text{volumetric moisture content of soil (dimensionless)} \\ K_d = mL/g \end{cases}$$

26. Rate of solute movement

$$v_c = \frac{v_x}{R_d} \ \Big| \ v_c = \frac{v_x}{\left\{1 + \left(\frac{\rho_b}{\theta}\right) \cdot K_d\right\}}$$

27. Net inorganic charge Balance (NICB)

$$NICB = \left(\frac{T_{z^+} - T_{z^-}}{T_{z^+}}\right) \times 100$$

28. Hardness of water (mg/L)

$$H_T = 2.5\,Ca + 4.1\,mg$$

29. Sodium Adsorption Ratio (SAR)

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+}) + mg^{2+}}{2}}}$$

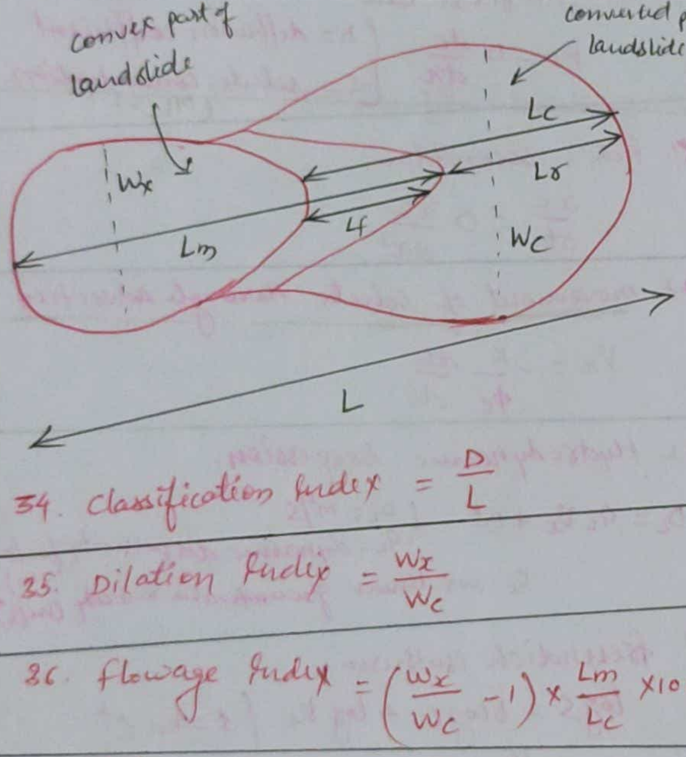
30. Ghyben-Herzberg Relationship

$z = 40 h_f$ { z = height of salt water column
h_f = hydraulic head above sea level

31. volume of precipitation = drainage basin area × rate of rainfall × time duration of rainfall

32. volume of water = Area of surface × height of water column

33. height of water column = $\frac{\text{volume of water}}{\text{Area of surface}}$



34. Classification Index = $\frac{D}{L}$

35. Dilation Index = $\frac{W_x}{W_c}$

36. flowage Index = $\left(\frac{W_x}{W_c} - 1\right) \times \frac{L_m}{L_c} \times 100\%$

37. displacement Index = $\frac{L_r}{L_c}$

38. ~~f~~ viscous flow Index = $\frac{L_f}{D_c}$

39. Tenacity Index = $\frac{L_m}{L_c}$

40. Safety factor = $\frac{R}{D}$ $\frac{\text{(Resistance)}}{\text{(driving force)}}$

41. ① magnetic susceptibility (↑K)
Dolomite < limestone < sandstone < Shale < granite < gabbro < basalt

42. Flaser bedding : sand > mud

43. Lenticular bedding or Outer tidal zone
mud > sand

44. wavy Bedding = mud = sand

1. Engineering Geology –

1. $w_{soil} = V_{soil} \times \rho_{soil} \times g$

2. $G_{soil} = \frac{\rho_{soil}}{\rho_{water}}$

(unit weight) $\gamma_{wet} = \frac{w_T}{V_T}$ / $\gamma_{dry} = \frac{w_{soil}}{V_T}$
3

4. $\rho_{bd} = \frac{w_T - V_w}{V_T} (w_{sp})$ / $\rho_{spd} = \frac{w_{sp}}{V_{sp}}$

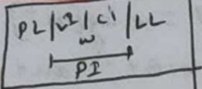
5. $w = \frac{w_{water}}{w_{sp}} \times 100$ {water content}

6. void Ratio, $e = \frac{V_{void}}{V_{soil}}$ | $\eta = \frac{V_v}{V_T}$

Degree of saturation, $S = \frac{V_{water}}{V_{p\,voids}} \times 100$
7

8 coefficient of uniformity, $C_u = \frac{D_{60}}{D_{10}}$ | $C_c = \frac{D_{30}{}^2}{D_0 D_{60}}$
curvature

9 $D_R = \frac{e_{max} - e_0}{e_{max} - e_{min}} \times 100$



10. $LI = \frac{w - PL}{PI}$ | $CI = \frac{LL - w}{PI}$

11. $PI = LL - PL$

tensile strenth, $\sigma_t = \frac{2F}{\pi L D}$
12.

uniaxil compressive
13. strength, $\sigma_c = \frac{F}{A}$

point load Index $\sigma_c = \frac{F}{D^2}$.
14.

modulus Ratio, $M.R = \frac{E_{t50}}{\sigma_{cs}}$
15.

$RQD = \frac{\Sigma \text{ length of core pieces} > 10\,cm}{\text{Total length of core Run}} \times 100$
16.

$\text{core Recovery} = \frac{\Sigma \text{ length of core pieces}}{\text{Total length of core Run}} \times 100$
17.

$RQD = 115 - 3.3 J_n$ ⑱

$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$ ⑲

Geological strength
20. Index, $GSI = 9 \log\left[\frac{RQD}{J_n} \times \frac{J_r}{J_a}\right] + 44$

$RM_i = \sigma_c \times J_p \begin{cases} 1 = \text{Intack Rock} \\ 0 = \text{crushed Rock.} \end{cases}$ ㉑

$SDI = \frac{A - D}{B - D} \times 100$ ㉒
↳ slack durability Index.

$\sigma_s = c + \sigma_n \tan\theta$ | $\sigma_s = c + \underbrace{(\sigma_n - \xi)}_{\text{effective Normal stress}} \tan\theta$
㉓

unconfined compressive strength, $q_u = \frac{4P}{\pi d^2}$ ㉔

Ring shear test – $S_s = \frac{2P}{\pi d^2}$ ㉕

$\boxed{\text{Triaxial test, } \sigma_1 = \frac{4P}{\pi d^2}}$ ㉖

Block punch test, $BPI = \frac{W}{t} \times (L_1 + L_2)$
W → failure load; t → thickness; $(L_1 + L_2)$ → length of shear

Loss Angeles Abrasion Test, $= \frac{w_1 - w_2}{w_1} \times 100$ ㉗
w_2 ← after test. w_1 → original weight

Hydro potential value, ㉘
$HP_{value} = \frac{RQD}{J_n} \times \frac{J_r}{J_K \times J_{af}} \times J_w$
→ aperture factor

29.
consolidation of soil, m_v
$m_v = \frac{\text{volumetric change in vertical direction}}{\text{unit of press. ↑ in vertical direction}}$

sensitivity of clay, $S_t = \frac{C}{C_R} = \frac{\text{peak undistourbed strength}}{\text{Remolded strength}}$ 30

31
Classification Index $= \frac{D}{L}$

32
Dilation Index $= \frac{w_x}{w_c}$

33
Flowage Index $= \left(\frac{w_x}{w_c} - 1\right) \times \frac{L_m}{L_c} \times 100\,\%$

34
Displacement Index $= \frac{L_r}{L_c}$

35
viscous flow Index, $= \frac{L_f}{D_c}$

36
Tenuity Index $= \frac{L_m}{L_c}$

37
Safety factor $= \frac{R}{D} \frac{\text{(Resistance)}}{\text{driving force}}$

Activity of soil sample, $A = \frac{PI\,\%}{\%\text{ of clay size particle}}$ 38

39. $S = \frac{C_c}{(1+e)} \times H \times \log \frac{\sigma_f}{\sigma_i}$

40. $\eta = 1 - \frac{\rho_{bd}}{\rho_{spd}}$

(P–1)

2. Geochemistry formula

→ 1. $\log K_{sp} = \frac{-\Delta_r G^\circ}{2.303RT}$ | $\Delta G^\circ = -RT\ln K$

2. $SI = \log\left(\frac{IAP}{K_{sp}}\right)$ | $I = \frac{1}{2}\Sigma(m_i z_i^2)$

3. $E_{cell} = E^\circ_{cell} - \frac{0.0591}{\eta}\log Q$

4. Zero ⇒ $C = Kt$
first ⇒ $C = C_0 e^{-kt}$ | $T_{1/2} = \frac{0.693}{K}$

5. $\tau = \frac{1}{K}$ (mean life τ)

A. Equili. or Batch crystallization

6. $\frac{C_l}{C_l^\circ} = \frac{1}{F(1-K_d)+K_d}$ | $\frac{C_s}{C_l^\circ} = \frac{K_d}{F(1-K_d)+K_d}$

B. fractional / Rayleigh crystallization

7. $\frac{C_l}{C_l^\circ} = F^{(K_d-1)}$ | $\frac{C_s}{C_l^\circ} = K_d F^{(K_d-1)}$

C. Equili. or Batch melting

8. $\frac{C_l}{C_s^\circ} = \frac{1}{F(1-P)+D_0}$ | $\frac{C_s}{C_s^\circ} = \frac{D_0}{F(1-P)+D_0}$

D. fractional / Rayleigh melting

D1. modal fracti. melting

9. $\frac{C_L}{C_s^\circ} = \frac{1}{D_0}(1-F)^{\left(\frac{1}{D_0}-1\right)}$

D2. Non-modal fracti. melting.

10. $\frac{C_L}{C_s^\circ} = \frac{1}{D^\circ}\left(1-\frac{PF}{D_0}\right)^{\left(\frac{1}{P}-1\right)}$

11 $\left(\frac{B}{B'}\right)_t = \left(\frac{B}{B'}\right)_0 + \left(\frac{A}{B'}\right)_t (e^{\lambda t}-1)$

12 $t = 1.72\times10^{10}\ \frac{Ar^{40}}{K^{40}}$

13 $\delta^{8}O = \left(\frac{\left(\frac{O^{18}}{O^{16}}\right)_{sample}}{\left(\frac{O^{18}}{O^{16}}\right)_{smow}} - 1\right)\times10^3$

14 $\delta^{18}O_{PDB} = 1.03086\,\delta^{18}O_{smow} + 30.86.$

15 fractionation factor, $\alpha = \frac{R_A}{R_B}$, $R = \frac{18O}{16O}$

16 Enrichment factor, $\Delta_{A-B} = \delta^{18}O_A - \delta^{18}O_B$

17. $\Delta \simeq (\alpha-1)\times10^3 \simeq 10^3\ln\alpha$

Global meteoric water line 18 !

$$\delta^2H = 8\,\delta^{18}O + 10$$

$P = P_0 e^{-\lambda t}$ / $D = P_0 - P$ / $D = P(e^{\lambda t}-1)$ 19

$$D_t = D_0 + D = D_0 + P(e^{\lambda t}-1)$$

- Alpha (α) decay = ${}^4_2X$ $(2p^+)X(2p^+ + 2n^\circ) = U$ 20
- Beta (β) decay = $n^\circ = p^+ + e^-$ (Rb - Sr) 21
- Electron capture = Reverse of Beta $p^+ + e^- = n^\circ$
(K - Ar) 22

Tritium Dating - $T_{1/2} = 12.4$ year 23

$$t = \frac{T_{1/2}}{\ln 2}\times\ln\left(\frac{3He}{3H}+1\right)$$

1 mole = 6.022×10^{23} 24

$1PPM = 1g/m^3 = 1\,mg/L = 1\,\mu g/mL = 1\,mg/kg$

$PH = -\log[H^+]$ 25

1Kcal = 4184 J and 1J = 0.239 cal

26

$\log\frac{K_2}{K_1} = \frac{\Delta H}{2.303R}\left[\frac{T_2-T_1}{T_1T_2}\right]$

$C_p = \frac{dH}{dT}$ (enthalpy) | $\frac{dS}{dT} = \frac{C_p}{dT}$ (s - entropy) 27

$Q = nRT\ln\frac{V_f}{V_i}$ | $\Delta S = \frac{Q}{T} = nR\ln\frac{V_f}{V_i}$ 28

$R = 8.314\ J/mol\text{-}K.$

Clapeyron Equation - $\frac{dP}{dT} = \frac{\Delta S}{\Delta V}$ 29

$E_h = E_h^\circ + \frac{RT}{nF}\ln Q$ $\begin{cases} R = 8.314\ J/mol\text{-}K \\ F = 96405\ C/mol. \end{cases}$

$E_h = E^\circ + \frac{0.059}{n}\log K$ 30

A. upper stability limit of water 31
$E_h = 1.23 - 0.059\,PH$

B. lower stability of water 32
$E_h = -0.059\,PH$

Activity coefficient for neutral species - 33
$\gamma = 10^{0.1I}$

$E^\circ_{cell} = E^\circ_{reduction} + E^\circ_{oxidation}$ 34

$ENd(t) = \left(\frac{\left(\frac{Nd}{Nd}\right)_{sample}}{\left(\frac{Nd}{Nd}\right)_{CHUR}} - 1\right)\times10^4$ 35

3. Geophysics Geology formula

① Kepler 3rd law $\frac{T^2}{a^3} = \frac{4\pi^2}{GM}$ | $U = -\frac{GM}{r}$ (J/kg) J/kg

polar flattenning, $f = \frac{a-c}{c}$ | $a_c = \omega^2 r = \frac{v^2}{r}$ ②

$\boxed{v = r\omega}$

③ 1 mGal = 10 gu = 10^{-5} m/s² = 10^{-6} g

$g_n = g_e(1 + \beta_1 \sin^2\lambda + \beta_2 \sin^2 2\lambda)$

$T = 2\pi\sqrt{\frac{L}{g}}$ ④

1. Terrain correction ⑤

$\Delta g_T = G\rho\phi\left(\sqrt{r^2+h^2} - r_1\right) - \left(\sqrt{r^2+h^2} - r_2\right)$

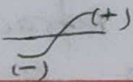
2. Bouguer plate correction

⑥ $\Delta g_{BP} = 2\pi G\rho h \; \{0.0419 \times 10^{-3}\rho$ mgal/m

ρ = kg/m3

3. freeair correction

$\frac{dg}{dr} = -\frac{2g}{r}$, $\Delta g_{FA} = 0.30625$ mgal ⑦



4. combined elevation correction ⑧

	BC	FAC	Result
Above S.L.	−0.1	+0.3	+0.2 mgal/m
below SL	+0.1	−0.1	−0.2 mgal/m

5. Lattitude correction

⑨ $\Delta g_\lambda = 0.841 \sin 2\lambda$ mgal/km²

6. Eotvos correction

$\delta g_{Eot} = 4.040\, v \sin\alpha \cos\lambda + 0.00121 v^2$ mgal

⑩ v - speed (km/hr)

λ = latitude, α - direction of travel.

$z = 0.652w$ |. $w = 2x$

(A) sphere

⑪ $\Delta g_z = \frac{4}{3}\pi G \Delta\rho R^3 \frac{z}{(z^2+x^2)^{3/2}}$

(B) Horizontal cylinder $z = 0.5 \times w$

⑫ $\Delta g_z = 2\pi G R^2 \frac{z}{(x^2+z^2)}$

(C) thin sheet finite l ⑬

(C1) $\Delta g_z = 2G\Delta\rho t\left[\tan^{-1}\frac{x_2}{z} - \tan^{-1}\frac{x_1}{z}\right]$

⑭ semifinite l

(C2) $\Delta g_z = 2G\Delta\rho t\left[\frac{\pi}{2} + \tan^{-1}\frac{x}{z}\right]$

(C3) $\Delta g_z = 2\pi G \Delta\rho t$ ← Infinite ⑮

1. Airy $r_1 = \frac{h_1 \rho_c}{\rho_m - \rho_c}$ | $r_0 = \frac{d(\rho_c - \rho_w)}{(\rho_m - \rho_c)}$ ⑯

2. pratt, $\rho_1 = \frac{D\rho_c}{(h_1 + D)}$ | $\rho_0 = \frac{D\rho_c - \rho_w d}{(D - d)}$ ⑰

$v_p = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}} = \sqrt{\frac{\lambda + 2\mu}{\rho}}$ | $V_s = \sqrt{\frac{\mu}{\rho}}$ ⑱

$\lambda + \frac{2}{3}\mu = K$ | $v_p^2 - \frac{4}{3}V_s^2 = \frac{K}{\rho}$ ⑲

$E = \frac{\mu(3\lambda + 2\mu)}{\lambda + \mu} = 3K(1 - 2\nu) = 2\mu(1 + \nu)$ ⑳

$\nu = \frac{\lambda}{2(\lambda + \mu)}$ | $\nu = \frac{1}{2}\left(\frac{V_p^2 - 2V_s^2}{V_p^2 - V_s^2}\right)$ | $Z = \rho \times v_p$ ㉑

Reflection coefficient,

$RC = \frac{Z_2 - Z_1}{Z_2 + Z_1}$, $TC = 1 - RC = \frac{2Z_1}{Z_2 + Z_2}$ ㉒

Energy reflected ㉓

$E_r = (RC)^2$, $E_t = 1 - E_r$

$V_{LR} = 0.92 \times V_s$ | $\beta_1 < V_{LQ} < \beta_2$ ㉔

$t_s - t_p = t_p\left(\frac{V_p}{V_s} - 1\right)$ | $t_s - t_p = D\left(\frac{1}{V_s} - \frac{1}{V_p}\right)$ ㉕

focal depth, $h = \frac{V_p}{2}(t_{pp} - t_p)$ ㉖

$M_s = \log\left(\frac{A}{T}\right)_{max} + 1.66 \log(\Delta) + 3.3$ ㉗

Earthquake frequency, $\log(N) = a - bM$ {$b \simeq 1$ ㉘

Earthq. energy, $\log_{10}(E) = 4.8 + 1.5 M_s$ ㉙

earth. Intensity, $I_{max} = 1.5 M_s - 1.8 \log h + 1.7$ ㉚

Seismic moment, $m_0 = \mu SD$ (N-m) ㉛

moment magnitude, $m_w = \frac{2}{3}(\log m_0 - 9.1)$ ㉜

(A) Elastic modulus = $\frac{\text{Stress}}{\text{Strain}}$ ㉝

(B) young modulus $E = \frac{\text{longitudinal stress}}{\text{longitudinal strain}} = \frac{F/A}{\Delta l/l}$ ㉞

(C) Bulk modulus, $K = \frac{\text{volume stress}}{\text{Volume strain}} = \frac{P}{\Delta V/V}$ ㉟

P-3

(D) Shear modulus

㊱ $$\mu = \frac{\text{shear stress}}{\text{shear strain}} = \frac{\tau}{\tan\psi}$$

(E) poisson's Ratio

㊲ $$\sigma = \frac{\text{transverse contractional strain}}{\text{longitudinal extensional strain}}$$

1. Energy - amplitude Relationship of a wave

㊳ $$E \alpha A^2$$

2. (2A) Intensity (or ~~de~~ energy density I_b) of body wave

㊴ $$I_b(r) = \frac{E_b}{2\pi r^2}$$ {r = distance

(2B) Intensity of surface wave (I_s)

㊵ $$I_s(r) = \frac{E_s}{2\pi r d}.$$

3. Relation b/t Intensity of a wave (I) and its amplitude (A)

㊶ $$I \alpha A^2$$

4. Anelastic damping (absorption)

㊷ $$\frac{2\pi}{Q} = -\frac{\Delta E}{E}$$

Quality factor → Q

ΔE → energy lost

E → total energy.

5. ㊸ $$\frac{1}{v_b} = \frac{\phi}{v_f} + \frac{1-\phi}{v_m}$$

6. Slope of wadati diagram or plot -

㊹ $$= \frac{T_S - T_P}{T_P} = \frac{T_S}{T_P} - 1$$

7. Gutenberg - Richter Recurrence law / Earthquake frequency -

㊺ $$\text{Return period} = \frac{1}{\text{annual Rate of exceedance}}$$

8. ㊻ $$\text{No. of fold }(n) = \frac{\text{No. of Geophones or Reciever} \times \text{reciever spacing}}{2 \times \text{shot spacing}}$$

9. Total Reflection

㊼ $$\frac{\sin\theta_c}{\sin 90^\circ} = \frac{v_1}{v_2} \Rightarrow \theta_c = \sin^{-1}\left(\frac{v_1}{v_2}\right)$$

P-4

㊽ $$t_{direct} = \frac{x}{V_1} \quad \Big| \quad t_0 = \frac{2d}{V}$$

㊾ $$t_{reflected} = \frac{\sqrt{x^2 + 4z^2}}{v_1}$$

㊿ $$t_{refracted} = \frac{x}{v_2} + \frac{2z\cos\theta}{v_1}$$

(51) $$\text{slope} = \frac{1}{v_2}$$

$$\text{Intercept on time axis} = \frac{2z\cos\theta_c}{v_1} \quad \text{or} \quad \frac{2z}{v_1 v_2} \times \sqrt{(v_2^2 - v_1^2)}$$

(52) $$\text{move out} = t_2 - t_1 = \frac{x_2^2 - x_1^2}{2v^2 t_0}$$

(53) Normal moveout (NMO) -

$$NMO = \Delta T = t_x - t_0 = \frac{x^2}{2v^2 t_0}$$

(54) $$x_{cross} = 2d\sqrt{\frac{V_1 + V_2}{V_2 - V_1}}$$

(55) critical Refraction

$$\theta_c = \sin^{-1}\left(\frac{V_1}{V_2}\right)$$

(56) $$t^2 = t_0^2 + \frac{x^2}{v^2}$$

A. complete compensation = (-ve) gravity anomaly (57)

Real Root = computed Root

B. over compensation = (-ve) gravity anomaly (58)

Real roots >> computed Root

C. undercompensation = (+ve) gravity anomaly (59)

Real Root << computed Root

(60) $$v_P > v_S > V_L > V_R$$

$$\frac{v_P}{v_S} = \sqrt{\frac{2\sigma - 2}{2\sigma - 1}} \quad \Big| \quad \nu = \frac{1}{2}\left[\frac{\left(\frac{v_P}{v_S}\right)^2 - 2}{\frac{v_P^2}{v_S^2} - 1}\right]$$

$$\frac{P_1}{2S} = \frac{\cos\theta_2}{\sin(\theta_1 + \theta_2)} \quad \Big| \quad \frac{P_2}{2S} = \frac{\cos\theta_1}{\sin(\theta_1 + \theta_2)}$$

$$d_n = 0.4 + 0.3 \times 2^{n-2} \quad \text{for } n \geq 2$$

$$t_s - t_p = D$$

$$\frac{\sin i}{\sin r} = \frac{\alpha_1}{\alpha_2} = \frac{V_1}{V_2}$$

$$\frac{180}{\pi R} \times \Delta(\text{km}) = \cancel{x}^\circ$$

(61) Ohm's law - $V = IR$

(62) Resistance $(\Omega) = \frac{1}{\text{Conductance}(S)}$

(63) Resistivity (ρ), $R = \frac{\rho L}{A}$

(64) conductivity $(\sigma) = \frac{1}{\text{Resistivity}(\rho)}$

$(\Omega^{-1}m^{-1})$ $(\Omega \cdot m)$

(65) current density $J = \frac{I}{A}$ (A/m^2)

(66) capacitance $(C) = \frac{Q}{V}$ → charge, → potential diff.

1. pole-pole

(67) $r_1 = a, r_2 = \infty, r_3 = \infty, r_4 = \infty$

$$K = \frac{2\pi}{\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right)} = \frac{2\pi}{\left(\frac{1}{a} - 0\right)} = 2\pi a$$

2. pole-dipole

(68) $r_1 = na, r_2 = \infty, r_3 = a(n+1), r_4 = \infty$

$$K = \frac{2\pi}{\left(\frac{1}{na} - 0 - \frac{1}{a(n+1)} + 0\right)} = 2\pi an(n+1)$$

3. dipole-dipole

$r_1 = na, r_2 = a(n+1), r_3 = a(n+1)$
$r_4 = a(n+2)$

(69) $K = \pi an(n+1)(n+2)$ $\left\{ \rho_a = \frac{\Delta V}{I} K \right.$

4. wenner array

(70) $r_1 = r_4 = a, \; r_2 = r_3 = 2a$

$\rho_a = 2\pi a \frac{\Delta V}{I}$

5. Schulumberger Array

$r_1 = r_4 = \frac{L-a}{2}, \; r_2 = r_3 = \frac{L+a}{2}$

(71) $\rho_a = \pi \left(\frac{L^2 - a^2}{4a}\right) \frac{\Delta V}{I}$

6. electrical law of Refraction

(72) $\frac{\tan\theta_1}{\tan\theta_2} = \frac{\rho_2}{\rho_1}$

7. Resistivity Contrast

(73) $K = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1}$

$A = \rho_1 < \rho_2 < \rho_3$ (74)
$H = \rho_1 > \rho_2 < \rho_3$
$K = \rho_1 < \rho_2 > \rho_3$
$Q = \rho_1 > \rho_2 > \rho_3$

(P-5)

1 gauss $= 10^{-4}$ T / gamma $(\gamma) = 10^{-5}$ gauss (75)
$= 10^{-9}$ T or nT

polar angle, $\theta = 90 - \lambda$ (λ magnetic latitude) 76
$\tan I = 2\cot\theta = 2\tan\lambda$ (I - m. inclination)

$$B_r = -\frac{\mu_0}{4\pi} \frac{2m\cos\theta}{r^3} = -\frac{\mu_0}{4\pi} \frac{2m\sin\lambda}{r^3}$$ (77)

$$B_\theta = -\frac{\mu_0}{4\pi} \frac{m\sin\theta}{r^3} = -\frac{\mu_0}{4\pi} \frac{m\cos\lambda}{r^3}$$ (78)

$$B_t = \sqrt{B_r^2 + B_\theta^2} = \frac{\mu_0 m}{4\pi} \frac{\sqrt{1 + 3\cos^2\theta}}{r^3}$$ (79)

$$= \frac{\mu_0 m}{4\pi} \frac{\sqrt{1 + 3\sin^2\lambda}}{r^3}$$

$B_t = 30000$ nT at Equator / $B_t = 60000$ nT at poles. (80)

Altitude correction - $\frac{\partial B_t}{\partial r} = -\frac{3}{r} B_t$ (81)

At equator, 0.015 nT m^{-1} / At pole, 0.030 nT m^{-1} (82)

Latitude correction, $\frac{\partial B_t}{r\partial\theta} = \frac{3B_t \sin\theta \cdot \cos\theta}{r(1 + 3\cos^2\theta)}$ (83)

maxi. value of 5nT/km at intermediate latitude. (84)

(A) magnetic anomaly for sphere (85)

$$\Delta B_z = \frac{1}{3} \mu_0 R^3 \Delta M_z \frac{(2z^2 - x^2)}{(z^2 + x^2)^{5/2}} \quad \{\Delta M = (K - K_0)F$$

(B) Horizontal cylinder (86)

$$\Delta B_z = \frac{1}{2} \mu_0 R^2 \Delta M_z \frac{z^2 - x^2}{(z^2 + x^2)^2}$$

1. Koenigsberger Ratio (Q) (87)

$$Q = \frac{\text{Remanent magnetization}}{\text{Induction magnetization}}$$

2. Larmor frequency or processional frequency

$2\pi f = \gamma B$ (88)

Global = 1000 - 10000 km
Regional = 100 - 1000 km
macroscopic = 10 - 100 km
mesoscopic = 1cm - 100 m (hands sample)
microscopic = 10^{-8} - 10^{-6} km (optical microscope)
Submicroscopic = less than 10^{-8} km (TEM, SEM

4. Geomoophology formula

①
Drainage density, $D = \frac{L}{A}$

Texture ration $T = \frac{N}{P}$ – No. of crenulation → perimeter of basin ②

Bifurcation Ratio, $R_b = \frac{N_u}{N_{u+1}}$ ③

Drainage basin Asymmetry,

$A_f = \frac{A_r}{A_t} \times 100$ → Area Right site of stream ④ → total Basin area.

Drainage Basin Shape, $R_f = \frac{A_t}{L^2_b}$ → Basin Area. → Basin length ⑤

Discharge, $Q = w.d.v$ ⑥

meander wavelength, $L = KQ^x$ ⑦

→ Sinuosity Index, $S = \frac{\text{stream length}}{\text{valley length}} = \frac{\text{thalweg length}}{\text{valley length}} = \frac{\text{channel length}}{\text{meander length}}$ ⑧

Ripple Index $RI = \frac{\text{Ripple length or wavelength}}{\text{ripple hight}}$ ⑨

Symmetry Index, $SI = \frac{\text{stoss length}}{\text{lee length}}$ ⑩

Roundness Index, $RDI = \frac{a}{b}$ ⑪

Iribarren Number –

$\epsilon = \frac{\tan\alpha}{\sqrt{\frac{H}{L_0}}}$ – angle of seaward slope of a structure. – wave hight – deep water wavelength. ⑫

⑬
Reynolds Number

$Re = \frac{\rho u L}{\mu} = \frac{uL}{v}$

Froude Number, $f_r = \frac{u_0}{\sqrt{g_0 l_0}}$ – flow velocity – length $\left(\frac{v}{\sqrt{gd}}\right)$

⑭

steady flow	unsteady flow
$\frac{dv}{dt} = 0$	$\frac{dv}{dt} \neq 0$ (v – flow velocity)
$\frac{d(d)}{dt} = 0$	$\frac{d(d)}{dt} \neq 0$ (d – depth)

⑮

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uniform flow	Non-uniform flow
$\frac{dv}{dx} = 0, \frac{d(d)}{dx} = 0$	$\frac{dv}{dx} \neq 0, \frac{d(d)}{dx} \neq 0$

⑯

channel gradient or channel Bedslope (S)

$S = \frac{dz}{dx}$ – elevation – distance along the channel. ⑰

$S = \tan\theta$.

⑱
watted perimeter (P_w) $= w + 2d$ (width of open channel; channel depth.)

⑲
Stream power (ω) $= \rho_w \cdot g \cdot Q \cdot S$ ← slope

Hydraulic Radius, $R_h = \frac{A}{P_w}$ → cross sectional area of flow in channel → watted perimeter. ⑳

㉑
Driving force, $w_s = w \sin\theta$ ← weight of water

$= \rho_w \cdot g \cdot v \cdot \sin\theta$ → angle of inclination

Bed shear Stress or Depth Slope product ㉒

$\tau_b = \rho_w \cdot g \cdot S \cdot R_h = \rho_w \cdot g \cdot S \cdot d$.

㉓
frictional force of Resistance (f_R)

$\tau_b = \frac{f_R}{A_{CB}} = \frac{f_R}{(2d+w)L}$

$A_{CB} = wL + 2dL = (2d+w)L$

㉔
A. chezy equation

mean flow velocity – $v = C\sqrt{R_h \cdot S}$ → channel gradient. ↳ hydraulic Radius

㉕
B. manning's equation for open channel flow –

$v = \frac{1}{n} \cdot R_h^{2/3} \cdot S^{1/2}$

㉖
stream's kinetic energy

$E_K = \frac{1}{2} \cdot m \cdot v^2$

Flint's law – $S = K_s \cdot A^{-\theta}$ → concavity index. ㉗

channel steepness

stream concavity index

㉘ $$SCI = \frac{\text{Area (unshaded)}}{0.5}$$

Drainage density,

㉙ $$D_d = \frac{\sum_1^i L}{A_b}$$
$\sum L$ - stream length
A_b - drainage basin area.

㉚ Relief Ratio (R_h) = $\frac{\text{Relief of Basin (H)}}{\text{length of Basin (L)}}$

㉛ Ruggedness Number = Basin Relief (H) × drainage density (Dd)

elongation Ratio (Re)

㉜ $$R_e = \frac{D}{L} = \frac{2}{L}\sqrt{\frac{A_b}{\pi}}$$

circularity Ratio (Rc)

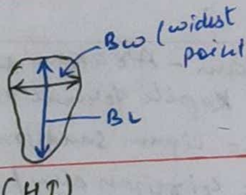
㉝ $$R_c = \frac{\text{Area of Basin}}{\text{Area of desired circle}} = \frac{A_b}{\left(\frac{P^2}{4\pi}\right)} = \frac{4\pi A_b}{P^2}$$

stream length gradient index (S_L)

㉞ $$S_L = \left(\frac{\Delta H}{\Delta L}\right) \times L$$

Basin shape index (B_s)

㉟ $$B_s = \frac{B_L}{B_w}$$



Hypsometric integral (HI)

㊱ $$HI = \frac{h_{mean} - h_{min}}{h_{max} - h_{min}}$$

mountain front sinuosity (S_{mf})

㊲ $$S_{mf} = \frac{L_{mf}}{L_s}$$
L_s → length along straight line.

valley floor width to height Ratio (V_f)

㊳ $$V_f = \frac{2V_{fm}}{E_{ld} + E_{rd} - 2E_{sc}}$$
V_{fm} → width of valley floor
E_{sc} - elevation of valley floor

Glacial flow, shear stress

$$\tau_0 = \rho_i \cdot g \cdot h \cdot \sin\beta$$

㊴

weathering index (wi)

㊵ $$wi = \left(\frac{(X_s/I_s)}{(X_p/I_p)} - 1\right) \times 100$$

$X_{s/p}$ - concentration desired / ~~[illegible]~~ element in sample

I_s - concentration of immobile in primary rock.

weathering Ratio (WR) ㊶

$$WR = \frac{CaO + MgO + Na_2O}{ZrO_2}$$

Chemical Index of Alteration (CIA) ㊷

$$CIA = \left[\frac{Al_2O_3}{Al_2O_3 + CaO + Na_2O + K_2O}\right] \times 100$$

Chemical Index of weathering (CIW) ㊸

$$CIW = \left[\frac{Al_2O_3}{Al_2O_3 + CaO + Na_2O}\right] \times 100$$

→ Deviatoric stress (shape change only)

$\sigma_{dev} = \sigma_n - \sigma_m$ | $\sigma_m = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3}$

→ Dilation - change in size (volume)

→ Differential stress = $\sigma_1 - \sigma_3$

→ Effective stress, = σ_N - pore fluid pressure

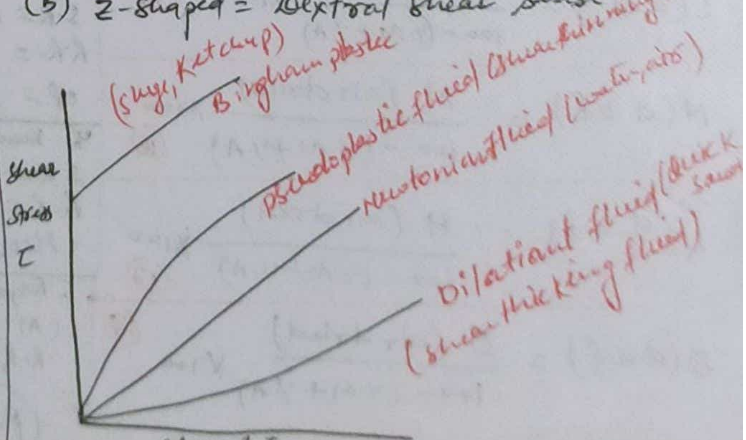
→ $\sigma_{total} = \sigma_m + \sigma_{dev}$

→ (A) in fracture = $\perp \sigma_3$ and $= \sigma_1$

→ (B) in foliation = $\perp \sigma_1$ and $= \sigma_3$

→ (A) S-shaped = Sinistral shear sense

(B) Z-shaped = Dextral shear sense



5. Ore Geology formula

① fixed carbon, $fc = 100 - (\%M + \%A + \%vm)$

② $$\%M = \frac{\text{weight loss}}{\text{weight of sample}} \times 100$$

③ $$\%VM = \frac{\text{weight loss due to VM}}{\text{weight of sample}} \times 100$$

④ weight loss due to VM = Total weight loss − moisture

⑤ $$\%A = \frac{\text{weight of Residual}}{\text{weight of sample}} \times 100$$

⑥ Ash = mineral matter − water of Hydration

⑦ $$\text{Fuel Ratio} = \frac{\text{fixed carbon}}{\text{volatile matter}}$$

⑧ $$V.M(d.a.f.) = \frac{V.M(\text{air dried})}{100 - (\%M + \%A)} \times 100$$

(dry ash free)

⑨ % mineral matter = $1.1 \times A\%$

⑩ Oxygen % = $100 - (C\% + H, N, S, A\%)$

⑪ % Fc on dry basis = $100 - (\%M + \%A)$

⑫ % Fc on dry Ash free basis = $100 - \%vm$

⑬ $$\%A \text{ or } \%VM(\overset{dry}{\cancel{daf}}) = \frac{\%A \text{ or } \%VM}{(100 - \%M)} \times 100$$

⑭ Analysis on dry ash free basis

$$= \frac{\%VM}{100 - (M\% + A\%)} \times 100$$

⑮ $$C(daf.) = \frac{C(\text{air dried})}{100 - (\%M + \%A)} \times 100$$

⑯ $$N(d.a.f.) = \frac{N(\text{air dried})}{100 - (\%M + \%A)} \times 100$$

⑰ $$H(d.a.f) = \frac{H(\text{Air dried})}{100 - (\%M + \%A)} \times 100$$

⑱ $$O(d.a.f) = \frac{O(\text{air dried})}{100 - (\%M + \%A)} \times 100$$

calorific value = $82\,fc + \alpha.VM$ Calories

⑲ $$\alpha = \frac{VM \times 100}{fc + VM}$$

⑳ Humic coal

- vitrain = vitreous lusture/conchoidal fracture
- Clarain = Silky lustrous/Alternating Bands B/D
- Durain = Dull lust/Break into lumps
- fusain = soft, friable/black fibrous powder

Sapropelic coal (Non Banded)

- channel = unstratified very hard
- Boghead = Brown streak.

㉑ Tonnage = volume of ore body x specific gravity

㉒ metal content = tonnage x grade (Assay value)

㉓ $$API = \frac{141.5}{\text{specific gravity of crude oil}} - 131.5$$

Reserve Estimation-

porosity

water saturation

㉔ $$STOIIP = GRV \times \frac{N}{G} \times \phi \times 1 - Sw \times \frac{1}{Bo}$$

formation volume factor (Bo)

1. Assam - Arakan Basin -
   S.R = Kopili formation (Eocene)
   R.R = Tipam sandstone (miocene), Barail fm
   oligocene
   C.R. = Girujan clay / Kopili formation
   - Naharkatiya, Lakwa, Rudrasagar, Digboi, mukum

2. Cambay Basin -
   S.R = cambay shale (paleocene - Eocene)
   R.R = Kalol fm, Ankhleshwar fm
   CP = Tarapur Shale.
   - Kalol, Nawgam, cambay, Ankleshwar

3. Cauvery Basin -
   S.R = sattapadi shale (cretaceous)
   R.R. = Bhuvangiri and Nannilam fm
   CP = sattapadi Shale

4. mumbai offshore
   S.R = panna fm (paleocene - Eocene)
   R.R = Limestone (miocene)
   - Heere, panna, Basseen, Neelam, mukta, Ratna

5. Rajasthan Basin
   (A) Jaisalmer Basin = S.R = Baisakhi Shales
   R.R = Baisakhi, Goru, sanu sst and fractured lmt of Jaisalmer fm
   (B) Bikaner Nagpur Basin
   S.R = Karampur Shale / RR = Jodhpur sst, Nagpur Nagaur sst.

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6- Structure Geology formula -

$$\sigma_n = \frac{\sigma_3+\sigma_1}{2} + \frac{\sigma_1-\sigma_3}{2}\cos(2\theta)$$ ①

$$\tau = \frac{\sigma_1-\sigma_3}{2}\sin 2\theta$$ $\left\{ \begin{array}{l} \theta \text{ - is the angle} \\ \text{plane makes} \\ \text{with } \sigma_3 \end{array} \right.$ ②

(A) Hydrostatic pressure (water) or lithostatic pressure (Rock) ③

$$\sigma_1 = \sigma_2 = \sigma_3 = P$$

(B) uniaxial stress

(B₁) uniaxial compression - ④

$$\sigma_1 > 0, \quad \sigma_2 = \sigma_3 = 0$$

(B₂) uniaxial tension - ⑤

$$\sigma_3 < 0, \quad \sigma_1 = \sigma_2 = 0$$

(C) Biaxial stress - ⑥

$$\sigma_2 = 0, \quad \sigma_1 > 0 > \sigma_3$$

(D) General triaxial stress ⑦

$$\sigma_1 > \sigma_2 > \sigma_3 \neq 0$$

mohr - coulomb fracture criteria ⑧

$$\tau = \sigma_n \tan\theta + c$$

Griffith tensional criteria ⑨

$$\tau^2 \ast 4T\sigma_n - 4T^2 \rightarrow T = \text{critical tension stress}$$

$$\tau = \eta\gamma \left\{ \begin{array}{l} \eta = \text{modulus of Rigidity} \\ \gamma = \text{Shear strain} \end{array} \right.$$ ⑩

$$\tau = \mu\frac{du}{dy} \left\{ \begin{array}{l} \frac{du}{dy} \text{ - velocity gradient} \\ \mu \text{ - viscosity.} \end{array} \right.$$ ⑪

Shear strain, $\gamma = \tan\psi$ ⑫

$$\sigma = E\varepsilon \left\{ \begin{array}{l} E = \text{young's modulus} \\ \varepsilon = \text{longitudinal} \end{array} \right.$$ ⑬

$$\sigma = -K\theta \left\{ \begin{array}{l} \theta = \text{fractional change in volume} \\ K = \text{Bulk modulus} \end{array} \right.$$ ⑭

$$\sigma = 2\mu\dot{e} \left\{ \begin{array}{l} \mu = \text{viscosity} \\ e = \text{strain Rate} \end{array} \right.$$ ⑮

Elongation (engineering is extension) ⑯

$$e = \frac{l_f - l_0}{l_0}$$

stretch, $T = \frac{l_f}{l_0} = 1+e$ ⑰

Quadratic elongation, $I = T^2 = (1+e)^2$ ⑱

Natural strain (Logarithmic strain) ⑲

$$E = \ln(1+e) = \ln T$$

Biot - Ramberg equation ⑳

$$L = 2\pi t\left(\frac{\mu_1}{6\mu_2}\right)^{1/3}$$

(A) High viscosity contrast result in long wavelength ㉑

(B) low viscosity contrast results in short wavelength and produces layer thickening ㉒

thicker layer also produces longer wavelength

$$\tan(\text{dip angle}) = \frac{\text{contour interval}}{\text{contour spacing}}$$ ㉓

$$\text{Net slip} = \sqrt{(\text{strike slip})^2 + (\text{dip slip})^2}$$ ㉔

$$\text{Dip of fault plane} = \tan^{-1}\left(\frac{\text{throw}}{\text{Heave}}\right)$$ ㉕

$$\text{Hade of fault} = 90 - \text{dip of fault plane} = \tan^{-1}\frac{\text{Heave}}{\text{throw}}$$ ㉖

$$\text{Dip slip of fault} = \sqrt{(\text{throw})^2 + (\text{Heave})^2}$$ ㉗

$$\tan(\text{plunge}) = \frac{\text{contour interval}}{\text{contour spacing in direction of plunges.}}$$ ㉘

$$\sigma_{\text{Total}} = \sigma_m + \sigma_{\text{dev}} \rightarrow \text{deviatoric stress}$$ ㉙

$$\swarrow \text{ mean stress} = \frac{\sigma_1+\sigma_2+\sigma_3}{2}$$

(A) Extensional Duplex = strike slip + Normal slip

↳ Normal / Negative flower structure / tulip structure

(B) Contractional Duplex -

= strike slip + Reverse slip

↳ Reverse / positive flower structure / palm structure

(C) Radius, $\frac{\sigma_1-\sigma_3}{2}$ and (D) center, $\frac{\sigma_1+\sigma_3}{2}$

7. sedimentology – formula

$$C_E = \frac{\text{Entraining forces}}{\text{Resisting forces}}$$ ①

$$C_T = \frac{\text{Transporting forces}}{\text{Resisting forces}}$$ ②

impact force $F = \frac{\Delta P}{\Delta t}$ – change in momentum of the body

$P = mv \left(\frac{kg \cdot m}{sec}\right)$ ③

Bernoulli Equations – ④

$$E = PV + mgh + \frac{mv^2}{2} = \text{constant}$$

Total energy per unit volume ⑤

$$\underbrace{\rho g h}_{\text{potential energy}} + \underbrace{\tfrac{1}{2}\rho v^2}_{\text{kinetic energy}} + \overset{\uparrow}{P} + E_{loss} = \text{constant}$$

pressure energy

Drag force, $f_{drag} = \frac{1}{2} C_D \cdot A \cdot \rho \cdot v^2$ ⑥

terminal or settling velocity – ⑦

$$V_s = \frac{D^2 \cdot g \cdot (\rho_s - \rho_f)}{18 \mu}$$ { D-grain diameter of particle

phi scale, $\phi = -2 \log_2(\text{graindiameter mm})$ ⑧

$$\text{Ripple Index (RI)} = \frac{\text{Ripple wavelength}}{\text{Ripple height}} =$$ ⑨

$$= \frac{\text{lee length} + \text{stoss length}}{\text{Ripple height}}$$

Ripple Symmetry Index (RSI) ⑩

$$RSI = \frac{\text{stoss length}}{\text{lee length}}$$

(A) Rock mud supported
(i) mudstone (grains < 10%)
(ii) wackestone (grains > 10%)
(A) Rock grain supported
(i) pack stone (mud > 10%)
(ii) Grainstone (mud < 10%)

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6. Krishna Godavari Basin –

(A) pre trappean petroleum System

SR = Kommugudem fm (upper early permian)
R·R = mandapeta sst (permo-triassic)
CR = tight layer within mandapeta sst and overlying argillaceous Red Bed.

(B) late Jurassic cretaceous petroleum system

S·R = Raghavapuram shale (lower cretaceous)
R-R = Tirupati sst (upper cretaceous) Gollapalli fm
CR = Raghavapuram shale and Razole fm

(C) post Trappean petroleum system

SR = palakollu shale (paleocene)
R-R = pasarlapudi fm (lower to middle eocene)
CR = laterally persistent shale within pasarlapudi fm and palakollu shale.

(A) Turbidites have rippled or flat top.
(B) Densite have sand volcanoes or flat top.
(C) Noncohesive debrite have flat top
(D) cohesive debrite irregular top.

→ Bouma sequence from bottom to top –
(A) massive sand > (B) laminated sand > (C) cross laminated sand > (D) laminated silt sand > (E) laminated mud.

→ ① order of sedimentary Rock – mudstone > sandstone > limestone.

→ ooids formation are (Agitated) shallow environment, tropics, supersaturated with calcium carb.

→ froude No. is ratio of flow inertia to external field.

→ Hypolimnion layer in lake, coldest in summer and warmest in winter.

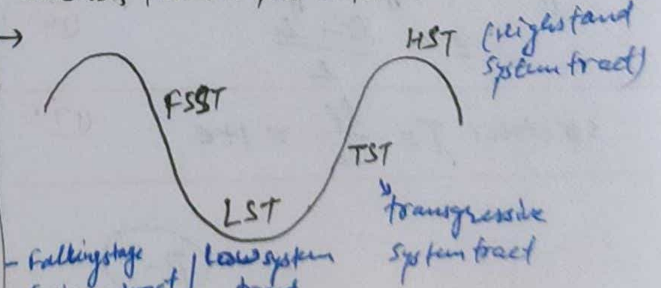
→ Sorting gets better as one goes from proximal fan (Head) – mid fan – distal fan (end)

→ Geodes are pseudomorphs of evaporites nodules inside a spherically cavity.

→ more sand in flaser bedding and more mud in lenticular bedding.

→ stable facies = atectonic, / flysch facies = pre-tectonic / molasses facies = post tectonic

→



1. Triclinic
$a \neq b \neq c$
allangle $\neq 90$

- 1 — None - pedial
- $\bar{1}$ — i - pinacoidal - Ex - microcline, plagioclase, turquoise, wollastonite

2. monoclinic
$a \neq b \neq c$
a/b and b/c $= 90^\circ$
but c/a $> 90^\circ$

- 2 — $1A_2$ - Domatic (Sphenoidal) - Ex = Amicite, calcioferrite
- m — $1m$ - prismatic → Antigorite
- $2/m$ — $i, 1A_2, 1m$ → Ex - mica, Azurite, chlorite, cpx, epidote, gypsum, malachite, Kaolinite, orthoclase, talc

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3. orthorhombic
$a \neq b \neq c$
allangle $= 90^\circ$

- 222 - $3A_2$ - Rhombic disphenoidal
- $2mm$ - $1A_2, 2m$ - Rhombic-pyramidal - Hemimorphite
- $2/m\ 2/m\ 2/m$ - $i, 3A_2, 3m$ - Rhombic-dipyramidal - Ex - Andalusite, → anthophyllite, Aragonite, Barite, cordierite, olivine, sillimanite, stibnite, Sulfur, topaz

4. tetragonal
$a_1 = a_2 \neq c$
allangle $= 90^\circ$

- 4 - $1A_4$ - Tetragonal pyramid → wulfinite mineral
- $\bar{4}$ - $\bar{A}_4$ - tetragonal disphenoidal
- $4/m$ - $i, 1A_4, 1m$ - tetragonal dipyramidal - scheelite, scapolite mineral.
- 422 - $1A_4, 4A_2$ - tetragonal trapezohedral
- $4mm$ - $1A_4, 4m$ - ditetragonal pyramidal
- $\bar{4}2m$ - $1\bar{A}_4, 2A_2, 2m$ - tetragonal scalenohedral - chalcopyrite, stannit
- $4/m\ 2/m\ 2/m$ - $i, 1A_4, 4A_2, 5m$ - ditetragonal dipyramidal - Anatase, → Cassiterite, Apophyllite, zircon, vesuvianite

5. Hexagonal
$a_1 = a_2 = a_3 \neq c$
all a_{1-3} to c $= 90^\circ$
all angle b/t axis $= 60^\circ$

- 3 - $1A_3$ - trigonal pyramidal
- $\bar{3}$ - $1\bar{A}_3$ - Rhombohedral
- 32 - $1A_3, 3A_2$ - Trigonal trapezohedral
- $3m$ - $1A_3, 3m$ - ditrigonal pyramidal
- $\bar{3}\ 2/m$ - $1\bar{A}_3, 3A_2, 3m$ - Hexagonal scalenohedral
- 6 - $1A_6$ - ~~Trigonal~~ Hexagonal pyramid
- $\bar{6}$ - $1\bar{A}_6$ - trigonal dipyramid
- $6/m$ - $i, 1A_6, 1m$ - Hexagonal dipyramid
- 622 - $1A_6, 6A_2$ - Hexagonal trapezohedral
- $6mm$ - $1A_6, 6m$ - Dihexagonal - pyramidal
- $\bar{6}m2$ - $1\bar{A}_6, 3A_2, 3m$ - ditrigonal dipyramidal
- $6/m\ 2/m\ 2/m$ - $i, 1A_6, 6A_2, 7m$ - dihexagonal - dipyramidal

6. isometric
$a = b = c$
all angle 90°

- 23 - $3A_2, 4A_3$ - Tetrartoidal
- $2/m\ \bar{3}$ - $3A_2, 3m, 4\bar{A}_3$ - diploidal
- 432 - $3A_4, 4A_3, 6A_2$ - Gyroidal
- $\bar{4}3m$ - $3\bar{A}_4, 4A_3, 6m$ - hextetrahedral
- $4/m\ \bar{3}\ 2/m$ - $3A_4, 4\bar{A}_3, 6A_2, 9m$ - hexoctahedral

→ Qtz wedge = 0-3800 nm

→ mica plate = 150 nm

→ Gypsum plate = 550nm

1. Triclinic System - (A) Albite law - plagioclase, shows albite polysynthetic twining
(B) twin law - {010} - twin occur perpendicular to crystallographic axis.
(C) pericline law - [010] as the twin axis

- combination of pericline and albite twining produce cross hatched pattern, called tartan twining
spangolite

2. monoclinic system - (A) manebach law - {001} B- orthoclase
(B) carlsbad law - [001]
(C) Braveno law - {021}
(D) Swallow tail twin - {100} Ex- Gypsum, also known Butterfly twin
Hardorite ⇄ fish tail and dove tail twins.

3. orthorhombic system - (A) cyclical twins - {110} Ex - Aragonite ($CaCO_3$), chrysoberyl ($BeAl_2O_4$), cerrusite ($PbCO_3$)
(B) staurolite law - Ex - staurolite mineral

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4. Tetragonal system - It is cyclinic twin
(A) Rutile (TiO_2)
(B) cassiterite (SnO_2)
(C) Geniculated - Rutile

$\bar{2}$ is not unique ($\bar{2}=m$)
$\bar{3}$ is unique
$\bar{4}$ is unique
$\bar{6}=\frac{3}{m}$ (Not unique)

Hexagonal Crystal $h+k+i=0$
uniaxil - Hexagonal, tetragonal
Biaxial - mono, triclinic, cubic

$\Delta = t(\underset{\text{slow}}{n_1} - \underset{\text{fast}}{n_2})$
(A) if $\omega > \varepsilon$ = Negative (calcite)
(B) $\omega < \varepsilon$ = positive (Qtz)
(C) RI ⇑ then velocity ⇓

5. Hexagonal System -
(A) calcite twin < {0001} / {01$\bar{1}$2} - Rhombohedron
(B) Quartz < Brazil law - {11$\bar{2}$0} / Dauphine law [0001] / Japanese twin {11$\bar{2}$2} - contact twin that result from accidents during growth.
sphene | titanite

6. isometric system -
(A) spinel law - {$\bar{1}\bar{1}$1} - spinel ($MgAl_2O_4$) Galena {penetration twin = Diamond, chalcopyrite, Cinnabar, Dyscrasite, tetrahedrite)
(B) [111] - A_3 Rotational symmetry
(C) iron cross - [001] - pyrite (FeS_2)

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1. Triclinic System :- microcline, chalcanthite, Amblygonite, axinite, kyanite, microcline, feldspar (including Amazonite and aventurine), plagioclase feld (including labradorite), rhodonite, and turquoise, wollastonite, Kaolinite.

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uniaxial
- (A) positive - QTZ (prolate shape), leucite, Rutile, stishovite, zircon, ~~cas~~ cassiterite, Apophyllite, zincite, cinnabar, Brucite, Aluvite
- (B) Negative - calcite (oblate shape), cristobalite, Nepheline, tourmaline, Apatite, corundum, Dolomite, magnesite, scapolite, Beryl, siderite, Hematite,

biaxial
- (A) positive - forsterite, (> angle) chlorite, Topaz, Albite, Gypsum, coesite, olivine, Jadeite, Azurite, monzite,
- (B) negative - muscovite, orthoclase, Sanidine, Talc, fayalite, Biotite, Glauconite, Lepidolite, microcline, Glaucophane, Anorthite, (< angle) chlorite, wollastonite, Andalusite, Hbl, kyanite, epidote

1. Triclinic System - microcline, chalcanthite, Amblygonite, axinite, Kyanite, microcline feldspar (including amazonite and aventurine), plagioclase feldspar ((including labradorite), rhodonite and turquoise, wollastonite, Kaolinite, albite

2. monoclinic system - Sphene, Augite, epidote, chlorite, Glaucophane, Hornblende, Actinolite, trona, Kernite, lephitoloite, azurite, brazilianite, crocoite, datlite, diopside, jadeite, lazulite, malachite, orthoclase feldspar (including albite moonstone) Gypsum, Talc, muscovite, Biotite, tremolite, Hyalophane, celsian, calaverite

3. orthoclase system -
- Anthrophyllite, Barite, wavelite, Nagyagite, Andalusite, celestite, chrysoberyl ((including alexandrite), Cordierite, iolite, danburite, zoisite, tanzanite, thulite, enstatite, hummimoophic fibrolite, sillimanite, hypersthene, olivine, peridot, sulfur, topaz, Enargite, sterolite.

4. Tetragonal System - Apophyllite, idocrase, Rutile, scapolite, wulfenite, zircon, Bornite, leucite.

5. Hexagonal System -
Apatite, Beryl (including Aquamarine, emerald, Heliodor, morganite), taaffeite, zincite, siderite, Quartz, calcite, pyromorphite, Niccolite, nepheline, molybdenite,

6. Trigonal system - cassyrite, smithsonite, corundum, Ruby and sapphire, Tourmaline,

7. isometric system [cubic] -
Garnet, Diamond, Fluorite, Gold, lapis, galena, ~~Smaet~~ Smactite, Argenite, lazuli, pyrite, silver, sodalite, sphalerite, spinel, almandine.

(A) BCC = Reflection absent if h+k+l = odd, (100) ✗, (110) ✓ (111) ✗ (200) ✓ (210) ✗ (211) ✓ (200) ✓

(B) FCC = Absent unless h, k, l are all odd or even, (100) ✗ (110) ✗ (111) ✓ (200) ✓ (210) ✗ (211) ✗ (220) ✓

Name	No. of Bravias lattice	primitive	Base centred	Body centred	Face centred
Triclinic	1	✓			
monoclinic	2	✓	✓		
orthorhombic	4	✓	✓	✓	✓
tetragonal	2	✓		✓	
cubic	3	✓		✓	✓
Trigonal	1	✓			
Hexagonal	1	✓			

$r^+ + r^- = \frac{\sqrt{3}}{4}a$ [for BCC]

$r^+ + r^- = \frac{a\sqrt{2}}{2}$ [for FCC]

$\text{Radius Ratio} = \frac{\text{Radius of cation}}{\text{Radius of anion}}$

→ Inclined = Andesine, Hornblende, Kyanite, Augite, microcline,

→ symmetrical extinsion (CPP) - mica (All triclinic and many monoclinic)

→ parallel = muscovite, Beryl, Biotite, Hypersthene, opx,

→ wavy extinction - Qtz, microcline

→ Anisotropic - Hornblende, calcite, Biotite, Tourmaline,

→ isotropic - Garnet (Almandine)

→ Birefringence = < High - Zircon, sphene, olivine, calcite, → muscovite / Biotite high } epidote [Grunerite (Amosite)]
Low - Garnet, staurolite, Arfvedsonite, Anthophyllite, Gedrite, cummingtonite, tremolite
moderate = Tourmaline, Actinolite, Hornblende, Glaucophane, sillimanite

→ Pleochorism -

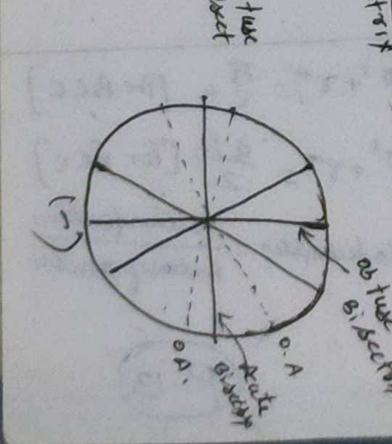
(A) present - Rutile, Hypersthene, Tourmaline, sphene, epidote, staurolite, chloride, Glacophane, chlorite, Hbl, Bio,

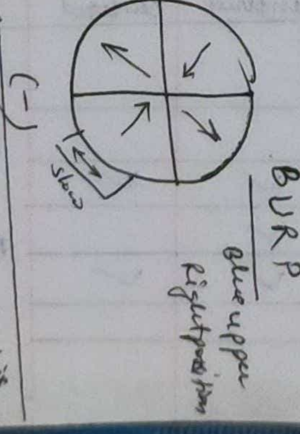
(B) Absent - wollastonite, olivine, Trimdite, muscovite, Augite.

→ Relief - (A) High - Kyanite, olivine, ~~Zircon~~, ~~sphene~~, garnet

(B) Low - nephaline

(C) moderate - Sillimanite, andalusite,





BURP

Blue upper Right position

$$\cos\theta = \frac{h_1h_2 + k_1k_2 + l_1l_2}{\sqrt{h_1^2+k_1^2+l_1^2} \times \sqrt{h_2^2+k_2^2+l_2^2}}$$

- {001} = perpendicular to c axis {family}
- [001] = parallel to c axis [plane]

1. pyroxene - $\underset{m_2}{X}\,\underset{m_1}{Y}\,Si_2O_6^{-4}$
2. olivine - $XSiO_4^{-4}$
3. Garnet - $A_3B_2Si_3O_{12}$
4. Amphiboles - $\underset{A}{W_{0-1}}\,\underset{m_4}{X_2}\,\underset{m_1/m_2/m_3}{Y_5}\,Si_8\,O_{22}^{-12}(OH,F,Cl)_2$
5. mica - $X_2\,Y_{4-6}\,Z_8\,O_{20}\,(OH,F)_4$
6. feldspar - $XAl(Al,Si)_3O_8$